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Understanding how unfamiliar faces become familiar

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Thesis submitted for the degree of Ph. D. in Cognitive Psychology/Neuropsychology

University of Kent

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June 2017

[Word count: 79,506]

Abstract

For most people, visual recognition of familiar faces is excellent and seems effortless, but recognition of unfamiliar faces is often poor. But how does an unfamiliar face become familiar? Seven behavioural and two event-related brain potential (ERP) experiments were carried-out to investigate the perceptual encoding process and subsequent recognition ability of same or other views when single-views or two-views had been learned. By systematically changing the types of views to be learned and tested, results from the behavioural experiments revealed that when two-views were accessed during recognition, integration and summation between these views and the information each view type afforded (i.e., its ‘view type utility’) directly influenced recognition performance of a novel view. ERP experimental findings further suggested that the FN400 ‘familiarity’ ERP component found during learning represented access to an established representation in memory, and in the recognition phase represented an approaching significant marker of ‘familiarity’, but only when two-views had been learned. This suggested that the FN400 two-view recognition effect, which was not present for single-views, represented access to a memorial representation that was qualitatively different from that of single-views. Taken together, behavioural and ERP results indicated that face learning occurred through the encoding of all visual information available at the time, and that learning more than one view imparted an advantage when tested on a novel view that was based on ‘view type utility’. Furthermore, the FN400 memorial representation for two-views may represent an association in memory that occurs due to within-identity variation between the two-views learned.

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Acknowledgements

I would like to thank the University of Kent and School of Psychology for the opportunity to carry out a course of doctoral study. I would also like to thank my family for allowing me to externalise my thoughts, while being consistently supportive and non-judgemental, during my undergraduate, masters and Ph. D experiences.

I would like to thank my academic and Ph. D colleagues who have provided objective comment when it was needed, and intellectual support when it was requested, particularly the Cognition and Neuroscience Group who have always been accessible and supportive. And I would like to make special mention of the School's support staff who have been found to be very knowledgeable, positive, helpful and efficient.

And finally, I would like to thank my supervisory team; Professor Robert Johnston, Dr Joseph Brooks and Dr Zara Bergström, who have provided guidance, support and a positive academic environment throughout, especially when transitioning to a new main supervisor in my final year. And my best wishes on his recovery, and appreciation, to Professor Bob Johnston, who initially encouraged me to take this journey, supported me along the way, and has been and remains a consistent motivation in pursuing an intellectual life.

Declaration

This thesis contains work completed by myself under the supervision of Professor Robert Johnston, Dr Joseph Brooks, and Dr Zara Bergström, and was supported by a University of Kent 50th Anniversary Ph. D Graduate Teaching Assistantship.

The data presented in Chapter Two has been published in the paper:

Etchells, D. B., Brooks, J. L., & Johnston, R. A. (2017). Evidence for view-invariant face recognition units in unfamiliar face learning. *The Quarterly Journal of Experimental Psychology*, 70(5), 874-889.
doi:10.1080/17470218.2016.1248453

And data has also been presented in poster form:

Etchells, D. B. and and Johnston, R. A. (2014). Evidence for Face Recognition Units using a face learning experiment. Poster presented at EPS London Meeting, 9th – 10th January 2014.

Etchells, D. B. and and Johnston, R. A. (2015). Assessing three-quarter face-view utility, compared to Face Recognition Unit formation, using a face learning experiment. Poster presented at EPS Leeds Meeting, 8th – 10th January 2015.

And the data were also presented as conference talks as:

Etchells, D. B. and and Johnston, R. A. (2014). Evidence for Face Recognition Units from transfer effects for recognising novel face views. Conference presentation at the EPS Canterbury Meeting, 15th – 17th April 2014.

Etchells, D. B. and and Johnston, R. A. (2014). Direct evidence that visual variation, not view variation, drives Face Recognition Unit Formation from two face learning experiments. Conference presentation at the BPS Cognitive Section Nottingham Meeting, 3rd – 5th September 2014.

Etchells, D. B. and and Johnston, R. A. (2015). Understanding structural and pictorial encoding accounts of face learning: The importance of abstraction. Conference presentation at the BPS Cognitive Section Canterbury Meeting, 1st – 3rd September 2015.

Etchells, D. B. and and Johnston, R. A. (2015). Understanding how unfamiliar faces become familiar. Or, how do we learn faces? Postgraduate Symposium presentation at the University of Kent, 22nd September 2015.

Chapter 1. Literature review

1.1 Introduction

Humans are excellent in determining if a presented face is familiar or not. Most people find it effortless recognising a close friend, family member or celebrity - their faces seem to just leap-out. In contrast, recognising an unfamiliar face is possible, but is often error prone. This has been repeatedly and extensively demonstrated empirically, finding that familiar and unfamiliar face recognition are different, with changes in view, expression and context all impairing unfamiliar but not familiar face recognition (for reviews see Hancock, Bruce & Burton, 2000; Johnston & Edmonds, 2009). And it has also been demonstrated that unfamiliar faces are not processed in the same manner as familiar faces, at least for identity, with unfamiliar and familiar face identity matching only reaching parity when faces were inverted, suggesting a qualitative as well as quantitative difference between unfamiliar and familiar face processing (e.g., Megreya & Burton, 2006).

The two predominant accounts of face learning that will be tested in this thesis differ in one critical regard, that is, what type of representation is formed from exposure to unfamiliar faces, leading to these becoming familiar, and what information from the face is necessary for this to occur?

The most complete formal theoretical account to date suggests that successive episodic traces of abstracted structural face codes become interlinked, forming a face recognition unit (FRU) for each identity (e.g., Bruce & Young, 1986; Burton, Bruce, & Hancock, 1999). While the other main account instead suggests that episodic traces of pictorial codes are stored individually, and this is often referred to as a ‘pictorial account’ (e.g., Liu & Ward, 2006; Longmore et al., 2017;

Longmore, Liu, & Young, 2008, 2015; Megreya & Burton, 2006). Critically, the FRU account proposes a ‘qualitative’ shift in the type of representation formed, where more than one example or view of an identity become ‘interlinked’. Whereas the ‘pictorial’ account instead proposes only a ‘quantitative’ shift, with more encounters or examples of an identity increasing the chances that a novel view will match, or be close in appearance to, one already seen, which presumably can also include a degree of on-line interpolation between those views stored.

With this brief introduction in mind, the current thesis will focus on investigating the type of representation formed during face learning. That is, is the representation ‘pictorial-like’ in nature, or is it more sophisticated than that, and perhaps ‘FRU-like’? The following review of the extant literature will first start by focusing on the Bruce and Young (1986) model of face processing, and subsequent Interactive Activation and Competition (IAC) implementation, to understand in detail, what was initially proposed, and how this has been extended. It will then proceed on to what is known about general visual object processing and how this relates to the category of faces, and will then move on to review work that suggests that unfamiliar and familiar faces are processed in qualitatively different ways. Finally, the review will then more directly consider learning specific elements that have been studied, to understand how these can be incorporated into an empirically supported face learning paradigm, and how they may inform face learning theorising overall.

1.2 Models of face processing

1.2.1 The Bruce and Young model (1986)

The theoretical framework proposed by Bruce and Young (see Figure 1.1) is the most complete cognitive theoretical model available of how familiar face recognition occurs, and the model to which most subsequent empirical findings are often compared. Bruce and Young intended that their model would provide an account of the perceptual and cognitive processes at play when we recognise familiar faces, clearly stating that their definition of ‘recognition’ in their model represented “any type of stored information from faces” (p. 305). To do this, they defined seven distinct types of information (i.e., *codes*) that can be derived from faces, and used these to account for different processing steps in their model. These were: “pictorial, structural, visually derived semantic, identity-specific semantic, name, expression, and facial speech codes” (p. 305), and this nomenclature intended to provide the face processing researcher with a set of terms that would allow inter-researcher empirical communication. However, it must be stated that their original definitions may have been somewhat misinterpreted since their inception, so clarity will be provided over the forthcoming review of the model, defining terms when it is critical to understanding their original conception. The most crucial point to make in understanding Bruce and Young’s model is that of distinguishing between *pictorial* and *structural* codes. Pictorial codes represented those codes derived from, “any visual pattern or picture” that is, “a record of a particular, static, visual event” (p. 307). In this sense, these codes can be thought of as representing ‘picture memory’, and although they do allow for some abstraction of face information, they are limited to the image itself and do not allow very good transference to another image, and therefore have little to say about face learning that is beyond learning an image that

just happens to be a face. Therefore, for face learning to occur, one must consider more abstract codes, and these are defined in the model as, ‘structural codes’.

Structural codes represent information obtained from a face that include the arrangement of features in relation to each other. In this way, we can regard the structural information abstracted to represent the ‘configuration’ of the face. Thus, for familiar faces, these codes can be said to represent those view-invariant qualities of the face which allow it to be recognised when a view-transformation takes place, and these structural codes can become elaborated over many encounters.

In comparing face recognition with object-centred recognition, Bruce and Young suggested that faces are not decomposed in the same way. For example, the fine-grained detail and variation required to distinguish one identity from another, especially when one considers that most faces consist of the same three-dimensional structure, implies that faces are a ‘special’ object category. They also contended that separate representations of distinct head angles, that are expression independent, may be formed, culminating in the proposal that, “a familiar face is represented via an interlinked set of expression-independent structural codes for distinct head angles, with some codes reflecting the global configuration at each angle and others representing particular distinctive features” (p. 309).

The structural code description provided is interpreted as meaning that the structural descriptions of faces are encoded as discrete representations that are ‘interlinked’ or ‘associated’. That is, multiple structural descriptions that may represent the configuration (e.g., layout of the eyes, nose and mouth) and dimensions of the face (e.g., dimensions of the skull) become ‘interlinked’ to form a representation for only that identity. How these are ‘interlinked’ or ‘associated’, and

when, or what determines when/won't perceptual information be 'interlinked' or 'associated', is not made clear in the model. However, it is relevant to state that the authors descriptions can be understood as intending to convey that structure is abstracted, and these episodic memory representations are associated – associated to the extent that they represent the same entity (i.e., identity), and not just the same category (i.e., faces).

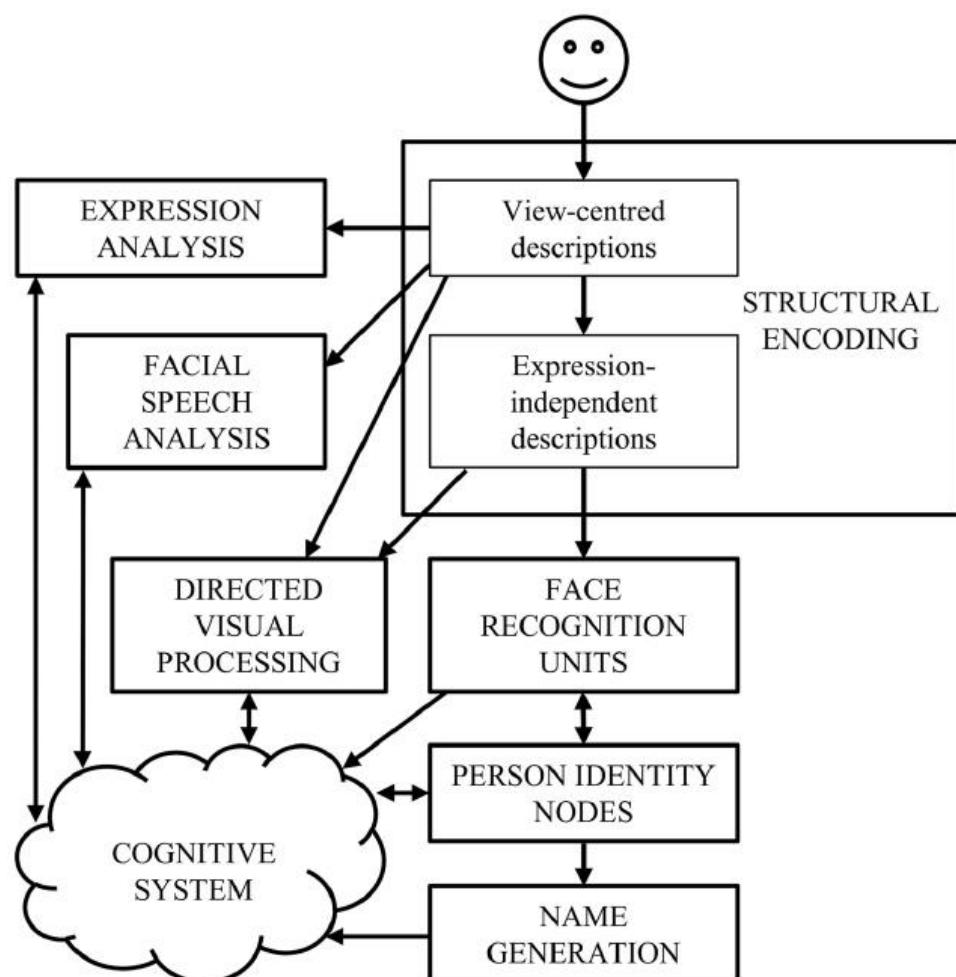


Figure 1-1. A functional model of face recognition (reproduced from Bruce & Young, 1986).

Furthermore, Bruce and Young highlighted that, ‘visually derived semantic codes’ were those which are formed from the appearance of the face, and can be applied to unfamiliar faces as well as familiar faces. For example, these can be experimentally manipulated, with judgements about age and gender being made purely based on the visual information provided, and thus can be subsequently accessed via ‘visually derived semantic codes’. ‘Identity specific semantic codes’, on the other hand, were suggested to represent person information that goes beyond merely their visual representation (e.g., the context in which they were viewed, their occupation, their associations with others, etc.). Bruce and Young explicitly distinguished between these two codes, rather than applying a broad semantic continuum, because they needed to account for semantic information related to unfamiliar and familiar faces. For instance, visually derived codes are available for both, but identity specific codes are only likely to be available for familiar, and therefore, known identities.

‘Name codes’ were described as representing ‘output codes’ that allowed for the generation of a name, and are distinguished from input codes that could be used for the recognition of written or spoken names. An example of why this code was proposed is that of recognition without being able to name the person, indicating that there was a dissociation between name retrieval and identity recognition (and see Hanley, 2011 for a review of face naming). ‘Expression codes’ were defined as representing visual information of expression derived from a person’s, “relative shapes or postures of facial features” (p. 310). In this way, such codes represented a way of establishing if the person was exhibiting happiness, sadness etc. Allied to this were ‘facial speech codes’. These were codes derived from the lip and tongue movements that were associated with heard speech. Together, ‘expression codes’

and ‘facial speech codes’ were not proposed to represent how faces are recognised, on their own or in conjunction, but are important in describing the finer grained additive accumulations of facial and identity information, and these codes described how recognition of familiar faces can be sequentially accessed, representing the “products of facial processing” (p. 311).

The most noteworthy and central part of the model concerns ‘Face Recognition Units’ (FRUs). Structural codes provide face information, and these can include, “view-centred descriptions as well as more abstract descriptions both of global configuration and of features” (p. 311). These ‘more abstract’ expression independent descriptions provide information for the construction of an FRU, which the authors denoted as representing a, “perceptual classification function” (p. 311). That is, they proposed that FRUs comprise identity associated stored structural codes for a face. Upon presentation of the face, the FRUs ‘signal’ to the cognitive system will depend on the degree to which the stored representation matches or resembles that provided by structural encoding of the stimulus. In addition, it was proposed that activation of the FRU could also be triggered or primed, indirectly, by the ‘person identity node’ (PIN), for example, when one has an expectation of seeing someone, or directly when the person has been seen recently.

PINs are described as associative nodes that represent identity-specific semantic memory which FRUs can access directly, but names are only accessed by PINs. Thus, an FRU can be activated by visual stimuli (i.e., seeing a face), but will not be activated by a voice or a name. PINs on the other hand can be activated by visual stimuli (i.e., seeing a face), or a voice, a name, or even an item of clothing.

Thus, FRU activation represents visual face recognition, and PIN activation represents person recognition. The point was also stressed that PINs are positioned outside the general ‘cognitive system’ because failures in recollection occur that are often ‘person specific’, rather than general semantic. For instance, recognising an actor but not being able to recall where you saw them (e.g., in which film). This point was also made in relation to the other ‘boxes’ of the model (see Figure 1.1), as they too were thought to represent ‘specific’ operations involved with face processing, rather than being part of the general cognitive system.

In comparing the model with word and object recognition, Bruce and Young clarified that the FRU metaphor had much in common with ‘pictogens’ and ‘logogens’ (and see, Bruce & Valentine, 1985). That is, FRUs, like pictogens and logogens, were proposed to represent all aspects of the same thing (in this case the visual representation of an identity), and for FRUs, this meant all visual variation within the same visual identity. Thus, ascribing FRUs to the same identity allowed more experimental focus to be placed on the nature of different coding processes and interrelatedness of these codes, rather than becoming too focussed on the way in which structural codes enable recognition. Indeed, the authors addressed this in their ‘unresolved issues’ section, stating that FRUs can be more precisely defined than structural encoding, and left it for future researchers to determine how structural encoding effects lead to FRU formation. Indeed, this point will be at the heart of the following experimental chapters, and forms much of the investigative work carried-out.

In sum, Bruce and Young’s functional model provides a language to understand how faces are learned and how face recognition might occur, and this has proved to be a useful and powerful tool in face research since its inception. Perhaps

the most striking and intriguing element, in terms of how we learn faces (and the topic of this thesis), is that of FRUs. Undoubtedly, we can learn ‘people’ and ‘identity’ by semantic information and/or naming alone, but in terms of visual face learning, these routes are inadequate and insufficient to allow us to become fully visually familiar with a face. This is the power of the FRU, as it allows one to test both ‘pictorial accounts’ and ‘structural accounts’ of face learning, with the implication being that a face will only become ‘truly’ learned and familiar through the visual abstraction of structural information and construction of an FRU. Testing this aspect of the model, and distinguishing between ‘structural’ and ‘pictorial’ effects must be the first step in understanding how unfamiliar faces become familiar.

1.2.2 The Interactive Activation and Competition model (IAC)

Burton, Bruce and Johnston’s (1990) IAC model (see Figure 1-2) was an attempt to describe the microstructure of the Bruce and Young (1986) model using an interactive activation implementation, and suggested some important modifications. The model concentrated on familiar individuals (i.e., celebrities) and sought to account for a range of empirical findings such as, semantic priming, repetition priming, and distinctiveness.

The model contained three central pools of units: FRUs, PINs, and semantic information. Although semantic information was not explicitly sectioned off into a ‘box’ in the Bruce and Young (1986) model, but rather was included in the general ‘cognitive system’, here a separate pool was created. Critically, the IAC model allowed decisions about familiarity to be made at the PIN node, which differed from the Bruce and Young model (i.e., in Bruce and Young, a decision about the

familiarity of a face was made at the FRU node). The reason for this departure was based on the authors' observation that information about people is often presented across many modalities, so restricting them to FRUs seemed implausible. Rather, a central familiarity decision node was chosen, and for the IAC model, the PIN was regarded as the most appropriate hub for such decisions. The authors also contended that in choosing PINs as the central familiarity decision location, also allowed for familiarity without access to semantic information, as this can be blocked (e.g., when recognition occurs without semantic recall). The model also did not allow for 'name generation', which the authors suggested could be addressed in later applications of the IAC approach.

The model essentially relied on iterations of processing that resulted in a predetermined threshold being reached, activating access to the PINs. This process can be described in the following way: first, input enters the system via the FRUs, this then activates a PIN, and associated semantic information can be generated. This means that a single FRU could activate a single PIN, but a single PIN activation could activate many semantic associations, and this in turn could allow the raising above threshold of many more associated PINs. They highlighted this by suggesting the following example: the face of the United States President Richard Nixon activates the FRU for Nixon, which in turn activates his PIN. Then, if not blocked, semantic information such as 'The Watergate Scandal' may become active, and associated content such as Kissinger (Secretary of State in Nixon's term as president) may also become active. Thus, the Nixon PIN is activated by the Nixon FRU (i.e., the face of Richard Nixon), and the Kissinger PIN is activated by the semantic association – providing the priming of Kissinger from the face of Nixon.

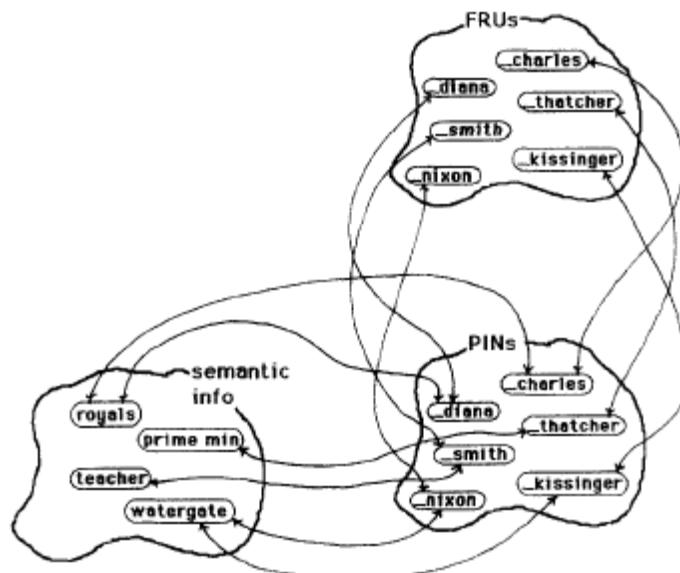


Figure 1-2. The central architecture of the interactive activation model (reproduced from Burton, Bruce & Johnston, 1990).

In understanding ‘distinctiveness effects’, the IAC authors needed to address the ‘expression-independent descriptions’ of the ‘structural encoding box’ of the Bruce and Young model. To do this they decided on somewhat arbitrary inputs such as, noses, eyes, and hair. The authors stated that these were chosen as examples of some metric of input, and were not necessarily indicative of the true segmentation of visual information input. Nevertheless, the ‘part-by-part’ input, although likely more sophisticated and abstract than this, did offer a way of conceptualising how visual information may be abstracted, and this was something that Bruce and Young (1986) accepted and noted, but did not detail. Therefore, the IAC model for distinctiveness allowed for a face to be segmented into nose, eyes and hair, with each providing separate input to the FRU node. When there was overlap between several FRUs that

shared the same featural input metric, their utility was signalled to the PINs, and the strongest signal allowed an attempt at correct recognition to be made. This implementation of a suggested featural input mechanism demonstrates, for instance, how caricaturing may fit into this conceptualisation, but does not adequately account for the very minor visual differences observed between or within familiar faces, and the large visual differences observed between unfamiliar faces, with concordant unsuccessful recognition (i.e., telling people apart).

It can therefore be seen from this later more detailed IAC implementation of the Bruce and Young (1986) model that it was necessary to propose some featural metric of structural encoding – that being eyes, nose and mouth, in this case. And while the Bruce and Young model provided the framework and nomenclature to further understand how faces are learned, it was clearly necessary in the IAC case to distinguish between the type(s) of information that may be abstracted during structural encoding, at least to the extent that was more than simply a record of the ‘pictorial’ information. Clearly then, the distinction between ‘pictorial’ and ‘structural’ codes, being at the ‘front-end’ of the Bruce and Young model are critical to clarify, if a theory of face learning is to be elaborated on and understood further. To that end, the following section will review work that concerns general visual object processing, and faces as a category within that, to determine what evidence is available that can shed light on whether faces are perceived and processed differently from other categories of visual input.

1.3 General visual object processing

To understand possible processes underlying ‘typical’ face processing, encoding and recognition, one must intuitively ask if these processes are the same as, similar to, or different from processes involved in processing other object categories. A review of visual object recognition by Logothetis and Sheinberg (1996; and see, Peissig & Tarr, 2007; Rugg & Yonelinas, 2003) highlighted that visual object recognition should not be considered a general purpose process applicable to all categories of objects (and see, de Gelder & Rouw, 2001; Wallis, 2013), but rather conceptualised as relying on different types of stored representations, each recruited to meet the subject of study. Subordinate level recognition, for instance in the case of identity matching and recognition of faces, can be regarded as primarily strongly view-dependent, becoming view-independent through a process of perceptual learning. This is particularly relevant when one considers the unfamiliar-familiar qualitative face matching recognition accuracy difference highlighted previously (Megreya & Burton, 2006).

Furthermore, Yonelinas' (2002) review of general visual recollection and familiarity research broadly concluded that familiarity is found to be a fast-acting ‘signal-detection-like’ process that operates independently of recollection, and supports memory for previously seen items only (e.g., familiar faces). Mandler (2008, and see Mandler, 1980) also clarified the familiarity-recollection independence distinction by referring to the ‘butcher on the bus phenomenon’, where one recognises a person through a sense of visual familiarity, but fails to adequately recall where or when from. Returning to the review of Yonelinas (2002), it was found that familiarity is not generally thought to support novel associations, as these do not yet have an established representation in memory, however, it can do so when

these items are studied and associated in some unitary way, which Yonelinas referred to as the ‘unitization hypothesis’. Yonelinas provided an example of this where familiarity can support associative recognition between different parts of the same faces when presented in an upright orientation, implying that associations between parts of the same face must have occurred, perhaps alluding to the way in which unfamiliar faces are learned. That is, based on Yonelinas’ view of novel associations and the ‘unitization hypothesis’, one might consider that this has something in common with Bruce and Young’s (1986) conception of what constitutes an FRU. In other words, novel associations, such as unfamiliar face learning, that Yonelinas refers to as undergoing ‘unitization’, might also be considered as a similar to the ‘interlinking’ of structural codes, forming an FRU..

Palmeri and Gauthier (2004) also provided a review of ‘visual object understanding’ and the connection between perception and cognition. The role that abstraction plays in this process is particularly relevant to the current thesis as it is at the heart of the question of whether representations formed during learning are view-specific (i.e., we store ‘pictorial’ representations and match/interpolate from these), or are truly view-invariant (i.e., we store ‘structural’ representations and these allow successful recognition from all viewpoints). Although not conclusive, the review highlighted that behavioural and neural evidence would seem to suggest that visual object ‘understanding’ uses, or has access to, both mental rotation pictorial processes, and structural abstraction processes (and see, Bulthoff & Edelman, 1992; Hill, Schyns & Akamatsu, 1997). For example, evidence indicates that the parietal lobe is engaged in mental rotation operations, but the fusiform gyrus is engaged in recognition (Gauthier et al., 2002), indicating that at the behavioural level, responses

can be observed as indistinct from each other, but may in fact be the result of separate brain region processes.

In summary, the evidence from general visual object processing reveals that faces, as well as other visual categories, may indeed be specialised ‘objects’ that differ in the type of representation formed, within each category, and that familiarity decisions, or more precisely a measure of recognition, can represent both ‘having been seen before’, such as in an old/new task, as well as truly familiar. The main implication from this last point is that to correctly measure true face learning (rather than simply ‘having been seen before’), one must carefully choose a metric that is indicative of a process taking place that is more than simply the result of image repetition recognition (i.e., a ‘pictorial’ effect). It is therefore important that some advantage be demonstrated for complete or partial view-invariance, beyond that which can be achieved from on-line interpolation from, for instance, a single view. In understanding the type of representation formed from learning faces, it is critical that one understands whether, as proposed by Megreya and Burton (2006), unfamiliar and familiar faces are truly qualitative different representations. Therefore, the following section will review in more detail, the evidence for this proposal, as it is a crucial distinction that will have important implications for the forthcoming experimental design.

1.4 Are unfamiliar and familiar faces processed in the same way?

A clear distinction is often made in the literature between unfamiliar and familiar faces (e.g. Hancock, Bruce & Burton, 2000), with a review by Johnston and Edmonds (2009) defining these two types of representation in terms of their

experimental context. For example,, unfamiliar faces can be regarded as those faces that have not been seen by the participant before they are presented for the first time. That is, when two or more views of a previously unseen identity are presented serially (e.g., using delayed matching) or simultaneously (e.g., presenting two or more images at the same time), and the participant has to respond if they are the same person or not (e.g., Bindemann, Avetisyan & Rakow, 2012; Bruce et al., 1999; Bruce, Henderson, Newman & Burton, 2001; Burton, White & McNeill, 2010; Davis & Valentine, 2009; Kemp, Towell & Pike, 1997; Megreya & Burton, 2008; White, Kemp, Jenkins, Matheson & Burton, 2014). These paradigms are referred to as a ‘matching tasks’ and can contain both matches and non-matches, with each able to represent the same identity (a match), or different identities (mismatch), and can also include view changes and lighting changes etc. In this case, the unfamiliar face is used to match/compare to another identity or the same identity, but is only encountered on a single or very few occasions within the experimental procedure, with the faces still being considered unfamiliar.

Familiar faces on the other hand can be regarded as having been seen before, and therefore represent an existing representation in memory, and are considered using old/new recognition paradigms, with personally familiar faces able to be recognised in the absence of conscious awareness (Gobbini et al., 2013), and after many decades (Bahrick, Bahrick & Wittlinger, 1975). Furthermore, electrophysiological research has found that familiar faces can be recognised within 200 milliseconds post presentation (e.g., Barragan-Jason, Cauchoix & Barbeau, 2014; Caharel, Ramon & Rossion, 2013), and that recognition accuracy of briefly presented familiar faces, compared to unfamiliar faces, is not reduced by blurring or the presentation of isolated internal features (Veres-Injac & Persike, 2009). It is

therefore evident that once a face has become familiar, and some representation is available from memory (i.e., in an old/new recognition paradigm), that this representation is able to be used to recognise many non-identical instances.

The empirical evidence would therefore seem to suggest that a familiar face must have some robust and established representation in memory that provides a recognition advantage, whereas an unfamiliar face would seem not to have such a representation, or at least not to the same extent. It is also relevant from an experimental point of view that one considers the level of familiarity. For instance, personally familiar faces which one may have had many years of experience with should not be assumed to have the same representation as those recently learned (e.g., in the laboratory) or recently encountered (e.g., in everyday life/work). And it is also important to state that familiarity is based entirely within the perceiver, so the same face/identity can be both familiar and unfamiliar between observers (e.g., Armann, Jenkins & Burton, 2016; Ritchie et al., 2015). Furthermore, famous people and celebrity faces may need to be differentiated by their method of exposure to the participant. For example, was their exposure gained pictorially, tele-visually, at a live sporting/entertainment event, and were the familiar faces provided to the participant in the same semantic context, for example, were politicians mixed with sports stars, or recent identities with historical identities?

So, it would seem reasonably straight forward to define when a face is unfamiliar, but problematic when a face is regarded as familiar. Indeed, even if one could restrict familiar faces to a single category (e.g., politicians), one cannot control how each participant was exposed to this face/identity, so very careful and objective rating procedures are often undertaken when investigating levels of familiarity in an experimental design (e.g., Clutterbuck & Johnston, 2002).

To further expand on this point, a study by Carbon (2008) compared differences in recognition accuracy for familiar famous faces over three levels of manipulated familiarity. These were: ‘iconic’ pictorial representations that were commonly available in media representations, modified versions of these ‘iconic’ pictures that were less common media images, and unfamiliar pictures that were not available media representations. These were then compared between participants using a familiar/not familiar (old/new) response paradigm, to similar levels of familiarity for personally known faces who were university lecturers that participants would typically be familiar with as they taught on their course.

The main finding from the experiment was that the famous group ‘iconic’ pictures (i.e., those most commonly available in the media) were more accurately recognised as familiar, than both modified ‘iconic’ and uncommon pictures. Carbon concluded that greater recognition accuracy with an iconic image over modified and uncommon images indicated that what had been learned and what the stimulus was being compared to from memory, was the stored image, and that this representation may not represent ‘face knowledge’ at all, but rather knowledge of the pictorial/media representation, or ‘iconic image’. However, for the personally familiar group (i.e., university lecturers), the effect across uncommon, modified, and original images resulted in no significant differences between these image types, suggesting that any representation(s) formed in memory for these people were sufficient to allow equal familiarity recognition across the three image types.

Taken together, this study highlights on one hand, an important empirical finding about the nature of ‘iconic’ media images and their possible representations in terms of whether they can truly be regarded as familiar faces, over familiar images. But also, on the other hand, it inadvertently highlights the problems

associated with representing personally familiar people, in this case, university lecturers. While this type of comparison is often carried out by researchers using different experimental paradigms, it is apparent from this study that there is a potential issue in comparing familiar faces of different types. That is, even if they are externally rated by objective observers, there is still the risk that one may be comparing ‘pictorial’ or media representations of ‘iconic’ images of famous celebrities against some other representation that may not be equivalent, such as personally familiar faces that are encoded and encountered ‘in-person’ or ‘face-to-face’, and are likely to be much richer and more robust.

Furthermore, and in terms of differences between unfamiliar and familiar faces, a review of face recognition research by Burton (2013) suggested that unfamiliar and familiar face recognition are qualitatively different and should not be conflated. And he went further, and proposed that conflating the two may well have held back face processing research for many years. Indeed, often research in this field can demonstrate differences between unfamiliar and familiar faces, but fails to provide a theoretical account of how one becomes the other. As an example of this, and over six behavioural experiments, Megreya and Burton (2006) examined unfamiliar face matching to establish if upright and inverted faces demonstrated the same or different processing. They found that for the inverted matching task, there was no difference between unfamiliar and familiar faces, suggesting that for inverted faces, the same featural decomposition approach was taken. However, when faces were in the upright orientation, an advantage was found for familiar over unfamiliar faces, suggesting that unfamiliar and familiar faces were being processed qualitatively differently.

From these experimental results, they contended that unfamiliar faces are not processed in the same configural manner that familiar faces often demonstrate. However, the authors themselves expressed that it was unlikely that ‘simple pattern matching’ (i.e., using ‘pictorial’ codes) was all that was used for matching unfamiliar faces in their six experiments. Instead, they suggested that it was much more likely that the process was more cognitively sophisticated than this, but was nevertheless qualitatively different from that used for familiar face matching. The authors also made the point that this argument holds only for identity based judgements, suggesting that ‘simple pattern matching’ was discounted as an explanation because matching faces of any level of familiarity is predominantly an ‘identity’ based judgement. However, no claims were made about how unfamiliar faces become familiar, just that the two must not be conflated as representing the same identification process.

Expanding on the different ways that faces may be processed, stored and recognised, empirical evidence has mainly focused on two main findings: (1) that faces are stored as ‘holistic’ representations that are not able to be decomposed into their individual face-parts (e.g., Richler & Gauthier, 2014; Richler, Mack, Gauthier & Palmeri, 2009); and, (2) that faces are processed based on their features and configuration of features, or relation between features (i.e., featural and configural processing; e.g., Piepers & Robbins, 2012; Tanaka & Sengco, 1997), with each of these two types of codes, arguably stored separately (e.g., Cabeza & Kato, 2000). On this last point, Cabeza and Kato produced evidence that supported a ‘dual-code’ view, in that it was argued that recognition of a face uses information about the whole of the face, and its parts, with each of these being discretely represented in memory.

Furthermore, Bartlett, Searcy and Abdi (2003) also clarified that configural processing of faces is not simply another explanation for holistic processing, but that holistic processing of faces is rather a broader concept that is separate to holistic processing, and is in general agreement with the ‘dual-code’ view of Cabeza and Kato. However, as Piepers and Robbins (2012) concluded in their review of these terms, both holistic and featural processing do seem to act in parallel and represent separable processing in face perception, but cautioned that what is included in holistic representations of faces is still unclear. However, what can be said for configural and featural processing is that there is evidence that familiar faces are processed by their configuration of features, particularly the internal features, whereas unfamiliar faces are found to be processed much more by the features themselves, rather than their configuration (e.g., Veres-Injac & Persike, 2009).

Taken together, the above research highlights a fundamental problem. That is, knowing that unfamiliar faces are unlikely to be processed in the same way as familiar, it is theoretically problematic to study the process of face learning by including and comparing to any type of uncontrolled familiar faces/identities. Instead, in understanding the process of how faces are learned, one must approach the question from first principals, and attempt to find a method of learning a number of unfamiliar faces in a controlled manner that can be demonstrated to display normal recognition attributes of familiar faces at test. Only in this way can one conclude that faces have been learned to a measurable standard that is indicative of everyday familiarity, and then attempt to understand how this occurred, how this process can be enhanced or damaged, and what may be important for successful face learning.

1.5 Literature that considers learning specific elements

The previous sections have reviewed the literature that dealt with the main and predominant empirical questions that have occupied the field of face processing research. However, the following section now considers in addition, more specific elements that have been found to be directly and sometimes indirectly diagnostic of face learning. It is suggested that, once reviewed, these elements can then be experimentally controlled and manipulated, and may therefore allow unfamiliar face learning to occur in a measurable way, using techniques that are empirically supported.

1.5.1 Learning from abstraction

Abstraction can be defined as a process by which the individual attributes of a face (e.g., eyes, nose, mouth, etc.) become integrated into a superordinate representation, with supporting evidence finding that faces are processed holistically (Richler & Gauthier, 2014). That is, there seems to be some process that aids the rapid encoding and abstraction of faces that is more than simply a featural or ‘part-by part’ encoding process, and this is often referred to as holistic processing. For example, it has been found that holistic processing of faces is apparent at very short perceptual encoding time restraints (Richler, Mack, Gauthier & Palmeri, 2009), which in turn suggests that the holistic processing of faces can be considered somewhat ‘automatic’, further implying that abstraction of the perceived features into a holistic Gestalt are organised in memory very rapidly.

To further clarify this observation, a study by Leder and Carbon (2005), which extended the findings of Tanaka and Farah (1993), which used schematic faces, by introducing real faces and examining whether part-recognition following part-learning was affected by the context of a full face at test, which Tanaka and Farah had not examined. They found that when participants were trained on facial parts (e.g., eyes, nose or mouth) using a ‘whole-to-part’ paradigm, that parts could not be successfully discriminated when presented at test in a whole face, but that learning parts and then testing parts was successful. The authors suggested that this ‘part-whole interference effect’ was evidence of holistic processing, in that once parts were displayed in the context of a whole face, it was the whole that interfered with ‘part-discrimination’, and therefore was indicative of the automatic holistic processing of faces.

Another study that investigated face learning tested two hypotheses (Arnold & Sieroff, 2012). The first was that the face would be learned by way of an ‘integrated-representation process’ (i.e., holistic processing), carried out by displaying different views shown in rapid-sequence, which it was thought would enhance the process of learning. The second tested a ‘view-matching process’, with different views shown in slow sequence which it was thought would enhance ‘pictorial-like’ processing. The main finding was that rapid-sequences (i.e., holistic processing) produced better recognition at test on all test views, compared to slow-sequences (i.e., pictorial-like processing). The authors concluded that faces learned from multiple views are “integrated into a unified representation rather than encoded as multiple associated views” (p. 813). However, they also went on to suggest that when an experienced view was seen again, the sequence could be accessed for recognition, and that when a novel view was seen, the sequence was used to produce

an average from which recognition could be attempted. This distinction is critical and somewhat supports the concept of FRUs suggested by Bruce and Young (1986), but differs importantly in one regard, that is, it suggests an average is accessed during recognition, rather than access to interlinked percept's.

To clarify this finding further, ‘face prototyping’ (which will be discussed specifically in a later section, but is included here as it pertains to abstraction) is often exemplified by better recognition of the unseen averaged face (prototype) than the original (seen) exemplar(s), and is a critical concept in understanding how faces might be represented in memory (e.g. Cabeza, Bruce, Kato & Oda, 1999; Wallis, Siebeck, Swann, Blanz, & Buelthoff, 2008). Or and Wilson (2013) investigated face prototype formation, its nature and extent, using synthetic faces which were defined in geometric terms in a ‘multidimensional face space’ (Valentine, 1991). That is, the Face Space model of Valentine (1991) proposed that individual faces are structurally encoded based on the statistical distance (in a multidimensional space) of their features, from those already stored (although the metric that formed these multidimensions was not explicitly defined), with the individual observers’ specific experience of faces acting as a pool from which a prototype can be extracted, and subsequent faces compared. In this way, the model provided a heuristic framework that could account for the way in which encounters with novel faces, and their relationship with a pool of already established faces, might be considered.

Continuing with the Or and Wilson (2013) design, eight exemplars were generated from a prototype and these were presented in the learning phase with a recognition test phase following shortly after. In the recognition phase, participants were presented with target faces seen at learning (exemplars), target faces not seen at learning (prototype), and distractor faces. The critical finding from the behavioural

results was that implicit prototyping occurred from face geometry. That is, the authors found that the prototype was generalizable across viewpoints, and could be extracted from two face-parts, internal features and head shape, and that the representation lasted for up to one week. The authors also stated intriguingly that, “the prototype serves as a crucial reference point that possess ‘zero identity’ for the purpose of facial discrimination” (p. 9). In other words, prototype formation may represent an automatic or implicit ‘perception-to-memory’ process that is engaged upon exposure to multiple exemplars of the same category (i.e., faces), and not necessarily the same identity. Whether this is face-specific or could be applied to other object categories is not elucidated by the authors.

In summary, abstraction of face stimuli has been shown to exhibit a holistic representation, which once established in memory is somewhat impervious to part-by-part decomposition recognition, with multiple encounters allowing the formation of an average or prototype of experienced exemplars. It has also been proposed that a ‘multidimensional face space’ model (Valentine, 1991) may help to explain how such representations may become statistically represented in terms of their similarity/dissimilarity to already established representations. In this way, one can envisage a process by which abstraction of face stimuli, once established as a holistic representation, may become associated based on visual similarity to previously encoded faces, resulting in associations in memory for the same person. It will therefore be important, when examining the forthcoming experiments, to understand whether unfamiliar face learning produces effects that support or contradict the principal of abstraction, over effects that can be attributed to individual or combinations of exemplar pictorial representations.

1.5.2 View type

In the face processing literature, for static image stimuli, it is common that the views seen in experiments fall within a fairly restricted range. The range normally consists of: a left profile view, a left three-quarter view, a front-facing view, a right three-quarter view, and a right profile view (e.g., Favelle, Palmisano & Avery, 2011), with one view in particular receiving special attention in the literature - the three-quarter (TQ) view.

Bruce, Valentine and Baddeley (1987) found that accuracy on a sequential identity matching task was significantly greater for TQ views than for front-facing views. However, the TQ advantage was only present when the identities were unfamiliar to participants, with the authors concluding that the TQ view was not ‘special’ or a “canonical view in the representation of familiar faces” (p. 119). And in support of this point, a critical review of the ‘TQ effect’ undertaken by Liu and Chaudhuri (2002), discussed its two main hypothesised advantages. These were: (1) when a TQ view has been seen to produce better generalisation to a different view, and (2) when a TQ view provided greater recognition of the same TQ view. Their literature review on the first count (TQ to different view) found mixed and inconclusive results when examining a TQ advantage. They concluded that it was simply impossible to say anything more than an effect of transference to the other view had taken place (or not), compared to any ‘special’ case being made for the TQ view learned or tested. On the second count (TQ to TQ – i.e., the same view learned and tested), similar conclusions were made, but in this case concerns of plausibility of the results reviewed focused on methodological concerns such as the small number of stimuli used and facial expression dissimilarities. This lead Liu and

Chaudhuri (2002) to design an experiment of their own that set out to specifically test the same-view advantage, but not restricted to one view in particular.

Results of their recognition accuracy experiments that used different view types (i.e., full-face, three-quarter, and profile), revealed that at test, participants were significantly more accurate at recognition when two training trials had been provided than when only a single trial had been provided, but this was the only main effect that was found significant, and no interaction with view type was found to be significant. Overall, their study demonstrated that not only was there an absence of a TQ view advantage, but that no view was able to provide a significant advantage over the others. Crucially, the authors had therefore demonstrated that the absence of a TQ view effect found previously for familiar faces (e.g., Bruce, Valentine & Baddeley, 1987), was also repeated for unfamiliar faces (Liu & Chaudhuri, 2002).

In summarising the reviewed evidence, it would seem that the TQ view, or any other view, does not offer any special ‘utility’ when considering both unfamiliar and familiar face processing. However, intuitively, the TQ view does seem to offer a greater range of structural information than other views (e.g., profile views). Therefore, and in terms of the forthcoming experiments, it is important to clarify, by using different view types together and in combination, what if any informational utility advantages each of the five-basic view types discussed previously might provide (i.e., a left profile view, a left three-quarter view, a front-facing view, a right three-quarter view, and a right profile view). That is, does learning different view combinations produce the same level of recognition performance of a novel view, is a difference measurable, and could such a difference be attributable to the type of information each view type provides?

1.5.3 Within-identity variation

Variation in visual perception of the world, and how one can maintain a seamless and continuing appreciation of the environment one inhabits and travels through, has interested many research fields. This also applies to how unfamiliar faces become familiar, in that familiar faces seem to provide a ‘seamless’ appreciation of identity, even when large variations occur. An explanation for how this might occur was proposed in a review of M. D. Vernon’s work on visual perception by the celebrated face researcher Dame Vicki Bruce (Bruce, 1994). Bruce discussed how difficulties with matching and recognition of unfamiliar faces could be better understood if one were to consider that stable representations of face stimuli (i.e., familiar faces) are produced by exposure to variation between exemplars of the same category (a face), and within the same sub-category (identity).

It was argued that within-identity variability, such as in expressions, angles of view, lighting changes, contrast and shadow etc., all combine to create the ‘stable representation’ that experimental researchers would characterise as a ‘familiar representation’ (and see, Burton, Jenkins, Hancock & White, 2005; Jenkins & Burton, 2011). Furthermore, it was also observed that variation within the same sub-category (identity), which can include variance in appearance (Burton, Kramer, Ritchie & Jenkins, 2016; Jenkins, White, Van Montfort & Burton, 2011), also aids familiarisation due to variation being linked to the same ‘identity’ (Burton et al., 2005; Jenkins & Burton, 2011), and that variation between exemplars provides more robust face learning over repetition of the same exemplars (Murphy, Ipser, Gaigg & Cook, 2015).

A paper that extends this view and returns to the Bruce and Young (1986) framework of familiar face recognition to understand the importance of within-identity variability, was that of Burton, Jenkins and Schweinberger (2011). Here the authors returned to the idea of FRUs, and specifically, Bruce and Young's proposal that both 'pictorial' and 'structural' codes are recruited in the encoding and recognition of familiar faces. Burton et al., proposed that the FRU concept must be updated as both pictorial and structural representations, as well as other contextual episodic representations, are necessary for any robust representation to become familiar. They further pointed out that future experimental work based on their revised idea of what constitutes an FRU must encompass the richness of within-identity variability in its design, while at the same time acknowledging that difficulties in constraining such variability in experimental settings in a search for ecological validity is not simplistic.

An applied example of when within-identity variation of unfamiliar identities can occur, is that of photo-identity documents, which was investigated by Bindemann and Sandford (2011). Their study provided three photo-identity cards for the same unfamiliar identity which included everyday within-identity variability, and tasked participants to make matching judgements to a set of foils that included the target identity. Matching performance was poor and in-line with other unfamiliar face matching research. In this relatively simple and elegant study, the authors clearly demonstrated that within-identity variability of someone unfamiliar can cause sufficient disruption to the task of matching, even when three examples of that target were shown amongst foils (and see Kemp, Towell & Pike, 1997, for similar results using credit cards).

More recently, a study by Andrews, Jenkins, Cursiter and Burton (2015), that involved participants undertaking two card sorting tasks of unfamiliar faces, found that when participants were left to sort the cards into separate identities, without any guidance on the number of identities present, participants performed poorly, producing a greater number of piles of separate identities than were present. However, when another set of participants were provided with the number of identities included in the card-set, performance became highly accurate. So, it would seem that providing the number of identities present changed the matching strategy of participants, such that they possibly no longer saw the individual cards of faces as individual people, but instead attempted to find constraints and commonalities between similar images that might represent the same identity. Essentially then, suggesting that a more part-by-part featural matching strategy approach was taken that may have focussed on perhaps similarities between the parts of the faces that shared structural similarities (e.g., nose width, length).

To further understand the way in which within-identity variability might lead to familiarity, a study by Kramer, Ritchie and Burton (2015) investigated ‘set-averaging’, using sequential and simultaneous presentation. The critical element of this study for the current discussion was that participants reported seeing an average of the set more often than was presented, as well as being accurate at matching to previously seen exemplars. This suggests that not only were pictorial representations stored and accessed (i.e., exemplars), but that providing multiple examples of the same identity with sufficient within-identity variability, seemed to generate an average representation as well, a representation that had not been seen before. This can be regarded as being very similar to the prototype effect discussed previously,

but importantly, proposed that both exemplars as well as the average were accessible during recognition.

It has also been found that providing greater numbers of visual examples of the same unfamiliar identity, with sufficient (high versus low) within-identity variation, leads to greater accuracy in matching ability (Ritchie & Burton, 2017), over and above any effect of trial-by-trial feedback (Dowsett, Sandford & Burton, 2016), and this can even be achieved with computer generated views based on photographic exemplars (Jones, Dwyer & Lewis, 2017). This evidence would therefore seem to suggest that visual variation within the same identity drives the process of learning, in that learning of unfamiliar faces is implied to have taken place by virtue of greater matching accuracy.

This was investigated in a study by Burton, Kramer, Ritchie and Jenkins (2016), testing the idea that learning faces involves a process of abstraction of within-identity variability. Using the computational method of Principal Components Analysis (PCA) between different exemplars of celebrity faces, they found that each identity possessed a set of constraints that were individual, as opposed to a set of rules that could be applied to any identity. This is an important distinction, in that it highlights how a visual cognitive system might statistically represent exemplars of the same entity (in this case the same celebrity), only once the system ‘knows’ that what it is exposed to represents the same thing. When this is not clear, as found in Andrews et al.’s (2015) unconstrained card sorting task, the cognitive system does not ‘know’ that the multiple images represent only a few identities, and so carries out a less efficient and less accurate matching process, leading to poor matching accuracy overall.

Furthermore, a study by Tong and Nakayama (1999) found that there seems to be an effective maximal level of representation for ‘overlearned faces’, such as one’s own face. That being said, it must be noted that faces change over time, due to aging and weight gain/loss, amongst other possible changes, so such a representation must be able to accommodate these variations and not be so rigid as to cause a lack of, or reduced, recognition ability. Indeed, in a review of their own model, Young and Bruce (2011) make this point by clarifying that FRUs must change over time, “just very slowly” (p. 970). Anecdotally, it can be observed that people often take longer to recognise a familiar face that is substantially different to the representation stored (e.g., if someone has not been seen for several years), but are very accurate nevertheless. Therefore, while Tong and Nakayama (1999) reported that very little additional information can be added to ‘overlearned faces’, intuitively, and as Young and Bruce (2011) concluded, the small adjustments and updates that do occur seem to be critical in allowing recognition of familiar people, even after substantial within-identity variation.

In summary, it seems that within-identity variation drives face learning, which is implied by greater matching and/or old/new recognition ability, and that the prototype effect and set-averaging (which may represent very similar processes), are somewhat close to the FRU idea proposed by Bruce and Young (1986). Clearly though, it seems that an FRU only requires that the abstracted structural codes are interlinked, and presumably separately accessible (similar to the set-averaging evidence). However, the prototype evidence seems to suggest that the average representation is more powerful than the exemplars, so to understand this apparent difference in more detail, the next section will directly review a selection of work that concerns the prototype-effect specifically.

1.5.4 The Prototype-effect

As was touched upon in the previous section, the prototype effect can be defined as better recognition accuracy for the unseen central value (prototype) of several exemplars than the exemplars themselves (e.g., Jenkins, White, Van Montfort & Burton, 2011; and see, Zheng, Mondloch & Segalowitz, 2012, for similar electrophysiological evidence). This finding is in some ways similar to the FRU as proposed by Bruce and Young (1986), in that the representation formed is the result of many episodic encounters that become interlinked and can aid recognition of a novel view, but as noted in the previous section, the FRU account does seem to imply that access to exemplars does seem possible, so this apparent implied difference will need to be clarified experimentally.

Further to the prototype effect itself, a study by Cabeza, Bruce, Kato and Oda (1999) found, across five experiments, a tendency to incorrectly accept the prototype as a previously seen image. However, the prototype effect was regarded as less powerful than a separate much simpler mechanism that compared test views to views already seen. In other words, when the viewpoint changed, it was argued that participants were using stored exemplars that were closest to the test viewpoint, which in turn suggests that on-line exemplar comparison and interpolation was a better explanation for the results they found. They also found that the prototype effect worked within identity but not between identities (i.e., it was dependent on within-identity variation), and that the prototype effect could lead to generating false memories of face representations for identities not encountered at all. In other words, this is suggestive of the idea that all exemplars are used to form a prototype, even when these exemplars may not represent the same identity, but are inferred by the cognitive system as representing the same identity. Or and Wilson (2013) also found

that the prototype was recognised more often as being seen before, rather than the exemplars, and that this effect lasted over one week's duration. However, their results and conclusions differed somewhat from those of Cabeza et al. (1999), in that they found that the prototype effect could generalise across viewpoint changes, concluding that head shape and internal features separately contributed to prototype formation found in their study.

Wallis, Siebeck, Swann, Blanz and Buelthoff (2008) also investigated the prototype effect by testing an abstract feature model. Over three experiments and an experimentally informed neural network model implementation, they used 3D images constructed from laser scanned heads. Prototype stimuli were constructed from the random sampling of different mouth, nose and eye regions of accumulated stimuli, and these prototypes were then used to generate each head type. These were classed in terms of their 'distance' from the prototype, such that one had 3 regions (i.e., a distance of 3: mouth, nose and eye regions) in common with the prototype, another had 2 regions (i.e., a distance of 2), another 1 region (i.e., a distance of 1), and the final having nothing in common with the prototype (i.e., a distance of 0). All three experiments provided a training and test phase, with Experiments 1 and 2 finding full support for better recognition of the prototype over exemplars. However, in Experiment 3 that tested recognition of both upright and inverted faces, it was found that recognition performance of each was in line with an advantage for the prototype, and additionally, that inverted face prototype recognition was significantly greater than upright prototypes. The authors concluded that their results supported a featurally based, 'multiple local feature analyser' processing model, in that featural abstraction could be said to have been used to construct the prototype, without the need for any global or holistic processing explanations. In other words,

the prototype advantage resulted from the encoding of sub regions of the face (i.e., mouth, nose and eyes in their experiments), rather than encoding based on the configuration of features and their relationship to each other (i.e., global or holistic encoding).

The studies reviewed so far suggest that the prototype effect provides a reasonably good explanation for many learning and recognition effects, and may help to explain how unfamiliar faces are learned. Indeed, as previously mentioned, the prototype effect seems to share many similarities with Bruce and Young's (1986) conception of an FRU, in that an accumulation of exemplars results in an 'average' representation. It is clear that research such as this supports the idea that information extracted from exposures to different exemplars, within the same identity, results in a representation that can be regarded as an accumulation of this information, and that this representation is more powerful and provides greater utility than individual exemplars alone – but as has been highlighted, this is not always the case.

However, the suggestion by Cabeza et al. (1999) that view change recognition processes rely on access to exemplars, and somewhat contradictory finding by Wallis et al. (2008) that concluded that prototype effects also assisted view change recognition of novel views, is somewhat at odds. It could for instance be the case that what these two fields of research found was a flexible representation that allowed access to prototypes and exemplars, based on the utility of each for the particular task demands at hand. In other words, this conclusion would simply imply that both exemplars and an accumulation of exemplars (i.e., the prototype), are not distinct entities or representations, but are instead better thought of as a pool of information that can be flexibly separated or combined, based on their utility for answering a recognition question. This characterisation is not that dissimilar to the

‘multidimensional face space’ model of Valentine (1991), and therefore careful reflection on the forthcoming experimental results will need to be considered in terms of these accounts.

1.5.5 Internal features

The internal features of a face have been found to be diagnostic of familiar face matching. A series of face matching studies by Clutterbuck and Johnston (2002; 2004), tested participants on the internal and external features of different levels of (independently rated) familiar faces. Their results indicated that matching performance, in terms of reaction time, were faster when matching familiar than unfamiliar faces on their internal features, and that external feature matching favoured familiar faces for correct rejections (i.e., correctly responding that faces did not match). They also tested the ‘internal feature advantage’ in an unfamiliar face training procedure, with a recognition test occurring on the following day. They found that training produced a shift to an internal feature matching advantage that resulted in greater matching accuracy for familiarised (learned) faces over unfamiliar faces, and familiar (famous) faces over familiarised (learned). They concluded that a shift to greater internal feature matching for familiarised faces (learned) over unfamiliar faces was evidence of acquired familiarity (and see, Osborne & Stevenage, 2008, for similar findings that additionally highlight configural processing being at the heart of this effect).

Meinhardt-Injac, Meinhardt and Schwaninger (2009) also compared internal and external feature matching, and concluded that internal features were processed by configuration sensitive mechanisms that were affected by orientation and

viewpoint, but that external features were restricted to the features themselves, rather than their orientation and viewpoint, and thus, configuration. This evidence suggests that the internal feature matching advantage co-occurs with the configuration of features, aiding recognition across viewpoint changes, and might represent the formation of an integrated representation that could be regarded as indicative of acquired face learning.

More recently, Longmore, Liu and Young (2015) also tested the internal feature advantage for unfamiliar faces, to understand which cues were most useful in generalising to novel views. They found that multiple exposures to a single image of an unfamiliar face produced better internal feature matching at test than when exposure had occurred only once – indicating that internal features were diagnostic of face learning. They then extended this finding by testing participants when the view was changed. Results provided evidence that learning the internal features of a face produced a representation that could withstand rotational differences between learned and tested views, and importantly, this advantage was demonstrated for learned, previously unfamiliar faces.

The Longmore et al. (2015) study, and the previously cited studies, clearly indicate that exposure to the internal features of a face, and their configuration, enables better recognition when a novel view occurs, but also that multiple exposures are required for this process to occur. This is perhaps not surprising, as the external features of a face are subject to constant change, but rarely do the internal features change, at least in a relatively rapid way. Of course, internal features do change over time with aging and weight gain/loss etc., but (apart from cosmetic surgery or injury), these changes are slow, and the changes can be applied to the familiar representation as ongoing updates. However, when large changes occur,

such as aging or weight gain/loss etc., and the person is not seen for a substantial period, people are still able to accurately recognise familiar faces (e.g., Bahrick, Bahrick & Wittlinger, 1975).

Clearly then, a shift toward an ‘internal feature processing advantage’ does seem to be diagnostic of familiar face processing, and encouraging or directing participants to the internal features of unfamiliar faces, when learning, should enable reasonably quick uptake of new identities. This may therefore provide a rapid and relatively easy route into training people in laboratory settings, so that a greater number of aspects of face learning can be investigated. Indeed, the later work of Longmore et al. (2015) that investigated the internal feature advantage by cropping external features, and produced a representation that could withstand rotational differences between learned and tested views, provides supporting evidence for this manipulation to be applied in the forthcoming experimental design.

1.5.6 Static/dynamic viewing

The role of motion is an important aspect of learning faces when one considers that most of our experiences with faces in the real world occurs through interactions that are kinetic, with famous face recognition demonstrated to be improved by distinctive motion (Lander & Chuang, 2005). Lander and Bruce (2003) investigated the influence of motion over four learning-test experiments that included two types of motion: rigid motion that included head nodding and shaking, in which the whole head and its orientation in space was considered; and non-rigid motion that included talking and expression, in which the face itself moved but the head did not. They found that an advantage was gained for learning faces in motion,

irrespective of whether they were rigid or non-rigid, compared to static images. The authors argued that the role of motion, compared to static face viewing, may simply be due to motion creating an attentional bias that encourages deeper encoding of the stimuli.

Allied to this idea is the role of motion in learning new faces when one considers ‘characteristic motion’, or such idiosyncratic motion that can become attributed to an identity. A study by Lander and Davies (2007; and see Butcher & Lander, 2017) involved participants watching either one, two, three, or four episodes of a television drama, and subsequently carrying out an identity recognition test in either static form or moving. They reported that a significant advantage was found in recognition accuracy only when the face had been learned in motion and tested in motion, but not when tested as static images, and that as exposure increased (i.e., single vs. multiple episodes), so recognition accuracy improved. They suggested that learning ‘characteristic motion’ is rapid, and speculated that the representation formed may be dynamic in nature, as recognition of static images was poor in comparison to moving images.

Taking this speculation further, an indirect test of the nature of motion in face learning can be made clearer in a study by Favelle, Tobin, Piepers, Burke and Robbins (2015), in which the question concerned whether moving faces were processed holistically, compared to static faces. They found no difference between moving and static faces after an initial period of extensive familiarisation that included feedback, and a subsequent test phase in which participants were required to provide the name for the top half of the static and moving composites. The authors concluded that, whether static or moving, faces are processed holistically, and that experiments that only employ static faces are still subject to the same

holistic processing constraints as moving faces. This is an important finding as it supports the use of static images in face learning experiments, and highlights that any advantage gained from motion is smaller than that gained from our natural tendency to process faces holistically (and see, Bonner, Burton & Bruce, 2003).

Taken together, the above studies highlight that motion is not necessary for face learning (e.g., Liu, Chen & Ward, 2015), but when included it becomes associated with, or bound to the representation formed, with greater detail and complexity (e.g., ‘characteristic movement’) enhancing its representation. It has also been found that active manipulation of 3D face images during learning and recognition, compared to passive viewing, can improve recognition accuracy (Liu, Ward & Markall, 2007). It can therefore be understood from the aforementioned studies that the process of forming a representation is not dependent on static or dynamic presentation, as neither has been shown to provide an advantage for learning over the other, and both are processed in a holistic manner. However, it does seem to be the case that the representation can be enhanced by the introduction of movement cues, but only when the representation at test is itself dynamic. For the forthcoming experiments then, stimuli will be presented during learning and test in the same static form, for different or same views, so that any effect of idiosyncratic movement cues can be ruled out as a route to learning and/or recognition.

1.6 Thesis aims and overview

The Bruce and Young (1986) model has provided face researchers with a language and set of concepts with which to test many of its predictions. At the heart of the model was the proposition that each identity was represented by a Face Recognition Unit (FRU). This FRU representation was suggested to be produced from the accumulation of abstracted visual structural code information that represented the ‘arrangement of features’, and that these become ‘interlinked’ to form an FRU for each identity. However, as the authors stated themselves, how structural encoding leads to an FRU was left for future researchers to investigate. Clarity of this crucial ‘missing’ operation has led researchers to investigate how this might take place and what form of structural encoding might be required in producing an FRU. It has alternatively been suggested that FRU formation may not be an accurate description of how faces are learned, and instead suggest a ‘pictorial’ account of face learning, in which a greater number of episodic traces leads to better recognition (e.g., Liu & Ward, 2006; Longmore et al., 2017; Longmore, Liu, & Young, 2008; Megreya & Burton, 2006).

To further clarify findings that support ‘pictorial accounts’, the work of Longmore, Liu and Young (2008), over six experiments, examined the effect of providing multiple exposures and views of unfamiliar faces, when tested on the same image or transformed views. Each experiment had the same three consecutive phases: a ‘first presentation’ phase, a ‘training’ phase, and a ‘testing’ phase. The ‘first presentation’ phase included viewing only a single presentation with a name, the ‘training’ phase then involved participants matching names to presented faces, with all name options presented simultaneously with each face image, and accuracy feedback was provided. In this phase, participants were required to correctly name

all faces in a block to continue onto the next block, with correct responses removed and errors re-presented until all were accurately responded to, and training was completed when all faces were correctly named on three occasions. Finally, in the ‘testing’ phase, participants had to decide if the face presented was from the training set or not, but were not required to recall or recognise the name.

For Experiment 1, transformations of lighting or pose were compared when learned from single or multiple images of a single view, finding that novel view recognition was equally poor whether exposed to single or multiple images. Experiment 2 then tested if recognition accuracy was equally poor for a pose change or was graded as a function of pose change, with results revealing that recognition accuracy declined as a function of degree of rotation from that learned. Experiments 3, 4 and 5 then provided multiple exposures to more than one image, compared to single image learning, finding that generally, novel three-quarter view recognition accuracy was greater after two-views were learned, compared to single-views, but this was not significant; however, two-view accuracy on the novel-view was found to be significantly poorer than same view learned and tested. Experiment 6 finally tested pose and lighting transformations together and separately, finding similar results to Experiment 1, where recognition performance reduced as a function of difference from the image learned.

Overall, it was concluded that all results could be accounted for by image effects. That is to say, the ‘pictorial’ properties of the images were encoded over any evidence of ‘structural’ encoding, and these ‘pictorial’ codes were used to answer novel-views or images, with two-views providing better (but not significant) recognition of a novel-view, over single-views, due to both views being available for comparison, rather than any effect of combination of these views (i.e., an FRU

account). It is therefore possible to conclude from Longmore et al.'s (2008) experiments that no evidence of structural abstraction leading to FRU formation was found, and that face learning must therefore rely on the accumulation of exemplars, with successful recognition of a novel-view being dependent on its proximity in 'pictorial' similarity with one already stored.

These two versions of how faces might be learned and represented may at first seem to be contradictory and in opposition, but other work on the 'prototype effect' and 'set-averaging' have revealed that both pictorial and structural representations may be available when a recognition decision is required, and that the utility of each for the task at hand might be recruited individually or simultaneously to answer a recognition question. It is this lack of finer detail of what is necessary for faces to be learned that has tasked researchers, and clearly requires further examination.

This thesis will therefore examine how faces become familiar by examining the type of representation formed during unfamiliar face learning, using empirically supported techniques that are thought to encourage the rapid visual learning of new identities. These learning techniques will include: cropping external features to encourage an internal feature processing advantage, providing static images in single-views and two-views in rapid succession to allow multiple encounters with many identities, and using a one-back matching procedure to encourage within-identity variation matching, and therefore learning. This learning technique will then be assessed by testing participants using an old/new recognition task on the same single view(s) learned, or critically, a novel view (see Figure 1-3 for a visual representation of the basic experimental design for all experiments).

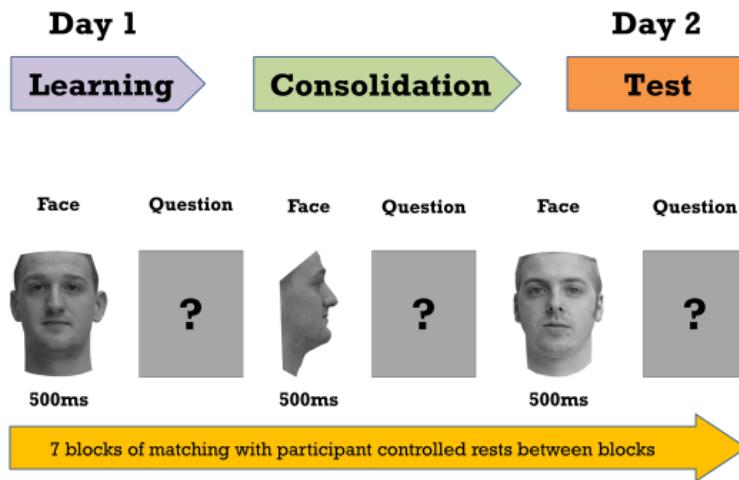


Figure 1-3. Design for all behavioural experiments that include a period of overnight consolidation (i.e., Experiment 1, 3, 4, 5, 6 and 7).

If the Bruce and Young FRU account of face learning is supported, then recognition of a novel view will be significantly greater when two-views were learned compared to only one of the single views. However, if a ‘pictorial’ account is supported then there will not be a significant advantage from learning two-views. Therefore, the central hypothesis that will be tested over all experiments is that face learning occurs through the encoding of abstracted structural information from face images, and that these will become interlinked (i.e., when two-views are learned) to form an FRU for each identity, that will aid recognition accuracy of a novel view (i.e., testing the model of Bruce and Young, 1986). The type of representation formed will further be tested by changing the the type and extent of structural information provided by the single views and two-views learned, and this will help

to establish whether the information provided in each view type learned influences the utility of the representation formed.

The experiments are split into four main chapters. Chapter Two includes three behavioural experiments, with the first of these (Experiment 1) examining whether learning two different views (front-facing and right-profile) of unfamiliar faces leads to better recognition of a novel test view (right three-quarter view), when compared to having only learned one of these views. And will include a period of overnight memory consolidation which it is thought will strengthen any representation formed. The second experiment (Experiment 2) will then extend the findings of the first experiment by testing whether a period of overnight consolidation is in fact necessary for view-invariant recognition to occur (i.e., an FRU effect). And the third experiment (Experiment 3) then will further extend the findings of the previous two experiments by testing participants on a novel test view that is outside the rotation of those views learned (i.e., a left three-quarter novel test view when those learned were a front-facing and right-profile view). This will be carried out to establish if an FRU representation that might be formed could assist in recognising a novel view, without relying on interpolation between those views learned.

Building on the findings from Chapter two, Chapter Three, which includes four behavioural experiments, will first (Experiment 4) examine to what extent does the ‘construction’ of an FRU require variation in the two images learned. To investigate this, mirrored profile views will be used during the learning phase that only vary in the direction of each image, but are otherwise the same image, and will be tested on those views learned, and a novel front-facing view. The second experiment (Experiment 5) will then proceed to tests true profile views, on the same

novel test view (front-facing view), so that a comparison can be made with the results from the previous experiment (mirrored profile views, Experiment 4). This will be carried out to establish whether FRU formation is dependent on within-identity visual variation, rather than just image variation. The third experiment (Experiment 6) then moves on to test two-views that are true three-quarter views, using the same novel front-facing test view, to understand if view-utility, in the form of assumed increased structural information provided by three-quarter views, will result in better performance on the novel front-facing test view, compared to having only learned one of these views. And the final experiment in this chapter (Experiment 7) will then test whether two views that overlap substantially in structural information (i.e., left profile and left three quarter view), will also produce an FRU representation that can aid novel view recognition. Taken together, Chapter Three intends to assess how different view types perform based on their image similarity and structural utility, in terms of the formation of an FRU representation.

Chapter Four then builds on the previous behavioural chapters by introducing electroencephalography (EEG) to the learning and recognition phases. Two Event Related Potential (ERP) components which have been found to be markers of perceptual repetition and memorial effects associated with face identity processing will be investigated (i.e., N250r & FN400). The purpose of introducing the EEG/ERP method to the study was to establish if it would be possible to identify differences between perceptual processing effects when single-views and two-views were being matched during the learning phase, and recognition memory effect differences in the test phase. It was anticipated that if sufficient learning had taken place, which replicated the results of the previous behavioural experiment (i.e.,

Experiment 1), then the EEG/ERP method would allow a quantitative investigation of potential electrophysiological differences between the type of view(s) learned and recognition memory effects based on such learning. Finally, Chapter Six summarises the main findings of the current work, and concludes by discussing possible future directions.

Chapter 2: Learning unfamiliar faces using a sequential matching procedure

2.1 General introduction

The following three experiments were designed to test the hypothesis that face learning occurs through the abstraction of structural information which become interlinked to form a face recognition unit (FRU) for each identity (Bruce & Young, 1986), and that formation of such an FRU representation aids recognition of a novel view. To test this, participants learned either one of two single views of unfamiliar identities, or both-views. If the FRU account of face learning is supported, then recognition of a novel view of learned identities will be significantly greater when two-views were learned compared to either of the single views.

2.2 Experiment 1: Recognition accuracy after overnight consolidation

For the first experiment, participants underwent a learning phase and recognition test phase, separated by an overnight period of consolidation, with views to be learned being either a single front-facing view or single right-profile view, or both of these views, with the test views being the same single views learned, or a novel right three-quarter view (i.e., a previously unseen view). Due to face learning and recognition experiments being predominantly carried out on the same day, with at best only a few minutes between the learning and test phases, it was decided that a period of overnight memory consolidation (i.e., a process by which long term memories undergo progressive maintenance after acquisition) be afforded. An opportunity for memory consolidation was included to provide any representation

formed (i.e., ‘pictorial’ and/or FRU) the greatest chance of becoming ‘robust’, and thus aiding recognition accuracy for all view types learned (i.e., single-views and both-views).

The role of sleep in declarative memory formation is widely known (e.g., Ellenbogen, Payne & Stickgold, 2006; Tronson & Taylor, 2007). For example, research on novel word learning has suggested that consolidation does not necessarily occur immediately after learning, but instead may occur later after a period of sleep, despite no further encounters with the learned items (e.g., Dumay & Gaskell, 2007). A review of literature in relation to the role of sleep in declarative memory consolidation (Ellenbogen, Payne & Stickgold, 2006) concluded that ‘permissive consolidation’ and ‘active consolidation’ during sleep supported the idea that sleep itself provided properties that encouraged memory consolidation to take place, which in turn supported improvements in recognition accuracy.

A study by Wagner, Kashyap, Diekelmann and Born (2007) specifically addressed this concept in terms of recognition for faces with different facial expressions (and see, Thornton & Kourtzi, 2002). Participants were in one of two groups. The first was a group that had one night’s sleep immediately following learning, and the other group did not sleep after learning, but were awake during an equated period of eight hours. The principal result was that those in the sleep group were significantly more accurate in the recognition test stage than those without sleep, and that this did not depend on expression type, indicating that the variable of sleep was instrumental in greater recognition accuracy, and a review of memory ‘reconsolidation’ (Tronson & Taylor, 2007) further suggested that memories can be modified, post-establishment.

The previously mentioned evidence supports the view that memory consolidation is, at the very least, improved by a normal period of sleep when compared to wakefulness (e.g., Dumay & Gaskell, 2007; Ellenbogen, Payne & Stickgold, 2006; Wagner, Kashyap, Diekelmann & Born, 2007). It is therefore important to consider, in face learning experiments, that a period of consolidation be included to accurately measure familiarity, so that short term memory effects are avoided, and the consolidation of different views and/or different identities can be assessed on an equal basis. For instance, it may be that short-term learning depends on different mechanisms leading to memory formation, and that this may not be equally applicable to different stimuli constructions (i.e., such as single views, multiple views, etc.). In terms of Bruce and Young's (1986) conception of FRUs, it is suggested that an overnight period of sleep consolidation would assist such a representation, so a minimum period of consolidation will be provided to test the formation of FRU-like representations.

2.2.1 Method

Participants

Twenty-seven Caucasian undergraduates (22 females, 5 males) aged between 18 and 32 years (mean age, 19.7 years) participated in exchange for course credit. All participants had normal or corrected-to-normal visual acuity (self-report) and no history of neurological illness (self-report). All participants gave informed consent and the procedures were approved by the University of Kent, School of Psychology Ethics Committee.

Materials and Apparatus

Images were presented on a 17-inch LCD monitor (display resolution, 1440 x 900). Responses were made using a standard computer keyboard and the experiment was controlled with SuperLab 4 (Cedrus, Phoenix, Arizona, USA). All images were 15° (13.5 cm) vertically and ranged from 6.3° to 13.5° horizontally. The faces of 59 Caucasian men, taken from the Glasgow Unfamiliar Face Database (GUFD: Burton, White & McNeill, 2010), were manually cropped using Adobe Photoshop Elements (version 11) to remove background detail and head hair, and all were free of non-face distinguishing features (e.g., tattoos, glasses and jewellery). The database contained two sets of greyscale photographs, representing the same identities taken with different cameras (camera sets 1 and 2) and from various viewpoints. For all identities, six types of image were prepared from each camera set: two front-facing (FF), two right-profile (RP), and two right three-quarter (RTQ). The RTQ views were used only in the test phase. Five identities were used in the practice session and were not used again in the learning or test phases. Twenty-seven identities were randomly selected for use in the learning session and shown as images from camera set one. This set was the same for all participants. During the test phase these same identities were shown but with images from camera set two. The remaining 27 identities were not seen in the learning phase and were only encountered as distractors in the recognition test session. See Figure 10 in the appendix for examples of each view type for four identities.

Design

The learning phase comprised a 7x3 within-subjects design with block number (1-7) and learned view: front-facing view only (FF), right-profile view only (RP), and two-views (TV), as factors, with each identity appearing in only one of the learned views for each participant. To counterbalance the 27 identities across the learned view conditions, identities were randomly split into three learning groups (A, B, and C) of nine identities, assigned to the learned view conditions according to a Latin square design (see Table 2-1, top table), with these further broken down into three levels for each learning group (A1-3, B1-3 and C1-3), so that identity could be counterbalanced with test view type.

The recognition test phase then comprised a 3x3 between-subjects design, with learned view (FF, RP and TV) and test view (FF, RP and right three-quarter view – RTQ) as factors. The test phase between-subjects design (learned view x test view) was chosen because although each participant was tested on all three test views, they did not all equally map onto a single learned view factor for each of the identities (see Table 2-1, bottom table). Therefore, each target identity appeared in each of the three test views (i.e., 27 identities as FF, RP and RTQ), and this was counterbalanced by an equal number of distractors, providing nine learned view by test view means in each cell (see Table 2-1, bottom table). The percentage of hit responses to target identities (i.e., saying ‘yes’ to faces previously encountered in the learning phase), and the percentage of correct rejection response to distractor identities (i.e., saying ‘no’ to faces not previously encountered in the learning phase), were measured in both phases. No feedback on accuracy was provided in either of the phases, but accuracy was encouraged over speed of response.

Table 2-1

Learning and Test Phase matrix, indicating learned view type and test view type, as well as identities used in each phase (top table), and Learning Group assignments to each learned view x test view cell (bottom table).

Participant	Learning Group	Learn Two-View Identity	Learn Front View Identity	Learn Profile View Identity	Test Three-quarter View Identity	Test Front View Identity	Test Profile View Identity
1-3	A1	1-9	10-18	19-27	1-9	10-18	19-27
4-6	A2	1-9	10-18	19-27	10-18	19-27	1-9
7-9	A3	1-9	10-18	19-27	19-27	1-9	10-18
10-12	B1	19-27	1-9	10-18	1-9	10-18	19-27
13-15	B2	19-27	1-9	10-18	10-18	19-27	1-9
16-18	B3	19-27	1-9	10-18	19-27	1-9	10-18
19-21	C1	10-18	19-27	1-9	1-9	10-18	19-27
22-24	C2	10-18	19-27	1-9	10-18	19-27	1-9
25-27	C3	10-18	19-27	1-9	19-27	1-9	10-18

	Test Front-view	Test Right three-quarter view	Test Right-profile view
Learn Two-views	A3, B2, C1	A1, C2, B3	A2, B1, C3
Learn Front-view	A1, C2, B3	A2, B1, C3	A3, B2, C1
Learn Right-profile	A2, B1, C3	A3, B2, C1	A1, C2, B3

Procedure

During both the learning and test phases, participants were seated approximately 50cm from the screen and the face stimulus was presented at the centre of the screen against a white background. Before the learning phase commenced, participants completed a short practice session which had the same format as the learning phase (described below) but with only five identities (not seen in the rest of the experiment) and 19 trials. No feedback was given about accuracy. Upon successfully completing this, participants initiated the first experimental learning phase block with a button press. Participants were not explicitly informed that they would be tested on their memory for the faces they had been exposed to in the matching procedure.

Each of the seven blocks of the learning phase comprised 162 face stimuli. Each face appeared in the centre of the screen for 500ms and was followed by a blank screen for 500ms. This was then followed by a message (black text on a grey rectangle) asking participants whether the last identity they saw was the same as the one before (i.e., a one-back identity matching procedure), responding by means of a key-press: ‘c’ for yes and ‘n’ for no. Responses were only recorded once the message appeared (i.e., participants had to wait to make a response). Participants were instructed to favour accuracy over speed and no feedback was provided.

Within each block, each identity appeared six times. Two-view identities were presented as two triplets of the same identity in the different views (i.e., 6 in total - FF/RP/FF and RP/FF/RP). Single view identities (FF or RP) were presented as two pairs of trials with the same image (i.e., RP/RP or FF/FF), plus two additional single trials of that image interspersed amongst the triplets and pairs to form a

pseudo-random sequence of trials (i.e., totalling 6 single views). The triplets and pairs structure ensured that the sequence would contain sufficient occurrences of match trials than if they had just been randomly ordered (i.e., one-back identity matches would have been less likely to occur if a randomised structure was imposed).

The trials were organized such that TV, FF and RP consecutive matches were alternately presented and separated by mismatches (e.g., TV-FF1, TV-RP1, TV-FF1, FF10, FF10, RP19, FF10, RP19, RP19, etc.). This also ensured that each identity and each view type was seen equally often. The trial order was different between blocks, but the same across participants. However, for participants with the different assignment of identities to conditions (see identity counterbalancing in the design section above), the exact identities for each trial would have been different but the pattern of responses identical across participants. Thus, again, particular assignment of identities to conditions was not confounded with manipulations of learned view and test view. Overall, each participant saw each identity a total of 42 times over the entire learning phase. Participants took breaks between blocks and proceeded when they were ready. For each block of trials in the learning phase there were 36 match trials for the two-views stimuli (i.e., two per triplet), and 18 match trials (i.e., one per pair) for each single view condition (FF & RP). That is, 36 matches in total across the two single view conditions. Thus, there were 72 match trials (36 TVL + 18FFL + 18 RPL) and 90 non-match trials, summing to a total of 162 responses per block.

For the test phase, participants returned the following day (a strict 24-hour return was not required). The test phase consisted of 54 face images presented in random order. Twenty-seven were target identities encountered on the previous day, and the other 27 were distractor identities that had not been encountered before. The

54 test phase images were presented in the centre of the screen at the same size as the learning images, but in a different random order for each participant. Images remained on the screen until the participant made a response via the keyboard to indicate whether the face matched an identity which they had seen in the learning phase ('y' for yes and 'n' for no). Participant response times were unlimited, and accuracy was emphasised over speed of response, with a two second interval provided between the participant's response and the next stimulus onset. Participants saw each identity only once and were not provided with any feedback. Upon completion, the participant was thanked for their time and provided with a debriefing document.

2.2.2 Results

From the learning phase data, the percentage of correctly identified matches (hits) was analysed with a 3x7 repeated-measures ANOVA with learned view type and block as factors. Departures from sphericity were corrected using the recommendation of Girden (1992): for epsilon values greater than .75 the Huynh-Feldt correction was applied, and for epsilon values less than .75 the Greenhouse-Geisser correction was applied. Effect sizes were considered based on Cohen's (1988) recommendation of .02 for a small effect, .13 for a medium effect, and .26 for a large effect.

The main effect of view type was found significant, $F(2, 52) = 19.38$, $MSE = 185.73$, $p < .001$, $\eta_p^2 = 0.42$ (Observed power = 1), with front-facing view hits greater than two-views ($p < .001$) and right-profile views ($p < .001$), and right-profile view hits were greater than two-views ($p = .013$), see Figure 2-1 for mean hits.

However, there was no main effect of block, $F(2.83, 73.58) = 1.64$, $MSE = 432.12$, $p = .189$, $\eta_p^2 = 0.05$ (Observed power = .40), but the view type x block interaction was significant, $F(12, 312) = 10.27$, $MSE = 49.46$, $p < .001$, $\eta_p^2 = .28$ (Observed power = 1).

The two-way interaction was first broken down by examining the simple main effect of block within each view type. Block was found to be significant for all view types (TV, FF and RP, all p 's $< .031$. See Table 2-2 for statistics and Figure 2-1 for means). Pairwise analysis concentrated on whether mean hit matching accuracy increased or decreased significantly between the start of the learning procedure compared to the end (i.e., block 1 versus block 7). Analysis revealed that for the TV view type, block 7 means were greater than block 1 and approached significance ($p = .050$), indicating that matching accuracy increased by the end of the learning phase. However, for the FF and RP view types, block 1 mean hits were significantly greater than block 7 ($p = .002$, $p = .008$, respectively), indicating that for each of these single views, matching accuracy decreased by the end of the learning phase.

For the simple main effect of view type at each block, it was found that this was significant in blocks 1 to 5 (all p 's $< .003$. See Table 2-2 for statistics and Figure 2-1 for means), however by blocks 6 and 7, performance was not significantly different between view type conditions (both p 's $> .070$). Pairwise analysis of blocks 1 to 5, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., $.05/3$ learned view type comparisons), revealed that at block 1, FF hits were greater than TV ($p < .001$) and RP ($p = .006$), and RP hits were greater than TV ($p < .001$); at block 2, FF hits were greater than TV ($p < .001$) and RP hits were greater than TV ($p < .001$); at block 3, FF hits were greater than TV ($p < .001$) and RP ($p =$

.003); at block 4, FF hits were greater than TV ($p = .001$); and at block 5, FF hits were greater than TV ($p = .001$) and RP ($p = .001$).

Table 2-2

Block x View type interaction simple main effects.

	df	F	MSE	p	η_p^2	Power
Two-views x Block	3.54, 92.18	2.93	163.89	= .030	.10	.73
Front-facing view x Block	3.09, 80.52	5.21	199.13	= .002	.16	.92
Right-profile view x Block	3.34, 86.90	5.14	185.13	= .002	.16	.93
Block 1 x View type	2, 52	32.99	85.89	< .001	.55	1
Block 2 x View type	1.63, 42.53	24.23	85.12	< .001	.48	1
Block 3 x View type	2, 52	13.20	61.99	< .001	.33	.99
Block 4 x View type	2, 52	6.89	62.55	= .002	.21	.90
Block 5 x View type	2, 52	7.96	83.29	= .001	.23	.94
Block 6 x View type	2, 52	0.63	54.73	= .532	.02	.15
Block 7 x View type	2, 52	2.80	64.44	= .070	.09	.52

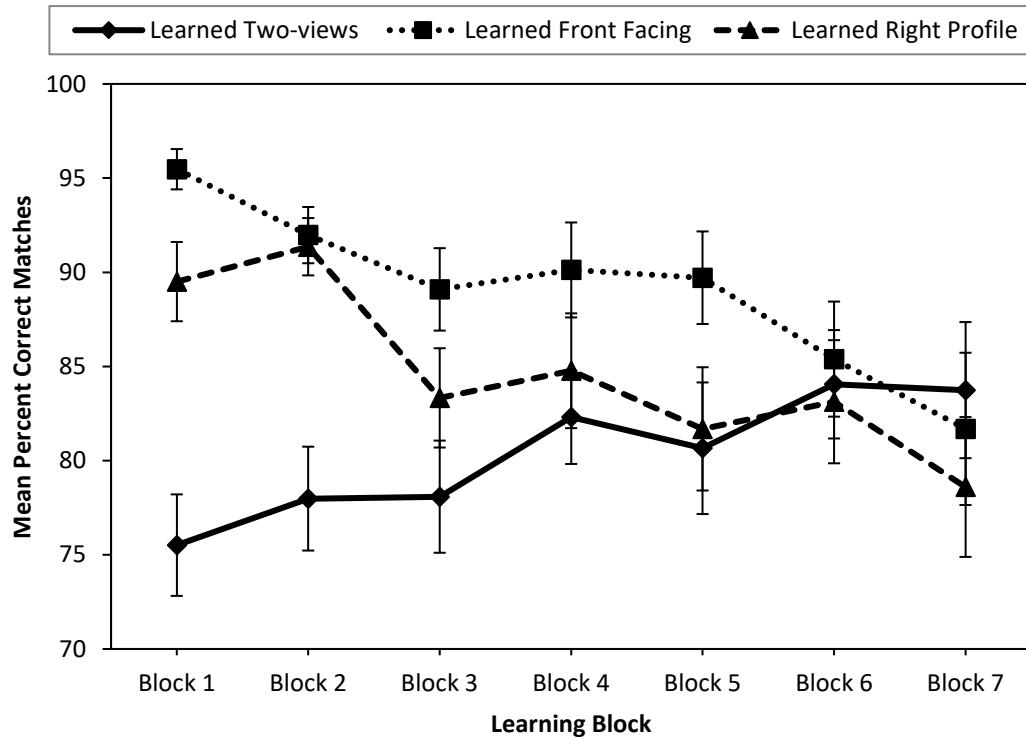


Figure 2-1. Experiment 1 Learning Phase Results. Mean percent correct one-back matching responses are plotted as a function of learned view (Two-views, Front-Facing view & Right-Profile view) at each block of learning. Error bars represent standard error of the mean.

Analysis of correct rejections, that is correctly saying ‘no’ when two successive faces did not match by identity, were analysed between each learning group (i.e., group A, B & C - referred to in the Design section), and by block (1-7), to establish whether participants were responding significantly differently between the three ‘counterbalancing by identity’ learning groups. Therefore, these two factors were subjected to a 3x7 mixed-factors design with learning group as a between-subjects factor and block as the within-subjects factor, and the dependent variable was mean percent correct rejections. Analysis revealed that the between subjects

main effect of learning group was not significant, $F(2, 24) = 1.776$, $MSE = 171.691$, $p = .191$, $\eta_p^2 = 0.12$ (Observed power = .33), the main effect of block was not significant, $F(1.740, 41.757) = 8.09$, $MSE = 142.448$, $p = .437$, $\eta_p^2 = 0.03$ (Observed power = .17), and the two-way interaction between learning group and block was not significant, $F(12, 144) = 0.757$, $MSE = 41.307$, $p = .693$, $\eta_p^2 = .05$ (Observed power = .42).

Having established that the learning phase produced an equivalent level of performance for each of the three view types by the end of the session (blocks 6 and 7), and that correct rejections were not modulated by learning group or block, analysis of the test phase was carried out. A hit rate was calculated for each participant and condition by computing the percentage of targets which received a “yes” response within each condition. These values were processed with a 3x3 between-subject’s ANOVA, with learned view (Two-views; Front-Facing Learned view; Right-profile Learned view) and test view (Front-Facing Tested view; Right Three-Quarter Tested view; or Right-profile Tested view) as factors, and hits as the dependent variable (see Figure 2-2 for mean hits). Again, effect sizes were considered based on Cohen’s (1988) recommendation of .02 for a small effect, .13 for a medium effect, and .26 for a large effect.

Analysis of recognition (hit) rates in the test phase revealed that the main effect of learned view was significant, $F(2, 72) = 21.49$, $MSE = 448.89$, $p < .001$, $\eta_p^2 = 0.37$ (Observed power = 1), with TV hits greater than FF ($p < .001$) and RP ($p < .001$), and FF hits greater than RP ($p = .042$). The main effect of test view was also found significant, $F(2, 72) = 3.68$, $MSE = 448.89$, $p = .030$, $\eta_p^2 = 0.09$ (Observed power = .65), with mean hits for RP test views greater than FF test views ($p = .008$),

but mean hits were not significantly different between TQ and FF test views ($p = .203$), and TQ and RP views ($p = .158$). Importantly, the critical interaction between learned view and test view was found significant, $F(4, 72) = 14.58$, $MSE = 448.89$, $p < .001$, $\eta_p^2 = .44$ (Observed power = 1).

Simple main effect univariate analysis of the significant two-way interaction first focused on the critical comparison to test for the FRU effect, that is, an advantage in recognition of the novel three-quarter view for identities learned from two-views over those learned from single views (i.e., comparing the three data points in the central column of Figure 2-2). The result was significant, $F(2, 72) = 5.63$, $MSE = 448.865$, $p = .005$, $\eta_p^2 = .13$ (Observed power = .84). Pairwise comparisons, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., $.05/3$ learned view comparisons), revealed that when two-views had been learned (diamond, centre column, Figure 2-2), performance was significantly greater on the three-quarter test view than when only full-frontal views ($p = .006$; square, centre column, Figure 2-2) or right-profile views ($p = .004$; triangle, centre column, Figure 2-2) were learned. Moreover, there were no significant differences between FF and RP learned views when tested with the right three-quarter view ($p = .902$).

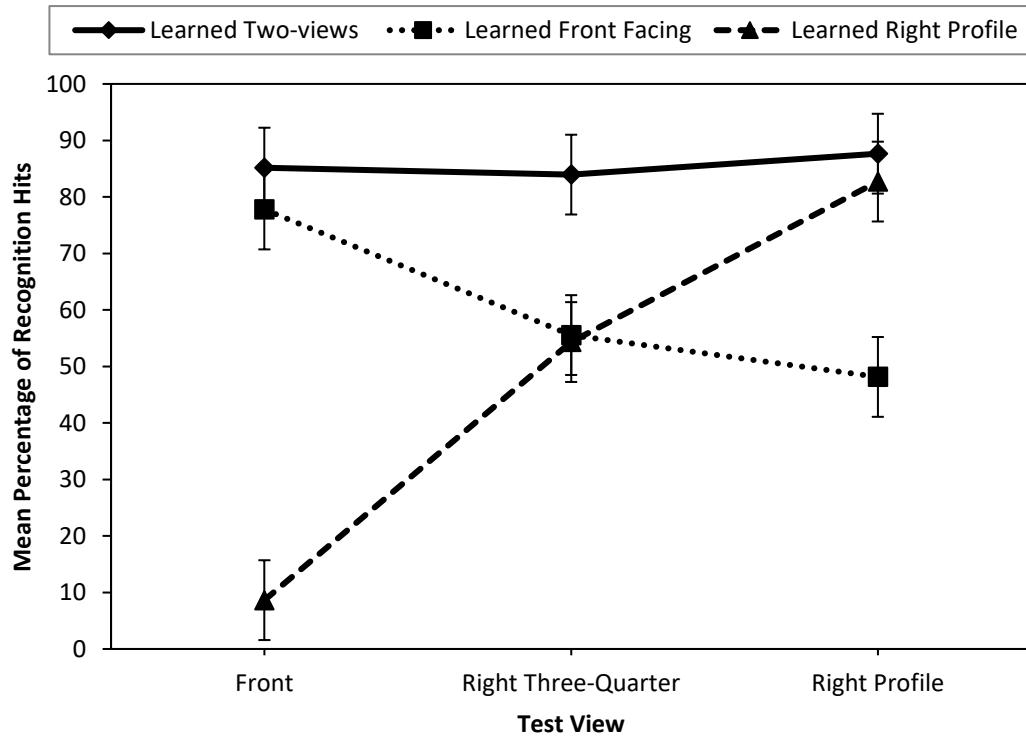


Figure 2-2. Experiment 1 Test Phase Results. Mean percent recognition hits of previously seen faces as a function of learned view and test view. The results indicate the overall effects of learning two-views or one view on recognition accuracy for three test views. Error bars represent standard error of the mean.

When the test view was a front-facing view (i.e., comparing the three data points in the left column of Figure 2-2), learned view was significant, $F(2, 72) = 35.735$, $MSE = 448.865$, $p < .001$, $\eta_p^2 = .49$ (Observed power = 1), with pairwise comparisons, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., $.05/3$ learned view comparisons), revealed that when two-views had been learned (diamond, left column, Figure 2-2), mean hits were significantly greater than when right-profile views were learned ($p < .001$; triangle, left column, Figure 2-2), and front-facing view mean hits were significantly greater than right-profile views (p

$< .001$; triangle, left column, Figure 2-2), but the difference between two-views and front-facing views was not significant ($p = .461$). When the test view was a right-profile view (i.e., comparing the three data points in the right column of Figure 2-2), learned view was significant, $F(2, 72) = 9.290$, $MSE = 448.865$, $p < .001$, $\eta_p^2 = .20$ (Observed power = .97), with pairwise comparisons again adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., .05/3 learned view comparisons), revealed that when two-views had been learned (diamond, right column, Figure 2-2), mean hits were significantly greater than when front-facing views were learned ($p < .001$; square, right column, Figure 2-2), and right-profile view mean hits were significantly greater than front-facing views ($p < .001$; square, right column, Figure 2-2), but the difference between two-views and right-profile views was not significant ($p = .622$).

Simple main effect univariate analysis of the two-way interaction (learned view x test view) was also carried out for each learned view, to understand if each learned view produced view-invariance across the three test views. It was found that when two-views had been learned, mean hit differences between test views were not significantly different, $F(2, 72) = 0.071$, $MSE = 448.865$, $p = .931$, $\eta_p^2 = .002$ (Observed power = .06). But, when front-facing views had been learned, test view mean hits were significantly different, $F(2, 72) = 4.767$, $MSE = 448.865$, $p = .011$, $\eta_p^2 = .011$ (Observed power = .77), with pairwise comparisons, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., .05/3 test view comparisons), finding that mean hits for the front-facing test view were significantly greater than the right-profile test view ($p = .004$), but not between the three-quarter test view and right-profile test view ($p = .461$), or front-facing test view and three-quarter test view ($p = .029$). Finally, when right-profile views had been learned, test

view mean hits were again significantly different, $F(2, 72) = 28.003$, $MSE = 448.865$, $p < .001$, $\eta_p^2 = .043$ (Observed power = 1), with pairwise comparisons, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., .05/3 test view comparisons), finding that mean hits for the right-profile test view were significantly greater than the front-facing test view ($p < .001$), and the three-quarter test view ($p = .006$), and mean hits for the three-quarter test view were significantly greater than the front-facing test view ($p < .001$).

A one-way ANOVA of correct rejections, with test view as a factor, showed that there was a significant effect of this factor, $F(2, 78) = 17.40$, $MSE = 229.32$, $p < .001$, $\eta_p^2 = 0.30$ (Observed power = 1), with pairwise comparisons revealing that mean correct rejections of RP test views were significantly lower than FF test views ($p < .001$) and RTQ test views ($p < .001$), but that FF and RTQ views were not significantly different from each other ($p = .138$). Mean percent correct rejections were: FF test view, 94%; RTQ test view, 88%; and, RP test view, 73%.

2.2.3 Discussion

The current experiment sought to test the functional model of Bruce and Young (1986) which proposed that face learning occurs through the abstraction of structural codes which become ‘interlinked’ to form a face recognition unit (FRU) for each identity, and that formation of such a representation aids recognition of novel views. Logically, this means that more than one example of an identity is necessary for them to become ‘interlinked’ (i.e., two-views in the current experiment), and that if only a single example is provided (i.e., single-views in the current experiment), then an FRU cannot be formed for that identity. However, it

was unclear whether this implied that single views would be encoded by their ‘pictorial’ or ‘structural’ attributes, so this aspect of the current results and previous findings (e.g., Liu & Ward, 2006; Longmore et al., 2017; Longmore, Liu, & Young, 2008; Megreya & Burton, 2006) is important to clarify. Critically though, the experiment focused on whether learning two-views of a previously unfamiliar identity produced a significant advantage over having learned either of the single-views, with recognition performance on the ‘novel’ view being the focus.

The current results revealed that indeed, recognition of the novel right three-quarter test view was significantly greater when two-views were learned compared to having learned either of the single-views, and differences between single-views were not significant on this test view. Furthermore, it was found that recognition of all test views were not significantly different when two-views were learned, indicating view-invariance which was absent for single learned views. Therefore, and based on the novel test view recognition results alone, the FRU account of face learning is supported by the evidence. That is, based on the Bruce and Young account, it is suggested that this occurred because structural codes were abstracted from two different views, and these became ‘interlinked’ to form an FRU representation for each identity. This is in contrast to learning single views that it is suggested could not become ‘interlinked’ because they only represented one example of each identity. However, to further understand this result in terms of whether ‘structural encoding’ and/or ‘pictorial encoding’ effects were present for single and/or two-views, and how these may have affected recognition performance at test, an examination of the learning phase for each view type, and performance in the recognition phase, needs to be fully considered in addition to the critical novel test view results.

The learning phase of the current experiment revealed that when two-views of the same identity were consecutively matched, performance significantly increased by the end of the session compared to the beginning (i.e., block 7 mean hits were larger than block 1), whereas single-view matching performance significantly decreased. Similar two-view (front-facing and profile) matching accuracy increase over blocks of trials has also been observed in previous research (e.g., Alenzi, Bindemann, Fysh & Johnston, 2015), and it is therefore considered that the current two-view matching pattern reflects learning of previously unfamiliar identities, and thus increasing familiarity. Increasing matching accuracy has also been found for single front-facing views over consecutive blocks of trials (e.g., Fysh & Bindemann, 2017), so the current decrease for single views (front-facing and right-profile) is at odds with previous findings. Although it is possible that this result was particular to the current participant cohort, it remains to be seen in comparison to subsequent experiments if this pattern will be repeated, so further discussion of this effect will be held until further evidence emerges (see section 4.4, General Discussion).

It was also found, somewhat unexpectedly, that correct rejection rates differed significantly across the different test view types, with correct rejection rates significantly lower for right-profile test views than for the other views. This means that participants were more likely to say “yes”, they remembered seeing the identity in the learning phase, and less likely to correctly say “no” to distractors which were right-profile views, than for the other views. This could be explained if one considers that identification of profile-views has been found to be poorer than front-facing and three-quarter views (e.g., McKone, 2008). Therefore, the correct-rejection effect reported here could reflect a response bias for the profile test view type, and may in

turn indicate that the hit rates in the right-profile test conditions were inflated.

Importantly though, this difference cannot be used to explain the FRU effect which is of primary interest here, as the conditions associated with the FRU effect all had the same test view type (i.e., RTQ - centre column, Figure 2-2).

Returning now to the previously stated differences between FRU (e.g., Bruce & Young, 1986; Burton, Bruce, & Hancock, 1999) and ‘pictorial’ accounts of face learning (e.g., Liu & Ward, 2006; Longmore et al., 2017; Longmore, Liu, & Young, 2008; Megreya & Burton, 2006). The FRU account proposes a ‘qualitative’ shift in the type of representation formed, where more than one example or view of an identity becomes ‘interlinked’ via the abstraction of ‘structural’ codes, forming an FRU. In contrast, the ‘pictorial’ account instead suggests only a ‘quantitative’ shift, with more encounters with, or examples of an identity, increasing the chances that a novel view will match, or be close in appearance to one already seen, with a degree of interpolation and/or comparison possible online. However, for clarity it is considered important to restate that Bruce and Young’s (2008) model defined ‘pictorial’ codes as representing, “any visual pattern or picture” that is, “a record of a particular static event” (p. 307), whereas ‘structural’ codes were defined as representing, “view-centred descriptions as well as more abstract descriptions both of global configuration and of features” (p. 311).

Clarifying this distinction further, ‘pictorial’ effects have been suggested to represent ‘image learning’ rather than ‘face learning’ per se (e.g., Bruce, 1994), and the experiments of Longmore et al. (2008, Experiments 3, 4 and 5) demonstrated this extensively by showing declines in recognition accuracy when single as well as two-views were learned, and subsequently tested on a novel view. However, in a later study by the same authors (Experiment 2, Longmore et al., 2015), which repeated the

same method of learning as their previous experiments (2008), a significant two-view advantage was reported on a novel test view, which was achieved by simply cropping their face images. The authors concluding that cropping the stimuli and providing two-views, “promoted the integration of information across different study views of a face, leading to enhanced generalization of recognition to a previously unstudied view” (p. 258).

Notably, the views that Longmore et al. (2015) used were the same as the current experiment, and the critical result was the same, but they did not explicitly discuss the types of codes that might have been used to achieve this result. It is argued that their more recent findings and conclusions (i.e., Longmore et al., 2015) would seem to suggest that something more than ‘pictorial effects’ were responsible for their findings, and their conclusion of ‘integration of information’ would further seem to suggest processes akin to those proposed by the FRU account. Indeed, it can be argued that ‘image learning’ (e.g., Bruce, 1994) by way of ‘pictorial’ codes, is insufficient to explain the current two-view advantage and that of Longmore et al. (2105). Instead, what was learned from two-views, at the very least, would seem to include something about the structure and/or configuration of the face that can in turn become ‘interlinked’ (i.e., the FRU account) or undergo an ‘integration of information’ (i.e., Longmore et al., 2015), which goes beyond the definition of ‘pictorial’ codes provided by Bruce and Young’s (1986) model, and instead fits well within an abstracted ‘structural code’ definition. Indeed, a study by Armann, Jenkins and Burton (2016) demonstrated this by finding that familiar faces can undergo a process by which their ‘pictorial’ detail is lost in favour of more abstract representations, whereas unfamiliar faces tend to retain their ‘pictorial’ form. This finding suggests that faces are initially learned by their ‘pictorial’ attributes, and then

over time and/or additional encounters, that more abstract representations emerge.

However, this does not seem to be supported by the findings of Longmore et al. (2015), in comparison with their earlier ‘pictorial’ findings (Longmore et al. 2008, Experiments 3, 4 and 5). Instead, it would seem to be the case that simply cropping their stimuli produced the same effect as that reported in the current experiment.

Furthermore, when addressing whether structural and/or pictorial encoding can be identified as being present when two-views were learned compared to single-views in the current experiment, the learning data alone does not allow this to be addressed on its own. However, the pattern of results in the test phase can be used to infer the type of encoding that might have taken place. It was found that when single front-facing views were learned, recognition of the same test view was very good, and was significantly better than when the test view was a right-profile view, however, recognition of the three-quarter test view was not significantly different to that of the front-facing test view. Therefore, it seems that learning a single front-facing view allows recognition of the same test view and the novel test view equally, but declines when the test view is a right-profile view. However, when right-profile views were learned, recognition of the front-facing and novel three-quarter test view declined significantly, and between these views, with three-quarter test view hits significantly greater than front-facing test views. This in turn suggested that this learned view type did not allow equivalent transference to either view that was different from that learned, again suggesting that profile views are particularly poor views compared to other view types (e.g., McKone, 2008). It would therefore seem to be evident that the type of view learned as a single view impacts the type(s) of view of the same identity that can be correctly recognised, indicating that something more than image effects (i.e., ‘pictorial’ codes) are being encoded and used to

answer a different test view. However, it must be noted that although Bruce and Young's 'pictorial' codes did allow integration of the properties of the face from an exemplar image, and were somewhat abstract in nature, they were still regarded as individual exemplars and not 'interlinked' or associated with other exemplars, for that to happen, and according to their model, an FRU would need to be formed from abstracted structural codes.

Clearly, the current findings and those of Longmore et al. (2008) are contradictory in terms of how they account for face learning. But, as stated previously, later work by the same authors (2015), who's critical result was replicated in the current experiment, attributed the two-view effect they found to internal feature processing and the 'integration of information'. In an attempt to encompass all of the available evidence (i.e., the current results and those of Longmore et al. 2008; 2015), and find a possible solution to this apparent contradictory accounting of face learning, as well as accounting for 'pictorial' and 'structural' encoding effects, it is suggested that the 'biological bar code' work of Dakin and Watt (2009) may offer a way to collapse 'pictorial' and 'structural' encoding effects into one visually derived perceptual encoding process.

Dakin and Watt demonstrated that faces are encoded as a series of vertically arranged horizontal light and dark areas representing one-dimensional horizontal components which they termed, 'bar codes'. They argued that these 'bar codes' were particularly important for the perceptual encoding and recognition of faces, allowing transference to the same and other views that are in the same orientation (i.e., upright). They further found that such horizontal 'bar codes' are resistant to transformations such as lighting and pose, and are disrupted by polarity reversal and inversion. An application of this finding was later reported by Goffaux and Dakin

(2010), who tested one-back face-matching across viewpoint changes using cropped unfamiliar front-facing and three-quarter views. Their findings indicated that the structure of the face transferred well from front-facing to the three-quarter view, which was suggested to be due to the bilateral symmetry of front-facing views. Although this experiment was not carried out in reverse (i.e., three-quarter to front-facing views) but is assumed to work to the same degree, it was confirmed that horizontal ‘bar codes’ that represent the encoding of spatial position from the geometric structure of faces, allowed successful recognition across this view change. It is also notable that the types of views and one-back matching that was used is somewhat similar to the current learning phase for two-views (although these were front-facing and right-profile), and may therefore provide strong evidence for how two-view matching might have been achieved.

Pachai, Sekuler and Bennett (2013) then extended this finding by again using cropped face views, but this time they provided left and right oriented viewpoints (but not profiles) first, and thus eliminated recognition effects based on simple image-matching, with recognition tested using a one-back, one-in-ten ‘line-up’ style set of front-facing views. It was found that again, horizontal encoding of the spatial relations of face parts allowed transference from different face orientations to the front-facing novel test views, extending and supporting the ‘bar code’ conceptualisation of perceptual visual encoding and recognition proposed by Dakin and Watt (2009).

From the above discussion of ‘bar code’ perceptual encoding and recognition routes to explain the perceptual visual encoding and recognition of unfamiliar face views, it is suggested that the current experimental results fit comfortably within this perceptual encoding framework. For example, the properties of the image (i.e.,

previously referred to as ‘pictorial’ codes) and the arrangement of features and their relation to each other (i.e., previously referred to as ‘structural’ codes), can both exist within ‘vertically arranged horizontal light and dark areas representing one-dimensional horizontal components of the face’ (i.e., ‘bar codes’). For example, it can be envisioned that learning single front-facing and single right-profile learned views, when tested on the same views, that correct recognition can be accomplished simply by repetition of the same horizontal ‘bar codes’ (i.e., the vertical arrangement of the same light and dark areas), an effect that would normally be attributed to ‘pictorial’ effects (i.e., view repetition). However, it is speculated that because profile views are lacking the dark area provided by the shadow afforded from the nose projection, that recognition of another view will be poor, even though they may share the same horizontal light/dark ‘bar code’ structure in the main, there will always be a minor but important mismatch. Furthermore, when two different views were matched in the current learning phase (front and profile), and two representations therefore existed for the same identity, then the Bruce and Young FRU conceptualisation can be used to explain an association in memory between those representations that share the same vertically arranged horizontal light and dark areas (i.e., ‘bar codes’), and thus successful recognition of all test views is possible. However, it must be stated that it is not necessary for the ‘interlinking’ of these representations to occur in a somewhat ‘hidden’ memorial operation. Instead, it can also be argued that access to such ‘bar code’ representations can occur online at the moment a novel view that shares the same ‘bar code’ information is presented. Therefore, differentiating between the FRU memorial effect and ‘bar code’ perceptual effect is not possible, as both can be argued to be supported by the evidence reviewed.

In conclusion, the perceptual route to face matching in the learning phase, and recognition within and between view types in the test phase, can be adequately accounted for by ‘bar codes’ that do not rely on distinguishing between ‘pictorial’ and ‘structural’ encoding. In addition, it has been demonstrated here that learning two-views that were cropped to encourage ‘internal feature processing’, and those of Longmore et al. (2015), produced a significant advantage over learning either single view when tested on a novel view. Although these results do support an FRU account of face learning in terms of what the model would predict, this is not necessarily the only conclusion that one can draw. As stated previously, FRU ‘interlinking’ is a somewhat ‘hidden’ memorial operation, and it is not possible based on a single test of its predictions to fully support it as accounting for face learning, without also testing different learned and test views. Therefore, the next experiments will test if the ‘FRU effect’ found in this experiment is consistent across manipulations that include time between learning and test (i.e., testing consolidation), and varying the type of novel test view, so that further insights into the process of face learning can be considered.

2.3 Experiment 2: Recognition accuracy without overnight consolidation

2.3.1 Introduction

In Experiment 1, the learning and test phases were conducted on separate days with an overnight period of consolidation afforded. To test whether this delay and putative consolidation period was necessary for the FRU effect, Experiment 2

was conducted as a replication of Experiment 1, but with both phases on the same day, and only a short delay between them. Therefore, if a period of overnight consolidation is required for the creation of an FRU, then it would be predicted that the advantage when two-views were learned over single-views, when tested on the novel view, will fail to emerge in the current experiment. Alternatively, if similar results are observed in Experiment 2, then this would suggest that an FRU can be set-up immediately during learning and have an immediate impact on face recognition familiarity.

2.3.2 Method

Participants

Twenty-seven Caucasian undergraduates (20 females, 7 males) aged between 17 and 23 years (mean age, 19.52 years) participated in exchange for course credit. This group was different from those in Experiment 1 but recruited from the same pool. All participants had normal or corrected-to-normal visual acuity (self-report) and no history of neurological illness (self-report). All participants gave informed consent and the procedures were approved by the University of Kent, School of Psychology Ethics Committee.

Design, Materials and Apparatus

The design, materials, and apparatus were the same as in Experiment 1. See Figure 10 for examples of each view type for four identities.

Procedure

The procedure repeated that of Experiment 1, except that the learning and test phases were carried out on the same day. Participants completed the learning phase and were then provided with ten basic maths questions, which they were not required to complete fully, and were intended to act only as a filler task while the test phase of the experiment was set-up. This took on average ten minutes. Participants then completed the test phase which was exactly the same as Experiment 1.

2.3.3 Results

From the learning phase data, the percentage of correctly identified matches (hits) was analysed with a 3x7 repeated-measures ANOVA with learned view type and block as factors. Departures from sphericity were corrected using the recommendation of Girden (1992): for epsilon values greater than .75 the Huynh-Feldt correction was applied, and for epsilon values less than .75 the Greenhouse-Geisser correction was applied. Effect sizes were considered based on Cohen's (1988) recommendation of .02 for a small effect, .13 for a medium effect, and .26 for a large effect.

The main effect of view type was found significant, $F(1.27, 33.06) = 32.97$, $MSE = 440.21$, $p < .001$, $\eta_p^2 = 0.55$ (Observed power = 1), with FF view hits greater than TV ($p < .001$) and RP views ($p = .003$), and RP view hits were greater than TV ($p < .001$), see Figure 2-3 for mean hits. However, the main effect of block was not significant, $F(3.12, 81.21) = 0.943$, $MSE = 307.32$, $p = .427$, $\eta_p^2 = 0.03$ (Observed

power = .25), but the view type x block interaction was significant, $F(12, 312) = 9.96$, $MSE = 60.80$, $p < .001$, $\eta_p^2 = .27$ (Observed power = 1).

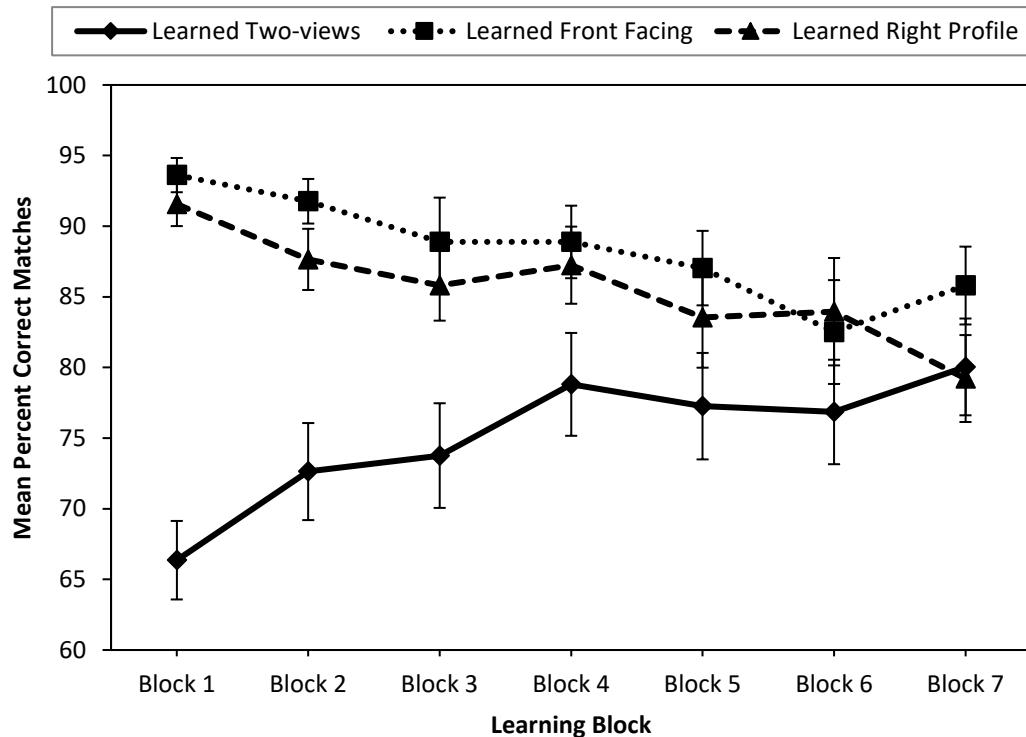


Figure 2-3. Experiment 2 Learning Phase Results. Mean percent correct one-back matching responses are plotted as a function of learned view (Two-views, Front-Facing view & Right-Profile view) for each block of learning. Error bars represent standard error of the mean.

As with Experiment 1, the two-way interaction was first broken down by examining the simple main effect of block within each view type. Block was found to be significant for all view types (TV, FF and RP, all p 's $< .003$. See Table 2-3 for statistics and Figure 2-3 for means). Pairwise analysis concentrated on whether mean

hit matching accuracy increased or decreased significantly between the start of the learning procedure compared to the end (i.e., block 1 versus block 7). Analysis revealed that for the TV view type, block 7 mean hits were greater than block 1 ($p < .001$), indicating that matching accuracy increased by the end of the learning phase. However, for the FF and RP view types, block 1 mean hits were significantly greater than block 7 ($p = .002$, $p < .001$, respectively), indicating that for each of these single views, matching accuracy decreased by the end of the learning phase.

Table 2-3

Block x View type interaction simple main effects.

	df	F	MSE	p	η_p^2	Power
Two-views x Block	3.50, 91.09	5.65	177.46	= .001	.17	.96
Front-facing view x Block	4.65, 120.91	4.93	96.97	= .001	.15	.97
Right-profile view x Block	5.36, 139.49	3.94	114.97	= .002	.13	.95
Block 1 x View type	1.30, 33.82	73.177	130.70	< .001	.73	1
Block 2 x View type	1.24, 32.23	25.95	170.24	< .001	.50	1
Block 3 x View type	1.70, 44.27	17.63	114.86	< .001	.40	.99
Block 4 x View type	2, 52	8.53	92.48	= .001	.24	.95
Block 5 x View type	2, 52	7.32	90.36	= .002	.22	.92
Block 6 x View type	1.70, 44.34	4.14	107.54	= .028	.13	.65
Block 7 x View type	2, 52	4.24	81.78	= .020	.14	.71

For the simple main effect of view type at each block, it was found that this was significant for all blocks (all p 's $< .029$. See Table 2-3 for statistics and Figure 2-3 for means). Pairwise analysis, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., .05/3 learned view type comparisons), revealed that at block 1, FF hits were greater than TV ($p < .001$) and RP hits were greater than TV ($p < .001$); at block 2, FF hits were greater than TV ($p < .001$) and RP ($p = .004$), and RP hits were greater than TV ($p < .001$); at block 3, FF hits were greater than TV ($p < .001$) and RP were greater than TV ($p < .001$); at block 4, FF hits were greater than TV ($p = .002$) and RP hits were greater than TV ($p = .003$); at block 5, FF hits were greater than TV ($p < .001$); and at block 7, FF hits were greater than RP ($p = .010$).

Correct rejections were analysed as Experiment 1, revealing that the main effect of learning group was significant, $F(2, 24) = 4.688$, $MSE = 155.202$, $p = .019$, $\eta_p^2 = 0.28$ (Observed power = .73), with mean correct rejections greater for group A (95.59%) than group C (89.03%), and group B (93.84%) than group C (all p 's $< .041$). But the main effect of block was not significant, $F(6, 144) = 2.010$, $MSE = 13.863$, $p = .068$, $\eta_p^2 = 0.07$ (Observed power = .71), and the two-way interaction between learning group and block was not significant, $F(12, 144) = 1.671$, $MSE = 13.863$, $p = .079$, $\eta_p^2 = .12$ (Observed power = .83).

For the test phase, a hit rate was calculated for each participant and condition by computing the percentage of targets which received a “yes” response within each condition. These values were processed with a 3x3 between-subject's ANOVA, with learned view (Two-views; Front-Facing Learned view; Right-profile Learned view) and test view (Front-Facing Tested view; Right Three-Quarter Tested view; or

Right-profile Tested view) as factors, and hits as the dependent variable (see Figure 2.4 for mean hits). Effect sizes were considered based on Cohen's (1988) recommendation of .02 for a small effect, .13 for a medium effect, and .26 for a large effect..

Analysis of recognition (hit) rates in the test phase revealed the main effect of learned view was significant, $F(2, 72) = 27.20$, $MSE = 444.70$, $p < .001$, $\eta_p^2 = 0.43$ (Observed power = 1), with TV hits greater than FF ($p < .001$) and RP ($p < .001$). The main effect of test view was also found significant, $F(2, 72) = 4.99$, $MSE = 444.70$, $p = .009$, $\eta_p^2 = 0.12$ (Observed power = .79), with hits for FF test view hits greater than TQ test views ($p = .005$) and RP hits greater than TQ ($p = .012$). Importantly, the critical interaction between learned view and test view was also found significant, $F(4, 72) = 32.65$, $MSE = 444.70$, $p < .001$, $\eta_p^2 = .64$ (Observed power = 1).

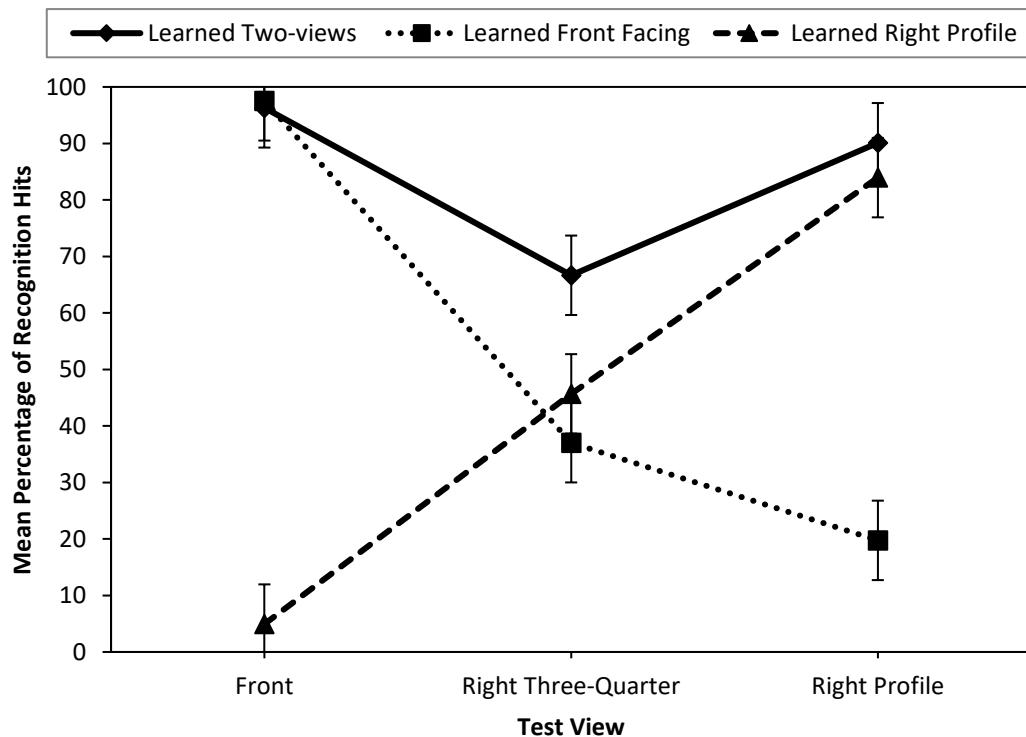


Figure 2-4. Experiment 2 Test Phase Results. Mean percent recognition hits of previously seen faces as a function of learned view x test view. The results indicate the overall effects of learning two-views or one view on recognition accuracy for three test views. Error bars represent standard error of the mean.

Simple main effect univariate analysis of the significant two-way interaction first focused on the critical comparison to test for the FRU effect, that is, an advantage in recognition of the novel three-quarter view for identities learned from two-views over those learned from single views (i.e., comparing the three data points in the central column of Figure 2-4). The result was significant, $F(2, 72) = 4.69$, $MSE = 444.673$, $p = .012$, $\eta_p^2 = .11$ (Observed power = .77). Pairwise comparisons, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., $.05/3$ learned view comparisons), revealed that when two-views had been learned

(diamond, centre column, Figure 2-4), performance was significantly greater on the three-quarter test view than when front-facing views were learned ($p = .004$; square, centre column, Figure 2-4), but not right-profile views ($p = .038$; triangle, centre column, Figure 2-4), but there were no significant differences between FF and RP learned views when tested with the right three-quarter view ($p = .388$). However, when the test view was a front-facing view (i.e., comparing the three data points in the left column of Figure 2-4), learned view was significant, $F(2, 72) = 57.080$, $MSE = 444.673$, $p < .001$, $\eta_p^2 = .61$ (Observed power = 1). Pairwise comparisons, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., $.05/3$ learned view comparisons), revealed that when two-views had been learned (diamond, left column, Figure 2-4), performance was significantly greater on the front-facing test view than when only right-profile views were learned ($p < .001$; square, left column, Figure 2-4), and front-facing view means were significantly greater than when right-profile views were learned ($p < .001$; triangle, left column, Figure 2-4), but the difference between two-views and front-facing learned views was not significant ($p = .902$). When the test view was a right-profile view (i.e., comparing the three data points in the right column of Figure 2-4), revealed that learned view was significant, $F(2, 72) = 30.735$, $MSE = 444.673$, $p < .001$, $\eta_p^2 = .46$ (Observed power = 1). Pairwise comparisons, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., $.05/3$ learned view comparisons), revealed that when two-views had been learned (diamond, right column, Figure 2-4), performance was significantly greater on the right-profile view test than when only front-facing views were learned ($p < .001$; square, right column, Figure 2-4), and right-profile view mean hits were significantly greater than when front-facing views

were learned ($p < .001$; square, right column, Figure 2-4), but the difference between two-views and right-profile learned views was not significant ($p = .537$).

Simple main effect univariate analysis of the two-way interaction (learned view x test view) was also carried out for each learned view, to understand if each learned view produced view-invariance across the three test views, finding that when two-views had been learned, mean hit differences between test views were significant, $F(2, 72) = 4.946$, $MSE = 444.673$, $p = .010$, $\eta_p^2 = .12$ (Observed power = .79), with pairwise comparisons, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., .05/3 test view comparisons), finding that mean hits for the front-facing test view were significantly greater than the three-quarter test view ($p = .004$), but the right-profile test view was not significantly greater than the three-quarter test view ($p = .021$), and not between the front-facing test view and right-profile test view ($p = .537$). When front-facing views had been learned, test view was again found to be significant, $F(2, 72) = 33.758$, $MSE = 444.673$, $p < .001$, $\eta_p^2 = .48$ (Observed power = 1), with pairwise comparisons, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., .05/3 test view comparisons), finding that mean hits for the front-facing test view were significantly greater than the three-quarter test view ($p < .001$) and the right-profile test view ($p < .001$), but not between the three-quarter test view and right-profile test view ($p = .086$). And when right-profile views had been learned, test view was again found to be significant, $F(2, 72) = 31.599$, $MSE = 444.673$, $p < .001$, $\eta_p^2 = .46$ (Observed power = 1), with pairwise comparisons, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., .05/3 test view comparisons), finding that mean hits for the right-profile test view were significantly greater than the front-facing test view ($p < .001$) and the three-quarter test view ($p = .086$).

.006), and mean hits for the three-quarter test view were significantly greater than the front-facing test view ($p < .001$). A one-way ANOVA of correct rejections, with test view as a factor indicated that the percentage of correct rejections did not differ as a function of test view, $F(2, 78) = 0.780$, $MSE = 52.759$, $p = .462$, $\eta_p^2 = 0.02$ (Observed power = .17): FFT view, 96%; RTQT view, 93%; and, RPT view 95%.

It was found in the current experiment that when two-views had been learned, and an almost immediate test on the novel right three-quarter view was carried out, that mean hits were 66%, whereas in Experiment 1, in which the test phase was the next day, mean hits were 83%. The numerical mean hit difference between Experiments 1 and 2, that differed only by immediate test and next day test respectively, was suggestive of sleep/consolidation improving recognition performance in Experiment 1, however, this needed to be tested statistically. By adding an additional between groups factor of experiment, the analysis was processed with a 2x3x3 between-subject's ANOVA, with experiment (Experiments 1 and Experiment 2), learned view (Two-views; Front-Facing Learned view; Right-profile Learned view) and test view (Front-Facing Tested view; Right Three-Quarter Tested view; or Right-profile Tested view) as factors, and hits as the dependent variable (see Figure 2-4 for mean hits). Again, effect sizes were considered based on Cohen's (1988) recommendation of .02 for a small effect, .13 for a medium effect, and .26 for a large effect.

Analysis revealed that the main effect of experiment was not significant, $F(1, 144) = 1.972$, $MSE = 446.76$, $p = .162$, $\eta_p^2 = 0.01$ (Observed power = .28), but the main effect of learned view was, $F(2, 144) = 48.189$, $MSE = 446.76$, $p < .001$, $\eta_p^2 = 0.40$ (Observed power = 1), with TV hits greater than both FF ($p < .001$) and RP

views ($p < .001$), and FF view hits were greater than RP views ($p = .024$). The main effect of test view was also found significant, $F(2, 144) = 4.073, MSE = 446.76, p = .019, \eta_p^2 = 0.05$ (Observed power = .71), with RP test view hits greater than TQ test view hits ($p = .005$), and the two-way interaction between learned view and test view was significant, $F(4, 144) = 45.001, MSE = 446.76, p < .001, \eta_p^2 = 0.55$ (Observed power = 1). The two-way interaction between experiment and test view was significant, $F(2, 144) = 4.592, MSE = 446.76, p = .012, \eta_p^2 = 0.06$ (Observed power = .77), with pairwise analysis revealing that the simple main effect of experiment was significant for the TQ test view only, $F(1, 144) = 6.632, MSE = 446.76, p = .011, \eta_p^2 = 0.04$ (Observed power = .72), with mean hits for Experiment 1 greater than Experiment 2 ($p = .011$). The simple main effect of test view was also found to be significant for Experiment 1, $F(2, 144) = 3.698, MSE = 446.76, p = .027, \eta_p^2 = 0.04$ (Observed power = .67), and Experiment 2, $F(2, 144) = 4.967, MSE = 446.76, p = .008, \eta_p^2 = 0.06$ (Observed power = .80), with pairwise comparisons, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., .05/3 test view comparisons), revealing that for Experiment 1, RP test view means were significantly greater than FF test views ($p = .007$), and for Experiment 2, FF test views were greater than TQ ($p = .005$), and RP greater than TQ ($p = .011$).

The three-way interaction between experiment, learned view and test view approached significance, $F(4, 144) = 2.151, MSE = 446.76, p = .078, \eta_p^2 = 0.05$ (Observed power = .62), and it was decided that this would be examined further. The three-way interaction was broken down into three separate two-way interactions for the simple main effect of experiment, learned view, and test view, at each level of the other two factors (see Table 2-4 for interaction univariate tests, and Figures 2-2 and 2-4 for mean hits for each experiment). Critically, the simple main effect of

experiment at the three-quarter test view when two-views had been learned (i.e., to test for the FRU effect), only approached significance ($p = .085$, see Table 2-4), with pairwise analysis, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0056 (i.e., .05/9 learned view x test view comparisons), revealing that the difference between experiments was confirmed as not significant ($p = .085$). Indeed, the simple main effect of experiment was only found to be significant for the LFF x TFF two-way interaction ($p = .049$), and the LFF x TRP interaction ($p = .005$), but adjusted (i.e., an alpha of .0056) pairwise analysis revealed that Experiment 1 mean hits were significantly greater than Experiment 2, only for the LFF x TRP interaction ($p = .0050$). All other interactions not significant (all p 's $> .065$).

Further analysis of the three-way interaction, for the simple main effect of learned view, found that learned view was significant for all two-way experiment x test view interactions ($p < .012$, see Table 2-4). Pairwise comparisons of significant effects, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0084 (i.e., .05/6 experiment x test view comparisons), revealed that for Experiment 1, when the test view was TFF, mean hits for LTV views were greater than LRP views ($p < .001$), and LFF view hits were greater than LRP views ($p < .001$). When the test view was TTQ, mean hits for LTV views were greater than LFF views ($p = .005$), and LRP views ($p = .003$); and, when the test view was TRP, mean hits for LTV views were greater than LFF views ($p < .001$), and LRP view hits were greater than LFF views ($p = .001$). For Experiment 2, when the test view was TFF, mean hits for LTV views were greater than LRP views ($p < .001$), and LFF view hits were greater than LRP views ($p < .001$); and when the test view was TTQ, mean hits for LTV views were greater than LFF views ($p = .003$). When the test view was TRP, mean

hits for LTV views were greater than LFF views ($p < .001$), and LRP view hits were greater than LFF views ($p = .001$).

Furthermore, the simple main effect of test view was found to be significant for all two-way interactions ($p < .011$), except when two-views were learned in Experiment 1 ($p = .931$, see Table 2-4). Pairwise comparisons of significant effects, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0084 (i.e., .05/6 experiment x learned view comparisons), revealed that for Experiment 1, when the learned view was LFF, mean hits for TFF views were greater than TRP views ($p = .003$), and when learned view was LRP, mean hits for TTQ views were greater than TFF views ($p < .001$), and TRP view hits were greater than TFF views ($p < .001$) and TTQ views ($p = .005$). For Experiment 2, when the learned view was LTV, mean hits for TFF views were greater than TTQ views ($p = .003$), and when the learned view was LFF, mean hits for TFF views were greater than TTQ views ($p < .001$) and TRP views ($p < .001$); and, when learned view was LRP, mean hits for TTQ views were greater than TFF views ($p < .001$) and TRP view hits were greater than TFF views ($p < .001$) and TTQ views ($p < .005$).

In summary, it was found that the difference in mean hit recognition performance between experiments when two-views had been learned and tested on the critical novel right three-quarter test view, only approached significance (i.e., Exp x LTV x TTQ, $p = .085$), and mean hits were only found to be significantly greater for Experiment 1 than Experiment 2, only when front-facing views were learned, and the test view was a right-profile view.

Table 2-4

Experiment (Exp: Exp1 & Exp2) x learned view (LV: LTV, LFF & LRP) x test view (TV: TFF, TTQ & TRP) interaction univariate tests.

	df	F	MSE	p	η_p^2	Power
Exp x LTV x TFF	1, 144	1.243	446.769	= .267	.009	.19
Exp x LTV x TTQ	1, 144	3.009	446.769	= .085	.020	.40
Exp x LTV x TRP	1, 144	0.061	446.769	= .805	.0004	.05
Exp x LFF x TFF	1, 144	3.930	446.769	= .049	.027	.50
Exp x LFF x TTQ	1, 144	3.454	446.769	= .065	.023	.45
Exp x LFF x TRP	1, 144	8.121	446.769	= .005	.053	.80
Exp x LRP x TFF	1, 144	0.138	446.769	= .711	.001	.06
Exp x LRP x TTQ	1, 144	0.752	446.769	= .387	.005	.13
Exp x LRP x TRP	1, 144	0.015	446.769	= .902	.0001	.05
LV x Exp1 x TFF	2, 144	35.903	446.769	< .001	.333	1
LV x Exp1 x TTQ	2, 144	5.660	446.769	= .004	.073	.85
LV x Exp1 x TRP	2, 144	9.334	446.769	< .001	.115	.97
LV x Exp2 x TFF	2, 144	56.812	446.769	< .001	.441	1
LV x Exp2 x TTQ	2, 144	4.667	446.769	= .011	.061	.77
LV x Exp2 x TRP	2, 144	30.591	446.769	< .001	.298	1
TV x Exp1 x LTV	2, 144	0.072	446.769	= .931	.001	.06
TV x Exp1 x LFF	2, 144	4.790	446.769	= .010	.062	.78
TV x Exp1 x LRP	2, 144	28.135	446.769	< .001	.281	1
TV x Exp2 x LTV	2, 144	4.923	446.769	= .009	.064	.80
TV x Exp2 x LFF	2, 144	33.600	446.769	< .001	.318	1
TV x Exp2 x LRP	2, 144	31.451	446.769	< .001	.304	1

2.3.4 Discussion

The current experiment was a replication of Experiment 1, but with the test phase carried out almost immediately, and intended to assess the impact of affording a period of overnight consolidation in Experiment 1. First, analysis within the current experiment revealed that the FRU effect was present when two-views were learned compared to learned single front-facing views, on the novel right three-quarter test view, but it was not present when right-profile single views were learned, and there were no significant differences between test view correct rejections. Additionally, results from the learning phase replicated those of Experiment 1, with two-view performance significantly increasing by the end of the session compared to the beginning (i.e., block 7 mean hits were larger than block 1), and single-view matching significantly decreasing. But, as noted in Experiment 1, discussion of this learning view matching effect will be held back until all experiments are concluded (see section 4.4, General Discussion).

When analysis was carried out between Experiments 1 and 2, to establish whether consolidation had a significant effect, it was found that the main effect of experiment was not significant, but learned view was, with two-view hits greater than front and profile single views, and front views hits were greater than profile views, and the main effect of test view was also found significant, with profile test view hits greater than the novel test view. The significant two-way interaction between experiment and test view also revealed that mean hits on the novel three-quarter test view were significantly greater for Experiment 1 than Experiment 2, and right-profile test views were greater than front-facing test views for Experiment 1, and front-facing and right-profile test views were greater than three-quarter test views for Experiment 2.

Therefore, although it was observed that between experiments, three-quarter test view recognition across all learned views significantly differed between experiments, it could not be determined from this two-way interaction alone, in which direction it occurred. However, examination of the approaching significant three-way interaction between experiment, learned view and test view could assist with this. The three-way interaction between experiment, learned view and test view revealed that mean hit recognition performance when two-views had been learned and tested on the critical novel right three-quarter test view only approached significance ($p = .085$). However, mean hits were found to be significantly greater for Experiment 1 (next day test) compared to Experiment 2 (same day test), but only when front-facing views were learned, and the test view was a right-profile view. It can therefore be concluded that affording a period of overnight consolidation (Experiment 1) did not significantly improve performance on the novel three-quarter test view, even though numerical differences were observed.

Results from the current experiment, although not significantly different to those of Experiment 1 on the critical novel test view, are suggestive of not only a decline in performance across all learned view types for a view change, but particularly the front-facing single learned views. Added to this was a significant difference between three-quarter test view accuracy between experiments, that in light of the above observation suggests that affording consolidation aided three-quarter test view accuracy, but this was not significant. Clearly, the same amount of learning was provided for each experiment, so it is unlikely that the differences observed are learning related, or related to the immediate representation formed during learning. But it does seem that the representations formed for each view type were less ‘robust’ than when a period of overnight consolidation was afforded, and

although this cannot be demonstrated to be a significant effect, a lack of overnight consolidation does seem to have reduced performance of all learned view types in this experiment on a view change test.

In terms of assessing the model of Bruce and Young (1986), the two-view advantage found in Experiment 1 (i.e., the FRU effect) was not repeated here to the same extent. Therefore, support for an FRU account can on one hand be said to be absent over right-profile single learned views, and present over front-facing single learned views, but this is of course an unsatisfactory conclusion. The current test phase results also differed from those of Experiment 1 for single views, in that front-facing learned single view accuracy on the same test view was now significantly greater than on the novel three-quarter test view, suggesting that the representation formed was less able to allow recognition of another view. It was also found that when two-views had been learned that view-invariance was absent, and differed from Experiment 1, with a significant decline in accuracy between front-facing test views and the novel view, however the difference between the profile test view and novel test view was not significant.

Of course, this is not a conclusive finding, but is suggestive of consolidation of encoded information having some (if not significant) effect on the type of representation formed. Whether these are representations ‘interlinked’ based on identity (i.e., an FRU), or are an accumulation of separate unrelated representations, it is argued that insufficient consolidation had a non-significant, but observed, numerical detrimental impact on the robustness of any representation formed. Therefore, affording a period of overnight consolidation will be included in all subsequent experiments, with the test phase carried out the day following the

learning phase, so that all/any representations formed are at least ‘as robust’ as those in Experiment 1 that found support for the FRU effect.

2.4 Experiment 3: Recognition accuracy when the novel view was an external rotation, after overnight consolidation

2.4.1 Introduction

Experiment 1 provided evidence in support of an FRU account of face learning, but for Experiment 2, results were inconclusive. However, in both experiments the novel view that was tested was a right three-quarter view, which was between those views learned. That is, it was an internal (shortest distance) rotation between the two learning phase views (i.e., front-facing and right-profile). Therefore, it can be seen that Experiment 1 clearly demonstrated that the representation formed from learning two-views supported recognition of at least one view along this ‘internal rotation’ (i.e., around the head’s vertical axis). It is assumed that other novel views along this ‘internal rotation’ would also show a similar benefit from learning two-views, as speculatively, this could have been achieved by employing mental rotation along the shortest path (i.e., rotating around the head’s vertical axis), between the two-views. However, it is unclear whether any representation formed can also afford better recognition of a novel view that is outside the rotation of those views learned. Therefore, and to further understand how such a representation might aid novel-view recognition, the question in Experiment 3 was whether the benefit of the representation is strictly limited to views along this internal rotation between

learned views, or whether the representation could also enhance recognition of rotations at a wider range of angles around the axis of rotation, but outside of the set of views that fall between the learned views.

This question arises because, although recognition of non-face objects can also show a two-view learning advantage (i.e., like the FRU effects found in Experiment 1), this occurs only for internal rotations between the two-views. That is, it does not generalise to external rotations (e.g., a left three-quarter view would be an external rotation from frontal and right-profile views) from the learned views (e.g., Wong & Hayward, 2005; and see Hayward, 2003). While these studies used non-symmetric Amoeboid and Geon stimuli, and their lack of symmetry may have played a critical role in poorer recognition at external rotations from the learned view, for approximately symmetric objects such as faces (i.e., symmetric along the head's vertical axis when viewed from the front), distinguishing features along the internal rotation from a front-facing view to a right-profile view is likely to be highly similar, though not completely identical. Furthermore, there is presumably a strong expectation of symmetry and regular structure of faces which could afford generalisation from internal rotations to other views which are expected to be near mirror symmetric, so an FRU representation may allow transference to externally rotated novel views.

To be clear, the left three-quarter view of a face is not strictly a mirror symmetric reflection of the right three-quarter view because faces are not perfectly symmetrical. Nonetheless, given that there is substantial informational overlap between these two three-quarter views that is perhaps afforded by ‘bar codes’ (e.g., Dakin & Watt, 2009; Goffaux & Dakin, 2010; Pachai, Sekuler & Bennett, 2013), it would be expected that a flexible FRU representation would be able to generalise its

benefit to these very similar external rotations. However, it is important to note that it is not necessary for this to be the case, as the FRU could be strictly limited and mirror reflection invariant, so it was considered important for Experiment 3 to test this aspect of the FRU representation.

To do this, the right three-quarter novel view at test used in Experiments 1 and 2 was replaced with a novel left three-quarter view, noting that the external rotation should have substantial, but not complete, mirror symmetry with the internal rotation novel view used in Experiments 1 and 2. The database that was used for current face stimuli contained both left and right three-quarter views, therefore a true left three-quarter view was used. Based on the expectation of mirror symmetry of faces, and previous findings for ‘bar code’ perceptual and recognition effects, it was expected that the FRU representation effect that was observed previously in Experiment 1 would appear again in Experiment 3, but now for the left three-quarter novel test view, when two-views were learned, and a period of overnight consolidation was afforded.

2.4.2 Method

Participants

Twenty-seven Caucasian undergraduates (22 females, 5 males) aged between 18 and 24 years (mean age, 19.22 years) participated in exchange for course credit. This group was different from that in Experiments 1 and 2. All participants had normal or corrected-to-normal visual acuity (self-report) and no history of neurological illness (self-report). All participants gave informed consent and the

procedures were approved by the University of Kent, School of Psychology Ethics Committee.

Design, Materials and Apparatus

These were the same as Experiments 1 and 2, with the exception that the critical test view was a left three-quarter view (LTQT), selected from the same database as used in Experiments 1 and 2. See Figure 10 for examples of each view type for four identities.

Procedure

The procedure was the same as Experiment 1, meaning that the test phase occurred on the following day after a period of overnight consolidation, as this seemed to enhance recognition accuracy. However, although not significant between experiments, it was considered an important additional learning enhancement to include in this experiment.

2.4.3 Results

Learning phase one-back matching accuracy was analysed as Experiments 1 and 2, with the percentage of correctly identified matches (hits) analysed with a 3x7 repeated-measures ANOVA with learned view type and block as factors. Departures from sphericity were corrected using the recommendation of Girden (1992): for epsilon values greater than .75 the Huynh-Feldt correction was applied, and for

epsilon values less than .75 the Greenhouse-Geisser correction was applied. Effect sizes were considered based on Cohen's (1988) recommendation of .02 for a small effect, .13 for a medium effect, and .26 for a large effect.

A main effect of view type was observed, $F(1.34, 34.96) = 15.17, MSE = 212.50, p < .001, \eta_p^2 = 0.36$ (Observed power = .98), with front-facing view hits greater than two-views ($p < .001$) and right-profile views ($p < .001$), and right-profile view hits were greater than two-views ($p = .016$), see Figure 2.5 for mean hits. However, there was no main effect of block, $F(4.66, 121.37) = 0.71, MSE = 63.88, p = .602, \eta_p^2 = 0.02$ (Observed power = .24), but the view type x block interaction was significant, $F(9.61, 249.92) = 5.52, MSE = 47.73, p < .001, \eta_p^2 = .17$ (Observed power = 1).

Again, as with Experiments 1 and 2, the two-way interaction was first broken down by examining the simple main effect of block within each view type. Block was found to be significant for the TV learned view type ($p < .001$), but not the FF ($p = .117$) or RP ($p = .249$) learned view types (see Table 2-5 for statistics and Figure 2-5 for means). Pairwise analysis concentrated on whether mean hit matching accuracy increased or decreased significantly between the start of the learning procedure compared to the end (i.e., block 1 versus block 7), with analysis revealing that block 7 mean hits were greater than block 1 when two-views had been learned ($p < .001$), but that block 1 and block 7 mean hits for the front-facing and right-profile learned views were not significantly different (approaching, $p = .077$ and $p = .331$, respectively).

Table 2-5

Block x View type interaction simple main effects.

	df	F	MSE	p	η_p^2	Power
Two-views x Block	4.94, 128.45	8.05	49.63	< .001	.23	1
Front-facing view x Block	4.62, 120.14	1.83	36.61	= .117	.06	.58
Right-profile view x Block	4.77, 124.04	1.35	71.82	= .249	.04	.45
Block 1 x View type	2, 52	18.02	76.87	< .001	.40	1
Block 2 x View type	2, 52	12.19	52.12	< .001	.31	.99
Block 3 x View type	1.38, 36.09	20.62	60.22	< .001	.44	.99
Block 4 x View type	2, 52	5.28	60.42	= .008	.16	.81
Block 5 x View type	2, 52	2.16	55.50	= .125	.07	.42
Block 6 x View type	2, 52	1.31	34.73	= .276	.04	.27
Block 7 x View type	2, 52	1.31	50.85	= .278	.04	.27

For the simple main effect of view type at each block, it was found that this was significant in blocks 1 to 4 (all p 's < .009. See Table 2-5 for statistics and Figure 2-5 for means), however by blocks 5, 6 and 7, performance was not significantly different between view type conditions. Pairwise analysis of blocks 1 to 4, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., .05/3 learned view type comparisons), revealed that at block 1, FF hits were greater than TV ($p < .001$), and RP hits were greater than TV ($p = .002$); at block 2, FF hits were greater than TV ($p < .001$) and RP hits were greater than TV ($p = .007$); at block 3, FF hits were greater than TV ($p < .001$), and RP hits were greater than TV ($p < .001$); and, at block 4, FF hits were greater than TV ($p = .008$) and RP ($p = .007$).

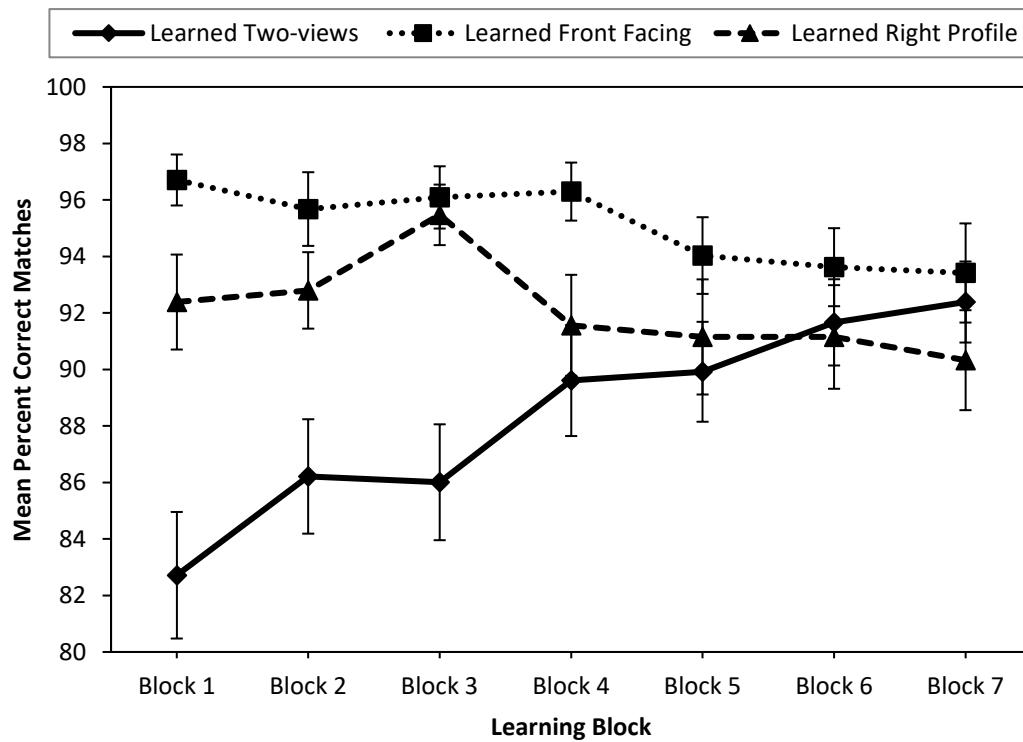


Figure 2-5. Experiment 3 Learning Phase Results. Mean percent correct one-back matching responses are plotted as a function of learned view (Two-views, Front-Facing view & Right-Profile view) at each block of learning. Error bars represent standard error of the mean.

Analysis of correct rejections was carried out as Experiments 1 and 2, revealing that the main effect of learning group was not significant, $F(2, 24) = 1.437$, $MSE = 467.437$, $p = .257$, $\eta_p^2 = 0.10$ (Observed power = .27), but the main effect of block was significant, $F(3.190, 76.562) = 9.622$, $MSE = 48.814$, $p < .001$, $\eta_p^2 = 0.28$, (Observed power = .99), with block 7 mean correct rejections greater than all previous blocks (all p 's $< .007$), and block 6 greater than block 1, block 5 greater than block 1, block 4 greater than block 1 and 2, block 3 greater than block 1, and block 2 greater than block 1 (all p 's $< .028$). But importantly, the two-way

interaction between learning group and block was not significant, $F(12, 144) = 0.569$, $MSE = 25.954$, $p = .864$, $\eta_p^2 = .04$ (Observed power = .31).

Having established that the learning phase produced an equivalent level of performance for each of the three view types by the end of the session (blocks 5, 6 and 7), and that correct rejections were not modulated by learning group, analysis of the test phase was carried out. A hit rate was calculated for each participant and condition by computing the percentage of targets which received a “yes” response within each condition. These values were processed with a 3x3 between-subject’s ANOVA, with learned view (Two-views; Front-Facing Learned view; Right-profile Learned view) and test view (Front-Facing Tested view; Left Three-Quarter Tested view; or Right-profile Tested view) as factors, and hits as the dependent variable (see Figure 2-6 for mean hits). Again, effect sizes were considered based on Cohen’s (1988) recommendation of .02 for a small effect, .13 for a medium effect, and .26 for a large effect.

Analysis of recognition (hit) rates in the test phase revealed that the main effect of learned view was significant, $F(2, 72) = 32.39$, $MSE = 384.09$, $p < .001$, $\eta_p^2 = 0.47$ (Observed power = 1), with LTV view mean hits greater than LFF ($p < .001$) and LRP hits ($p < .001$), and LFF mean hits greater than LRP hits ($p = .016$). However, the main effect of test view was not significant, $F(2, 72) = 1.44$, $MSE = 384.09$, $p = .243$, $\eta_p^2 = 0.039$ (Observed power = .30), but the critical interaction between learned view and test view was found significant, $F(4, 72) = 20.66$, $MSE = 384.09$, $p < .001$, $\eta_p^2 = .53$ (Observed power = 1).

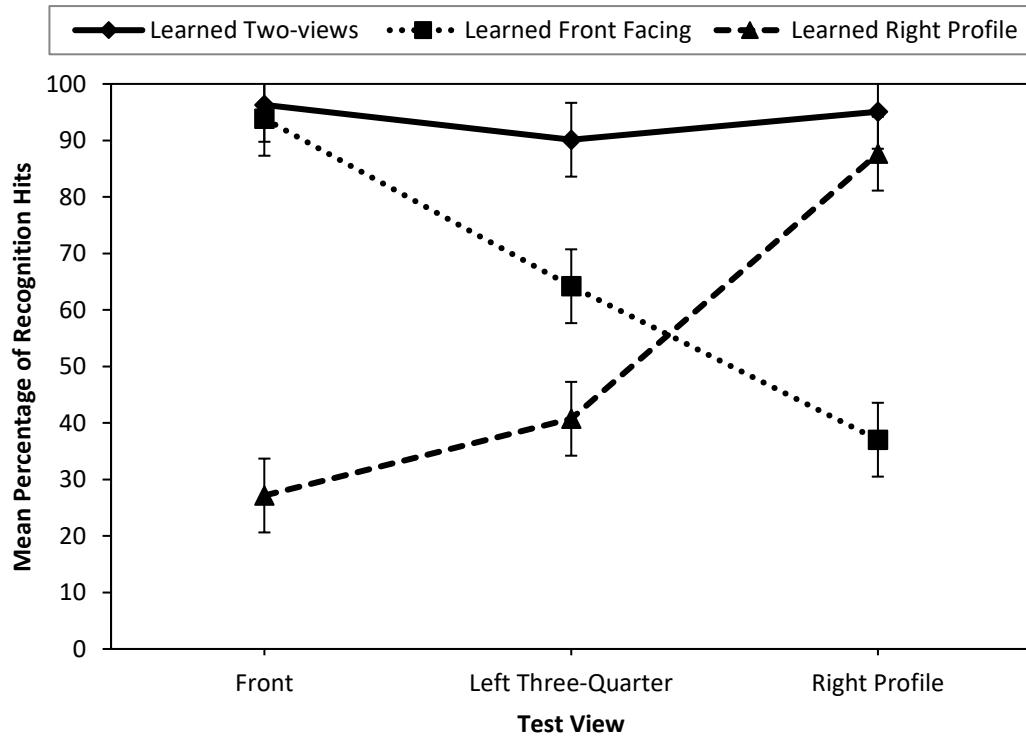


Figure 2-6. Experiment 3 Test Phase Results. Mean percent recognition hits of previously seen faces as a function of learned view and test view. The results indicate the overall effects of learning two-views or one view on recognition accuracy for three test views. Error bars represent standard error of the mean.

Simple main effect univariate analysis of the significant two-way interaction first focused on the critical comparison to test for the FRU effect, that is, an advantage in recognition of the novel three-quarter view for identities learned from two-views over those learned from single views (i.e., comparing the three data points in the central column of Figure 2-6). The result was significant, $F(2, 72) = 14.29$, $MSE = 384.088$, $p < .001$, $\eta_p^2 = .28$ (Observed power = .99). Pairwise comparisons, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., $.05/3$ learned view comparisons), revealed that when two-views had been

learned (diamond, centre column, Figure 2-6), performance was significantly greater on the left three-quarter test view than when only full-frontal views ($p = .006$; square, centre column, Figure 2-6) or right-profile views ($p < .001$; triangle, centre column, Figure 2-6) were learned. In addition, and in contrast to the results from Experiments 1 and 2, left three-quarter test performance was significantly higher for identities which were learned from full-frontal views than those learned from right-profile views ($p = .013$).

When the test view was a front-facing view (i.e., comparing the three data points in the left column of Figure 2-6), the result was significant, $F(2, 72) = 36.048$, $MSE = 384.088$, $p < .001$, $\eta_p^2 = .50$ (Observed power = 1). Pairwise comparisons, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., .05/3 learned view comparisons), revealed that when two-views had been learned (diamond, left column, Figure 2-6), performance was significantly greater on the front-facing test view than when only right-profile views were learned ($p < .001$; square, left column, Figure 2-6), and front-facing view means were significantly greater than when right-profile views ($p < .001$; triangle, left column, Figure 2-6) were learned, but the difference between two-views and front-facing learned views was not significant ($p = .790$). When the test view was a right-profile view (i.e., comparing the three data points in the right column of Figure 2-6), the result was significant, $F(2, 72) = 23.369$, $MSE = 384.088$, $p < .001$, $\eta_p^2 = .39$ (Observed power = 1). Pairwise comparisons, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., .05/3 learned view comparisons), revealed that when two-views had been learned (diamond, right column, Figure 2-6), performance was significantly greater on the right-profile view test than when only front-facing views were learned ($p < .001$; square, right column, Figure 2-6), and right-profile view

means were significantly greater than when front-facing views ($p < .001$; square, right column, Figure 2-6) were learned, but the difference between two-views and right-profile learned views was not significant ($p = .425$).

Simple main effect univariate analysis of the two-way interaction (learned view x test view) was also carried out for each learned view, to understand if each learned view produced view-invariance, finding that when two-views had been learned, differences between test views were not significant, $F(2, 72) = 0.250$, $MSE = 384.088$, $p = .779$, $\eta_p^2 = .007$ (Observed power = .08). However, when front-facing views had been learned, test view was significant, $F(2, 72) = 18.905$, $MSE = 384.088$, $p < .001$, $\eta_p^2 = .34$ (Observed power = 1), with pairwise comparisons, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., .05/3 test view comparisons) revealing that mean hits for front-facing test views were significantly greater than three-quarter test views ($p = .002$) and right-profile test views ($p < .001$), and three-quarter test view mean hits were significantly greater than right-profile test views ($p = .004$). Finally, when right-profile views had been learned, test view was again significant, $F(2, 72) = 23.607$, $MSE = 384.088$, $p < .001$, $\eta_p^2 = .39$ (Observed power = 1), with pairwise comparisons, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., .05/3 test view comparisons) revealing that mean hits for right-profile test views were significantly greater than front-facing test views ($p < .001$) and three-quarter test views ($p < .001$), and mean hits for three-quarter test views were significantly greater than front-facing test views ($p < .001$).

Analysis of correct rejections at test (i.e., saying “no” to an identity which had not been seen at learning), indicated that the percentage of correct rejections did

not differ as a function of view, $F(2, 78) = 2.970$, $MSE = 139.050$, $p = .057$, $\eta_p^2 = 0.07$ (Observed power = .56) - FFT view, 96%; RTQT view, 91%; and, RPT view 88%.

Finally, in order to understand which critical manipulations of the current chapter did or did not differ between experiments, an analysis was carried out with a 3x3x3 between-subject's ANOVA, with experiment (Experiment 1, Experiment 2, Experiment 3), learned view (Two-views; Front-Facing Learned view; Right-profile Learned view) and test view (Front-Facing Tested view; Novel view; or Right-profile Tested view) as factors, and hits as the dependent variable. Note that the manipulation of almost immediate test compared to next day test, which was investigated between Experiments 1 and 2 (see the Experiment 2 results section), was found not to be significant, so all three experiments were included in the current analysis. Effect sizes were considered based on Cohen's (1988) recommendation of .02 for a small effect, .13 for a medium effect, and .26 for a large effect.

Analysis of recognition mean hits in the test phase revealed that the main effect of experiment was significant, $F(2, 216) = 4.775$, $MSE = 425.875$, $p = .009$, $\eta_p^2 = 0.04$ (Observed power = .79), with Experiment 3 mean hits greater than Experiment 2 ($p = .002$). The main effect of learned view was significant, $F(2, 216) = 79.567$, $MSE = 425.875$, $p < .001$, $\eta_p^2 = 0.42$ (Observed power = 1), with TV mean hits greater than FF ($p < .001$) and RP ($p < .001$), and FF mean hits greater than RP ($p = .001$). The main effect of test view was also significant, $F(2, 216) = 5.173$, $MSE = 425.875$, $p = .006$, $\eta_p^2 = 0.04$ (Observed power = .82), with right-profile mean hits greater than novel test views ($p = .002$). Furthermore, the two-way interaction between experiment and test view was found significant, $F(4, 216) =$

$2.610, MSE = 425.875, p = .037, \eta_p^2 = 0.04$ (Observed power = .72), and the two-way interaction between learned view and test view was found significant, $F(4, 216) = 63.874, MSE = 425.875, p < .001, \eta_p^2 = 0.54$ (Observed power = 1). However, the three-way interaction between experiment, learned view and test view was found significant, $F(8, 216) = 2.112, MSE = 425.875, p = .036, \eta_p^2 = 0.07$ (Observed power = .83), and this was investigated further.

The three-way interaction was broken down into three separate two-way interactions for the simple main effect of experiment, learned view and test view, at each level of the other two factors (see Table 2-6 for interaction univariate statistics and Figures 2-2, 2-4 and 2-6 for means). Critically, for the simple main effect of experiment at the novel test view, when two-views were learned (i.e., to test for the FRU effect), the simple main effect of experiment was found to be significant ($p = .046$), but pairwise analysis, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0056 (i.e., .05/9 learned view x test view comparisons), revealed that differences in mean hits were not significantly different ($p = .077$, all p 's $> .017$). When front-facing views had been learned, and the test was a novel view, the simple main effect of experiment was again found to be significant ($p = .018$), with pairwise analysis (with an adjusted alpha of .0056), revealing that mean hits for Experiment 3 (i.e., the LTQ novel test view) were greater than Experiment 2 (i.e., the RTQ novel test view), but this only approached significance ($p = .006$). However, when a front-facing view was learned, and a right-profile was the test view, the simple main effect of experiment was again found to be significant ($p = .014$), with pairwise analysis (with an adjusted alpha of .0056), revealing that mean hits for Experiment 1 were significantly greater than Experiment 2 ($p = .004$). When right-profile views had been learned, and the test view was a front-facing view, the simple

main effect of experiment approached significance ($p = .052$), but pairwise analysis (with an adjusted alpha of .0056), revealed that differences between experiments were not significant (all p 's $> .023$). All other univariate tests for the simple main effect of experiment were found not to be significant (all p 's $> .100$, see Table 2-6).

For the simple main effect of learned view, all two-way univariate tests were significant (all p 's $< .009$, see Table 2-6 for interaction univariate statistics). Pairwise analysis, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0056 (i.e., .05/9 experiment x test view comparisons), revealed that for Experiments 1 and 2, when the test view was a novel view, two-view learning mean hits were significantly greater than FF views (Exp. 1, $p = .004$; Exp. 2, $p = .003$), and for Experiments 1 and 3, two view learning mean hits were significantly greater than RP views (Exp. 1, $p = .003$; Exp. 3, $p < .001$). For Experiments 1, 2 and 3, when the test view was an FF view, two-view learning mean hits were significantly greater than RP views (Exp. 1, $p < .001$; Exp. 2, $p < .001$; Exp. 3, $p < .001$), and front-facing view mean hits were significantly greater than RP views (Exp. 1, $p < .001$; Exp. 2, $p < .001$; Exp. 3, $p < .001$). Finally, for Experiments 1, 2 and 3, when the test view was an RP view, two-view learning mean hits were significantly greater than FF views (Exp. 1, $p < .001$; Exp. 2, $p < .001$; Exp. 3, $p < .001$), and RP view mean hits were significantly greater than FF views (Exp. 1, $p < .001$; Exp. 2, $p < .001$; Exp. 3, $p < .001$).

For the simple main effect of test view, two-way univariate tests were significant for Experiment 1 x LFF, and LRP; Experiment 2 x LTV, LFF and LRP; and, Experiment 3 x LFF and LRP (all p 's $< .008$, see Table 2-6 for interaction univariate statistics). However, for Experiment 1 x LTV and Experiment 3 x LTV, these were not significant ($p = .928$ and $p = .798$, respectively). Pairwise analysis,

adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0056 (i.e., .05/9 experiment x learned view comparisons), revealed that for Experiments 1 and 2, when the learned view was an RP view, novel test view mean hits were significantly greater than FF views (Exp. 1, $p < .001$; Exp. 2, $p < .001$), and RP test view mean hits were greater than FF test views (Exp. 1, $p < .001$; Exp. 2, $p < .001$), and novel test views (Exp. 1, $p = .004$; Exp. 2, $p < .001$). For Experiment 1, when FF views were learned, FF test views mean hits were significantly greater than RP test views ($p = .003$); for Experiment 2, FF test view mean hits were greater than novel test views ($p < .001$) and RP test views ($p < .001$); and for Experiment 3, FF test view mean hits were greater than novel ($p = .003$) and RP test views ($p < .001$). Finally, for Experiment 2, when the learned view was TV, FF test view mean hits were greater than novel test views ($p = .003$); and for Experiment 3, when the learned view was RP, RP test view mean hits were greater than FF ($p < .001$) and novel test views ($p < .001$).

Summarising the three-way interaction, it was found that the difference in mean hit recognition performance between experiments when two-views had been learned and tested on the critical novel three-quarter test view was significant (i.e., testing the ‘FRU effect’: Exp x LTV x TTQ, $p = .046$), but when pairwise analysis was carried out and adjusted for multiple comparisons, this failed to be significant ($p = .077$), critically revealing that the ‘FRU effect’ did not differ significantly between experiments.

Table 2-6

Experiment (Exp: Exp1, Exp2 & Exp3) x learned view (LV: LTV, LFF & LRP) x test view (TV: TFF, NOVEL & TRP) interaction univariate tests.

	df	F	MSE	p	η_p^2	Power
Exp x LTV x TFF	2, 216	0.870	425.875	= .421	.008	.19
Exp x LTV x NOVEL	2, 216	3.124	425.875	= .046	.028	.59
Exp x LTV x TRP	2, 216	0.301	425.875	= .741	.003	.09
Exp x LFF x TFF	2, 216	2.330	425.875	= .100	.021	.46
Exp x LFF x NOVEL	2, 216	4.069	425.875	= .018	.036	.71
Exp x LFF x TRP	2, 216	4.327	425.875	= .014	.039	.74
Exp x LRP x TFF	2, 216	2.996	425.875	= .052	.027	.57
Exp x LRP x NOVEL	2, 216	0.999	425.875	= .370	.009	.22
Exp x LRP x TRP	2, 216	0.140	425.875	= .870	.001	.07
LV x Exp1 x TFF	2, 216	37.664	425.875	< .001	.259	1
LV x Exp1 x NOVEL	2, 216	5.937	425.875	= .003	.052	.87
LV x Exp1 x TRP	2, 216	9.728	425.875	< .001	.083	.98
LV x Exp2 x TFF	2, 216	59.599	425.875	< .001	.356	1
LV x Exp2 x NOVEL	2, 216	4.907	425.875	= .008	.043	.80
LV x Exp2 x TRP	2, 216	32.092	425.875	< .001	.229	1
LV x Exp3 x TFF	2, 216	32.511	425.875	< .001	.231	1
LV x Exp3 x NOVEL	2, 216	12.895	425.875	< .001	.107	.99
LV x Exp3 x TRP	2, 216	21.076	425.875	< .001	.163	1
TV x Exp1 x LTV	2, 216	0.075	425.875	= .928	.001	.06
TV x Exp1 x LFF	2, 216	5.025	425.875	= .007	.044	.81
TV x Exp1 x LRP	2, 216	29.515	425.875	< .001	.215	1
TV x Exp2 x LTV	2, 216	5.164	425.875	= .006	.046	.82
TV x Exp2 x LFF	2, 216	35.248	425.875	< .001	.246	1
TV x Exp2 x LRP	2, 216	32.994	425.875	< .001	.234	1
TV x Exp3 x LTV	2, 216	0.225	425.875	= .798	.002	.08
TV x Exp3 x LFF	2, 216	17.050	425.875	< .001	.136	1
TV x Exp3 x LRP	2, 216	21.291	425.875	< .001	.165	1

2.4.4 Discussion

The current experiment replicated that of Experiment 1 but differed only by the novel test view used, with a left three-quarter test view used in this case, and sought to test if the FRU effect observed in Experiment 1 would also be produced when the novel view was outside the rotation of those views learned. Results revealed that again, when two-views were learned, recognition of the novel left three-quarter view was significantly greater than when either a front-facing and right-profile single view was learned, and two-view recognition did not significantly differ between the three test views, indicating view invariance. However, now a significant difference between the single views was present on the novel test view, with front-facing single views significantly greater than when right-profile single views were learned.

Furthermore, and in comparison to Experiment 1 where these differences were not significant, it was found in the current experiment that when a front-facing single view was learned, recognition of the three-quarter test view was significantly worse than the front-facing test view, and performance on the three-quarter test view was significantly worse than performance on the right-profile test view. In addition, results from the learning phase did not replicate those of Experiments 1 and 2, although two-view performance significantly increased by the end of the session compared to the beginning (i.e., block 7 mean hits were larger than block 1), single-view matching was not significantly different between blocks 1 and 7. Again, discussion of this learning view matching effect will be held back until all experiments are concluded (see section 4.4, General Discussion).

The two-view advantage and view invariance afforded when two-views were learned is again suggested to represent the action of an FRU representation being formed, and it is argued that this occurred because the two learned views became ‘interlinked’ in memory to form an FRU representation for each identity, in contrast to learning single views that could not become ‘interlinked’ because they only represented one example of each identity. As discussed in Experiment 1, it is proposed that distinguishing between ‘structural’ and ‘pictorial’ codes as accounting for these effects, as Bruce and Young (1986) proposed, may be more usefully accounted for by a perceptual visual ‘bar code’ encoding account that can be said to include both types of encoding (i.e., Dakin & Watt, 2009; Goffaux & Dakin, 2010; Pachai, Sekuler & Bennett, 2013).

One of the main advantages of collapsing these two codes ('pictorial' and 'structural') into one perceptual 'bar code' is that it enables discussion to be focused on whether the representation formed is truly qualitatively different (i.e., as the FRU account proposes) to that of a single learned view, and also allows discussion of single-view effects without needing to account for whether 'pictorial' and/or 'structural' codes are apparent. Admittedly, this is a departure from strict adherence to the Bruce and Young model, but does offer a way to understand so called, 'FRU effects', and whether there is evidence to support such a representation being formed. For example, when the novel test view in this experiment was outside the rotation of those views learned, recognition when two-views were learned was not affected, which would be further support for horizontal vertically aligned attributes (i.e., 'bar codes') which are not affected by left-right view changes, or internal-external notional rotation effects, primarily because faces are generally

approximately symmetrical (and see, Pachai, Sekuler & Bennett, 2013 for similar findings with left-right views).

In conclusion, the beneficial effect of learning two-views has been characterised here as representing an FRU-effect in support of the Bruce and Young model, however, it is also possible that the two-views learned do not need to be ‘interlinked’ to achieve these results. That is, when two-views were learned, these may remain separate in memory to be accessed online when a novel view matches the horizontal vertically aligned attributes of those representations (i.e., ‘bar codes’). However, it is argued that even if separate representations that share the same ‘bar code’ attributes are accessed to answer the novel view question (in the case of learning two-views), the action of one or other view alone did not achieve the two-view recognition performance advantage observed. It is therefore proposed that even if the representations are stored in memory separately, combining of their relative information to answer a novel view does seem to represent some form of ‘integration of information’, a conclusion that was also reached by Longmore et al. (Experiment 2, 2015). This will of course need to be investigated further by using different view types to establish whether the same advantage for two-view learning is repeated for views other than those used here, and whether a two-view recognition advantage is dependent of the types of view learned and their apparent informational utility.

2.5 General Discussion

Three experiments were conducted to investigate whether evidence could be found that was congruent with the development of Bruce and Young's (1986) notion of a face recognition unit (FRU), after substantial learning of unfamiliar faces, using a one-back matching procedure. An overall analysis between experiments was carried out, revealing that the three-way interaction between experiment, learned view and test view was significant. However, critically, it was found that differences between experiments were not significant when two-views had been learned and the test view was the novel three-quarter view (i.e., left and right three-quarter views), indicating that consolidation and differences between internally and externally rotated test views had no significant effect between experiments. However, when front-facing views were learned, and the test was a three-quarter view, Experiment 3 (LTQ) means were greater than Experiment 2 (RTQ), but this only approached significance, and when the test view was a right-profile, Experiment 1 means were significantly greater than Experiment 2. It was also found that in the learning phase, in Experiments 1 and 2, that two-view matching increased between blocks 1 and 7, and single-view matching decreased, and for Experiment 3, the same pattern for two-view matching was repeated, but now single-view matching was not significantly different between blocks 1 and 7.

However, it must be stated that all three learning phases were exactly the same, using the same learned view types, and only differed by participant group, with the only caveat being that participants in Experiment 2 may have surmised that they would be required to carry out a recognition test immediately after the learning phase, due to the time they were booked to be in the lab. That being said, it is difficult to reconcile why single-view matching decreased between the start and end

for two of the experiments, perhaps apart from speculating that for these experiments, participants decrease in accuracy was due to the ease of the task combined with an increase in misses due to a lack of attention. That is, matching two views that were identical should be considerably easier than matching two views that were not the same, and this ease of matching may perhaps have focused attentional resources on those matches that were considered more perceptually difficult, and thus errors crept in over time for single-view matches, although correct rejections were unchanged.

Furthermore, it is suggested that this may be related to the finding that telling people apart is often easier than telling them together (e.g., Andrews, Jenkins, Cursiter & Burton, 2015), in that more attentional resources may be applied to views that don't match, whether they are the same identity (i.e., two-view hits) or not (i.e., two-view correct rejections). It was also notable that correct rejections were not significantly different for each of the three experiments in the learning phase, but clearly hits reduced for single views, so rather than this highlighting differences in the type of views or encoding taking place, it is concluded that these effects were due to individual differences in attention to matches for two out of three experiments. It will be interesting to see if a similar pattern is observed for later experiments, and whether more weight can be attributed to the types of view being learned and whether they are single or two-view types, but this remains to be seen. Therefore, as it is unclear why these different learning patterns emerged, it is considered important that comment be postponed until all experiments are concluded, as there may be some apparent consistency that may help to identify why single-view matching accuracy reduced for Experiments 1 and 2, but not Experiment 3, and if this repeated for later experiments (see section 4.4, General Discussion).

Although the primary focus was on the critical effect of learning view type (i.e., two-views versus single-views) for the novel three-quarter test view, and thus the FRU effect, it is important to point out that the pattern of performance for the single learned-view conditions across experiments was very similar to those observed in Experiment 3 of Longmore et al. (2008). That is, for cases of learning from single views (dashed and dotted lines; Figures 2-2, 2-4, and 2-6), recognition performance generally declined significantly as a function of the viewing angle rotational difference between the learned and tested view, except for Experiment 1 where front-facing learned view accuracy on the same test view was not significantly different when tested on the three-quarter view. It would therefore seem to be the case that when single views were learned, recognition accuracy when a view change occurred was almost always significantly worse than when the test view was the same view. Normally, this would be attributed to an image-based ‘pictorial’ effect, but as has been mentioned previously, the decline in performance appears to be based on the attributes of the face and the information it conveys, rather than purely an image change.

Additionally, all experiments in this chapter produced very similar effects for two-views and single-views as those reported by Longmore et al. (2015) who also cropped their face images, however, in a study conducted by Jiang, Blanz and O’Toole (2007) which also investigated view-transfer effects for different view types, a different pattern emerged. Jiang et al. employed a face-adaptation metric in a familiarisation paradigm in which participants learned different levels of familiarity (low to extreme) that varied by the number of exposures and the number of cropped view types (i.e., front-facing and three-quarter views). In the familiarisation phase participants were tasked with learning names for the stimuli presented (i.e., a similar

approach to that of Longmore, Liu, & Young, 2008; 2105). In the test phase, participants identified ‘flashed’, briefly presented faces (200ms) that were either within-view (i.e., same view), or across-view (i.e., different views), varying in low to extreme familiarity. They found no evidence for a multiple-view advantage for highly familiar faces over highly familiar single views, and suggested that this unexpected (i.e., contrary to their hypothesis) result may have occurred due to the use of only two view types. However, they did find that familiarity influenced view-change identity aftereffects, concluding that, “faces are represented by multiple view-specific mechanisms that become associated, over time, with experience” (p. 530).

This conclusion does seem somewhat similar to ‘interlinking’ of structurally encoded representations proposed by Bruce and Young (1986), and the ‘integration of information’ findings of Longmore et al. (2015). However, as has been reported here, using the single/two-view learning regime with many encounters did produce greater recognition of a novel three-quarter test view than when single views were learned, but only when the recognition phase was carried out on the following day. It could therefore be that providing many more repetitions in the current learning phase, and affording a period of consolidation (i.e., Experiments 1 and 3), may have produced these effects over those of Jiang et al. It is also possible, in comparison to the lack of evidence for a multiple-view advantage for highly familiar faces over highly familiar single views reported by Jiang et al., that single view representations in the current studies may not be ‘as familiar’ as those learned from two-views, and may therefore represent a qualitative difference between single and two-view learned representations. However, as different levels of familiarity were not manipulated here, one can only say that differences between the current experiments and those of

Jiang et al., are likely due to the number of exposures afforded in the current experiment.

In conclusion, the three experiments carried out have provided evidence that learning two-views that were different conferred a recognition advantage over learning those views singularly, and that view invariance when two-views were learned, seemed to be affected by a lack of overnight consolidation, although this was not a significant effect between experiments. It was also found that the ‘barcode’ account of perceptual visual matching and recognition (i.e., Dakin & Watt, 2009; Goffaux & Dakin, 2010; Pachai, Sekuler & Bennett, 2013) could account for both the ‘pictorial’ and ‘structural’ encoding effects that are argued to be responsible for perceptual face learning and recognition, according to the Bruce and Young model (1986). That is, although it was not possible to distinguish between ‘pictorial’ and ‘structural’ codes alone as accounting for these effects, apart from inferring this from a supported FRU effect outcome based on theory, it was suggested that the ‘barcode’ findings provided a way of ‘collapsing’ all of the visual encoding and recognition effects into an empirically supported perceptual account that could be used to test different view effects. Furthermore, taking this approach also allows the fundamental question of whether an FRU is created from learning two-views, or whether online summation of the two views learned produces the recognition effects observed, to be tested. Therefore, to understand if the FRU effect reported in Experiments 1 and 3 is sensitive to the view type(s) learned, and whether this differs between single and two-views, the next chapter will provide different view types as single or two-views, and then test them on the same view learned, the other view learned, or a completely novel front-facing view.

Chapter 3. Testing learned view type combinations in unfamiliar face learning

3.1 General introduction

Extending the findings of Chapter Two, the following four experiments were designed to test different learned view types as single-views and two-views, so that the effect of learning such view types could be better understood in terms of the ‘view type utility’ each view type learned singularly or in combination, might afford. To be clear, the phrase ‘view type utility’ is used here to allow a distinction to be made between what may or may not become apparent between different learned view types, based on their interpreted informational attributes, and based on their ability (or lack of it) to aid recognition of the same test view as that learned, the other view not learned, or a completely novel front-facing test view. It was hoped that this approach would also allow consideration of previously the discussed ‘bar code’ perceptual visual encoding and recognition evidence (i.e., Dakin & Watt, 2009; Goffaux & Dakin, 2010; Pachai, Sekuler & Bennett, 2013). Again, and repeating the overall hypothesis of Chapter Two, if the Bruce and Young (1986) FRU account of face learning is supported, then recognition of a novel view of learned identities will be significantly greater when two-views are learned compared to either of the single views, on the novel front-facing test view, but it is anticipated that this may be tempered by their ‘view type utility’.

3.2 Experiment 4: Learning mirrored profile views singularly or both, when tested on a front-facing novel view

It was suggested that the FRU-effect reported in the previous chapter for Experiments 1 and 3 (Chapter 2), occurred because learning two different views of previously unfamiliar faces allowed those views to become ‘interlinked’, and that affording a period of overnight consolidation aided this representation in memory. Furthermore, in Experiments 1 and 3 (Chapter 2), the two learned views were a right-profile and a front-facing view, and therefore contained different, but arguably complementary visual information about the face. The current experiment therefore sought to test the idea that FRUs are formed from learning more than one view of an identity that possessed sufficient variation in view information, but was the same view type. It was therefore decided that for this experiment that profile views should be used, as identification of such views has been reported to be poorer than front-facing and three-quarter views (e.g., McKone, 2008), and should therefore allow the testing of a two-view advantage using a more stringent view type. It was also decided that to directly test whether within-identity variation was necessary to produce FRU-effects, mirrored profile images would be used because apart from view direction, they were exactly the same image. Therefore, if an FRU-effect occurred after learning two-views that were the same image, but only differed in view direction (i.e., left and right mirrored profiles), it would be possible to conclude that all an FRU requires for its formation is two different views that provide an orientation difference, but no other visual within-identity difference. Intuitively, and based on the previous argument that within-identity variation is necessary for an FRU to be formed, rather than just an orientation difference, it is predicted that for this ‘mirrored profile’ experiment, an FRU-effect will fail to emerge.

3.2.1 Method

Participants

Twenty-seven Caucasian undergraduates (16 females, 11 males) aged between 18 and 23 years (mean age, 19.4 years) participated in exchange for course credit. All participants had normal or corrected-to-normal visual acuity (self-report) and no history of neurological illness (self-report). All participants gave informed consent and the procedures were approved by the University of Kent, School of Psychology Ethics Committee.

Design, Materials, Apparatus and Procedure

The design, materials, apparatus and procedure were the same as in Experiment 1, including a period of overnight consolidation (see Chapter 2), with the exception that the two-views learned were mirrored profile views (i.e., the true left-profile was mirrored and used as a right-profile view), and the critical novel test view was a front-facing view. See Table 2-1 (Chapter 2) for typical counterbalancing of learned view and test view types, but note that although view types will be different, the same principal of counterbalancing has been applied.

3.2.2 Results

From the learning phase data, the percentage of correctly identified matches (hits) was analysed with a 3×7 repeated-measures ANOVA with learned view type and block as factors. Departures from sphericity were corrected using the

recommendation of Girden (1992): for epsilon values greater than .75 the Huynh-Feldt correction was applied, and for epsilon values less than .75 the Greenhouse-Geisser correction was applied. Effect sizes were considered based on Cohen's (1988) recommendation of .02 for a small effect, .13 for a medium effect, and .26 for a large effect.

The main effect of view type was found significant, $F(2, 52) = 6.388$, $MSE = 104.676$, $p = .003$, $\eta_p^2 = 0.19$ (Observed power = .88), with mirrored left-profile view hits greater than two-views ($p = .001$), however, there was no main effect of block, $F(2.57, 66.88) = 1.985$, $MSE = 374.25$, $p = .133$, $\eta_p^2 = 0.07$ (Observed power = .45), meaning that match hit accuracy did not change as a function of block, and the view type x block interaction was not significant, $F(10.339, 268.819) = 1.318$, $MSE = 45.797$, $p = .218$, $\eta_p^2 = .04$ (Observed power = .68). See Figure 3-1 for mean correct responses (hits).

Analysis of correct rejections, that is, correctly saying ‘no’ when two successive faces did not match by identity, were analysed between each learning group (i.e., group A, B & C - referred to in the Design section), and by block (1-7), to establish whether participants were responding significantly differently between the three ‘counterbalancing by identity’ learning groups. Therefore, these two factors were subjected to a 3x7 mixed-factors design, with learning group as a between subject’s factor and block as a repeated measure, the dependent variable being mean percent correct rejections. Analysis revealed that the main effect learning group was not significant, $F(2, 24) = 0.466$, $MSE = 682.697$, $p = .633$, $\eta_p^2 = 0.03$ (Observed power = .11), the main effect of block was not significant, $F(1.627, 39.045) = 1.038$, $MSE = 116.698$, $p = .351$, $\eta_p^2 = 0.04$ (Observed power = .20), and the two-way

interaction between learning group and block was not significant, $F(12, 144) = 0.514$, $MSE = 31.643$, $p = .903$, $\eta_p^2 = .04$ (Observed power = .28).

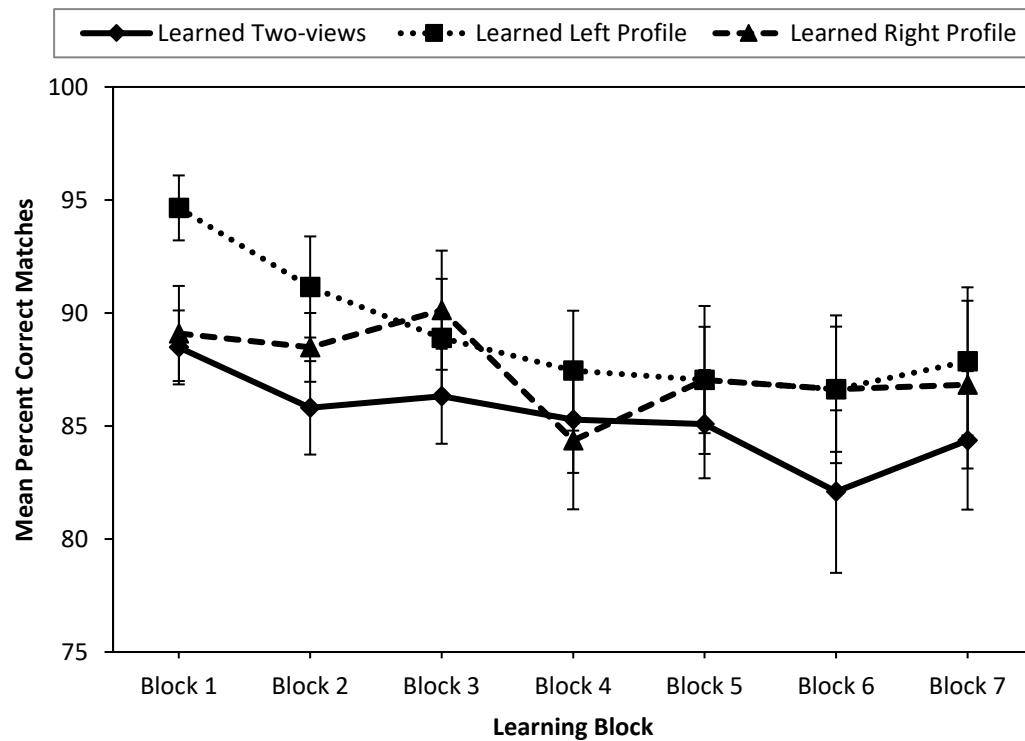


Figure 3-1. Experiment 4 Learning Phase Results. Mean percent correct one-back matching responses are plotted as a function of learned view (Two-views, Mirrored Left-profile view & Mirrored Right-Profile view) at each block of learning. Error bars represent standard error of the mean.

Having established that the three learned view types were not modulated by block, and that correct rejections were not modulated by learning group, analysis of the test phase was carried out. A hit rate was calculated for each participant and condition by computing the percentage of targets which received a “yes” response

within each condition. These values were processed with a 3x3 between-subject's ANOVA, with learned view (Two-views; Left-profile Learned view; Right-profile Learned view) and test view (Left-profile Tested view; Front-facing Tested view; or Right-profile Tested view) as factors. Effect sizes were considered based on Cohen's (1988) recommendation of .02 for a small effect, .13 for a medium effect, and .26 for a large effect.

Analysis of recognition (hit) rates in the test phase revealed that the main effect of learned view was not significant, $F(2, 72) = 0.102, MSE = 579.942, p = .903, \eta_p^2 = 0.003$ (Observed power = .06), but the main effect of test view was significant, $F(2, 72) = 11.953, MSE = 579.942, p < .001, \eta_p^2 = 0.24$ (Observed power = .99), with mirrored left-profile test view hits ($p = .001$) and mirrored right-profile test view hits ($p < .001$) greater than front-facing test views. However, the critical interaction between learned view and test view was not significant, $F(4, 72) = 0.110, MSE = 579.942, p = .979, \eta_p^2 = .006$ (Observed power = .07). See Figure 3-2 for mean correct responses (hits).

Analysis of correct rejections at test (i.e., saying "no" to an identity which had not been seen at learning), indicated that when a distractor was a left-profile test view, over 78% were correctly rejected; 77% for front-facing test views; and, 81% for right-profile test views. A one-way ANOVA with test view as a factor showed that this factor was not significant, $F(2, 78) = 0.235, MSE = 408.357, p = .791, \eta_p^2 = 0.006$ (Observed power = .08).

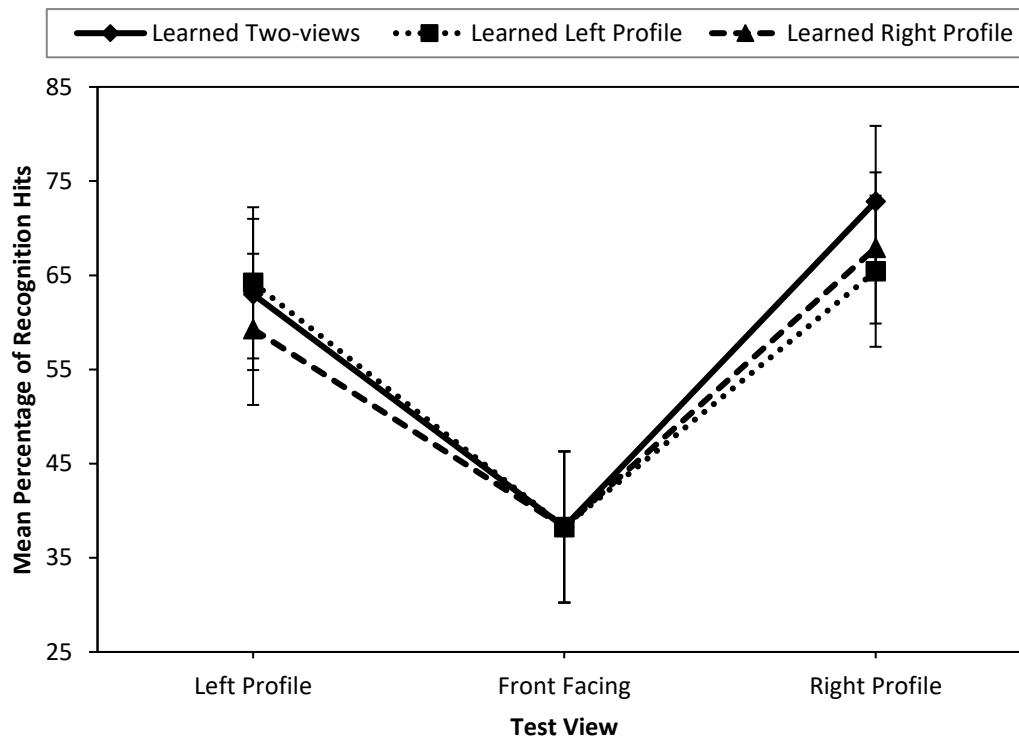


Figure 3-2. Experiment 4 Test Phase Results. Mean percent recognition hits of previously seen faces as a function of learned view and test view. The results indicate the overall effects of learning two-views or one view on recognition accuracy for three test views. Error bars represent standard error of the mean.

3.2.3 Discussion

The current experiment sought to test the idea that FRUs are formed from more than one encounter with an identity that possess some variation of view information, but it was not clear whether this could be produced from having two-views that simply differed by view direction, but were otherwise exactly the same image. To test this, mirrored profile views were chosen, with the critical novel view being a front-facing view. It was predicted that an FRU-effect would fail to emerge

because there would be no within-identity variation, with the current experimental results confirming this prediction.

Unlike the previous three experiments (see Chapter 2), there was no increase in matching accuracy over learning blocks for the two-views condition which suggests that the visual system dealt with these two-views as essentially the same percept. It was also notable that the left and right mirrored profiles as single views, and for each as part of the two-views condition at test, showed no advantage for the orientation learned. In other words, recognition for learned left-profile views and learned right-profile views (both as single views and as one of the two-views condition), when tested on the same view, were no different than the other profile view. This may therefore be used as evidence to support the claim that each mirrored view in the two-view condition was perceived as the same image, and view direction provided very little influence on recognition accuracy.

This view is supported by a functional magnetic resonance imaging (fMRI) study that tested participants at different face viewing orientations and found approximately equal recognition accuracy for the same left and right orientations, with the authors concluding that mirror symmetry encoding may aid more efficient construction of an identity representation (Kietzmann, Swisher, Koenig & Tong, 2012). For example, a left and right mirrored profile in this case, may be ‘collapsed’ into a single representation, as they do not differ substantially from each other.

Although the fMRI study did report insensitivity to their symmetrical computer-generated faces, it remained to be seen if real world face views that were the same view, but visually mismatching in terms of lower level visual differences such as surface contrast or configural differences within each view, would produce the same symmetry invariance. However, the work on ‘bar codes’ with real faces would seem

to suggest similar conclusions, in that low level visual differences between two views that were the same, allowed equal recognition of the other view (i.e., Dakin & Watt, 2009; Goffaux & Dakin, 2010; Pachai, Sekuler & Bennett, 2013).

In conclusion, the main finding from the current experiment is that learning two-views that only varied in view direction did not produce any advantage over learning either single view, and that the decrement in recognition accuracy on the front-facing novel view was equivalent between each of the learned view types. This suggests that within-identity visual variation is necessary for an FRU to be formed, but this conclusion will need to be tested using true profiles that do provide within-identity visual variation, other than view direction, to be able to confirm this hypothesis.

3.3 Experiment 5: Learning true profile views singularly or both, when tested on a front-facing novel view

3.3.1 Introduction

As predicted, when two mirrored profile views were learned (Experiment 4), an FRU-effect, or advantage for learning two-views, failed to emerge, and it was suggested this was due to an absence of within-identity variation between the two-views learned. Based on this contention, it was concluded that an appropriate test of this conclusion would be to test true profile views. True profile views contain all the same structural (silhouette) information (i.e., nose, chin, forehead depth etc.) as mirrored profiles, but importantly vary in lower level visual information, such as

contrast and minimal configural differences. It was therefore predicted that if an FRU requires visual within-identity variation to be formed (other than view direction alone, i.e., mirrored profiles), that providing true profile views should produce a recognition advantage on a front-facing novel view, compared to having learned either of the single profile views, which would again indicate the FRU-effect found in the previous experiments (i.e., Experiments 1 and 3, Chapter 2).

3.3.2 Method

Participants

Twenty-seven Caucasian undergraduates (19 females, 8 males) aged between 18 and 38 years (mean age, 20 years) participated in exchange for course credit. All participants had normal or corrected-to-normal visual acuity (self-report) and no history of neurological illness (self-report). All participants gave informed consent and the procedures were approved by the University of Kent, School of Psychology Ethics Committee.

Design, Materials, Apparatus and Procedure

The design, materials, apparatus and procedure were the same as in Experiment 1 (Chapter 2), with the exception that the two-views learned were true left and right profile-views, and the critical novel test view was again a front-facing view. See Table 2-1 (Chapter 2) for typical counterbalancing of learned view and test view types, but note that although view types will be different, the same principal of counterbalancing has been applied.

3.3.3 Results

From the learning phase data, the percentage of correctly identified matches (hits) was analysed with a 3x7 repeated-measures ANOVA with learned view type and block as factors. Departures from sphericity were corrected using the recommendation of Girden (1992): for epsilon values greater than .75 the Huynh-Feldt correction was applied, and for epsilon values less than .75 the Greenhouse-Geisser correction was applied. Effect sizes were considered based on Cohen's (1988) recommendation of .02 for a small effect, .13 for a medium effect, and .26 for a large effect.

The main effect of view type was significant, $F(1.13, 29.61) = 18.987, MSE = 984.95, p < .001, \eta_p^2 = 0.42$ (Observed power = .99), with left-profile mean hits greater than two-views ($p < .001$), and right-profile mean hits greater than two views ($p < .001$). There was no main effect of block, $F(3.38, 87.99) = 1.467, MSE = 171.75, p = .225, \eta_p^2 = 0.05$ (Observed power = .40), however, the view type x block interaction was significant, $F(6.06, 157.64) = 5.514, MSE = 127.64, p < .001, \eta_p^2 = .17$ (Observed power = .99). See Figure 3-3 for mean correct responses (hits).

The two-way interaction was first broken down by examining the simple main effect of block within each view type. Block was found to be significant for two-views (TV) only ($p = .001$, and see Table 3-1 for statistics and Figure 3-3 for means). Pairwise analysis focused on whether mean hit matching accuracy increased or decreased significantly between the start of the learning procedure compared to the end (i.e., block 1 versus block 7), with pairwise analysis revealing that block 7 mean hits were greater than block 1 ($p = .002$).

For the simple main effect of view type at each block, it was found that this was significant in blocks 1, 2, 3, 4, 5 and 7 (all p 's $< .048$. See Table 3-1 for statistics and Figure 3-3 for means), and approached significance at block 6 ($p = .059$). Pairwise analysis of blocks 1 to 7, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., $.05/3$ learned view type comparisons), revealed that at block 1, LP hits were greater than TV ($p < .001$) and RP hits were greater than TV ($p = .006$); at block 2, LP hits were greater than TV ($p < .001$) and RP hits were greater than TV ($p < .001$); at block 3, LP hits were greater than TV ($p < .001$) and RP hits were greater than TV ($p < .001$); at block 4, LP hits were greater than TV (approaching, $p = .017$) and RP hits were greater than TV ($p = .010$); at block 5, LP hits were greater than TV ($p = .010$) and RP hits were greater than TV (approaching, $p = .017$). However, at block 6, although LP hits were greater than TV ($p = .027$) and block 7 LP hits were greater than TV ($p = .027$), these were not significant when adjusted for multiple comparisons.

Table 3-1

Block x View type interaction simple main effects.

	df	F	MSE	p	η_p^2	Power
Two-views x Block	2.91, 75.70	6.24	207.80	= .001	.19	.95
Left-profile view x Block	6, 156	1.70	58.40	= .123	.06	.63
Right-profile view x Block	3.57, 93.05	1.85	111.69	= .131	.06	.51
Block 1 x View type	1.36, 35.36	40.65	180.69	< .001	.61	1
Block 2 x View type	1.80, 46.97	25.94	128.81	< .001	.49	1
Block 3 x View type	1.58, 41.27	17.33	144.08	< .001	.40	.99
Block 4 x View type	1.58, 41.09	5.97	146.08	= .009	.18	.79
Block 5 x View type	1.60, 41.79	6.11	183.44	= .008	.19	.80
Block 6 x View type	1.42, 37.16	3.39	241.65	= .059	.11	.51
Block 7 x View type	1.35, 35.20	3.81	234.41	= .047	.12	.54

Analysis of correct rejections was carried out as Experiment 4, revealing that the main effect learning group was not significant, $F(2, 24) = 0.493$, $MSE = 90.985$, $p = .617$, $\eta_p^2 = 0.03$ (Observed power = .12), but the main effect of block was significant, $F(4.963, 119.110) = 5.010$, $MSE = 11.320$, $p < .001$, $\eta_p^2 = 0.17$ (Observed power = .98), with mean correct rejections significantly greater at block 7 than block 1, 2 and 6 (all p 's $< .009$), block 5 correct rejections were greater than block 2 ($p = .015$), block 4 correct rejections were greater than block 2 and 6 (all p 's $< .006$), and block 3 correct rejections were greater than block 2 and 6 (all p 's $< .026$). But the two-way interaction between learning group and block was not significant, $F(12, 144) = 1.326$, $MSE = 9.363$, $p = .210$, $\eta_p^2 = .09$ (Observed power = .71).

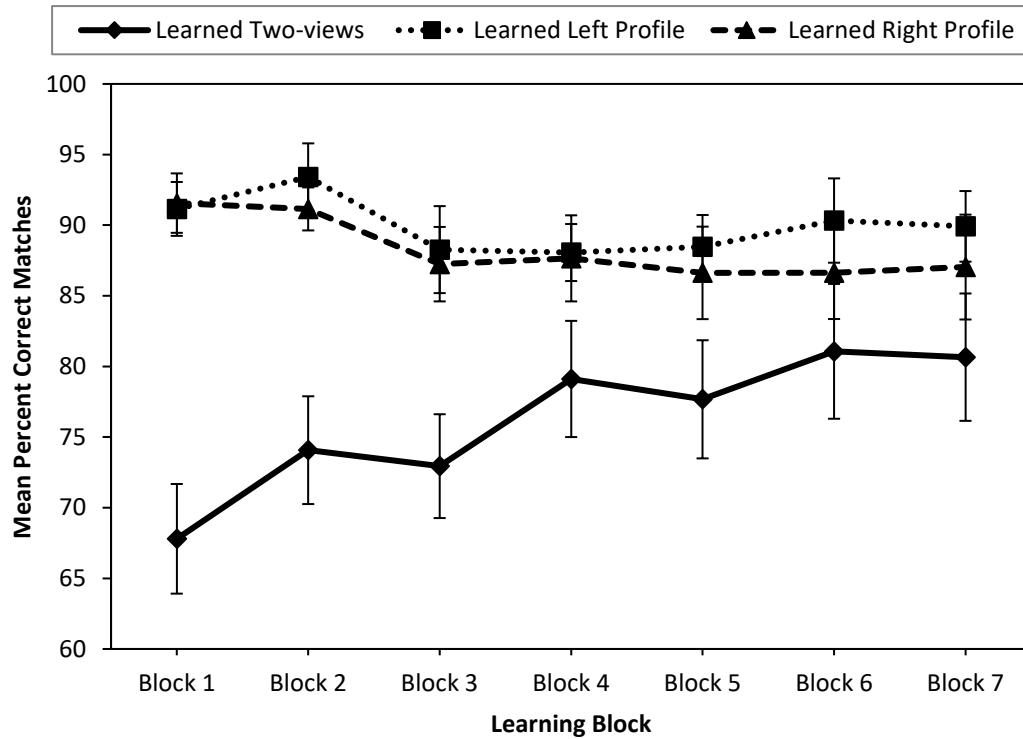


Figure 3-3. Experiment 5 Learning Phase Results. Mean percent correct one-back matching responses are plotted as a function of learned view (Two-views, True Left-profile view & True Right-Profile view) at each block of learning. Error bars represent standard error of the mean.

Having established that correct rejections were not modulated by learning group, analysis of the test phase was carried out, with a hit rate calculated as in Experiments 4, finding that the main effect of learned view was significant, $F(2, 72) = 13.467$, $MSE = 440.482$, $p < .001$, $\eta_p^2 = 0.27$ (Observed power = .99), with TV hits greater than LP ($p < .001$) and RP ($p < .001$) learned views, but LP and RP learned view types were not significantly different from each other ($p = .556$). The main effect of test view was also found significant, $F(2, 72) = 16.239$, $MSE = 440.482$, $p < .001$, $\eta_p^2 = 0.31$ (Observed power = .99), with hits for LP test views

greater than FF test views ($p < .001$), and hits for RP test views greater than FF test views ($p < .001$). Furthermore, the critical interaction between learned view and test view was found significant, $F(4, 72) = 2.567$, $MSE = 440.482$, $p = .045$, $\eta_p^2 = .12$ (Observed power = .69). See Figure 3-4 for mean correct responses (hits).

Simple main effect univariate analysis of the significant two-way interaction first focused on the critical comparison to test for the FRU effect, that is, an advantage in recognition of the novel front-facing view for identities learned from two-views over those learned from single views (i.e., comparing the three data points in the central column of Figure 3-4). The result was significant, $F(2, 72) = 3.488$, $MSE = 440.482$, $p = .036$, $\eta_p^2 = .08$ (Observed power = .63). Pairwise comparisons, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., $.05/3$ learned view comparisons), revealed that when two-views had been learned (diamond, centre column, Figure 3-4), mean hits were significantly greater on the front-facing test view than when left-profile views ($p = .015$; square, centre column, Figure 3-4), but not right-profile views ($p = .619$; triangle, centre column, Figure 3-4), were learned. However, the difference between left-profile and right-profile learned views when tested on the front-facing test view was not found to be significant after correcting for multiple comparisons ($p = .050$).

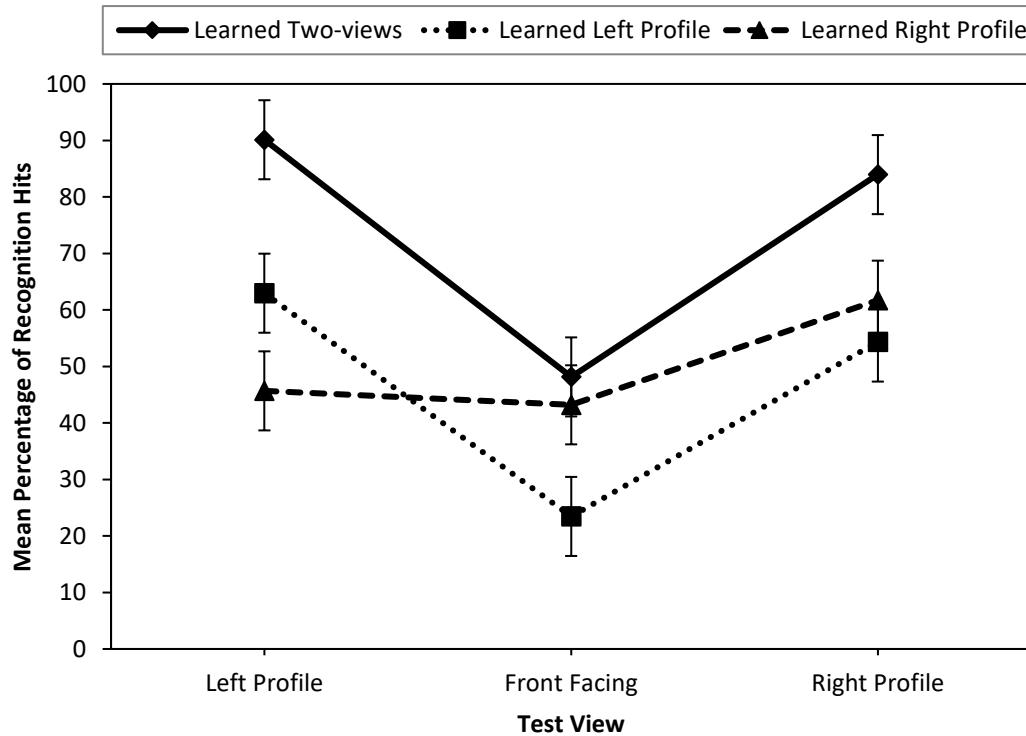


Figure 3-4. Experiment 5 Test Phase Results. Mean percent recognition hits of previously seen faces as a function of learned view and test view. The results indicate the overall effects of learning two-views or one view on recognition accuracy for three test views. Error bars represent standard error of the mean.

When the test view was a left-profile view (i.e., comparing the three data points in the left column of Figure 3-4), learned view was significant, $F(2, 72) = 10.256$, $MSE = 440.482$, $p < .001$, $\eta_p^2 = .22$ (Observed power = .98), with pairwise comparisons, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., $.05/3$ learned view comparisons), revealing that when two-views had been learned (diamond, left column, Figure 3-4), mean hits were significantly greater than when left-profile views were learned ($p < .001$; square, left column, Figure 3-4), and two-view means were significantly greater than right-profile views ($p < .001$;

triangle, left column, Figure 3-4), but the difference between left-profile views and right-profile views was not found to be significant after correcting for multiple comparisons ($p = .085$).

When the test view was a right-profile view (i.e., comparing the three data points in the right column of Figure 3-4), learned view was significant, $F(2, 72) = 4.858$, $MSE = 440.482$, $p = .010$, $\eta_p^2 = .11$ (Observed power = .78), with pairwise comparisons, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., .05/3 learned view comparisons), revealing that when two-views had been learned (diamond, right column, Figure 3-4), mean hits were significantly greater than when left-profile views were learned ($p = .004$; square, right column, Figure 3-4), but two-view mean hits were not found to be significantly greater than right-profile views after correcting for multiple comparisons ($p = .028$; triangle, right column, Figure 3-4), and the difference between left-profile views and right-profile views was not significant ($p = .456$).

Investigation of the two-way interaction (learned view x test view), for each learned view, to understand if each learned view produced view-invariance, found that when two-views had been learned, differences between test views were significant, $F(2, 72) = 10.495$, $MSE = 440.482$, $p < .001$, $\eta_p^2 = .22$ (Observed power = .98). Pairwise comparisons, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., .05/3 test view comparisons), revealed that left-profile test view mean hits were significantly greater than front-facing test views ($p < .001$), but not right-profile test views ($p = .535$), and right-profile test view mean hits were greater than front-facing test views ($p = .001$). When left-profile views had been learned, test view was significant, $F(2, 72) = 8.813$, $MSE = 440.482$, $p < .001$, $\eta_p^2 =$

.019 (Observed power = .96), with pairwise comparisons, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., .05/3 test view comparisons), revealing that mean hits for left-profile test views were significantly greater than front-facing test views ($p < .001$), but not right-profile test views ($p = .385$), and right-profile test view mean hits were significantly greater than front-facing test views ($p = .003$). However,, when right-profile views had been learned, test view was not significant, $F(2, 72) = 2.066$, $MSE = 440.482$, $p = .134$, $\eta_p^2 = .05$ (Observed power = .41).

Analysis of correct rejections at test (i.e., saying “no” to an identity which had not been seen at learning), indicated that when a distractor was a LPT test view, over 84% were correctly rejected; 81% for FFT; and, 82% for RPT. A one-way ANOVA with test view as a factor showed that this factor was not significant, $F(2, 78) = 0.175$, $MSE = 340.356$, $p = .840$, $\eta_p^2 = 0.004$ (Observed power = .07).

To understand if mean hits between mirrored and profile experiments were significantly different from each other, analysis was carried out with a 2x3x3 between-subject's ANOVA, with experiment (Experiment 4; Experiment 5), learned view (Two-views; Left-profile Learned view; Right-profile Learned view) and test view (Left-profile Tested view; Front-facing Tested view; or Right-profile Tested view) as factors. The main effect of experiment was not significant, $F(1, 144) = 0.037$, $MSE = 510.212$, $p = .847$, $\eta_p^2 = 0.0002$ (Observed power = .05), but the main effect of learned view was, $F(2, 144) = 6.947$, $MSE = 510.212$, $p = .001$, $\eta_p^2 = 0.08$ (Observed power = .92) with mean hits when two-views were learned greater than left-profile ($p = .001$) and right-profile ($p = .003$) views, but left and right profile view means were not significantly different from each other ($p = .777$). The main

effect of test view was also found to be significant, $F(2, 144) = 27.344, MSE = 510.212, p < .001, \eta_p^2 = 0.27$ (Observed power = 1), with left-profile test view mean hits greater than front-facing test views ($p < .001$), and right-profile test view hits greater than front-facing test views ($p < .001$), but left and right profile view means were not significantly different from each other ($p = .422$). The interaction between experiment and learned view was also found significant, $F(2, 144) = 4.796, MSE = 510.212, p = .010, \eta_p^2 = .06$ (Observed power = .78). All other interactions were not significant (all p 's $> .771$). See Figure 3-5 for mean correct responses (hits) for the interaction between Experiment and learned view.

Simple main effect univariate analysis of the significant two-way interaction between experiment and learned view revealed that the simple main effect of learned view was significant for Experiment 5 (true profiles), $F(2, 144) = 11.627, MSE = 510.212, p < .001, \eta_p^2 = .13$ (Observed power = .99), but not Experiment 4 (mirrored profiles), $F(2, 144) = 0.117, MSE = 510.212, p = .890, \eta_p^2 = .002$ (Observed power = .06). Pairwise comparison of the significant Experiment 5 learned view effect, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., .05/3 learned view comparisons), revealed that when two-views had been learned, performance was significantly greater than having learned either the right or left single profile views (all p 's $< .001$). It was also found that the simple main effect of experiment was significant for two-views, $F(1, 144) = 6.816, MSE = 510.212, p = .010, \eta_p^2 = .04$ (Observed power = .73), but not left-profile views, $F(1, 144) = 2.169, MSE = 510.212, p = .143, \eta_p^2 = .01$ (Observed power = .31), or right-profile views, $F(1, 144) = 0.645, MSE = 510.212, p = .423, \eta_p^2 = .004$ (Observed power = .12). Pairwise comparisons for the two-views significant effect, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .025 (i.e., .05/2

experiment comparisons), revealed that Experiment 5 (true profiles) mean hits were greater than Experiment 4 (mirrored profiles), $p = .010$.

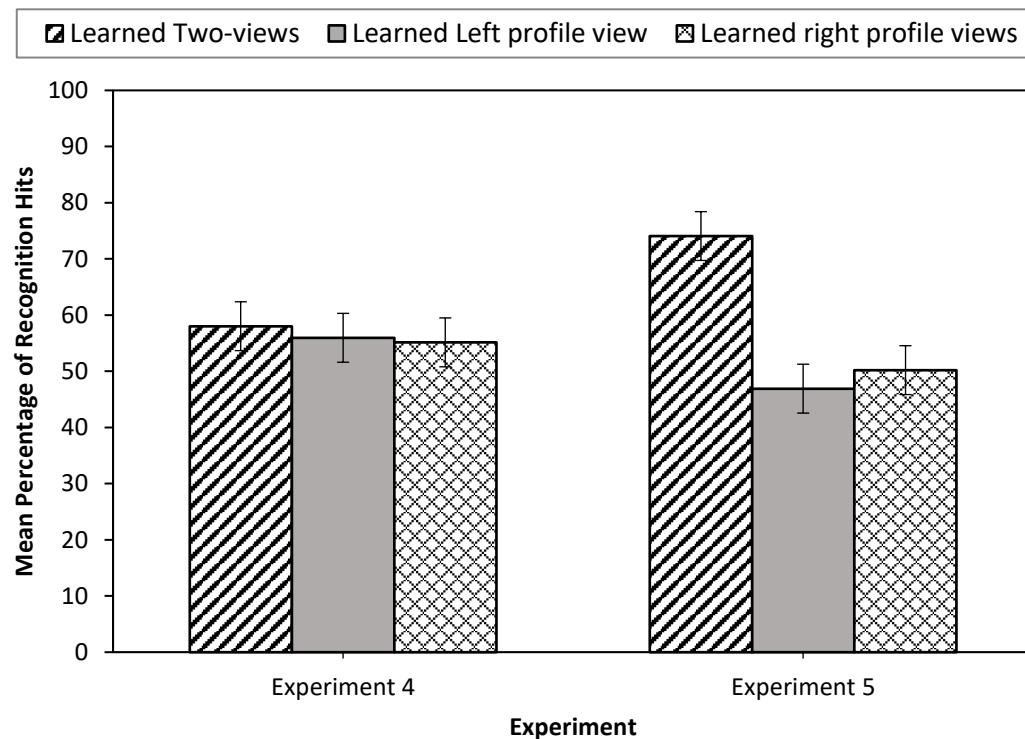


Figure 3-5. Experiment x Learned view interaction results. Mean percent recognition hits as a function of learned view and experiment (collapsed over test view). The results indicate the overall effects of learning two-views or one view, on recognition accuracy between Experiment 4 (mirrored profile views) and 5 (true profile views). Error bars represent standard error of the mean.

3.3.4 Discussion

The current experiment tested whether an FRU-effect, or advantage from learning two-views that were now true profile views, would result in significantly better recognition of a novel front-facing test view. Unfortunately, the results were somewhat contradictory, with two-view mean hits significantly greater when tested on the front-facing view, compared to having learned single left-profiles, but not single right-profiles, so any firm FRU-effect conclusions cannot be made based on this critical test view alone. However, and in contrast to the learning pattern in Experiment 4 that used mirrored profile views, current results indicated the same pattern of increasing matching accuracy for the two-views condition that was found in the previous experiments of Chapter 2 (i.e., two-view matching accuracy increasing between blocks 1 and 7). This supports the view that participants were correctly matching true profile views in the two-view condition for this experiment as separate percept's, rather than essentially the same image as reported in Experiment 4 for mirrored profiles. Also, and repeating the finding from Experiment 4 (mirrored profiles), single view matches did not vary significantly between blocks 1 and 7, and it will be interesting to see if in the forthcoming experiments whether this trend continues, which will be addressed in the general discussion of this chapter once all experiments have been completed.

What was surprising about the current true profile test results was the apparent numerical advantage gained from learning two-views over each of the single views, on the same test view (i.e., left-profile learned / left-profile tested & right-profile learned / right-profile tested). That is, the experiments in Chapter 2 did not produce this effect, and in fact when two-views were learned compared to single views, and tested on the same view, no differences in mean hits were found, with

performance always very good for both view types. To be clear, findings from the previous chapter would predict that the same view learned and tested, whether it was a single learned view or part of two-views, should result in approximately equal, and very good recognition performance. However, this did not occur in the current experiment where it was found that two-view hits were significantly greater on the left-profile test view than when either a left or right profile view had been learned, and when the test view was a right-profile view, mean hits when two-views had been learned were significantly greater than when left-profiles had been learned, and approaching significance when right-profiles had been learned.

Although the advantage from learning two-views was not significant over both learned single views, on the novel test view, the results are at least indicative of a boost in recognition performance from having learned two true profile views over single profile views, when tested on the same learned view. Furthermore, when analysis was carried out between the experiments (i.e., mirrored compared to true profiles), it was found that a significant experiment by learned view interaction resulted, with mean hits when two-views were learned in Experiment 5 (true profiles) significantly greater than when two-views were learned in Experiment 4 (mirrored profiles). It was also found from this interaction that two-view hits for Experiment 5, but not Experiment 4, were significantly greater than when either of the single profile views were learned. It can therefore be concluded from this analysis that single profile learned view performance was not significantly different between these two experiments, but that two-view performance favoured the true profiles experiment over the mirrored profile experiment, when collapsed across test views. Therefore, when comparing Experiments 4 and 5, it is suggested that learning two true profile views produced an advantage over learning two mirrored profile

views based entirely on within-identity visual variation afforded by learning two true profiles views, as this was the only manipulation between experiments, except from participant cohort. Whether this variation triggered a process in which an ‘interlinked’ representation was formed (i.e., an FRU) is unclear, but it can be seen that learning two-views that varied only in low level visual variation, and therefore within identity variation, produced an advantage over learning single views, when collapsed across test views.

It was argued in the previous chapter that perceptual ‘bar code’ encoding (i.e., Dakin & Watt, 2009; Goffaux & Dakin, 2010; Pachai, Sekuler & Bennett, 2013) could account for the effects reported, over those that relied on distinguishing between ‘pictorial’ and ‘structural’ encoding effects. It was also suggested in the previous mirrored profile experiment (Experiment 4) that this perceptual encoding and recognition account, and fMRI findings (Kietzmann, Swisher, Koenig & Tong, 2012), could help to explain why left and right facing profile views that were exactly the same image apart from view direction, resulted in insensitivity to a view change for the other profile view. However, the current results, and specifically the between experiments analysis, would seem to indicate that within-identity low level visual variation between the two-views learned was responsible for the recognition performance boost that was observed. It is therefore difficult to reconcile this with only a ‘bar code’ perceptual encoding and recognition account, without also addressing the role of within-identity variation.

For example, the ‘bar code’ account suggests that the same and different views of a face can be perceptually matched because they share the same vertically aligned horizontal attributes, and that recognition from memory of the same or novel view can occur for the same reason. However, the true profile results cannot be

explained simply by this broad horizontal perceptual attribute account unless one also considers that face or image based differences can be included in such codes. Dakin and Watt (2009) addressed this when they considered the two phases of the perceptual process: ‘face detection’ and ‘face encoding’. They explained that that the first stage involves detecting that a face exists in a scene or image, and the horizontal ‘bar code’ structure of faces enables them to be discerned from their surrounding visual information. Then, the ‘face encoding’ stage allows the finer one-dimensional horizontal ‘bar code’ information within the now identified ‘face image’ to be encoded in more detail than the first fairly broad stage of face detection within a scene or image.

A possible explanation of how within-identity variation might give rise to the true profile effects reported over those of mirrored profiles is the work of Burton, Kramer, Ritchie and Jenkins (2016). These authors addressed the finer detail of how faces might be learned and stored for the same identity, finding that their PCA (principal components analysis) approach revealed that the ‘dimensionality’ of a face for a particular person is represented by idiosyncratic statistical within-identity differences. That is to say, the perception and recognition of an identity that is unfamiliar is suggested to be primarily driven by perceptual similarity to and commonality with other examples that share the same visual attributes. It is then suggested that the specific ‘dimensionality’ of that identity, for instance in the present case from learning two-views, provides the idiosyncratic statistical constraints that allow other visual examples of the same identity to be incorporated into the same identity representational memorial space.

Intriguingly, they make the point that the representational space for each identity is separate to every other representational space for every other identity,

with person-based statistical constraints that allow occurrences of only that person to be categorised as being the same identity. It is interesting that the idiosyncratic representational space that Burton et al. hypothesise at first seems to suggest something similar to the FRU proposal put forth by Bruce and Young (1986), although to be clear, Burton et al. do not state this in their work. Instead, the Burton et al. characterisation on closer inspection is suggestive of a superordinate set of statistical constraints for each identity, rather than the FRU account which instead suggests that many FRUs exist for the same identity, and that FRU formation is a common process irrespective of individual identity differences. This fundamental difference in how identity might be represented in memory, and how additional examples of the same identity might become associated, which provides the statistical constraints that allow each identity to be learned and associated, is an interesting proposal and will need to be considered in the forthcoming experiments.

In conclusion, it has previously been stated that the critical test of learning two-views would be that recognition should be significantly greater than learning a single view, on a novel test view. However, here this was inconclusive, and instead the effect of learning two-views resulted in significantly (and approaching significantly) greater recognition on the same views learned and tested, when compared to learning either of the single views. As discussed, ‘bar code’ perceptual encoding and recognition cannot alone account for the same view true profile two-view advantage reported here, unless such codes can also incorporate idiosyncratic within-identity variation that can be discerned once the face has been detected. That is, if the views are the same, but an effect of combination of the two is present, does this imply that within-identity visual variation achieves the observed increase in performance from learning two true profile views?

Based on the work of Burton et al. (2016), which suggests that idiosyncratic statistical within-identity differences constrain the same perceived identity to the same representational space, can it be envisaged that visual ‘bar codes’ also provide subtle within-identity visual variation in one dimension, and thus provide dimensional constraints to be used in the identification of novel views? Clearly, these questions and points raised from the current and previous experiment (Experiment 4) need to be addressed, and it is hoped that by carrying out the next experiment, which again will use the same view type for both views but this time providing true three-quarter views, that more light will be shed on whether an FRU account can be supported over that of separate exemplar-like accounts that have previously been referred to as ‘pictorial’ accounts.

3.4 Experiment 6: Learning true three-quarter views singularly or both, when tested on a front-facing novel view

3.4.1 Introduction

The previous profile (mirrored and true) experiments suggested that profile views may not allow easy transference to a novel front view, and that overall low performance for the single profile views may have contributed to the two-view recognition advantage found over the same single learned and tested views. Therefore, the current experiment used true three-quarter views, as these were intuitively thought to contain more useful information with which to answer a novel front-facing test view. The three-quarter (TQ) view has been shown to be free from

any ‘special’ characteristics in terms of learning and/or recognition within view or between views, and has also been found to be no different than any other view type (e.g., Bruce, Valentine & Baddeley, 1987; Liu & Chaudhuri, 2002). Therefore, using true three-quarter views enabled a same-view comparison to be made with the results of the previous true-profile and mirrored-profile experiments, and it was hoped that this would also help to clarify the type for representation formed from learning single or two views, and the possible encoding routes to such representations.

3.4.2 Method

Participants

Twenty-seven Caucasian undergraduates (20 females, 7 males) aged between 17 and 49 years (mean age, 19.85 years) participated in exchange for course credit. All participants had normal or corrected-to-normal visual acuity (self-report) and no history of neurological illness (self-report). All participants gave informed consent and the procedures were approved by the University of Kent, School of Psychology Ethics Committee.

Design, Materials, Apparatus and Procedure

The design, materials, apparatus and procedure were the same as in Experiment 1 (including a period of overnight consolidation, see Chapter 2), with the exception that the two-views learned were true three-quarter views, and the critical novel test view was a front-facing view. See Table 2-1 (Chapter 2) for typical

counterbalancing of learned view and test view types, but note that although view types will be different, the same principal of counterbalancing has been applied.

3.4.3 Results

From the learning phase data, the percentage of correctly identified matches (hits) was analysed with a 3x7 repeated-measures ANOVA with learned view type and block as factors. Departures from sphericity were corrected using the recommendation of Girden (1992): for epsilon values greater than .75 the Huynh-Feldt correction was applied, and for epsilon values less than .75 the Greenhouse-Geisser correction was applied. Effect sizes were considered based on Cohen's (1988) recommendation of .02 for a small effect, .13 for a medium effect, and .26 for a large effect.

The main effect of view type was found significant, $F(1.580, 41.068) = 25.842$, $MSE = 142.413$, $p < .001$, $\eta_p^2 = 0.49$ (Observed power = 1), with left three-quarter view hits greater than two-views ($p < .001$), and right three-quarter view hits greater than two-views ($p < .001$) and left three-quarter views ($p = .006$). But, there was no main effect of block, $F(3.15, 81.94) = 1.417$, $MSE = 116.48$, $p = .243$, $\eta_p^2 = 0.05$ (Observed power = .37), however, the view type x block interaction was significant, $F(4.58, 119.23) = 4.392$, $MSE = 121.79$, $p = .001$, $\eta_p^2 = .14$ (Observed power = .95). See Figure 3-6 for mean correct responses (hits).

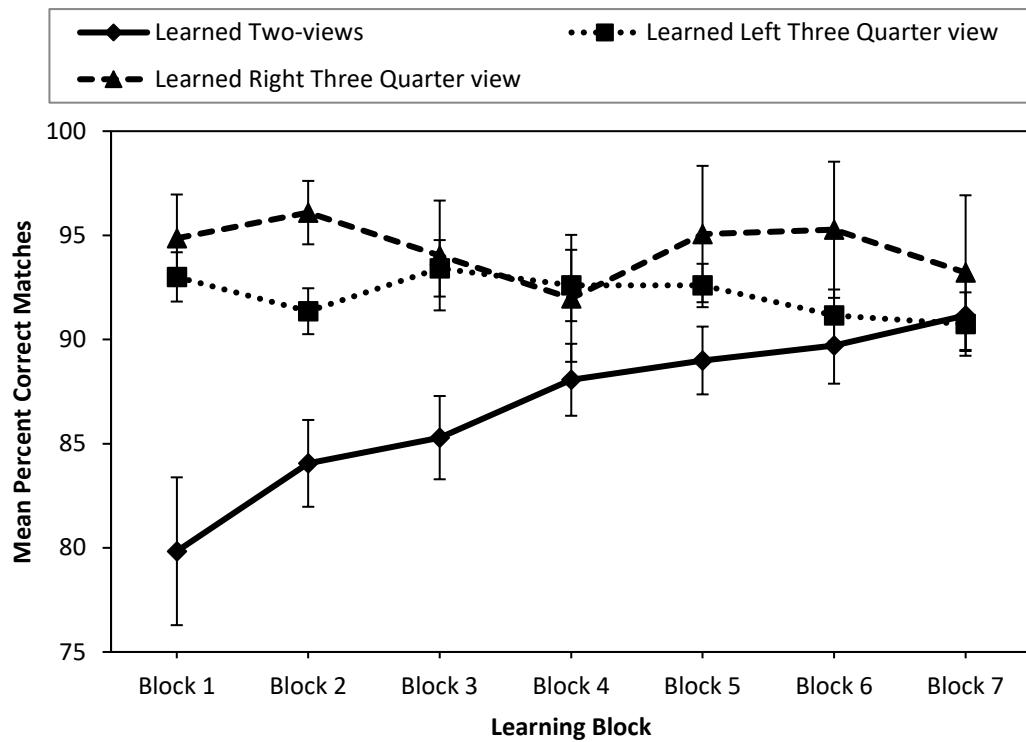


Figure 3-6. Experiment 6 Learning Phase Results. Mean percent correct one-back matching responses are plotted as a function of learned view (Two-views, Left Three-quarter view & Right Three-quarter view) at each block of learning. Error bars represent standard error of the mean.

The two-way interaction was first broken down by examining the simple main effect of block within each view type. Block was found to be significant for two-views (TV) only ($p = .009$), see Table 3-2 for statistics and Figure 3-6 for means. Pairwise analysis concentrated on whether mean hit matching accuracy increased or decreased significantly between the start of the learning procedure compared to the end (i.e., block 1 versus block 7). Analysis revealed that for the TV view type, mean hits at block 7 were greater than block 1 ($p = .004$).

For the simple main effect of view type at each block, it was found that this was significant in blocks 1 to 6 (all p 's < .029. See Table 3-2 for statistics and Figure 3-6 for means), however by block 7, performance was not significantly different between view type conditions ($p = .342$). Pairwise analysis of blocks 1 to 6, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., .05/3 learned view type comparisons), revealed that at block 1, LTQ mean hits were greater than TV ($p < .001$) and RTQ hits were greater than TV ($p < .001$); at block 2, LTQ mean hits were greater than TV ($p = .001$), and RTQ mean hits were greater than TV ($p < .001$); at block 3, LTQ mean hits were greater than TV ($p < .001$), and RP were greater than TV ($p < .001$); at block 4, LTQ mean hits were greater than TV ($p = .013$); at block 5, RTQ mean hits were greater than TV ($p < .001$); and at block 6, RTQ mean hits were greater than TV ($p = .010$).

Analysis of correct rejections was carried out as Experiment 4, revealing that the main effect learning group was not significant, $F(2, 24) = 0.029$, $MSE = 156.782$, $p = .971$, $\eta_p^2 = 0.002$ (Observed power = .05), or the main effect of block, $F(5.393, 129.432) = 1.917$, $MSE = 11.863$, $p = .090$, $\eta_p^2 = 0.07$ (Observed power = .65), and the two-way interaction between learning group and block was not significant, $F(12, 144) = 1.330$, $MSE = 10.663$, $p = .208$, $\eta_p^2 = .10$ (Observed power = .71).

Table 3-2

Block x View type interaction simple main effects.

	df	F	MSE	p	η_p^2	Power
Two-views x Block	2.12, 55.20	4.93	237.288	= .009	.16	.80
Left TQ view x Block	6, 156	0.69	41.07	= .656	.02	.27
Right TQ view x Block	5.22, 135.76	1.79	33.59	= .114	.06	.61
Block 1 x View type	1.30, 33.89	14.55	190.88	< .001	.35	.98
Block 2 x View type	2, 52	16.87	58.85	< .001	.39	1
Block 3 x View type	2, 52	14.16	45.40	< .001	.35	.99
Block 4 x View type	2, 52	3.83	42.41	= .028	.12	.67
Block 5 x View type	1.43, 37.32	8.17	42.88	= .003	.23	.88
Block 6 x View type	2, 52	4.79	46.76	= .012	.15	.77
Block 7 x View type	2, 52	1.09	43.09	= .342	.04	.23

Having established that the learning phase produced an equivalent level of performance for each of the three view types by the end of the session (blocks 7), and that correct rejections were not modulated by learning group or block, analysis of the test phase was carried out. A hit rate was calculated as in Experiments 4, revealing that The main effect of learned view was significant, $F(2, 72) = 11.108$, $MSE = 239.293$, $p < .001$, $\eta_p^2 = 0.23$ (Observed power = .99), with TV mean hits greater than LTQ ($p < .001$) and RTQ views ($p = .008$), and RTQ mean hits were greater than LTQ (approaching, $p = .054$). The main effect of test view was significant, $F(2, 72) = 11.357$, $MSE = 239.293$, $p < .001$, $\eta_p^2 = 0.24$ (Observed power = .99) with mean hits for LTQ test views greater than FF test views ($p = .001$), and mean hits for RTQ test views greater than FF test views ($p < .001$). The critical interaction between learned view and test view was also found significant,

$F(4, 72) = 2.854$, $MSE = 239.293$, $p = .030$, $\eta_p^2 = .13$ (Observed power = .74), see Figure 3-7 for mean correct responses (hits).

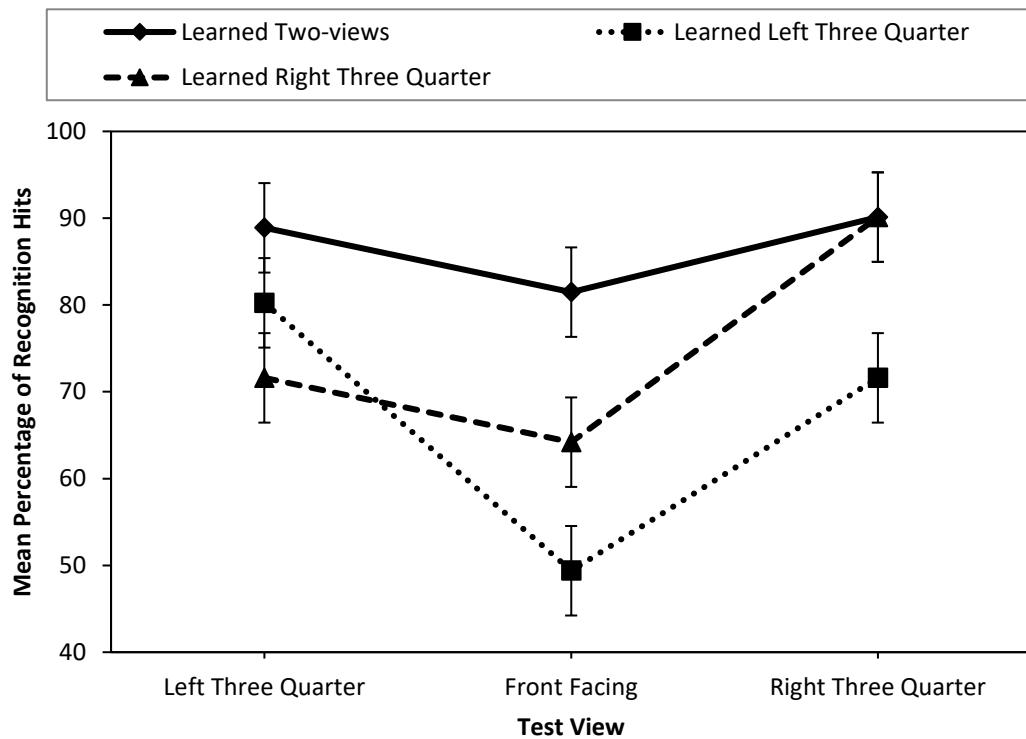


Figure 3-7. Experiment 6 Test Phase Results. Mean percent recognition hits of previously seen faces as a function of learned view and test view. The results indicate the overall effects of learning two-views or one view on recognition accuracy for three test views. Error bars represent standard error of the mean.

Simple main effect univariate analysis of the significant two-way interaction first focused on the critical comparison to test for the FRU effect, that is, an advantage in recognition of the novel front-facing view for identities learned from two-views over those learned from single views (i.e., comparing the three data

points in the central column of Figure 3-7). The result was significant, $F(2, 72) = 9.707$, $MSE = 239.293$, $p < .001$, $\eta_p^2 = .21$ (Observed power = .97). Pairwise comparisons, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., .05/3 learned view comparisons), revealed that when two-views had been learned (diamond, centre column, Figure 3-7), performance was significantly greater on the front-facing test view than when only left three-quarter views were learned ($p < .001$; square, centre column, Figure 3-7), but only approached significance when right three-quarter views were learned (approaching, $p = .020$; triangle, centre column, Figure 3-7). Furthermore, the difference between left three-quarter and right three-quarter learned views when tested with the front-facing test view, after adjustment for multiple comparisons, was not significant ($p = .046$).

When the test view was a left three-quarter view (i.e., comparing the three data points in the left column of Figure 3-7), learned view approached significance, $F(2, 72) = 2.809$, $MSE = 239.293$, $p = .067$, $\eta_p^2 = .07$ (Observed power = .53), with pairwise comparisons, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., .05/3 learned view comparisons), revealing that when two-views had been learned (diamond, left column, Figure 3-7), performance was greater than when right three-quarter views were learned, but this only approached significance ($p = .020$; triangle, left column, Figure 3-7), and two-view means were greater than left three-quarter views, but this was not significant ($p = .240$; square, left column, Figure 3-7), and the difference between left three-quarter views and right three-quarter views was also not significant ($p = .240$). When the test view was a right three-quarter view (i.e., comparing the three data points in the right column of Figure 3-7), learned view was significant, $F(2, 72) = 4.299$, $MSE = 239.293$, $p = .017$, $\eta_p^2 = .10$ (Observed power = .73), with pairwise comparisons, adjusted for

multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., .05/3 learned view comparisons), revealing that when two-views had been learned (diamond, right column, Figure 3-7), performance was significantly greater than when left three-quarter views were learned ($p = .013$; square, right column, Figure 3-7). However, two-view means were not significantly greater than right three-quarter views ($p = 1.00$; triangle, right column, Figure 3-7), and right three-quarter views were significantly greater than left three-quarter views ($p = .013$).

Simple main effect univariate analysis of the two-way interaction (learned view x test view) was also carried out for each learned view, to understand if each learned view produced view-invariance across the three test views, finding that when two-views had been learned, differences between test views were not significant, $F(2, 72) = 0.822$, $MSE = 239.293$, $p = .444$, $\eta_p^2 = .02$ (Observed power = .18). However, when left three-quarter views had been learned, test view was significant, $F(2, 72) = 9.535$, $MSE = 239.293$, $p < .001$, $\eta_p^2 = .20$ (Observed power = .97), with pairwise comparisons, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., .05/3 test view comparisons), finding that mean hits for the left three-quarter test view were significantly greater than the front-facing test view ($p < .001$) but not the right three-quarter test view ($p = .240$), and right three-quarter test views were significantly greater than front-facing test views ($p = .003$). Finally, when right three-quarter views had been learned, test view was again found significant, $F(2, 72) = 6.707$, $MSE = 239.293$, $p = .002$, $\eta_p^2 = .15$ (Observed power = .90), with pairwise comparisons, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., .05/3 test view comparisons), finding that mean hits for the right three-quarter test view were significantly greater than the left

three-quarter ($p = .013$) and front-facing test views ($p = .001$), but left three-quarter test views were not significantly different to front-facing test views ($p = .313$).

Analysis of correct rejections at test (i.e., saying “no” to an identity which had not been seen at learning), indicated that when a distractor was a left three-quarter test view, over 84% were correctly rejected; 90% for front-facing test views; and, 82% for right three-quarters test views. A one-way ANOVA with test view as a factor showed that this factor was not significant, $F(2, 78) = 2.241$, $MSE = 245.507$, $p = .113$, $\eta_p^2 = 0.05$ (Observed power = .44).

Finally, an analysis was carried out between experiments that had the same view type as a single-view or two-views, in each experiment (i.e., mirrored profiles, true profiles, and three-quarter views), when the test view was the same novel front-facing view. The analysis was a 3x2 between-subject's ANOVA, with experiment (Experiment 4: mirrored profiles views, Experiment 5: true profiles views, Experiment 6: true three-quarter views) and learned view (two-views, single-views) as factors, and hits as the dependent variable. Effect sizes were considered based on Cohen's (1988) recommendation of .02 for a small effect, .13 for a medium effect, and .26 for a large effect.

It was found that the main effect of experiment was significant, $F(2, 75) = 14.768$, $MSE = 478.150$, $p < .001$, $\eta_p^2 = 0.28$ (Observed power = .99), with Experiment 6 (TQ views) mean hits significantly greater than Experiment 4 ($p < .001$, mirrored profiles) and Experiment 5 ($p < .001$, true profiles), although differences between Experiment 4 (mirrored profiles) and 5 (true profiles) were not significant ($p = .697$). The main effect of learned view was also found to be significant, $F(1, 75) = 6.529$, $MSE = 478.150$, $p = .013$, $\eta_p^2 = 0.08$ (Observed power

$\eta_p^2 = .71$), with mean hits when two-views were learned, significantly greater than when single-views were learned. However, the two-way interaction between experiment and learned view was not significant, $F(2, 75) = 1.938$, $MSE = 478.150$, $p = .151$, $\eta_p^2 = 0.04$ (Observed power = .39).

The previous analysis revealed that the two-way interaction between experiment (Experiment 4: mirrored profiles views, Experiment 5: true profiles views, Experiment 6: true three-quarter views) and learned view (two-views, single-views), when the test view was a front-facing novel view, was not significant. However, because the main effect experiment and learned view were significant, but would not allow a distinction to be examined between these two factors, it was decided to separately test single and two learned views between experiments, again on the front-facing novel view, to understand if the type of view learned benefitted novel front-facing view recognition. To do this, separate univariate analyses were carried out for two-views and single views, with experiment (Experiment 1: mirrored profiles views, Experiment 2: true profiles views, Experiment 3: true three-quarter views) as a between subjects' factor, and mean hits when a front-facing view was the test view, the dependent variable.

Analysis for two-views revealed that the main effect of experiment was significant, $F(2, 24) = 9.519$, $MSE = 484.719$, $p = .001$, $\eta_p^2 = 0.44$ (Observed power = .96), with Experiment 6 (left and right three-quarter views) mean hits significantly greater than Experiment 4 ($p < .001$, mirrored profiles) and Experiment 5 ($p = .004$, true profiles), but the difference between Experiments 4 and 5 was not significant ($p = .351$). When single views had been learned, the main effect of experiment was again significant, $F(2, 51) = 5.796$, $MSE = 475.058$, $p = .005$, $\eta_p^2 = 0.18$ (Observed

power = .85), with Experiment 6 (left and right three-quarter views) mean hits significantly greater than Experiment 4 ($p = .014$, mirrored profiles) and Experiment 5 ($p = .002$, true profiles), but the difference between Experiments 4 and 5 was not significant ($p = .500$).

In summary, from the above analysis it can be seen that when the view learned as two-views and single-views were three-quarter views, that recognition of a novel front-facing view was significantly greater than when profiles (i.e., mirrored and true profiles) were learned. Furthermore, whether the profile views were learned as two-views or single views, and bearing in mind that Experiment 4 used mirrored profiles and Experiment 5 true profiles, the difference between Experiments 4 and 5 were not significant.

3.4.4 Discussion

The current experiment sought to shed light on the apparent advantage gained from learning two-views that were true profiles, over single true profile views, when tested on the same view, and it was thought that three-quarter views would contain more useful information (i.e., ‘view type utility’) for recognition of a novel front-facing view compared to profile views alone. Indeed, in the test phase, the FRU-effect was found when two-views had been learned and were tested on the novel front-facing view, but only when compared to left three-quarter learned single views, and approaching significance when compared to the learned right three-quarter single views. Furthermore, when single views had been learned, and tested on the novel front-facing view, differences between these learned view types were not significant. Therefore, confirmation of FRU effects from learning two three-quarter

views over single views are inconclusive, although the pattern is suggestive of an advantage gained from learning two-views that were three-quarter views.

Interestingly, it was also found that during the learning phase, the same pattern of increasing matching accuracy over blocks was evident for two-view matching, with block 7 mean hits significantly greater than block 1, but single view matching did not vary between these blocks, repeating the same pattern as Experiments 4 and 5, which will be addressed in the general discussion for this chapter.

Adding support to the apparent but not entirely significant advantage gained from learning two-views, is that there were no significant differences found when two-views had been learned, across all test view types, indicating view-invariance. However, when a view change occurred for single learned views, recognition accuracy significantly declined from the same test view to the novel front-facing test view. Furthermore, when single left three-quarter views were learned, performance on the other view was not significantly different to recognition of the same view learned and tested (i.e., learn LTQ, test RTQ, versus, learn LTQ, test LTQ), but when right three-quarter single views were learned, recognition of the other three-quarter view was now significantly worse than the same view learned and tested (i.e., learn RTQ, test LTQ, versus, learn RTQ, test RTQ). This suggests that the right three-quarter single view representation was less able to allow recognition of a change in view, as both the front-facing and left three-quarter test view recognition hits were not significantly different from each other, but both significantly worse than the right three-quarter test view. It was also found that two-views and same view learned and tested recognition performance was significantly greater than the other single three-quarter view when the test view was a right three quarter view, but only approaching significance when the test view was a left three-quarter view.

It was intuitively thought that the three-quarter view might provide a greater degree of structural and/or configural information in comparison to other view types, although it must be stated that this did not seem to be supported by the empirical evidence (e.g., Bruce, Valentine & Baddeley, 1987; Liu & Chaudhuri, 2002). However, the question that these authors were addressing concerned whether the three-quarter view was a canonical view (i.e., better than any other view type), and did not test for informational advantages for this view type, this point being clarified by Liu and Chaudhuri (2002) in their discussion. Clearly though, learning two three-quarter views in this experiment allowed invariant recognition across all test views, which true profiles did not, and it can therefore be concluded that the information each view type contains (i.e., its ‘view type utility’) is directly related to its ability to aid novel view recognition.

Additional analysis confirmed this when all three same view experiments were analysed between two-views and single-views for the front-facing novel test view. It was found that the main effect of experiment was significant when two-views were learned that were three-quarter views (Experiment 6), with mean hits significantly greater than when either profile type was learned (Experiments 4 and 5), and differences between these profile experiments were not significant. The main effect of learned view was also significant, with two-view mean hits greater than single-view mean hits, but the two-way interaction was not significant. It was therefore decided, in order to understand whether three-quarter views provided better ‘view type utility’ than the profile views, which seemed to be indicated, that two-views and single-views would be analysed separately between experiments. It was revealed that for both two-views and single-views, three-quarter view mean hits were significantly greater than either profile view experiments, and the differences

between the two profile experiments was not significant. It can therefore be concluded that the ‘view type utility’ afforded by three-quarter views learned as single-views as well as two-views, was greater than that of profile views, confirming that while the three-quarter view may not be a ‘canonical’ view (e.g., Bruce, Valentine & Baddeley, 1987; Liu & Chaudhuri, 2002), the information afforded by them is significantly greater than that of profile views.

In summary, by testing views that were the same but provided sufficient within-identity variation between them (i.e., true profiles and true three-quarter views), it has been possible to confirm that three-quarter views provide more ‘view type utility’ than do mirrored and true profile-views, and that this directly impacted recognition accuracy of the novel view, producing view-invariance across all test views in the current experiment. Therefore, the next experiment will bring profile and three-quarter views together to test whether within-identity visual variation is indeed dependent on the ‘view type utility’ each view provides in answering novel front-facing view recognition.

3.5 Experiment 7: Learning true left three-quarter views and left-profile views singularly or both, when tested on a front-facing novel view

3.5.1 Introduction

Findings from the previous two experiments (i.e., Experiments 5 and 6) suggest that learning two-views of the same identity, that importantly vary in their configuration and/or structural information (other than only view direction, i.e.,

Experiment 4), produced recognition advantages over learning single views. However, the two-views used previously either provided very similar configural and/or structural information (i.e., they were true profiles or true three-quarter views), or differed substantially in their configural and/or structural information (i.e., they were a profile and a front-facing view – see Chapter 2). It was therefore thought that a ‘middle ground’, two-view type was needed to further understand ‘view type utility’ differences in relation to FRU formation, that could be informed by the earlier view type experiments. Results from the previous true profile and true three-quarter view type experiments suggested that profile views were poor views with which to recognise identities, but three-quarter views were significantly better. Therefore, these findings can be used to test whether the representation formed from learning two views can be seen as a summation of separately stored representations, or perhaps the action of an ‘interlinked’ representation (i.e., an FRU).

The final behavioural experiment therefore sought to clarify whether an FRU-effect would be detected if the information learned from the two-views overlapped in their configural and/or structural information, and in their direction of view, without being the same view (i.e., not two-profiles or two three-quarter views). To test this, left three-quarter views and left-profile views were chosen, and these were tested on the same view, the other view, or a critical novel front-facing view which was also external in rotation to those views learned. It was predicted that the two-view significant advantage (i.e., an FRU-effect) would again be present, when tested on a novel front-facing view, but it was unclear whether differences on the novel test view would be found between the two-single view types, as three-quarter single views have been demonstrated in the previous experiment to provide significantly greater ‘view type utility’ than profile views alone or as two-views. In

addition, and based on the true profile view results (Experiment 5), it was thought that single profile views would again perform poorly on any view type other than the same view type, but that the three-quarter view would produce better transference to other views because they contain a greater degree of structural and/or configural information. Notably, left-profile and left three-quarter views were chosen, as right facing views had been observed to be somewhat problematic in terms of recognition performance of another view, and therefore any right sided facing view effect (whatever its mechanism) was explicitly avoided for the current experiment.

3.5.2 Method

Participants

Twenty-seven Caucasian undergraduates (25 females, 2 males) aged between 18 and 24 years (mean age, 19.18 years) participated in exchange for course credit. All participants had normal or corrected-to-normal visual acuity (self-report) and no history of neurological illness (self-report). All participants gave informed consent and the procedures were approved by the University of Kent, School of Psychology Ethics Committee.

Design, Materials, Apparatus and Procedure

The design, materials, apparatus and procedure were the same as in Experiment One 1 (including a period of overnight consolidation, see Chapter 2), with the exception that the two-views learned were left-profile and left three-quarter views, and the critical novel test view was a front-facing view. See Table 2-1

(Chapter 2) for typical counterbalancing of learned view and test view types, but note that although view types will be different, the same principal of counterbalancing has been applied.

3.5.3 Results

From the learning phase data, the percentage of correctly identified matches (hits) was analysed with a 3x7 repeated-measures ANOVA with learned view type and block as factors. Departures from sphericity were corrected using the recommendation of Girden (1992): for epsilon values greater than .75 the Huynh-Feldt correction was applied, and for epsilon values less than .75 the Greenhouse-Geisser correction was applied. Effect sizes were considered based on Cohen's (1988) recommendation of .02 for a small effect, .13 for a medium effect, and .26 for a large effect.

From the learning phase data, analysis was carried out as Experiment 4, revealing that the main effect of view type was significant, $F(1.23, 32.13) = 8.422$, $MSE = 554.29$, $p = .004$, $\eta_p^2 = 0.24$ (Observed power = .85), with left three-quarter view mean hits greater than two-views ($p = .003$) and right-profile views ($p = .040$), and right-profile view mean hits were greater than two-views ($p = .016$), see Figure 3-8 for mean hits. However, there was no main effect of block, $F(3.05, 79.48) = 1.680$, $MSE = 220.59$, $p = .177$, $\eta_p^2 = 0.06$ (Observed power = .42), but the view type x block interaction was significant, $F(9.939, 258.410) = 5.852$, $MSE = 72.114$, $p < .001$, $\eta_p^2 = .18$ (Observed power = 1). See Figure 3-8 for mean correct responses (hits).

The two-way interaction was first broken down by examining the simple main effect of block within each view type. Block was found to be significant for left three-quarter (LTQ, $p = .009$) and left-profile (LP, $p < .001$) view types, and approaching significance for two-views (TV, $p = .056$), see Table 3-3 for statistics and Figure 3-8 for means. Pairwise analysis concentrated on whether mean hit matching accuracy increased or decreased significantly between the start of the learning procedure compared to the end (i.e., block 1 versus block 7). Analysis revealed that for the TV view type, mean hits were greater at block 7 than block 1 ($p = .028$), for the LTQ view type mean hits were greater for block 1 than block 7 ($p = .005$), and the same pattern emerged for the LP view type, with block 1 mean hits greater than block 7 ($p = .002$).

For the simple main effect of view type at each block, it was found that this was significant in blocks 1, 2, 3 and 6 (all p 's $< .048$. See Table 3-3 for statistics and Figure 3-8 for means), however, at block 4, 5 and 7 performance was not significantly different between view type conditions (all p 's $> .124$). Pairwise analysis, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., .05/3 test view comparisons), revealed that at block 1, LTQ hits were greater than TV ($p < .001$), and LP hits were greater than TV ($p < .001$); at block 2, LTQ hits were greater than TV ($p < .001$), and LP hits were greater than TV ($p < .001$); however, at block 3, LTQ hits were greater than TV ($p = .034$), and LP hits were greater than TV ($p = .028$), but these were not significant when pairwise adjustments were made; and, at block 6, LTQ hits were greater than LP, but this only approached significance ($p = .019$).

Table 3-3

Block x View type interaction simple main effects.

	df	F	MSE	p	η_p^2	Power
Two-views x Block	2.66, 69.34	2.74	190.24	= .056	.09	.60
Left TQ view x Block	5.11, 133.07	3.18	86.31	= .009	.10	.87
Left-profile view x Block	4.67, 121.54	5.72	94.53	< .001	.18	.98
Block 1 x View type	1.21, 31.50	19.60	188.10	< .001	.43	.99
Block 2 x View type	1.22, 31.76	15.46	157.60	< .001	.37	.98
Block 3 x View type	2, 52	4.17	118.31	= .021	.13	.71
Block 4 x View type	2, 52	1.92	104.53	= .156	.06	.38
Block 5 x View type	1.62, 42.30	2.27	117.48	= .124	.08	.39
Block 6 x View type	2, 52	3.24	101.83	= .047	.11	.59
Block 7 x View type	2, 52	0.21	70.35	= .809	.008	.08

Analysis of correct rejections was carried out as Experiment 4, revealing that the main effect learning group was not significant, $F(2, 24) = 0.781$, $MSE = 182.327$, $p = .469$, $\eta_p^2 = 0.06$ (Observed power = .16), but the main effect of block was significant, $F(5.254, 126.087) = 3.895$, $MSE = 13.332$, $p = .002$, $\eta_p^2 = 0.14$ (Observed power = .94), with mean correct rejections greater at block 3 than block 1 and 2, block 5 greater than block 2, and block 7 greater than block 1, 2, 4 and 6 (all p 's < .049). But the two-way interaction between learning group and block was not significant, $F(12, 144) = 1.471$, $MSE = 11.673$, $p = .141$, $\eta_p^2 = .10$ (Observed power = .77).

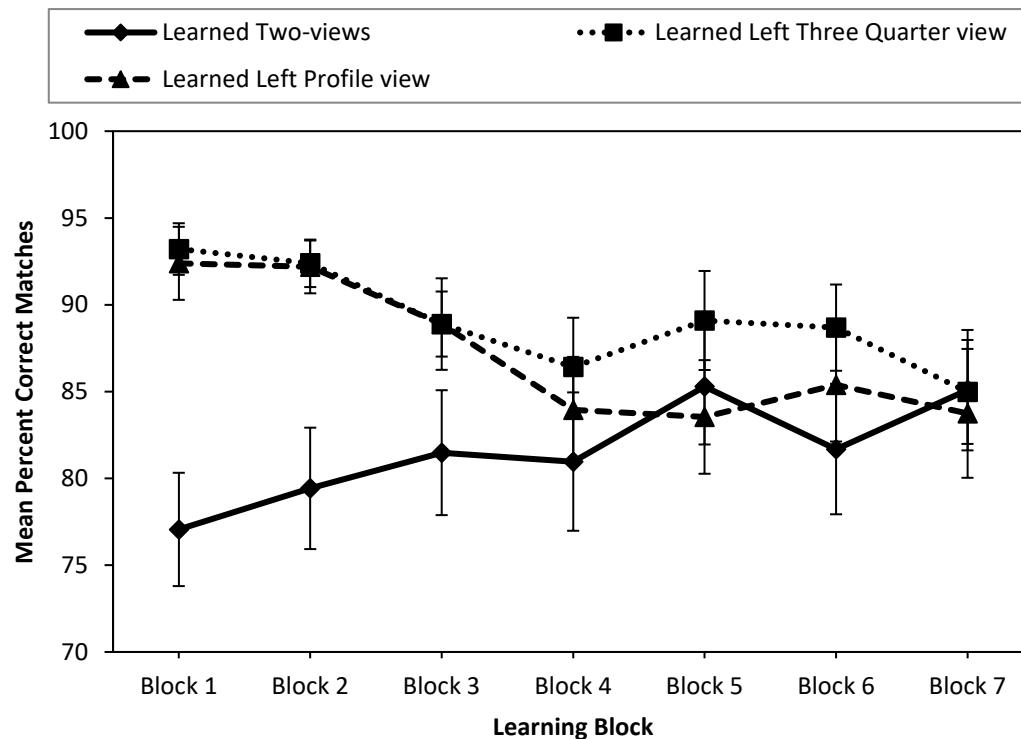


Figure 3-8. Experiment 7 Learning Phase Results. Mean percent correct one-back matching responses are plotted as a function of learned view (Two-views, Left Three-quarter view & Left-profile view) at each block of learning. Error bars represent standard error of the mean.

For the test phase, a hit rate was calculated as in Experiments 4. Analysis of recognition (hit) rates in the test phase revealed that the main effect of learned view was significant, $F(2, 72) = 19.696$, $MSE = 366.179$, $p < .001$, $\eta_p^2 = 0.35$ (Observed power = 1), with TV mean hits greater than LTQ ($p = .044$) and LP ($p < .001$), and LTQ mean hits greater than LP ($p < .001$). The main effect of test view was significant, $F(2, 72) = 23.105$, $MSE = 366.179$, $p < .001$, $\eta_p^2 = 0.39$ (Observed power = 1), with mean hits for LTQ test views greater than FF test views ($p < .001$), and mean hits for LP test views greater than FF test views ($p < .001$). The critical

interaction between learned view and test view was also found significant, $F(4, 72) = 4.375$, $MSE = 366.179$, $p = .003$, $\eta_p^2 = .19$ (Observed power = .91). See Figure 3-9 for mean correct responses (hits).

Simple main effect univariate analysis of the significant two-way interaction first focused on the critical comparison to test for the FRU effect, that is, an advantage in recognition of the novel front-facing view for identities learned from two-views over those learned from single views (i.e., comparing the three data points in the central column of Figure 3-9). The result was significant, $F(2, 72) = 4.982$, $MSE = 366.179$, $p = .009$, $\eta_p^2 = .12$ (Observed power = .79). Pairwise comparisons, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., $.05/3$ learned view comparisons), revealed that when two-views had been learned (diamond, centre column, Figure 3-9), performance on the front-facing test view, compared to when only left three-quarter views were learned, was not significant ($p = .079$; square, centre column, Figure 3-9), but was significant when compared to left-profile views ($p = .002$; triangle, centre column, Figure 3-9), however, the difference between left three-quarter and left-profile learned views were not significant ($p = .175$).

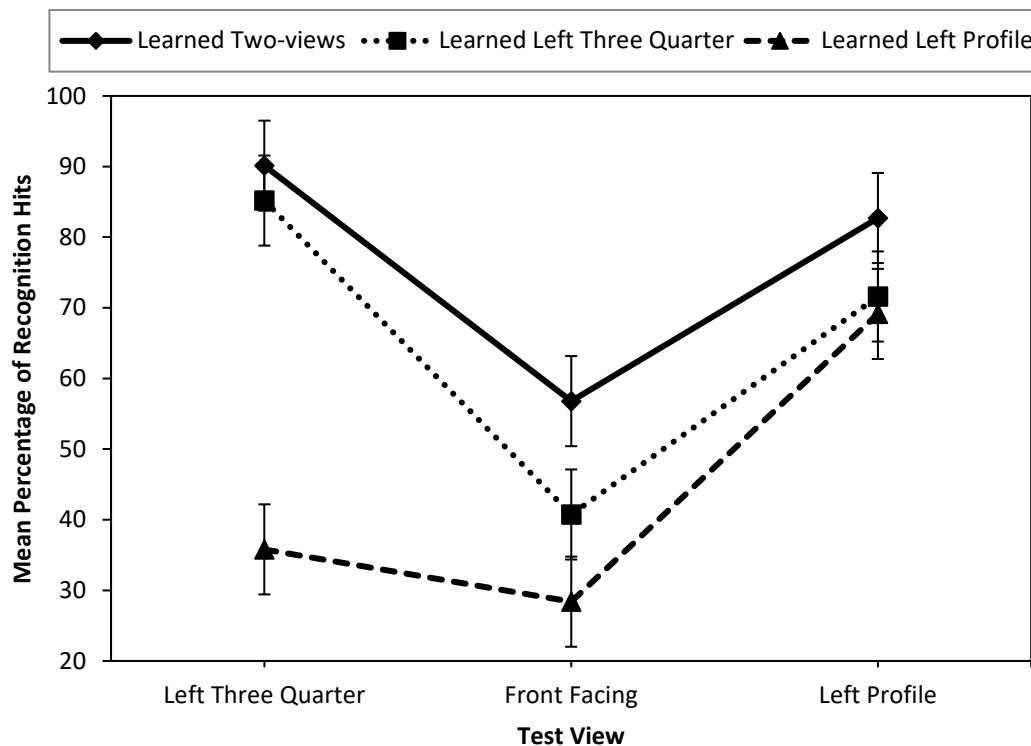


Figure 3-9. Experiment 7 Test Phase Results. Mean percent recognition hits of previously seen faces as a function of learned view and test view. The results indicate the overall effects of learning two-views or one view on recognition accuracy for three test views. Error bars represent standard error of the mean.

When the test view was a left three-quarter view (i.e., comparing the three data points in the left column of Figure 3-9), learned view was significant, $F(2, 72) = 22.177$, $MSE = 366.179$, $p < .001$, $\eta_p^2 = .38$ (Observed power = 1), with pairwise comparisons adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., $.05/3$ learned view comparisons), revealing that when two-views had been learned (diamond, left column, Figure 3-9), performance was not significantly different than when left three-quarter views were learned ($p = .586$; square, left column, Figure 3-9), but two-view means were significantly greater than left-profile

views ($p < .001$; diamond, left column, Figure 3-9), and the difference between left three-quarter views and left-profile views was also significant ($p < .001$). However, when the test view was a left-profile view (i.e., comparing the three data points in the right column of Figure 3-9), learned view was not significant, $F(2, 72) = 1.286$, $MSE = 366.179$, $p = .283$, $\eta_p^2 = .03$ (Observed power = .27).

Simple main effect univariate analysis of the two-way interaction (learned view x test view) was also carried out for each learned view, to understand if each learned view produced view-invariance across the three test views, finding that when two-views had been learned, differences between test views were significant, $F(2, 72) = 7.530$, $MSE = 366.179$, $p = .001$, $\eta_p^2 = .17$ (Observed power = .93). Pairwise comparisons, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., .05/3 test view comparisons), revealed that left three-quarter test view mean hits were significantly greater than front-facing test views ($p < .001$), and left-profile test view mean hits were significantly greater than front-facing test views ($p = .005$), but not between left three-quarter and left-profile test views ($p = .414$).

When left three-quarter views had been learned, test view was significant, $F(2, 72) = 12.749$, $MSE = 366.179$, $p < .001$, $\eta_p^2 = .26$ (Observed power = .99), with pairwise comparisons, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., .05/3 test view comparisons), finding that mean hits for the left three-quarter test view were significantly greater than the front-facing test view ($p < .001$), but not the left-profile test view ($p = .137$), and left-profile test view mean hits were significantly greater than front-facing test views ($p = .001$). When left-profile views had been learned, test view was again significant, $F(2, 72) = 11.575$, $MSE = 366.179$, $p < .001$, $\eta_p^2 = .24$ (Observed power = .99), with pairwise comparisons, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0167 (i.e., .05/3 test view

comparisons), revealing that mean hits for the left-profile test view were significantly greater than left three-quarter and front-facing test views (all p 's < .001), but mean hits were not significantly different between left three-quarter test views and front-facing test views ($p = .414$).

Analysis of correct rejections at test (i.e., saying “no” to an identity which had not been seen at learning), indicated that when a distractor was a left three-quarter test view, over 82% were correctly rejected; 88% for front-facing test views; and, 80% for left-profile test views. A one-way ANOVA with test view as a factor showed that this factor was not significant, $F(2, 78) = 1.430$, $MSE = 320.777$, $p = .245$, $\eta_p^2 = 0.03$ (Observed power = .29).

From the above analysis, it was observed that when left three-quarter single views were learned, recognition of the left profile test view was as good, with this difference not proving to be significant, however, when left-profile single views were learned and tested on the left three-quarter view, performance was found to be significantly lower. Added to this, when two-views were learned, recognition of the novel front-facing view was significantly greater than when a single left-profile view had been learned, but not when a single left three-quarter view had been learned, and the difference between left three-quarter and left profile learned views on the novel test view were not significant. Separating out the contributions of left three-quarter and left-profile views that constituted the two-views condition was not statistically possible, so a further analysis was carried out between the learned views and test views of Experiments 6 and 7 to try and establish the relative contributions of each single view on the same test view, the other test view not previously encountered but

forming one of the two learned view types, and the novel front-facing test view that had not been encountered during learning.

To do this, a hit rate was processed with a 3x3 between-subject's ANOVA, with learned view (Left three-quarter view; Left-profile view; or Right three-quarter view) and test view (Same view; Other view; or Novel front-facing view) as factors. Effect sizes were considered based on Cohen's (1988) recommendation of .02 for a small effect, .13 for a medium effect, and .26 for a large effect. It was found that the main effect of learned view was significant, $F(2, 99) = 19.279$, $MSE = 363.943$, $p < .001$, $\eta_p^2 = 0.28$ (Observed power = 1), with LTQ hits significantly greater than LP ($p < .001$), RTQ hits greater than LTQ (approaching, $p = .052$) and LP views ($p < .001$). The main effect of test view was also found to be significant, $F(2, 99) = 27.299$, $MSE = 363.943$, $p < .001$, $\eta_p^2 = 0.35$ (Observed power = 1), with same test view hits significantly greater than novel ($p < .001$) and the other ($p < .001$) test view, and the other test view hits were significantly greater than than the novel test view ($p = .004$). But, the learned view by test view interaction was not found to be significant, $F(2, 99) = 1.698$, $MSE = 363.943$, $p = .156$, $\eta_p^2 = 0.06$ (Observed power = .50).

Finally, analysis was carried out for each of the two-view learning conditions in the current chapter for each experiment when the test view was the novel front-facing view, to establish which two-view combinations did or did not differ from each other. Univariate analysis therefore included experiment (Experiment 4: mirrored profiles views, Experiment 5: true profiles views, Experiment 6: true three-quarter views, Experiment 7: left-profile views and left three-quarter views) as a between subjects' factor, and mean hits when a front-facing view was the test view, was the dependent variable. Results revealed that the main effect of experiment was

significant, $F(2, 50) = 11.153$, $MSE = 446.662$, $p < .001$, $\eta_p^2 = 0.40$ (Observed power = .99), with Experiment 6 (left and right three-quarter views) mean hits (81.48%) significantly greater than Experiment 4 (38.27%, $p < .001$, left and right mirrored profiles), Experiment 5 (48.14%, $p = .002$, left and right true profiles), but not Experiment 7 (81.48%, $p = .547$, left-profile and left three-quarter); and, Experiment 7 (left-profile and left three-quarter) mean hits (81.48%) were greater than Experiment 4 (38.27%, $p < .001$, left and right mirrored profiles) and Experiment 5 (48.14%, $p = .001$, left and right true profiles), but Experiments 4 and 5 mean hits were not significantly different from each other ($p = .326$, i.e., mirrored and true profiles respectively).

3.5.4 Discussion

The final behavioural experiment sought to clarify whether an FRU-effect could be detected if the information learned from two-views overlapped considerably, without being the same image. It was predicted that the FRU-effect would again be evident, and that there would be a difference between the way the two single views performed on the same view and each other view, at test.

Results from the test phase of this experiment indicated that the FRU-effect was present only over the learned left-profile single view, but not the left three-quarter view, when tested on the novel front-facing view, and there was no effect of view-invariance for the two-learned view condition between all test view types. Furthermore, when two-views and single left three-quarter views were learned, and tested on the left three-quarter test view, recognition hits were significantly greater than when a left-profile single view had been learned. But, two-view, left three-

quarter, and left-profile learned views were not significantly different when tested on the left-profile view. It was also found that learned single left three-quarter views allowed equal recognition of the same view learned and tested, and the other left-profile test view, indicating that three-quarter views provided sufficient ‘view type utility’ to answer both of these test views. However, when single left-profile views were learned, recognition of either view change test view was significantly worse than the same test view, and recognition of these other two test views were not significantly different from each other. It was also found in the learning phase that two-view matches increased significantly by the end of the session, and single view matching significantly decreased by the end of the session, and this learning phase pattern will be addressed in the general discussion of this chapter.

Overall, the results from the test phase suggest that the two-view advantage reported over the left-profile single learned view could be attributed to the more useful ‘view type utility’ of the left three-quarter learned view part of the two-view condition, rather than any effect that relied on memorial ‘interlinking’, essentially arguing that the three-quarter view did most of the work. In fact, it can be concluded that unequal summation of the two-views had occurred, with the majority of the summation accounted for by the three-quarter view over that of the left-profile view, which also reveals that when two-views were learned, these were separately available, due to the apparent unequal influence of each view type. However, in terms of testing an FRU-account, which proposes that two-views would become ‘interlinked’, and would provide a recognition advantage over a novel view, these criteria have been somewhat met, albeit there was an apparent unequal contribution from the two views learned. This can also be said to result from ‘pictorial’ effects (e.g., Liu & Ward, 2006; Longmore et al., 2017; Longmore, Liu, & Young, 2008;

Megreya & Burton, 2006), but as stated previously, ‘pictorial’ codes were only meant to represent image properties, and clearly the face configuration/structure throughout these experiments can be seen as directly contributing to the effects reported, so ‘pictorial’ explanations in the Bruce and Young (1986) sense cannot be supported.

Furthermore, when Experiments 6 and 7 learned single views were compared, when tested on the same view, the novel view, or the other view not seen test view, it was found that learning either three-quarter single view produced significant advantages over learning left-profile views. It was also found that when the same view was learned and tested, that recognition exceeded that of the novel front-facing test view and the other not seen test view, and the other not seen test view mean hits exceeded that of the novel front-facing test view. So, based on this analysis it was confirmed that single three-quarter views did provided a greater ‘view type utility’ advantage, but as confirmed in discussion of the interaction for the current experiment, this powerful single three-quarter learned view effect could not exceed the performance when both the three-quarter and left-profile views were learned as two-views, as was seen in Experiment 6.

In summarising this experiment it has been found that the type of view learned and its ‘view type utility’, is directly related to the ability of learning two-views to answer a novel front-facing test view. This effect was largely due to the presence of the left three-quarter view over that of the left-profile view, but the two-view advantage was not entirely due to the left three-quarter view alone, as can be seen from the between experiments analysis and discussion. That is, a left three-quarter view learned as a single view did not allow significant recognition of the front-facing novel test view, compared to only learning the single left-profile view,

so the combination of two-views can be seen to be more powerful than that of either single view alone. It is argued that this can still be considered an FRU-effect, due the advantage of learning two-views, but it remains unclear whether the views become ‘interlinked’ in memory or are separately represented and summed on presentation of a view that perhaps matches by virtue of their similarity in horizontal ‘bar code’ structure (i.e., Dakin & Watt, 2009; Goffaux & Dakin, 2010; Pachai, Sekuler & Bennett, 2013). It is also possible that when two-views were matched by identity in the learning phase, that a generalised mechanism such as an FRU was not created, but perhaps the fact that these two views represented the same identity constrained these two separate representations into the same representational space (i.e., Burton, Kramer, Ritchie & Jenkins, 2016). However, by using views whose effects have been reported in previous experiments in this chapter, it has been possible to support an advantage for learning two-views that highlights the ‘view type utility’ of the views learned, and the effect that this has when recognition of a novel front-facing view is required.

3.6 General Discussion

The current chapter intended to test different learned view types as single-views and two-views, so that the effect of learning different views could be better understood in terms of the ‘view type utility’ each view type learned singularly or in combination might afford. The phrase ‘view type utility’ was used to allow a distinction to be made between what may become apparent between different learned view types, based on their informational attributes and ability to aid recognition of the same test view as that learned, the other view not learned, or a completely novel

front-facing test view. It was hoped that this approach would also allow the previously discussed ‘bar code’ perceptual encoding and recognition evidence to be considered further (i.e., Dakin & Watt, 2009; Goffaux & Dakin, 2010; Pachai, Sekuler & Bennett, 2013).

First, now that all experiments have been completed, the learning phase pattern of matching for this and the previous chapter can be fully considered. For identity matches in the two-view condition, where these were either the same view or different views, mean hit performance significantly increased between block 1 and block 7, across all experiments, apart from when these were mirrored profiles (Experiment 4), and this pattern has also been found when the two views differed (e.g., Alenzi, Bindemann, Fysh & Johnston, 2015), and when they were the same (e.g., Fysh & Bindemann, 2017, for front-facing views only). However, for identity matches in the single-view condition when the list of faces only included the same view types, where these were mirrored profiles, true profiles, and true three-quarter views, mean hit matching performance for Experiments 4, 5 and 6 did not significantly differ between block 1 and block 7. But crucially, for identity matches in the single-view condition when the list of faces included two different views (Experiments 1, 2 and 7), mean hit matching performance significantly decreased from block 1 to block 7, with the only exception to this pattern being that of Experiment 3 where single view matches did not change between blocks 1 and 7.

The pattern of increasing matching accuracy to approximately the same level of performance across experiments for the two-view condition, and that of single-view non-significant differences when the view types were the same and in lists of the same view type, can both be regarded as representing face identity learning over blocks of trials, which can be supported by previous matching findings (e.g., Alenzi,

Bindemann, Fysh & Johnston, 2015; Fysh & Bindemann, 2017). However, declining matching by identity performance for same-views requires further explanation. For this pattern, note that single-view matches by identity in these cases were always within a list of targets that were different view types, although of course single-view matches were always consecutive same-views, they did occur between two-view by identity matches. Also, note that the same match-mismatch structure and occurrences were the same for all experiments in the seven experiments, so frequency of matches and mismatches cannot account for the difference observed. With all of this in mind, it would seem to be the case that the declining pattern of accuracy cannot be based on view type or frequency effects, as the other experiments also contained these views, had the same list structure frequency, but importantly differed in view type list structure.

It is suggested therefore that work on visual cognitive control and selective attention may be a possible solution in accounting for these learning phase results. Park, Kim and Chun (2007; and see Minamoto, Shipstead, Osaka & Engle, 2105 for similar results) investigated working memory load and selective attention to discover if manipulating working memory load modulated distractor processing and interference, using face and house matching. The consistent finding in such experiments was that as cognitive load increased, for instance when target stimuli and distractor stimuli were visually different, that selective attention increased distractor interference (i.e., selective attention was unequal between targets and distractors), resulting in an increase in misses for targets. However, when working memory and selective attention was shared between targets and distractors, because they shared similar visual attributes, that distractor interference facilitated target selection (i.e., selective attention was equal between targets and distractors). Their

overall conclusion therefore suggested that when working memory load and attentional resource effects are considered in lists of stimuli, that similarity or dissimilarity between targets and distractors can produce each of these outcomes, so list structure and stimulus similarity must be considered when trying to account for apparent differences in matching accuracy.

With regard to the decline in matching accuracy for single views in a list of different views (i.e., Experiments 1, 2 and 7), it is first important to mention that single view target matches were always the same view type, and mismatches (or distractor effects in terms of the above-mentioned studies), were always different views, and for the two-view condition, target matches were also always different views. It is therefore proposed that target matches and mismatches in these particular learning lists (i.e., Experiments 1, 2 and 7) can be seen to contain both low and high working memory load that is caused by the effects of selective attention due to stimulus similarity and difference respectively. That is, target matches for the same view can be considered a low load condition because the visual stimuli are the same, but because mismatches are visually dissimilar stimuli, cognitive load is unequal (i.e., low for same view matches and high for mismatches), so distractor interference increases, resulting in an increase in misses between block 1 and block 7. However, for target matches that were two different views, but shared visual similarity with mismatches, which were also two different views, a high load condition can be said to exist because the cognitive load is shared equally between targets and mismatches. Therefore, mismatch accuracy can be said to facilitate attention on two-view target matches, and thus accuracy for target matches was not affected by interference from mismatches (i.e., distractors). This last point can also be applied to Experiments 4, 5 and 6 where all stimuli were similar between targets and mismatches (i.e.,

profile/profile, and three-quarter/three-quarter), and so again, accuracy for target matches was not affected by interference from mismatches (i.e., distractors).

Clearly, accounting for the learning patterns between all of the previous experiments was only possible once all experiments were completed, and so testing this hypothesis *a priori* was not possible. However, it would be interesting for future research to specifically study face matching and learning paradigms to establish whether such effects can be repeated or manipulated further, as many face learning experiments use such lists, and it would also be useful to control for such effects. Finally, it is possible that in Experiments 1, 2 and 7 that the single-view matching decline between block 1 and block 7 might imply that learning was unequal between single-views and two-views. However, because correct rejection rates were not significantly different in the learning phase, and it was clear that participants were discriminating accurately, results in the recognition phase cannot be accounted for by these list wise learning phase effects.

Considering now the first two experiments in the recognition test phase (Experiment 4: mirrored profiles, and Experiment 5: true profiles). Individual analysis revealed that view direction alone (mirrored profiles) did not produce an advantage from learning two-views, but that learning true profiles did. Although this advantage was not present when tested of the front-facing novel view for true profiles, it did appear over the same view learned and tested when compared to single view learning, which was further confirmed by a between experiments analysis, indicating a two-view advantage when two true profiles had been learned over mirrored profile views. It was therefore concluded that the true profile two-view advantage occurred due to within-identity variation that was not present when mirrored profiles were learned as two-views. However, it was not able to be

confirmed if this was due to the formation of an FRU (i.e., Bruce & Young, 1986). But, as stated previously, the FRU account only predicts an advantage from learning two-views (i.e., ‘interlinking’ of abstracted structural codes), so on this account the FRU-effect might be supported here from learning two true profile views. It was further proposed that the ‘bar code’ perceptual visual encoding and recognition account (i.e., Dakin & Watt, 2009; Goffaux & Dakin, 2010; Pachai, Sekuler & Bennett, 2013) could only be supported as route to the effects seen for same views, if such codes could also incorporate idiosyncratic within-identity variation (i.e., Burton, Kramer, Ritchie & Jenkins, 2016). It therefore remained to be seen if subsequent experiments might be able to shed further light on these observations, and so the next experiment tested true three-quarter views (Experiment 6).

When participants learned two-view that were true three-quarter views (Experiment 6), view-invariance resulted across all test view types, but the FRU effect was only significant over left three-quarter single views, and approaching significance over right three-quarter single views, when tested on the novel view. It was suggested that the information that each view provided (i.e., its ‘view type utility’), directly influenced its ability as a single view or as two-views, to answer a novel view. This was confirmed when investigative pairwise analysis was carried out between the three same-view experiments (i.e., Experiments 4, 5 and 6), albeit on a non-significant interaction. It was found that for both single learned views and two learned views that three-quarter view mean hits were significantly greater than mirrored and true profile views, but mirrored and true profile mean hits were not significantly different from each other. This supported the hypothesis that the ‘view type utility’ of three-quarter views was greater than that of profile views, and that

single learned three-quarter views could not overcome the advantage from learning two-views.

Furthermore, discussion of the previous experiments in this chapter (i.e., mirrored and true profile views) suggested that an advantage in recognition when two views were learned, over the same views learned and tested that were true profiles, indicated that within-identity variation led to the effects reported. Furthermore, it was suggested that the ‘bar code’ account of perceptual visual matching and recognition (i.e., Dakin & Watt, 2009; Goffaux & Dakin, 2010; Pachai, Sekuler & Bennett, 2013) was insufficient to explain these effects without also including for within-identity variation between two views that were the same view type. It was further argued that such within-identity variation may lead to idiosyncratic statistical constraints that are identity specific (i.e., Burton, Kramer, Ritchie & Jenkins, 2016). That is, in the Burton et al. view of face learning, identity provides the constraint for subsequent assimilation of exemplars, whereas the FRU account proposes that many FRUs exist for each identity, and that additional exemplars become ‘interlinked’ to all of these FRU representations. The current results do not allow this difference in representation to be confirmed or disconfirmed, however, it is suggested that the type of information contained in three-quarter views (i.e., there ‘view type utility’) does positively influence the representation when two-views were learned over learning true profile views and mirrored profile views.

The final experiment (Experiment 7) then tested profile and three-quarter views to establish whether each view learned singularly or as two-views would produce effects that would shed further light on the ‘view type utility’ findings of the previous three experiments. It was found that the two-view advantage (i.e., FRU-

effect) was only present compared to learned single profile views but not three-quarter views, when tested on the front-facing novel test view. In using profile and three-quarter views, and informed by the findings from the previous three experiments, it was concluded that the ‘view type utility’ of the three-quarter view produced the two-view advantage over the profile learned view, and that unequal summation of these two views could account for the effects reported. Furthermore, ‘pictorial’ effects (Bruce & Young, 1986), as discussed in relation to Experiment 1 (see section, 2.2.3), could not be supported as accounting for any effects in these experiments, as clearly, the ‘view type utility’ effects reported throughout indicate that properties of the face were being encoded and used to answer test views, and not just the properties of the image.

When a between Experiments 6 and 7 analyses was carried out for learned single views, when tested on the same view, novel view, and other view not seen, it was again confirmed that the ‘view type utility’ of learned single three-quarter views provided a significant advantage over learning single profile views, but such a single learned view could still not overcome the advantage from learning two-views that were three-quarter views. Finally, an overall analysis for mean hits when two-views were learned was carried out between all experiments in this chapter (Experiments 4, 5, 6 and 7), when the test view was a novel front-facing view. It was found that Experiment 6 (left and right three-quarter views) and Experiment 7 (left-profile and left three-quarter views) mean hits were significantly greater than Experiments 4 and 5 (mirrored and true profile views respectively), but differences between Experiments 4 and 5, and Experiments 6 and 7, were not significantly different.

In summary, the recognition test results across the four experiments presented in this chapter indicate that learning two-views that contain within-identity

variation (i.e., not mirrored profiles), provides a recognition advantage over learning single views, and that the ‘view type utility’ of the particular view type(s) influences their ability to answer a novel view, and the same view as that learned in the case of true profiles. Furthermore, even though single three-quarter views were demonstrated to exceed profile view performance, they were still unable to overcome the advantage of learning two-views that were three-quarter views. However, it was observed in Experiment 7, which was influenced by the findings and interpretations of the previous experiments, that there was an apparent unequal contribution for the two-views learned (i.e., profile and three-quarter views), with three-quarter views seeming to provide most of the information needed to answer a novel front-facing test view, over that of the left-profile view.

On this last point, and in relation to the FRU account proposed by Bruce and Young (1986), if the interpretation of Experiment 7 is representative of all experiments in this chapter, and perhaps the previous chapter as well, then it can be concluded that when two views were learned, that each was available separately, and that the summation between them achieved the recognition effects observed. That is, the evidence to support an ‘interlinking’ of abstracted structural codes that the FRU account suggests must receive less support than an arguably much simpler account that finds that each exemplar is stored separately and is combined in an online fashion when a recognition decision is needed of a view that shares the same ‘bar code’ attributes of those exemplars. That is not to say that the FRU account is not accurate or representative of how memory processes deal with the encoded information, just that the resulting recognition advantages produced over seven experiments could be accounted for by a much simpler route. It is also not possible to say from the evidence reported that the Burton, Kramer, Ritchie and Jenkins

(2016) idiosyncratic identity constraint account is supported over that of the Bruce and Young FRU account, but it does offer a route to learning identity from within-identity variation that does receive some support from the mirrored and true profile experiments. However, it is hoped that the next chapter which uses electroencephalography (EEG) to understand the learning and test phases, will be able to shed more light on the current behavioural results and associated conclusions.

Chapter 4. An electroencephalography (EEG) investigation of event related brain potentials (ERPs) associated with face learning and recognition

4.1 General introduction and literature review

From the behavioural experiments reported in Chapters 2 and 3, it was found that repeatedly matching two different views of unfamiliar faces produced advantages during recognition of novel views and the same views learned, over having only been exposed to single views (with the exception of Experiment 4 which used mirrored profile views). These results were interpreted and applied to theory, such as how the Bruce and Young model (1986) might explain these effects, whether these effects were due to pictorial and/or structural codes, and to what extent did the theoretical construct of face recognition units (FRUs) explain and account for the behavioural effects reported. Therefore, and in light of the previous behavioural findings, it was decided that it would be useful to attempt to investigate the electrophysiological correlates of face learning and recognition processes. In particular, it was thought that it may be possible to identify ERP correlates that might differ between matching single-views and two-views, and thus track the formation of an FRU representation, as well as differences between view types (single or two) during recognition, and therefore access to an FRU.

Electroencephalography (EEG) allows non-invasive direct measurements of brain activity. Noting the timing of stimulus presentation (with or without a behavioural response), it has been possible for researchers to examine the raw EEG output associated with stimulus presentations, and correlate this temporally. Development of the technique enabled signal averaging, and this has proved to be

one of the main advantages to the brain researcher (Woodman, 2010). Indeed, this has proved to be an efficient method for understanding temporal brain responses at the millisecond (ms) level, when compared to other methods such as functional magnetic resonance imaging (fMRI) which provide good spatial accuracy but poorer temporal accuracy.

When considering learning faces and subsequent recognition, the ERP method is suited to establishing the time course and broad location of neural responses associated with visual stimuli presentation, which behavioural measurements alone are unable to clarify. It is therefore possible to relate known ERPs representing face processing to theory, such as the Bruce and Young (1986) model. It must be stated however that Bruce and Young's (1986) cognitive model did not make any claims about brain responses or electrophysiological effects, and that correlating brain processes with such a model may not be a simple matter. However, it is suggested that it is important to first attempt to correlate known ERP components with such face processing cognitive models so that a clearer understanding of the processes involved can be attempted. That is, whether they support theory or provide information that suggests alternative accounts. With this in mind, the next section will briefly review the literature relating to electrophysiological correlates of face processing (i.e., ERPs), with a view to identifying those that are particularly associated with identity effects, and can be used to investigate the type of representation formed during learning faces and recognition.

A review of the ERP literature has identified that the earliest electrophysiological correlates associated with face processing are the P1 and N170 ERP components. The P1 ERP component has been revealed to be associated with

recognising that a stimulus is a face and not any other visual category, and has also been found to be insensitive to configuration (i.e., it is not modulated by inversion), negation, and identity, and has been consistently found to be maximal at bilateral parietal electrode sites at approximately 100 ms post stimulus presentation (e.g., Bentin & Deouell, 2000; Dering, Martin, Moro, Pegna & Thierry, 2011; Itier & Taylor, 2004). The P1 ERP component can therefore be regarded as the earliest electrophysiological marker of visual category encoding for faces, and the N170 ERP component has been repeatedly found to represent different and slightly later effects (e.g., Caharel et al., 2002; Caharel, Jacques, d'Arripe, Ramon, & Rossion, 2011a; Caharel et al., 2011b; Eimer, 2000; Gosling & Eimer, 2011; Rossion et al., 1999; Rossion, 2014; Schweinberger & Neumann, 2016; Yovel, 2016). That is, unlike the P1 ERP component, the N170 has been demonstrated to be sensitive to configuration, in that the face image needs to be valid (i.e., in its ‘normal’ upright orientation and not inverted), and like the P1 ERP component, is also insensitive to identity (and see, Miyakoshi, Kanayama, Nomura, Iidaka & Ohira, 2008; Su, Chen, He & Fang, 2012, for view change effects).

Therefore, as these early ERP components do not represent ‘identity’ effects they are only briefly acknowledged here for clarity, and are not focused on in the current investigation as they do not allow investigation of the identity ‘representation’ formed. It is also relevant to mention later components such as the N400f and P600f ERP parietal components, as these have also been highlighted as representing stages of face processing. But, because these have been found to represent access to semantic/conceptual memorial representations of identity, and possibly access to Bruce and Young’s (1986) PINs (e.g., Bentin & Deouell, 2000; Eimer, 2000; Gosling & Eimer, 2011; Schweinberger & Neumann, 2016;

Schweinberger, Pickering, Burton & Kaufmann, 2002; Sun, Chan, & Lee, 2012), these ERPs are again acknowledged but will not be included in the current investigation, as explicit conceptual/semantic information is not controlled in these visual-only experiments. Therefore, the two components that will be investigated in both the matching and recognition phases are the N250r inferior-temporal and occipital component, and the FN400 mid-frontal component. The following section will therefore review the literature concerning these two ERP components, and will comment on these in relation to theory and research aims.

4.1.1 The N250r ERP component

With the above in mind, the earliest post P1 and N170 ERP component that has been revealed to be sensitive to identity is the N250r ('r' - repetition) ERP component. Zimmermann and Eimer (2013) investigated this component by presenting participants with two face images that displayed either the same or two different individuals in the same or two different views, these were presented in rapid succession over several blocks of trials, and participants had to perform an identity-matching task. They reported an 'identity repetition effect' that occurred in response to the repetition of identities. Specifically, the N250r ERP component was found to be significant in terms of a waveform amplitude difference between same and different identities when same images were repeated across blocks. Critically however, the N250r ERP only reached significance for view-change trials of the same identity in the second half of the experiment, presumably as the faces were becoming familiar, and therefore was suggested to represent identity repetition that took some time to become detectable, in comparison to single views. However, if the

N250r can be considered a marker of access to an FRU-like representation as the authors suggested, then this implies that single view learning also produces a similar representation, as it was found present across all blocks of trials for this view type.

Similarly, the N250r ERP component in learning unfamiliar faces has been demonstrated to represent a marker of previously unfamiliar faces becoming familiar (e.g., Kaufmann, Schweinberger & Burton, 2009). In this extensive single study, there were two phases: a learning phase and a test phase, with EEG recording only applied to the test phase. In the learning phase, participants viewed thirty second dynamic colour videos of unfamiliar faces, with half accompanied by audible semantic information (i.e., their name, profession, residence, and additional distinct semantic details), and these were termed, ‘semantic faces’. The other half did not include any audible information, just the video clips were shown, and these were termed, ‘non-semantic faces’. Participants were instructed to remember the faces and semantic information, if provided, and overt responses were not required.

During the test phase, neutral expression static grey scale images were displayed, taken from the learning video but not frames of the video that had been seen before. Therefore, the test images were completely novel, and had the background removed and were not in colour. This meant that image effects (i.e., ‘pictorial’ effects) were reduced, as recognition could not be made by simply pattern-matching to an already seen exemplar, and thus identity should be the primary factor in making a recognition decision. Participants made a two-alternative forced choice decision response (familiar/not-familiar) via a keypad. The test included four blocks of test trials, with each block consisting of equal thirds: semantic faces, non-semantic faces, and novel faces (i.e., distractors). EEG results of

the test phase were calculated on each learning face type ('semantic faces' vs. 'non-semantic faces'), by each block (1-4).

Critically, for the N250r ERP component, a main effect of learning condition was absent (i.e., 'semantic' versus "non-semantic"), as well as any interaction with this factor. But there was a main effect of block, which indicated an effect of increasing activation from early to late blocks for 'known' faces (i.e., a similar finding to Zimmermann & Eimer, 2013). However, analysis for learned faces versus novel faces at test revealed that semantic and non-semantic faces did elicit a significant repetition effect over novel faces, and a right hemisphere effect was also found for this comparison. Taken together, these results suggest that the N250r component was insensitive to semantic and non-semantic faces, but was affected by repetition for these learned face types, with the authors defining these effects as signifying access to, "stored perceptual face representations" (Kaufmann, Schweinberger & Burton, 2009, p. 637).

Using different experimental paradigms, the N250r has also been shown to be a marker task dependent identity memory (Zimmermann & Eimer, 2014). It was found that the N250r repetition effect was only significant when the task required that participants memorise the faces for a later identity decision task, and not when the task was only to respond to the detection of an inverted face target (i.e., identity recognition was irrelevant). Schweinberger and Neumann (2016) also found, in a review of ERP effects associated with faces, that the N250r repetition effect was consistently present for repeated unfamiliar faces of the same identity (and see, Schweinberger, Huddy & Burton, 2004; Shweinberger, Pickering, Jentzsch, Burton & Kaufmann, 2002; Trenner, Schweinberger, Jentzsch & Sommer, 2004, for similar findings with famous faces).

Further studies (Pierce et al., 2011) have also found that the N250r ERP was only present for individuated and established representations in memory, such as target faces and associated objects, as well as one's own face and associated objects, when compared to novel faces and objects. And a similar finding that investigated the 'own face effect', revealed that one's own face, compared to novel and learned faces, elicited a significant N250r across all blocks, but that learned faces only produced an N250r in the second half of test blocks (Tanaka, Curran, Porterfield, & Collins, 2006), which again provides a similar pattern of late block activation to that of Zimmermann and Eimer (2013).

In summary, the literature reviewed suggests that the N250r ERP component is present when exact image repetitions occur, across all blocks, as well as after multiple exposures to different images of the same identity, but only in later blocks of trials. Furthermore, the N250r has been demonstrated to be attention sensitive, in that it was only present when participants had to memorise faces for later recognition, and has also been found to be present when accessing established representations from memory. Therefore, on one hand, the N250r ERP would seem to occur after the 'structural encoding' stage of the Bruce and Young (1986) model, and may therefore represent access to or formation of FRUs, as it seems to be sensitive to stored representations and may therefore represent a marker of visual identity. In contrast, it has also been demonstrated to be sensitive to 'pictorial' image matches that presumably do not necessarily need to be identity related, so it is somewhat unclear whether it is a perceptual ERP and/or memorial ERP. However, as it has been found to represent "perceptual memory for faces" (e.g., Schweinberger, Huddy & Burton, 2004, p. 1502), it is an important 'identity-relevant' component to

investigate in the learning and recognition phases of the current study, as it may shed light on the type encoding and representation formed.

4.1.2 The FN400 frontal ERP component

The FN400 old/new mid-frontal ERP component, which normally occurs between 300-500 ms post stimulus presentation, and is characterised by a larger deflection for old items (targets) over new items (distractors), has been found to be consistently associated with stimulus familiarity that distinguishes old (studied/familiar) items from new (distractor/unfamiliar) items (e.g., Curran & Cleary, 2003; Curran & Hancock, 2007; Schweinberger & Neumann, 2016). However, Paller, Voss and Boehm (2007) have suggested that the FN400 ‘familiarity’ ERP must be treated with caution, as they point out that conceptual priming and familiarity are often indistinguishable from each other as mechanisms presenting the same electrophysiological outcome, and cautioned that the two should not be conflated when understanding this ERP component.

In terms of priming effects, they distinguished between perceptual and conceptual priming (and see, Voss & Federmeier, 2011; Wiese & Shweinberger, 2015, for similar findings). That is, perceptual priming is suggested to only include the physical properties of the stimulus, and its visual similarity to another stimulus, whereas conceptual priming can be implicit (i.e., the participant generates this themselves without experimental manipulation or control), as well as explicit (i.e., semantic information that the experimenter defines). The authors pointed out that perception is often a mixture of the two, and even the context of the experiment can implicitly add conceptual weight to an otherwise carefully controlled, purely visual,

perceptual experimental process. So, in this view, the caution advised by these authors must direct the experimenter, when drawing their conclusions, to consider the context in which the FN400 ERP is present (i.e., during matching or recall), and under what experimental controls (i.e., if semantic information is provided or not).

To further clarify the perceptual/conceptual issue, an N400 related mid-frontal component was investigated by Wiese and Schweinberger (2015). Using pre-experimentally unfamiliar faces that were either accompanied by semantic information or not, and were presented in pairs to participants, they found that the N400 ERP component was observed only for co-occurring visual information with shared semantics, concluding that this suggested that both the image and associated semantic information were important in person-related semantic memory formation. The important distinction of this study was that pre-experimentally unfamiliar faces were used, and therefore, explicit semantic encoding was controlled directly, so the N400 effects could be more confidently attributed to representing access to conceptual/semantic identity information, as N400 effects were absent for the non-semantic stimuli (i.e., faces presented alone).

Furthermore, a review by Rugg and Curran (2007) which discussed recognition memory and mid-frontal FN400 old/new effects, concluded that these effects cannot conclusively be explained by conceptual overlap between study and test items, and instead suggested that the FN400 ERP represented an index of familiarity that was based on implicit rather than explicit memory (and see, MacKenzie & Donaldson, 2007). And, a study by Wolk et al. (2006) investigated short (39 minutes) and long (24 hours) retention intervals for the FN400 frontal familiarity ERP for sets of words, using a remember/know paradigm. Although words were the stimuli in this experiment and not faces, their results are of interest in

relation to the FN400 ERP component as they found that for ‘know’ responses, compared to correct rejections, the retention interval (i.e., 39 minutes and 24 hours) had no effect on the FN400, demonstrating that its effects can be detected up to 24 hours after training.

In summary, the FN400 ERP component must be considered with caution and in light of the context in which it occurs, and must not simply be regarded as a marker of familiarity. Indeed, when explicit conceptual/semantic information is absent, such as in a visual only face image experimental design, one must regard such a component according to whether it is in a perceptual learning phase of an experiment, or in a recognition phase. In this way, conclusions regarding its occurrence and how it should be interpreted can be more accurately considered. However, based on the literature reviewed, it is unclear at this stage how the FN400 might be considered in terms of the Bruce and Young (1986) model when learning previously unfamiliar faces that are not accompanied by explicit conceptual/semantic information. The literature reviewed would seem to suggest that the FN400 ERP component does not necessarily represent an ‘all-or-nothing’ marker of familiarity. Yet, it does seem to represent an important ERP component to be considered when understanding how faces are learned, and what effect learning has on recognition of the same view, or novel views.

Clearly this component would seem to offer the most promising target for face learning and subsequent recognition testing, but it remains to be seen where it fits into the Bruce and Young model, or if indeed it does at all, as the context in which it occurs seems to affect how it is interpreted. For example, if it occurs in a learning phase and is present for later, but not earlier blocks of trials, then one may attribute it to accessing a ‘formed’ representation (i.e., a memorial effect). However,

if it is present across all blocks, then it may be attributed to the formation of a representation (i.e., a perceptual effect). The difference in interpretation based on the context in which it occurs is subtle but important. Therefore, this component will be investigated in both the learning and recognition phases, as the evidence reviewed, at the very least, does seem to show that it is only present for ‘known’ identities, and therefore will be a useful marker of learning and recognition of new identities.

4.2 Experiment 8: An ERP investigation of matching unfamiliar faces from single views (front-facing or profile), and both of these views

4.2.1 Introduction and research aims

The learning phase of the previous behavioural experiments (see Chapters 2 and 3) revealed that matching views of the same identity that were in the same view (i.e., single-views) was generally very accurate. However, when views of the same identity were different (i.e., two-views), matching accuracy was observed to increase over matching blocks, eventually producing an approximately equivalent level of matching accuracy as the single-views by the end of the session of blocks, but notably, not when these were mirrored-views. However, it was not possible to say any more about the two-view learning pattern other than it co-occurred with improved recognition accuracy. It was therefore decided that to understand the learning process in more detail, that the EEG/ERP method would be used, as the empirical evidence reviewed has demonstrated that the two ERP components identified have provided evidence in support of identity related learning effects. It

was anticipated that these could be interpreted and applied to the theoretical constructs of the Bruce and Young (1986) model, and thus may shed more light on the learning process. Therefore, using the same views as behavioural Experiment 1 which produced the clearest indication of FRU formation at test, the experiment focused on the two ERP components identified in the literature review (i.e., N250r & FN400).

Regarding its presence in the learning of new identities, the N250r ERP component has been shown to be present when sequential repetitions of the same image or view take place, but more importantly for the current investigation, it has also been found to be present only in later blocks of trials when two-views of the same identity were different, and therefore may represent access to or the formation of FRUs (e.g., Zimmermann & Eimer, 2013; 2015). However, in terms of the Bruce and Young (1986) model, FRU formation was proposed to require abstraction of ‘structural’ codes and not ‘pictorial’ codes, so on this account the N250r evidence reviewed would seem to indicate that both same-view and two different view matching are based on the same structural abstraction perceptual processes. Indeed, as the study of Schweinberger, Huddy and Burton (2004) revealed that the N250r ERP component represented perceptual memory for faces over the other object categories they included, and therefore cannot be linked simply to the, “repetition of visual stimuli in general” (p. 1504). Therefore, on this account, image based ‘pictorial’ codes would seem not be associated with this ERP, and further suggest that information about the face is encoded over just the properties of the image, as this ERP is linked with identity..

Therefore, and to test this hypothesis, the N250r ERP component will be investigated for same-view matches (i.e., single-view) and different-view matches

(i.e., two-view), compared to identity mismatches (i.e., correct-rejections), across four blocks of trials. If the hypothesis is supported then the N250r will be present for single-views across all blocks, but may only appear in later blocks for two-views. From this it could be concluded that structural abstraction takes place for all same identity matches, irrespective of view type, and that FRU formation only requires structural within-identity variation to produce such a representation. However, if this is not supported, and the N250r is absent for one or both of the same identity view types, then this hypothesis and theoretical account will need to be reconsidered.

Allied to possible N250r effects, the FN400 frontal ERP component has been demonstrated to be sensitive to familiarity and identity priming, and therefore offers the opportunity to discover if this can be detected as identities become ‘more familiar’ over blocks of matching. It is therefore hypothesised that the FN400 mid-frontal ERP component will prove an index of familiarity by being apparent in the early blocks for same-identity/same-view matches (and perhaps reducing over blocks), and will only be present in later blocks for same-identity/different-view matches, as it may take some time for these to become familiar representations. This pattern is predicted as matching accuracy for single-views in the behavioural experiments indicated that accuracy was very good at block one, so it is assumed that any learning and representation formation occurred early-on in the session. However, for two-views, because accuracy improved over blocks, and only reached approximate equivalence with single-view matching by the end of the session, it is assumed that learning and representation formation occurred later-on in the session.

4.2.2 Method

Participants

Thirty-Six Caucasian undergraduates (23 females, 13 males) aged between 18 and 27 years (mean age, 18.9 years), with 34 right handed and two left handed, participated in exchange for course credit. All participants had normal or corrected-to-normal visual acuity (self-report) and no history of neurological illness (self-report). All participants gave informed consent and the procedures were approved by the University of Kent, School of Psychology Ethics Committee.

Design

The experiment consisted of a one-back face identity serial matching task with eight blocks of trials. A total of 50 unfamiliar target and 100 unfamiliar distractor identities were used, half of each were included in each of the eight blocks, such that there were 25 targets and 50 distractors per block. Target identities 1-25 and distractor identities 1-50 appeared in blocks 1, 3, 5 and 7, and the rest appeared in the even blocks. There were three between-participants view type groups, with each group seeing one target identity view type during learning: (1) front-facing (FF); (2) right-profile (RP); and (3) both of these views (i.e., ‘two-views’, TV). Therefore, for each participant, each of the target and distractor identities occurred equally often in each view type group, resulting in an equivalence of exposure to all identities.

For the behavioural analysis, the dependent variable was the percentage of correct one-back matches (i.e., hits) and correct one-back mismatches (i.e., correct

rejections). This was measured for 4 sets of consecutive blocks (1-2, 3-4, 5-6, and 7-8) to allow each set to contain all 50 targets and 100 distractor identities (see distribution of identities to blocks above). The design comprised a 3x4 mixed-factors design with view type group as a between-subjects factor and block as the within-subjects factor.

Electrophysiological analysis included all trials. That is, they did not depend on a correct response being made, which meant that electrical activity could be coded as representing a target match (same-identity), or mismatch (different-identity). The ‘all trials’ approach was taken because although this study included the same views as had previously been used in Experiments 1 to 3, it was unclear whether the between view type groups approach and inclusion of many more identities than those used in the previous behavioural experiments would produce the same extent of matching accuracy found previously. Therefore, by including ‘all trials’ it was possible to relate electrophysiological responses to presentations of the different view types singularly or in combination, that was not dependent on a correct behavioural response or errors that might occur due to the difference between this learning phase design and that of the previous behavioural experiments.

Repeated measures analysis of variance (ANOVAs) were carried out for the factors electrode site, within each region for each ERP (i.e., N250r, inferior-temporal and occipital; and FN400, mid-frontal), block (block 1 to 4), and identity (same-identity or different-identity), with a between-subjects factor of view type group (learned two-views, learned front-facing view, or learned right-profile view).

Materials and Apparatus

Images were presented on a 17-inch LCD monitor (display resolution, 1280 x 1024). Responses were made using a standard computer keyboard and the experiment was controlled with PsychoPy 2 (Pierce, 2009). All images were 15° (13.5 cm) vertically and ranged from 6.3° to 13.5° horizontally. The faces of 153 Caucasian men were obtained from three face databases: (1) The CVL Face Database, The Computer Vision Laboratory, University of Ljubljana, Slovenia (Peer, 2005); (2) The CMU Multi-PIE Face Database (Gross, Matthews, Cohn, Kanade & Baker, 2010); and (3) The Glasgow Unfamiliar Face Database (Burton, White & McNeill, 2010). All images were converted to greyscale and cropped using Adobe Photoshop Elements (version, 11.0), to remove background detail and as much head hair as practicable, and all were free of non-face distinguishing features (e.g., tattoos, glasses and jewellery). For all identities, four images were prepared: two front-facing and two right-profile views. See Figure 10 for examples of each view type for four identities.

Procedure

During the experiment, participants were seated approximately 50cm from the screen and the face stimuli were presented in the centre of the screen against a white background. Before the data collection phase commenced, participants completed a short practice session which had the same format as the data collection phase (described below), but with only nine identities (note: these were not seen in the rest of the experiment) and 18 trials (consisting of 3 targets and 6 distractor identities). No feedback was given about accuracy. Upon successfully completing

this, participants initiated the first experimental block with a button press.

Participants were only informed that their task was to match a list of consecutive serially presented face images by identity. Note that although participants were aware they would be required to return the following day for the second part of the experiment (see Chapter 2), they were not explicitly informed why.

Each of the eight experimental blocks comprised 150 face stimuli. Each face appeared in the centre of the screen for a fixed period of 500 ms and was followed by a blank screen that was randomly presented as either 500 ms or 1000 ms. This was then followed by a message (black text on a grey rectangle) asking participants whether the last identity they saw was the same as the one before (i.e., a one-back identity matching procedure), and to respond by means of a key-press: ‘c’ for yes and ‘n’ for no. Responses were only recorded once the message appeared (i.e., participants had to wait to make a response) and were therefore not limited by time. There was then a further blank screen before the next face stimulus appeared, and this was also a random gap that was either 500 ms or 1000 ms. No feedback on accuracy was provided throughout the entire experimental block procedure.

Within each block, each target identity appeared four times (i.e., as two consecutive pairs within the overall sequential list of trials) with a distractor identity between each of these target pairs (i.e., target, target, distractor, etc.). Note that distractor identities per block only appeared once and were always a different view type to the preceding target identity (i.e., mismatches were both different identities and different view types). The target-distractor assignment was also counterbalanced, creating set one and set two, with set one targets becoming distractor identities in set two, and set one distractor identities becoming target identities in set two. Overall, each participant saw each target identity a total of 16

times over the entire blocks of trials (i.e., 4 images per identity per block x 4 blocks). The experiment lasted on average one hour, and participants were encouraged to favour accuracy over speed, and to take breaks between blocks when prompted, proceeding only when they were ready.

Electrophysiological measures

Electrophysiological data was collected using a BrainAmp DC amplifier and collected using Brain Vision Recorder (version, 1.2) and a 64-channel actiCAP set-up (Brain Products GmbH, Munich), with a sampling rate of 1000 Hz (electrodes were recorded according to the international 10-20 system). FCz acted as the on-line reference electrode and AFz as the on-line ground electrode. Scalp impedance was kept below 5 k Ω , and EEG data were off-line re-referenced to an average of the left and right earlobes and filtered (notch filter of 50 Hz; high cut-off 40 Hz, 12 dB/oct; low cut-off 0.01 Hz, 12 dB/oct) using Brain Vision Analyzer (version, 2; Brain Products GmbH, Munich). Horizontal electrooculogram (HEOG) was recorded from the outer canthi of the right eye and vertical electrooculogram (VEOG) was recorded from the left eye.

All EEG data sets were initially processed using Raw Data Inspector in semi-automatic format (maximal allowed voltage steps of 50 μ V/ms 200 ms before and after event; max-min difference of values of 200 μ V over an interval length of 200 ms; and bad intervals marked 200 ms before and after event for lowest activity allowed - 0.5 μ V over 100 ms intervals). Then, ocular correction was conducted via a semi-automatic Independent Components Analysis (ICA) based correction process. For data reduction, stimulus-synchronised segments were created with a total length

of 1050 ms, lasting from 50 ms before and 1000 ms after face image stimulus onset. Segments were then averaged within the target and mismatch conditions for each of the four blocks separately and baseline corrected (50 ms before and 50 ms after stimulus onset). Total segments for target matches were 100 (i.e., 25 target matches per block x 4 blocks), and 200 mismatches (i.e., 50 mismatches per block x 4 blocks).

Mean amplitude values were computed for two levels of the factor ‘identity’: same-identity (i.e., when there was a consecutive target match) and different-identity (i.e., when there was not a consecutive target match), at two separate regions of interest (ROIs), based on a priori information (similar to the approach taken by Kaufmann, Schweinberger & Burton, 2008). Based on the variation of electrode sites identified in previous research for the N250r ERP, it was decided that each of these would be targeted in the current experiment, and comprised inferior-temporal and occipital sites: P7, P8, PO7, PO8, PO9, PO10, O1 & O2. Because visual inspection of the waveform revealed that N250r ERP ROI for this experiment was later than that used by Zimmermann and Eimer (2013), it was decided that the ROI for this N250r ERP was to be 250-300 ms after onset of the face image stimulus. For mid-frontal sites (F3, Fz & F4), for the FN400 ERP, an ROI of 300-500 ms after onset of the face image stimulus was chosen, which was consistent with and based on previous research (e.g., Eimer, 2000; Schweinberger & Neumann, 2016).

4.2.3 Results

Behavioural data

The matching data was subjected to 3x4 mixed-factors design with view type group (FF, RP or TV) as a between-subjects factor, and block (1-4) as the within-subjects factor. The percentage of correct matches (i.e., hits) was the dependent variable. Departures from sphericity were corrected using the recommendation of Girden (1992): for epsilon values greater than .75 the Huynh-Feldt correction was applied, and for epsilon values less than .75 the Greenhouse-Geisser correction was applied. Effect sizes were considered based on Cohen's (1988) recommendation of .02 for a small effect, .13 for a medium effect, and .26 for a large effect.

It was observed that the between subject's main effect of view type group (FF, RP or TV) was significant, $F(2, 33) = 41.138$, $MSE = 641.307$, $p < .001$, $\eta_p^2 = 0.71$ (Observed power = 1), with mean hits for the front-facing view type group significantly higher than the two-view view type group ($p < .001$; mean hits, 94.41% & 52.25% respectively), and the left-profile view type group mean hits were also significantly greater than the two-view view type group ($p < .001$; mean hits, 91.56% & 52.25% respectively). The main effect of block approached significance, $F(2.776, 91.597) = 2.710$, $MSE = 23.978$, $p = .054$, $\eta_p^2 = 0.76$ (Observed power = .61), with block 1 mean hits (80.55%) greater and approaching significance over block 2 (78.30%, $p = .062$), and block 4 mean hits (80.63%) greater and approaching significance over block 2 (78.30%, $p = .055$), and significant over block 3 ($p = .010$). However, the two-way interaction between view type group and block was not significant, $F(6, 99) = 0.628$, $MSE = 22.185$, $p = .707$, $\eta_p^2 = 0.03$ (Observed power =

.24). See Figure 8-1 for mean correct responses (hits) for each view type group by block.

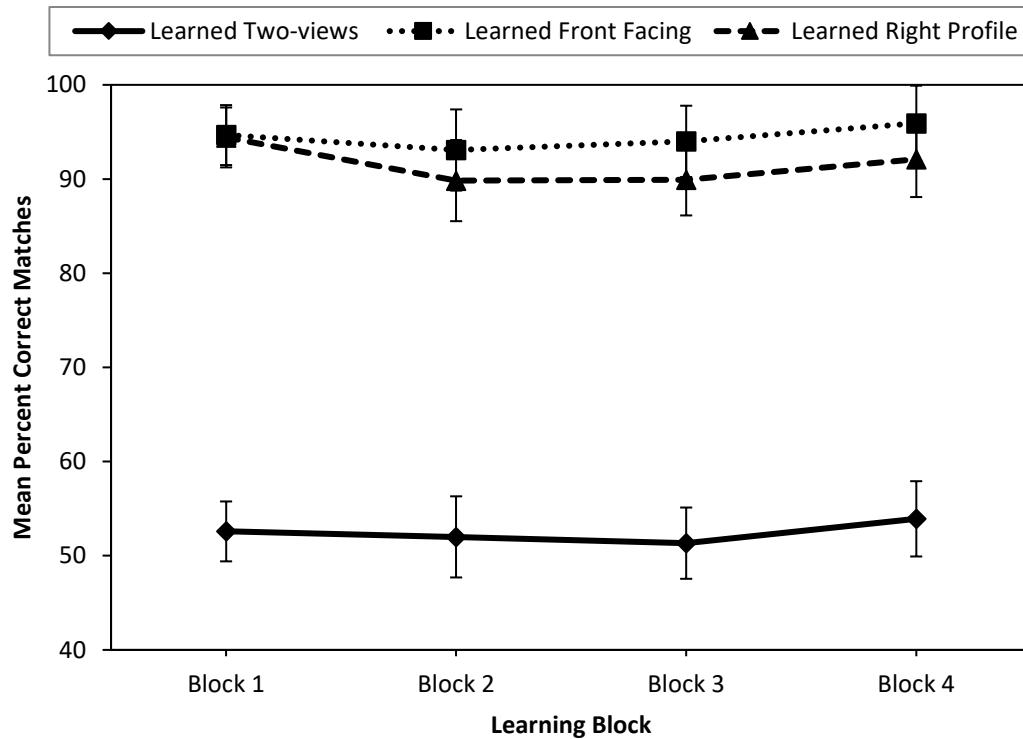


Figure 8-1. Behavioural Matching Results for Experiment 8. Mean percent correct one-back hits are plotted as a function of view type group (Two-views, Front-facing view & Right-Profile view), at each block of matching. Error bars represent standard error of the mean.

Analysis of correct rejections (i.e., correctly saying no to a mismatch) was subjected to the same 3x4 mixed-factors design, and revealed that the between subjects factor of view type group was not significant, $F(2, 33) = 0.537$, $MSE = 82.370$, $p = .589$, $\eta_p^2 = 0.03$ (Observed power = .13). However, the main effect of block was significant, $F(1.73, 57.27) = 11.468$, $MSE = 8.99$, $p < .001$, $\eta_p^2 = 0.25$ (Observed power = .98), with block 2 (94.18%), block 3 (94.58%) and block 4 (94.86%) means greater than block 1 (92.02%), all p 's < .001. But the two-way

interaction between view type group and block was not significant, $F(6, 99) = 1.493$, $MSE = 5.205$, $p = .188$, $\eta_p^2 = 0.08$ (Observed power = .55).

Electrophysiological Results

N250r (250-300 ms ROI)

Mean amplitudes for each participant were subjected to an 8x4x2x3 mixed-factors ANOVA with electrode site (P7, P8, PO7, PO8, PO9, PO10, O1 and O2), trial block (block 1-4) and identity (i.e., same-identities and different-identities) as repeated measures factors, and view type group as the between subject's factor (TV, two-views; FF, Front-Facing view; RP, Right-profile view). Departures from sphericity for the repeated measures factors were corrected using the recommendation of Girden (1992): for epsilon values greater than .75 the Huynh-Feldt correction was applied, and for epsilon values less than .75 the Greenhouse-Geisser correction was applied. Effect sizes were considered based on Cohen's (1988) recommendation of .02 for a small effect, .13 for a medium effect, and .26 for a large effect.

The between subject's factor of view type group was not significant, $F(2, 33) = 0.327$, $MSE = 1149.698$, $p = .723$, $\eta_p^2 = 0.01$ (Observed power = .09), but the repeated measure main effect of electrode was, $F(3.058, 100.906) = 12.222$, $MSE = 142.139$, $p < .001$, $\eta_p^2 = 0.27$ (Observed power = 1), with mean amplitudes at electrode P7 and P8 significantly lower than the rest (PO7, PO8, PO9, PO10, O1 and O2, all p 's < .003). The repeated measure main effect of block approached significance, $F(2.584, 85.280) = 2.739$, $MSE = 15.228$, $p = .056$, $\eta_p^2 = 0.07$

(Observed power = .60), with block 1 mean amplitudes greater than block 2 (approaching, $p = .053$), block 3 mean amplitudes greater than block 2 ($p = .003$), and block 4 mean amplitudes greater than block 2 ($p = .017$). However, the repeated measure main effect of identity was not significant, $F(1, 33) = 0.759$, $MSE = 16.083$, $p = .390$, $\eta_p^2 = 0.02$ (Observed power = .13). But, the two-way interaction between electrode and block was significant, $F(7.401, 244.246) = 2.230$, $MSE = 2.190$, $p = .030$, $\eta_p^2 = 0.06$ (Observed power = .84), as was the two-way interaction between electrode and identity, $F(2.860, 94.391) = 5.570$, $MSE = 2.536$, $p = .002$, $\eta_p^2 = 0.14$ (Observed power = .92), and the three-way interaction between electrode, identity and view type group was significant, $F(14, 231) = 5.322$, $MSE = 1.036$, $p < .001$, $\eta_p^2 = 0.24$ (Observed power = 1).

Further analysis focused on the three-way interaction between electrode, identity and view type group, which was broken down by each view type group for the two-way interaction between electrode and identity, to understand at which electrode the N250r ERP occurred (see Figures 8-2 to 8-6 for Grand-averaged waveforms at each electrode). When two-views had been learned, the main effect of electrode was significant, $F(3,234, 35.578) = 5.206$, $MSE = 33.939$, $p = .004$, $\eta_p^2 = 0.32$ (Observed power = .91), with mean amplitudes at electrodes P7 and P8 significantly lower than all other electrodes (all p 's $< .029$), and electrode PO10 mean amplitudes significantly lower than PO8 ($p = .041$). But the main effect of identity was not significant, $F(1, 11) = 0.285$, $MSE = 2.393$, $p = .604$, $\eta_p^2 = 0.02$ (Observed power = .07). However, the electrode by identity interaction was significant, $F(2.634, 28.978) = 4.249$, $MSE = 0.366$, $p = .016$, $\eta_p^2 = 0.27$ (Observed power = .77), but pairwise analysis, adjusted for multiple comparisons using a

Bonferroni adjusted alpha of .0018 (i.e., .05/28 electrode comparisons), revealed that identity was not significant at any electrode (all p 's $> .055$).

When front-facing views had been learned, the main effect of electrode was significant, $F(2.421, 26.627) = 4.274$, $MSE = 46.935$, $p = .019$, $\eta_p^2 = 0.28$ (Observed power = .74), with mean amplitudes at electrodes P7 and P8 significantly lower than electrodes PO8, PO10, O1 and O2 (all p 's $< .042$), and P7 lower than PO7 and PO9 (all p 's $< .009$). But the main effect of identity was not significant, $F(1, 11) = 5.389$, $MSE = 5.389$, $p = .736$, $\eta_p^2 = 0.01$ (Observed power = .06), and the electrode by identity interaction was not significant, $F(2.389, 26.275) = 2.493$, $MSE = 1.130$, $p = .094$, $\eta_p^2 = 0.18$ (Observed power = .49).

When right-profile views had been learned, the main effect of electrode was significant, $F(2.148, 23.633) = 4.992$, $MSE = 47.751$, $p = .015$, $\eta_p^2 = 0.30$ (Observed power = .77), with mean amplitudes at electrodes P7 and P8 significantly lower than electrodes PO8, PO10 and O2 (all p 's $< .024$), and P7 lower than PO7, PO9 and O1 (all p 's $< .011$). But the main effect of identity was not significant, $F(1, 11) = 0.456$, $MSE = 54.281$, $p = .513$, $\eta_p^2 = 0.04$ (Observed power = .09). However, the electrode by identity interaction was significant, $F(2.291, 25.200) = 10.461$, $MSE = 0.775$, $p < .001$, $\eta_p^2 = 0.48$ (Observed power = .98), but pairwise analysis, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0018 (i.e., .05/28 electrode comparisons), revealed that identity was not significant at any electrode (all p 's $> .010$). It can therefore be seen that the N250r ERP component was absent as a main effect of identity, and for the identity by electrode interaction for each learned view group, differences between electrode mean amplitudes accounted for the interaction.

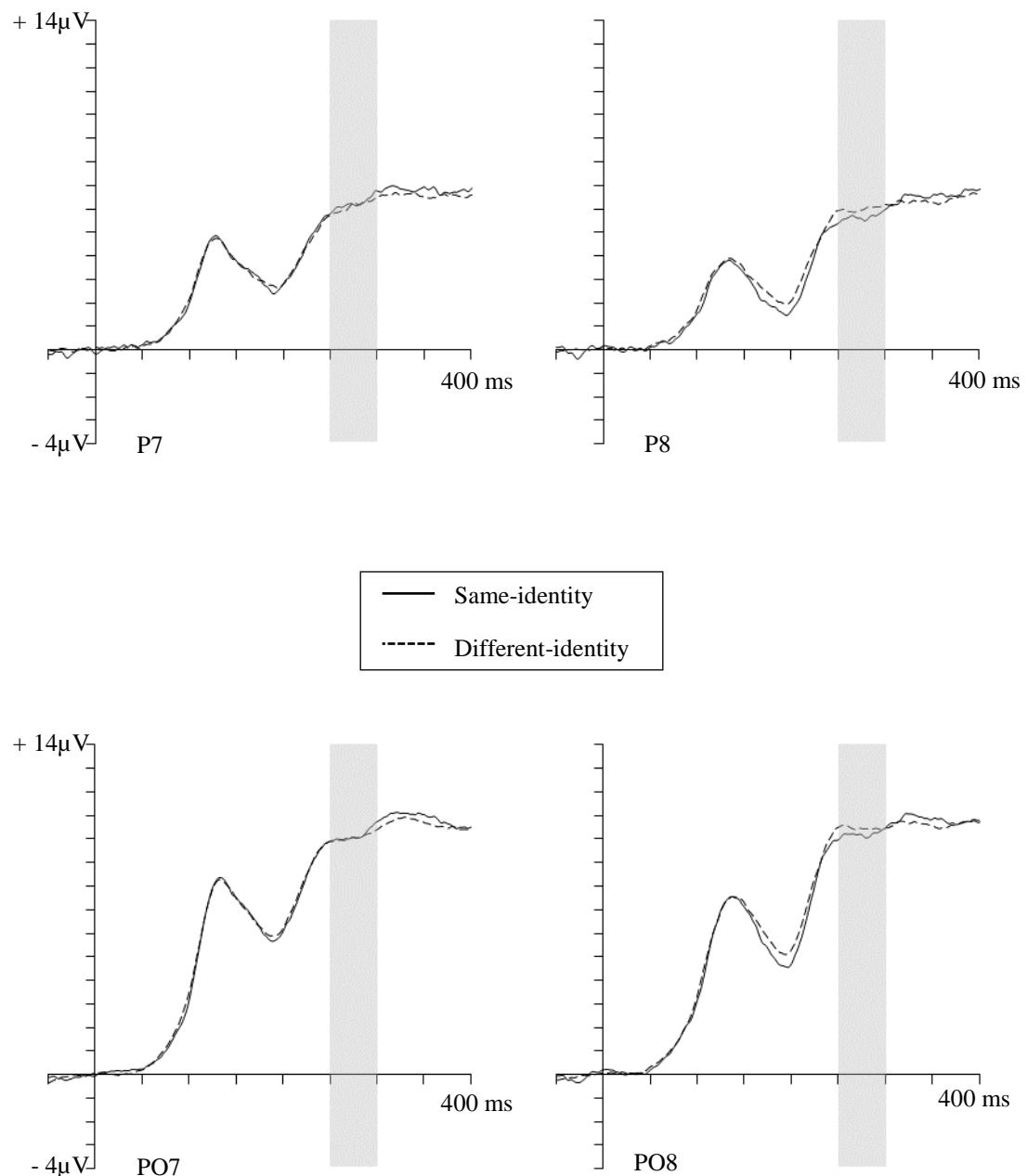


Figure 8-2. N250r (250-300 ms ROI highlighted) Grand-averaged ERPs for the two-view view type group, measured at inferior-temporal electrodes P7, P8, PO7 and PO8 in the 400 ms interval (50 ms increments) after onset of the second stimulus in a sequential face pair, for same-identity trials (solid line) and different-identity (dashed line), averaged across all four experimental blocks.

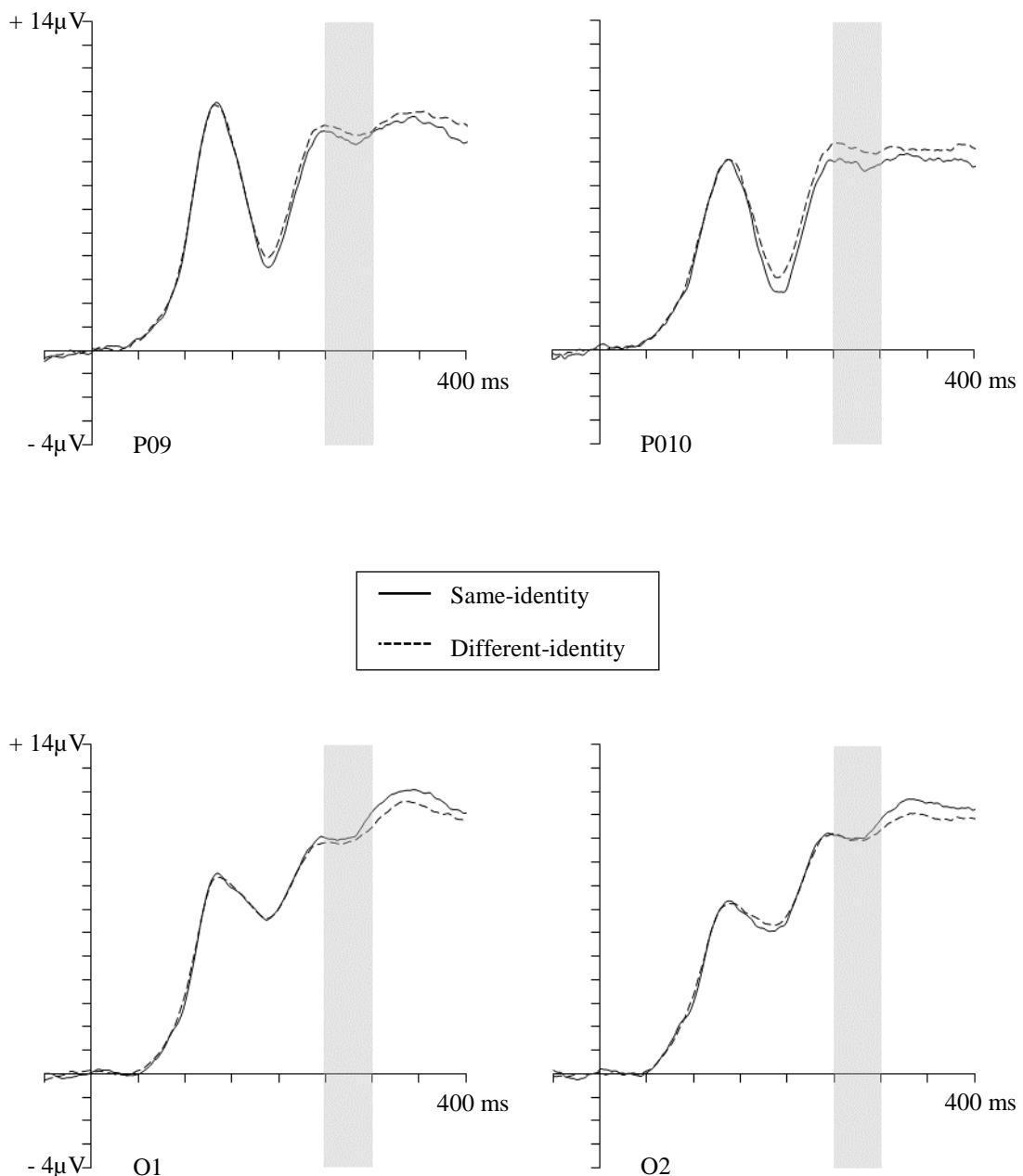


Figure 8-3. N250r (250-300 ms ROI highlighted) Grand-averaged ERPs for the two-view view type group, measured at inferior-temporal electrodes PO9, PO10, O1 and O2 in the 400 ms interval (50 ms increments) after onset of the second stimulus in a sequential face pair, for same-identity trials (solid line) and different-identity (dashed line), averaged across all four experimental blocks.

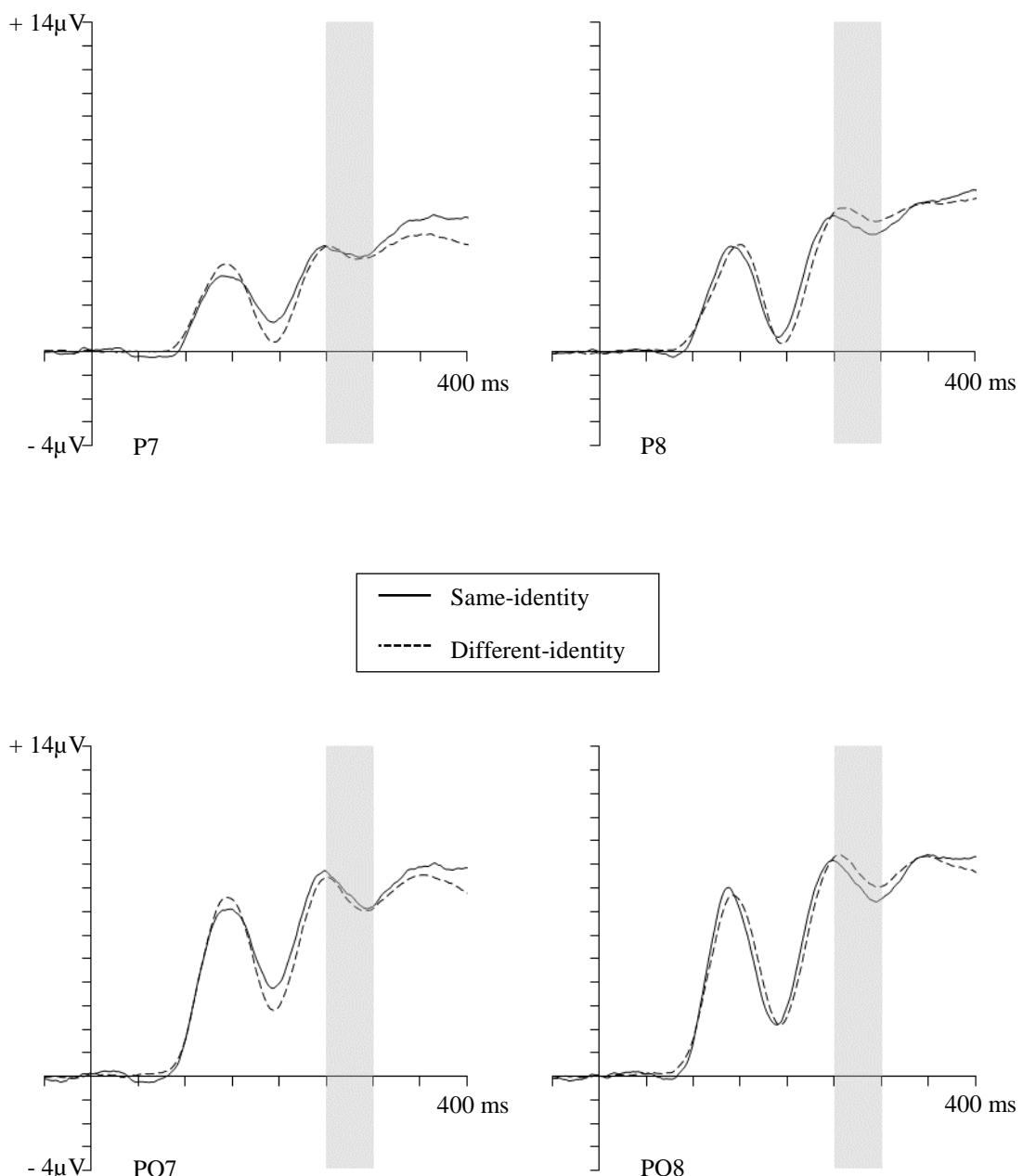


Figure 8-4. N250r (250-300 ms ROI highlighted) Grand-averaged ERPs for the front-view view type group, measured at inferior-temporal electrodes P7, P8, PO7 and PO8 in the 400 ms interval (50 ms increments) after onset of the second stimulus in a sequential face pair, for same-identity trials (solid line) and different-identity (dashed line), averaged across all four experimental blocks.

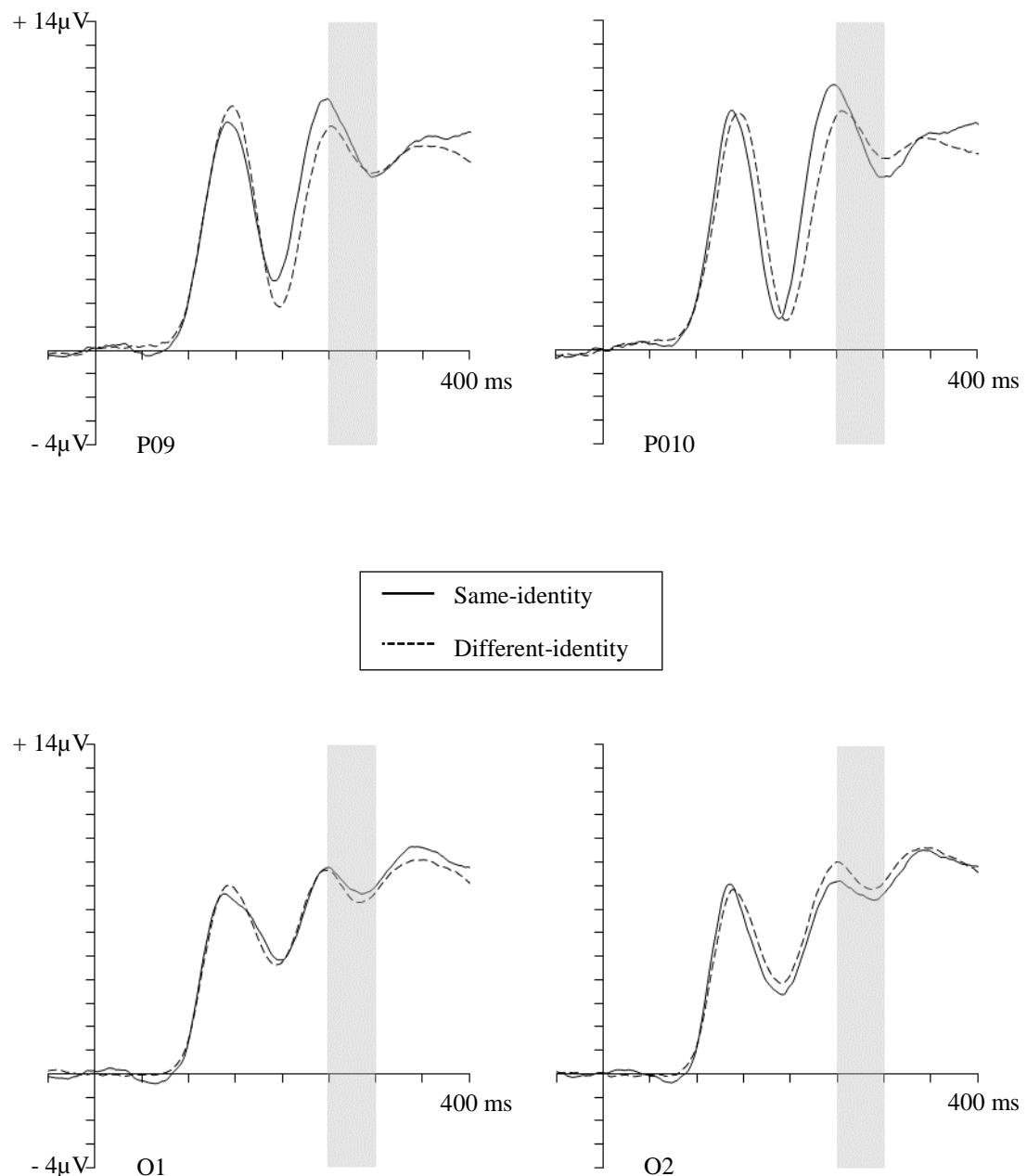


Figure 8-5. N250r (250-300 ms ROI highlighted) Grand-averaged ERPs for the front-view view type group, measured at inferior-temporal electrodes PO9, PO10, O1 and O2 in the 400 ms interval (50 ms increments) after onset of the second stimulus in a sequential face pair, for same-identity trials (solid line) and different-identity (dashed line), averaged across all four experimental blocks.

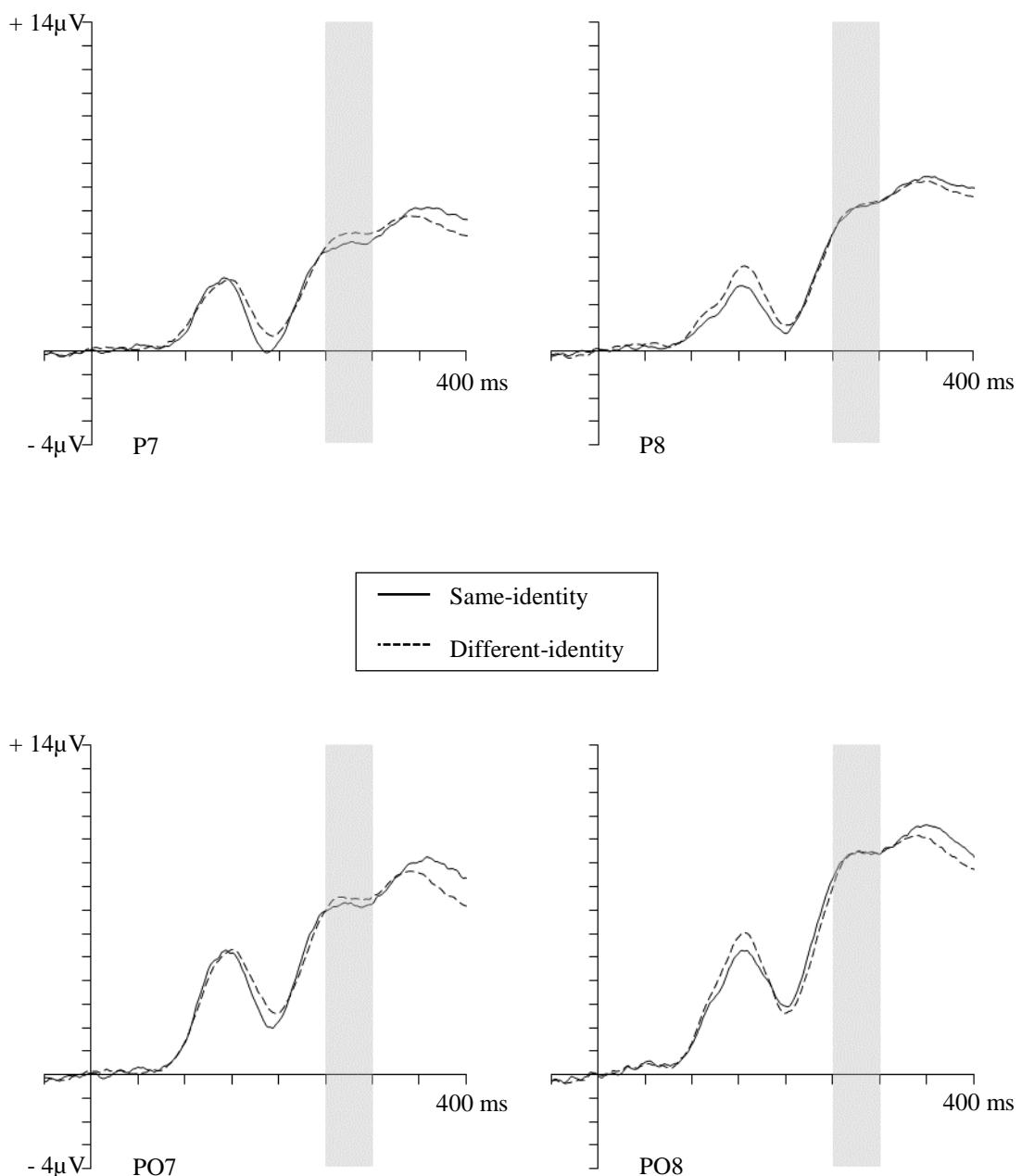


Figure 8-6. N250r (250-300 ms ROI highlighted) Grand-averaged ERPs for the right-profile view type group, measured at inferior-temporal electrodes P7, P8, PO7 and PO8 in the 400 ms interval (50 ms increments) after onset of the second stimulus in a sequential face pair, for same-identity trials (solid line) and different-identity (dashed line), averaged across all four experimental blocks.

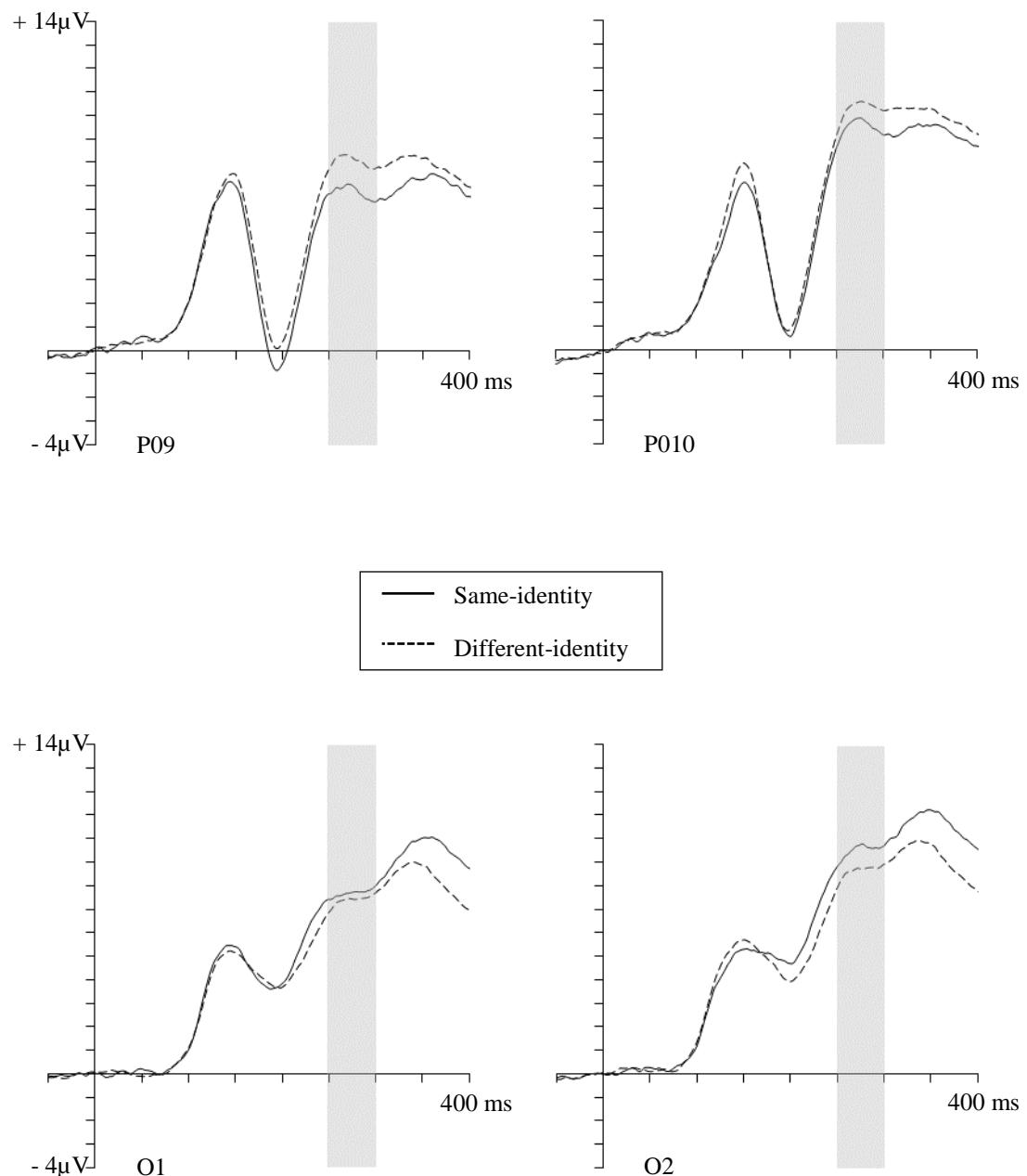


Figure 8-7. N250r (250-300 ms ROI highlighted) Grand-averaged ERPs for the right-profile view type group, measured at inferior-temporal electrodes PO9, PO10, O1 and O2 in the 400 ms interval (50 ms increments) after onset of the second stimulus in a sequential face pair, for same-identity trials (solid line) and different-identity (dashed line), averaged across all four experimental blocks.

FN400 (300-500 ms ROI)

Mean amplitudes for each participant were subjected to an 3x4x2x3 mixed-factors ANOVA with electrode site (F3, Fz and F4), trial block (block 1-4) and identity (i.e., same-identities and different-identities) as repeated measures factors, and view type group as the between subject's factor (TV, two-views; FF, Front-Facing view; RP, Right-profile view). Departures from sphericity for the repeated measures factors were corrected using the recommendation of Girden (1992): for epsilon values greater than .75 the Huynh-Feldt correction was applied, and for epsilon values less than .75 the Greenhouse-Geisser correction was applied. Effect sizes were considered based on Cohen's (1988) recommendation of .02 for a small effect, .13 for a medium effect, and .26 for a large effect.

The between-subjects factor of view type group was not significant, $F(2, 33) = 0.426$, $MSE = 309.812$, $p = .657$, $\eta_p^2 = 0.02$ (Observed power = .11), but the main effect of electrode was, $F(2, 66) = 3.905$, $MSE = 7.077$, $p = .025$, $\eta_p^2 = 0.10$ (Observed power = .68), with mean amplitudes at electrode F4, greater than F3 ($p = .013$). The main effect of block was also significant, $F(3, 99) = 19.749$, $MSE = 6.662$, $p = .036$, $\eta_p^2 = 0.08$ (Observed power = .68), with mean amplitudes at block 2 greater than block 3 ($p = .009$) and approaching significance at block 4 ($p = .057$). The main effect of identity was significant, $F(1, 33) = 23.531$, $MSE = 9.872$, $p < .001$, $\eta_p^2 = 0.41$ (Observed power = .99), with mean amplitudes for same identities greater than different identities ($p < .001$, i.e., the FN400 ERP). The two-way interaction between identity and view type group approached significance, $F(2, 33) = 2.899$, $MSE = 9.872$, $p = .069$, $\eta_p^2 = 0.14$ (Observed power = .52), the two-way interaction between electrode and identity was significant, $F(2, 66) = 3.234$, $MSE =$

$0.512, p = .046, \eta_p^2 = 0.08$ (Observed power = .59). The three-way interaction between electrode, identity and view type group was significant, $F(4, 66) = 4.629, MSE = 0.512, p = .002, \eta_p^2 = 0.21$ (Observed power = .93), and the three-way interaction between block, identity and view type group was found significant, $F(6, 99) = 2.851, MSE = 2.903, p = .013, \eta_p^2 = 0.14$ (Observed power = .87).

Further analysis focused on the three-way interaction between block, identity and view type group. This was broken down by each view type group for the two-way interaction between block and identity, to understand if the FN400 ERP component was modulated by block within each view type group (see Figures 8-7 to 8-9 for Grand-averaged waveforms at each block). When two-views had been learned, the main effect of block was not significant, $F(3, 33) = 0.390, MSE = 3.160, p = .761, \eta_p^2 = 0.03$ (Observed power = .11), but the main effect of identity was significant, $F(1, 11) = 5.044, MSE = 2.916, p = .046, \eta_p^2 = 0.31$ (Observed power = .53), with mean amplitudes for same identities significantly greater than different identities ($p = .046$, i.e., the FN400 ERP), and the interaction between block and identity was also found significant, $F(3, 33) = 4.702, MSE = 0.623, p = .008, \eta_p^2 = 0.29$ (Observed power = .85). Pairwise analysis of the interaction, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0084 (i.e., .05/6 block comparisons), revealed that identity was significant at block 4, $F(1, 11) = 13.907, MSE = 1.209, p = .003, \eta_p^2 = 0.55$ (Observed power = .92).

When front-facing views had been learned, the main effect of block was not significant, $F(3, 33) = 1.203, MSE = 1.555, p = .324, \eta_p^2 = 0.09$ (Observed power = .29), and the main effect of identity was not significant, $F(1, 11) = 1.755, MSE = 4.495, p = .212, \eta_p^2 = 0.13$ (Observed power = .22), but the interaction between

block and identity was significant, $F(3, 33) = 3.042$, $MSE = 0.842$, $p = .043$, $\eta_p^2 = 0.21$ (Observed power = .66). Pairwise analysis of the interaction, adjusted for multiple comparisons using a Bonferroni adjusted alpha of .0084 (i.e., .05/6 block comparisons), revealed that identity was not found to be significant at any block (all p 's $> .098$).

When right-profile views had been learned, the main effect of block was significant, $F(3, 33) = 4.723$, $MSE = 1.947$, $p = .008$, $\eta_p^2 = 0.30$ (Observed power = .85), with mean amplitudes at block 1 greater than blocks 3 and 4 ($p = .028$ and .035, respectively), and block 2 mean amplitudes greater than blocks 3 and 4 ($p = .016$ and .045, respectively). The main effect of identity was also significant, $F(1, 11) = 30.036$, $MSE = 2.461$, $p < .001$, $\eta_p^2 = 0.73$ (Observed power = .99), with mean amplitudes for same identities significantly greater than different identities ($p < .001$, i.e., the FN400 ERP), but the interaction between block and identity was not significant, $F(1.676, 18.440) = 0.107$, $MSE = 2.573$, $p = .867$, $\eta_p^2 = 0.01$ (Observed power = .06).

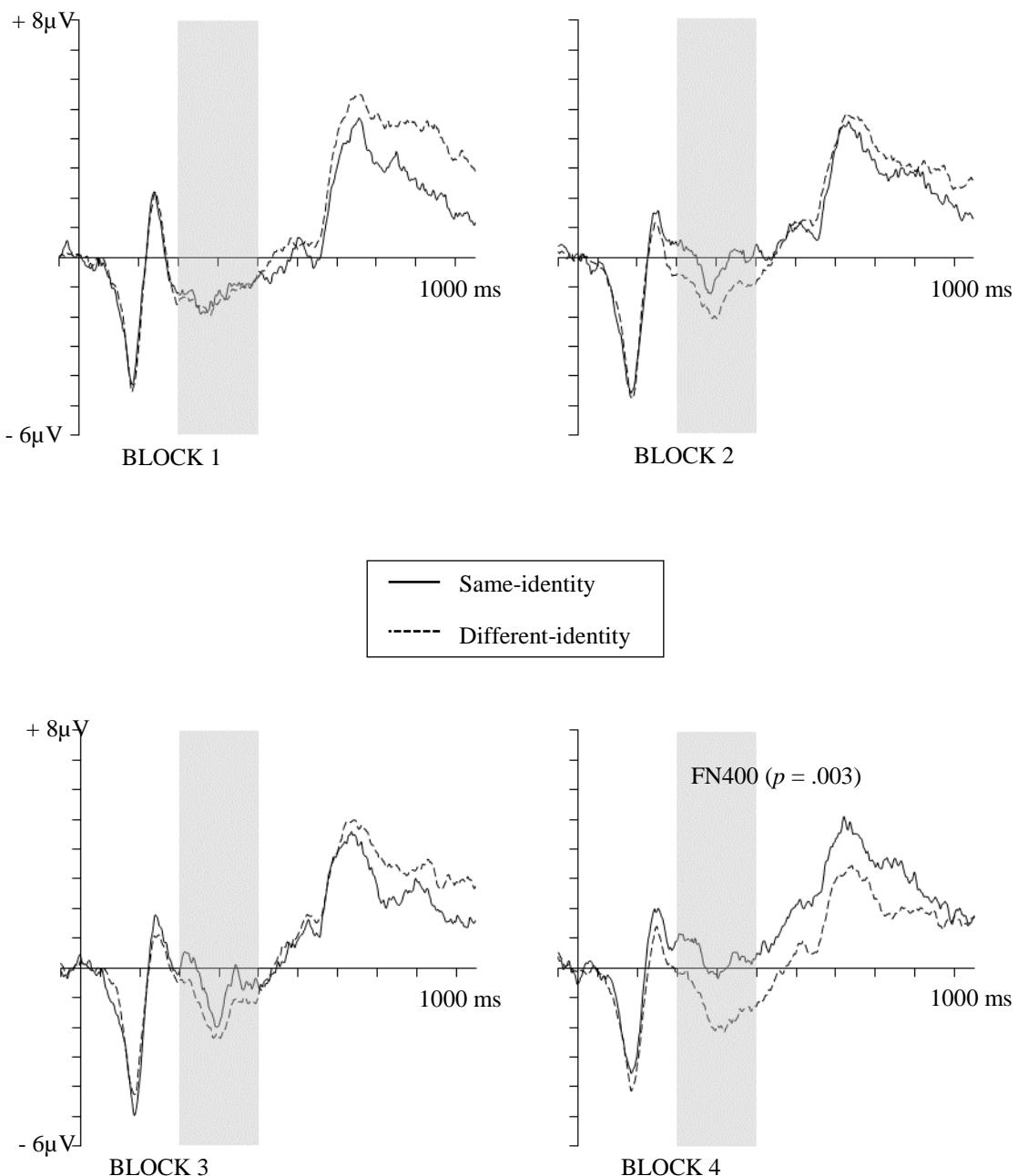


Figure 8-8. FN400 (300-500 ms ROI highlighted) Grand-averaged ERPs for the two-view view type group, measured at frontal electrode sites F3, Fz and F4 in the 1000 ms interval (100 ms increments) after onset of the second stimulus in a sequential face pair, for same-identity trials (solid line) and different-identity (dashed line), averaged across all three electrodes.

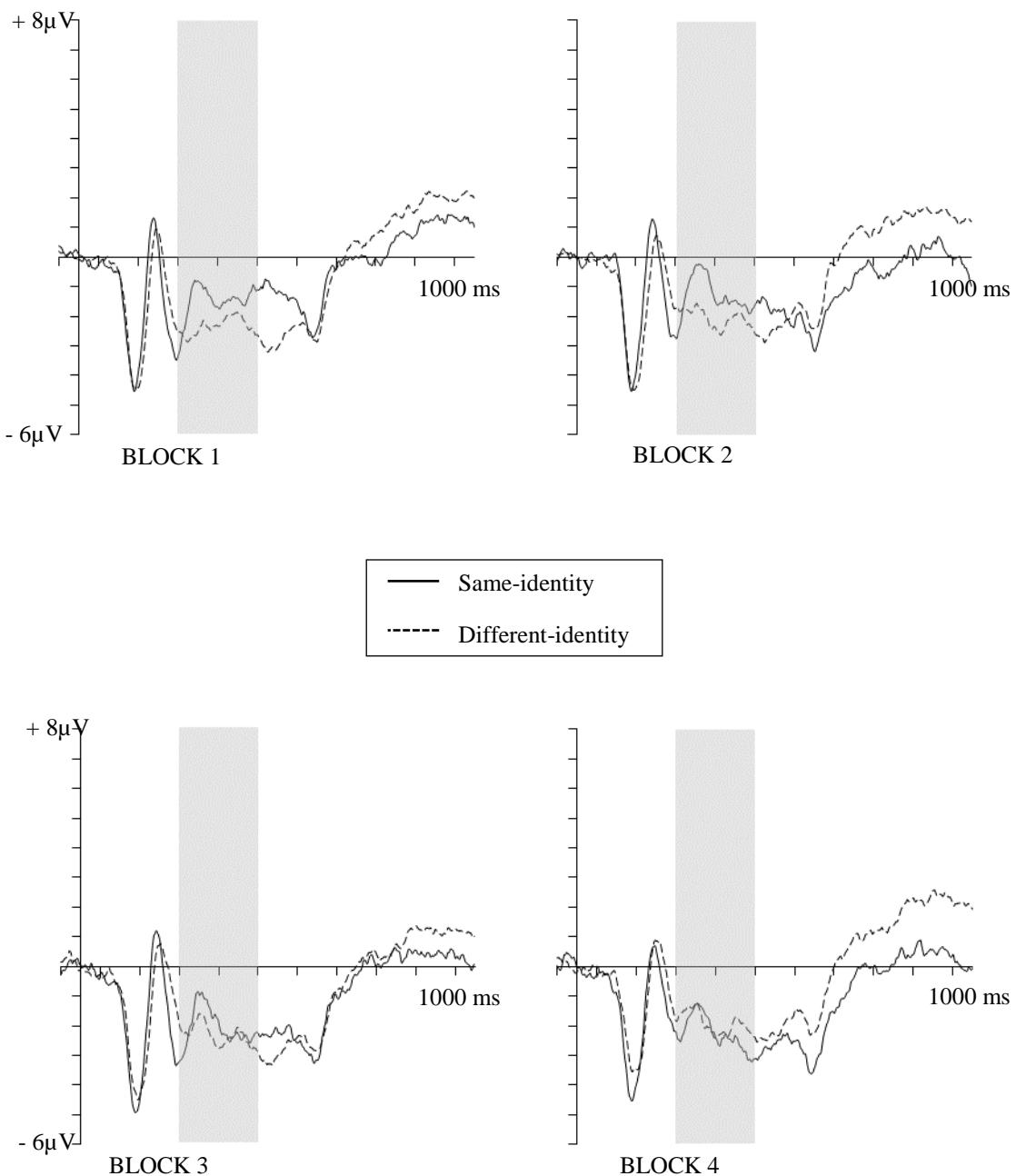


Figure 8-9. FN400 (300-500 ms ROI highlighted) Grand-averaged ERPs for the front-facing view type group, measured at frontal electrode sites F3, Fz and F4 in the 1000 ms interval (100 ms increments) after onset of the second stimulus in a sequential face pair, for same-identity trials (solid line) and different-identity (dashed line), averaged across all three electrodes.

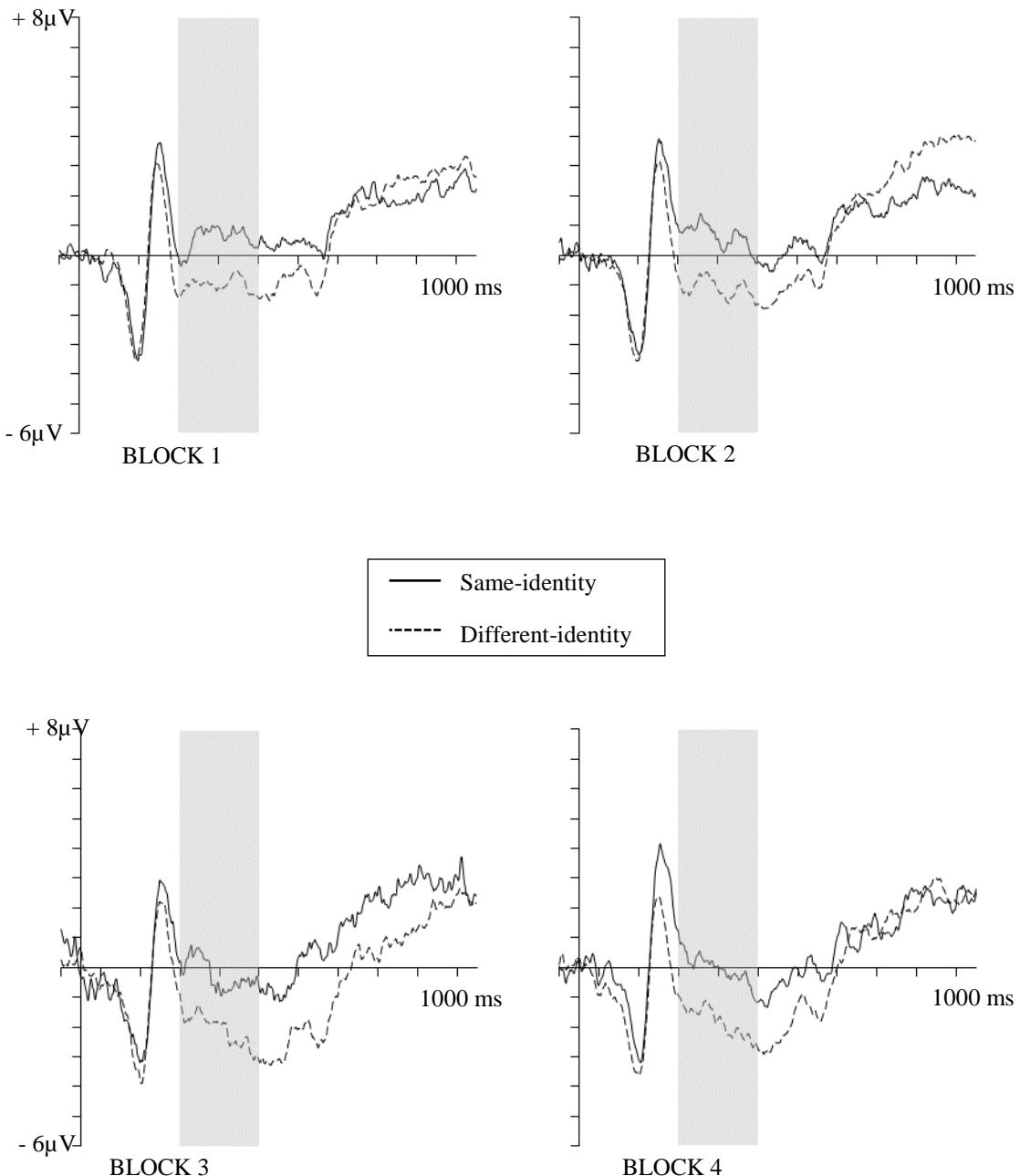


Figure 8-10. FN400 (300-500 ms ROI highlighted) Grand-averaged ERPs for the right-profile view type group, measured at frontal electrode sites F3, Fz and F4 in the 1000 ms interval (100 ms increments) after onset of the second stimulus in a sequential face pair, for same-identity trials (solid line) and different-identity (dashed line), averaged across all three electrodes.

4.2.4 Discussion

The current experiment set out to test participants visual matching of unfamiliar faces/identities using the same view types as behavioural Experiments 1, 2 and 3 (see Chapter 2), to establish whether the N250r and FN400 identity-sensitive ERPs would be present and change over time, which it was thought would help to clarify the type of encoding taking place, and type of representation underlying these components.

Unlike the behavioural results of Chapters 2 and 3, the behavioural results of the current experiment indicated that matching accuracy for different-view identity repetitions were significantly poorer than matching accuracy for same-view identity repetitions (i.e., hit rates for different-views was 52%, whereas hits for same-views was 92.5%, collapsed across all blocks). In addition, a significant main effect of block revealed that matching accuracy was greater at the beginning and end of the session than the middle two blocks, but view type group did not interact with block. It was also found that poor matching accuracy for different-views could not be attributed to participants guessing, as correct rejections were not significantly different between the three view type groups (i.e., correct rejections were greater than 92%). Although it was found that correct rejections were significantly lower at block 1 than all other blocks, across all view type groups, which means that false alarms (incorrectly saying ‘yes’ to mismatches) were higher for block 1, which in turn suggests that correct matches in block 1 should be treated with caution.

As a possible explanation for why two-view matching was found to poor in comparison to the experiments in Chapters 2 and 3, it must be noted that same-view and different-view target sequential matches in the current experiment were always

displayed in pairs (i.e., FF/FF, RP/RP for single-views, and FF/RP, RP/FF for two-views), whereas in the previous experiments in Chapters 2 and 3, two-views of target identities were always presented as triplets (e.g., FF/RP/FF or RP/FF/RP). It is therefore possible that the triplet target sequence in the learning phase of Chapters 2 and 3 could have engendered a greater degree of learning through perhaps apparent rotation of the head through consecutive images. However, although this could possibly have produced greater uptake of new identities in Chapters 2 and 3 compared to the current experiment, it is considered much more likely that reduced exposure to new identities in the current experiment had a greater bearing on the performance difference.

That is, participants in the current design were only exposed to 16 encounters with each identity (i.e., 4 encounters x 4 blocks), compared to 42 in previous experiments (i.e., 6 encounters x 7 blocks), meaning that participants received only 38% of the learning exposures compared to the previous Experiments. It is also relevant to note that participants in the current experiment were exposed to many more identities compared to previous experiments (i.e., 50 compared to 27), so it is also possible that this was simply too many new identities to match as two different views. However, it was noted that correct rejections were not significantly different between view type groups, so it can be concluded that participants were discriminating between target matches and mismatches accurately, although it is possible that they were achieving this purely by recognising a match-mismatch repetitive and regular structure within the learning lists. Clearly, all of these factors are relevant to understanding the differences in performance found, however, it was considered still useful and important to find out whether there were any ERP repetition effects that arose over the course of the learning phase that were not

expressed in the behavioural results, so all trials (i.e., trials where matches and mismatches occurred, that were not dependent on behavioural response) were included in the electrophysiological analysis.

Previous studies have associated the N250r inferior-temporal and occipital ERP component as representing a marker of access to, “stored perceptual face representations” (Kaufmann, Schweinberger & Burton, 2009, p. 637), individuated representations in memory (Pierce et al., 2011; Schweinberger & Neumann, 2016), and evidence of view-invariance and ‘identity repetition effects’ (Zimmermann & Eimer, 2013). However, the current N250r ERP results did not find a main effect of identity, and although identity did interact with electrode and view type group, after further analysis it was found that identity did not reach a level of significance for any of the three view type groups. It was also found that the main effect of view type group was not significant, but the main effect of electrode was, with mean amplitudes at electrode P7 and P8 significantly lower than all other electrodes sites, and a main effect of block revealed that mean amplitudes at later blocks were greater than early blocks.

Clearly, the N250r ERP component was not present over consecutive matches between or within (i.e., when the three-way interaction was broken down) the three view type groups, and therefore the ‘identity repetition effect’ reported by Zimmermann and Eimer (2013) failed to emerge. From the behavioural results it was revealed that two-view matching was generally poor, and even though all trials were included in the electrophysiological analysis, the N250r ERP could have failed to emerge on this view type due to matching being generally problematic for participants, an effect that could have also been present in the all trials analysis. However, matching performance for single-views was generally very high (92.5%),

and although this means that all trials that were valid in the electrophysiological analysis should also have been very high, though not exactly the same due to noise reduction and ocular activity reductions, the N250r ERP still failed to emerge.

As stated previously, the N250r has been repeatedly found to be present when image repetitions occur, and failing to reproduce this empirically supported and robust effect in the current experiment is clearly at odds with the literature, and this is possibly attributable to the design of the current experiment. Notably, in the Zimmermann and Eimer (2013) study, over eight blocks of trials, participants were exposed to twenty same-view identity matches per block, resulting 160 same-view matches overall for each of their four conditions, whereas in the current experiment, same-view identity matches occurred 100 times overall, so it is possible that the number of exposures was simply insufficient to produce the N250r repetition effect. In addition to this, and as mentioned previously, it is also possible that even though the behavioural results indicated accurate discrimination between matches and mismatches, participants could have achieved this by simply following the yes/no list structure alone, and EEG analysis could have been affected by this pattern of responding. This could in turn mean that participants may have viewed the images but not engaged in the task by matching by identity. On this last point, this would mean that participants may have learned the images of target identities, but not encoded them as representing the same identities, so this will need to be considered when assessing the overall results from the current learning phase, and later recognition phase.

Moving now to the later mid-frontal FN400 ERP component. This component has often been highlighted as representing a marker of ‘familiarity’ in recognition memory paradigms (e.g., Curran & Cleary, 2003; Curran & Hancock,

2007), although other researchers have cautioned that this component could also reflect conceptual and/or perceptual priming effects (e.g., Paller, Voss & Boehm, 2007; Rugg & Curran, 2007; Wiese & Schweinberger, 2015). Based on the perceptual all trials visual matching-by-identity nature of the current experimental context, and not being recognition based on previous learning, apart perhaps from the potential for a late block ‘familiarity’ effect, the ‘familiarity’ account of this component must be viewed with caution.

The electrophysiological analysis revealed that there was no main effect of view type group for this component, but the main effect of identity was found to be significant, with mean amplitudes for same identities greater than different identities, revealing the FN400 ERP component. The significant main effect of electrode revealed that mean amplitudes at electrode F4 were greater than at F3, revealing a left hemisphere effect, and the significant main effect of block revealed that mean amplitudes at block 2 were greater than block 3, and approaching significance over block 4. It was also found that identity significantly interacted with view type group and block (i.e., collapsed by electrode), with further analysis revealing that the FN400 ERP component was present for the two-view group at block 4, and for the right-profile group the main effect of identity was significant, indicating that the FN400 ERP component was present when collapsed by block. However, for the front-facing learned view group, even though the block by identity interaction was found significant, the FN400 failed to emerge when adjusted for pairwise comparisons. It was hypothesised that during a perceptual matching task that did not include any conceptual element and possibly only late block memorial familiarity effects, that the FN400 ERP component may become apparent as a repetition identity

effect when single-views and two-views of unfamiliar faces were learned. Clearly, the results reported would seem not to support this hypothesis.

It is acknowledged that direct investigations of repetition effects during perceptual matching tasks for the FN400 ERP frontal component are few in number, but are more numerous in recognition tasks that investigate familiarity and conceptual priming, mainly because the FN400 component is associated with recognition and not perceptual matching. However, it was speculated that a perceptual match by identity effect may become apparent for this component. Further to this, a study by Henson et al. (2003), specifically their perceptual matching stage (i.e., ‘Phase 1’ of their experiment) that included front-facing views of male and female familiar and unfamiliar faces and scrambled faces that were cropped to include only internal features, found that differences between familiar and unfamiliar faces in a 400-600ms time window (i.e., similar to that of the FN400 time window) at frontocentral electrodes, were not significant. They did however find a sustained frontocentral positivity for familiar faces at a later time window of 600-800ms. While accepting that the Henson et al. study investigated a different question from the current one, the perceptual repetition finding that no differences were found between familiar and unfamiliar cropped faces in a similar time frame to the FN400, but did produce an effect in a later time window (i.e., 600-800ms), suggests that the current finding may in fact represent an early onset ‘familiarity effect’. Clearly, this suggestion is speculative, as it was not present for front-facing views, was present as a main effect for right-profile views, and was only present at block 4 for two-views, which is somewhat contradictory if one ascribes perceptual ‘familiarity’ to the current FN400 findings.

However, a study that set out specifically to investigate repetition effects on the FN400 and parietal old/new ERP components (Griffin, DeWolf, Keinath, Liu & Reder, 2013), found that for the FN400 ERP, identical image perceptual repetitions produced a stronger FN400 than did conceptual repetitions during their encoding stage. It must be noted however that Griffin et al. set out to establish whether this component predicted subsequent memory retrieval, so aspects of the type of encoding taking place were not discussed, but they did find that the FN400 perceptual image repetition effect did predict an FN400 at test for words that were associated with the target images encoded. Therefore, based on the current pattern of results, it is suggested that the FN400 represents a perceptual image repetition effect as Griffin et al. found, as it appeared for profile image repetitions, but also access to a representation formed in memory that may be related to identity, as it also appeared for two-views at block 4. Furthermore, visual inspection of the grand averaged waveform for front-facing learned views does seem to suggest, at least in appearance, that the FN400 was apparent at blocks 1 and 2, but clearly this did not reach a level of significance.

Therefore, although speculative, as identity was not found significant for front-facing views, it is suggested that the FN400 effect reported represents access to an established memorial representation that is accessed when the same image and/or identity are seen again, which for single front-facing views occurred visually only (but not significantly) very early in the matching phase, perhaps due to the configural advantage of such views and thus ease of matching. However, for right-profile views, matching may have been more featural in nature and thus the FN400 only became evident when collapsed across blocks. But, when two-views were learned, the representation had not been formed and could not be accessed from memory until

block 4. In conclusion, the FN400 ERP component reported in the current experiment is suggested to be evidence of a representation formed in memory being accessed or referenced during matching, which arguably is associated with identity, but this is of course highly speculative.

In summarising the two ERPs targeted for this matching by identity study, it seems reasonable to suggest that linking the absence (N250r) or presence (FN400) of any of these effects to the Bruce and Young (1986) model would be speculative at best. Indeed, future ERP research on the matching of unfamiliar faces, and therefore learning, must consider the difficulties of providing a sufficient number of identities with which to average comparisons for ERP analysis, and the knock-on effects this has for participant time in the lab and associated interest and fatigue. As an example of the problems associated with comparison between the current experiment and the previous behavioural experiments, if an equivalent level of learning had been provided in the current study as that afforded in Experiment 1 (see Chapter 2), then participants would have been engaged in the matching process for over three hours, which is an unreasonable period. Nevertheless, alternative matching designs will need to be considered to more fully investigate the type of encoding and representations formed from such encoding, for a theory of face learning to be fully realised. Nevertheless, the finding that the FN400 ERP component was present during perceptual matching, and may speculatively represent access to an established representation in memory that may be identity specific, is a finding that it is suggested requires further investigation as it might be useful in determining the type of representation that exists and what type of encoding may have led to its establishment.

4.3 Experiment 9: Next day recognition of learned previously unfamiliar faces/identities

4.3.1 Introduction and research aims

The general introduction and literature review provided an overview of the EEG/ERP method and relevant ERPs of interest for both the learning phase and current recognition test phase (i.e., the N250r inferior-temporal and occipital ERP, and FN400 mid-frontal ERP). Focusing now on recognition specific effects, the N250r ERP component has been found to be present for same identity repetitions (e.g., Schweinberger, Huddy & Burton, 2004; Schweinberger, Pickering, Jentzsch, Burton & Kaufmann, 2002; Schweinberger & Neumann, 2016; Trenner, Schweinberger, Jentzsch & Sommer, 2004; Zimmermann & Eimer, 2013). It has also been demonstrated to be attention sensitive (Zimmermann & Eimer, 2014), and has been found to be present when accessing established representations from memory (e.g., Pierce et al., 2011; Tanaka, Curran, Porterfield, & Collins, 2006). Therefore, the N250r, in the recognition phase, arguably provides an inferior-temporal and occipital ERP that may represent a perceptual marker of ‘visual familiarity’ that precedes access to an FRU. That is, it may be sensitive to identity repetition of previously learned identities, but may not be sensitive to the type of view(s) learned. In this way, the N250r may represent identity recognition, which may occur prior to FRU access.

Conversely, the FN400 old/new mid-frontal ERP component has been found to distinguish old (studied/familiar) items from new (distractor/unfamiliar) items (e.g., Curran & Cleary, 2003; Curran & Hancock, 2007; Schweinberger & Neumann,

2016), and may represent an index of familiarity based on implicit memory (e.g., MacKenzie & Donaldson, 2007; Rugg & Curran, 2007), with its effects lasting for up to 24 hours after initial learning (Wolk et al., 2006). However, as has been previously discussed, the FN400 mid-frontal component must be assessed in the experimental context in which it may/may not occur (e.g., Paller, Voss and Boehm, 2007; Voss & Federmeier, 2011; Wiese & Shweinberger, 2015). Therefore, as the current context is novel view recognition (i.e., block 1), and priming effects can be regarded as absent, apart perhaps from same-view repetition effects over blocks of trials (i.e., blocks 1 to 10), the current experimental context can be characterised as visual recognition based on access to a memorial representation that has been formed from the previous learning phase. In this sense, the FN400 frontal ERP may speculatively be regarded as representing access to the Bruce and Young (1986) FRU.

Therefore, the current research aims will focus on two main aspects for each ERP component. That is, when participants are first exposed to the novel view of previously learned identities, and when these are repeated over all ten blocks of trials. This approach will enable an assessment to be made of each ERP in terms of novel view target identity recognition (i.e., block 1), and target identity repetition of the same novel view over time (i.e., blocks 1 to 10). In terms of hypotheses, for the N250r it is predicted that this ERP will be present for all view type groups (i.e., two-views, front-facing view, and right-profile view), but may only emerge over repetitions (i.e., blocks 1 to 10), and will represent ‘visual identity familiarity’. However, for the FN400 ERP, it is predicted that this will only occur for the two-view view type group, as it is thought to represent access to the theorised FRU representation formed during learning, which should not be present for same-view

representations as only one view was learned. However, it is not clear whether this later ERP will be present at block one, or will require repetition to become detectable. Also, note that in the learning phase it was suggested that participant by-identity discrimination may have been carried out by simply recognising and responding based on the yes/no list structure provided, so it may be argued that participants may not have ‘learned’ these identities by view, but at the very least they have been exposed to them in each orientation.

4.3.2 Method

Participants

These were the same participants as described in the matching phase.

Design

The experiment consisted of a single stimulus at a time, target-distractor recognition task with ten blocks of trials, with the learning phase having been completed the previous day (see Experiment 8). Note that a strict 24-hour return was not required, but it was anticipated that participants would have slept between the learning and test phases, and thus consolidation of any representation formed should have been possible. A total of 50 learned target identities and 50 unfamiliar distractor identities were used in each block of trials and these were presented in random order in each block. This design was identical for each participant, irrespective of view type group (two-views, front-facing view, or right-profile view), and the target and distractor view types were always novel right three-quarter views.

For the behavioural analysis, the dependent variable was the percentage of correct matches (i.e., hits) and correct mismatches (i.e., correct rejections). This was measured separately for each block of trials, resulting in the overall design for the face identity recognition task being a view type group (front-facing view type group, right-profile view type group, or two-views view type group) by block (block 1 - 10), between-subjects design. Note that for the electrophysiological analysis, responses included all trials, and did not depend on a correct response being made. This meant that the participants electrical activity could be coded as representing a recognition match for ‘target-identities’ (i.e., identities that were matched in the previous learning phase), and a recognition mismatch for ‘distractor-identities’ (i.e., identities that had not been seen before). There were therefore two levels of the factor ‘identity’ (target and distractor), with the dependent variable being mean amplitude.

Materials and Apparatus

The materials and apparatus were the same as detailed in the learning phase (see Experiment 8), with the exception that all images were novel right three-quarter views, and were presented 15° (13.5 cm) vertically and ranged from 6.3° to 13.5° horizontally. For all identities, only a single image was prepared, and this was a right three-quarter view which participants had not encountered before. Each stimulus was only presented once per block, no feedback was given on their accuracy, and participants were not limited in the time they had to respond, and were instructed to favour accuracy over speed. See Figure 10 in the appendix for examples of each view type for four identities.

Procedure

Participants were seated approximately 50 cm from the screen and the face stimuli were presented in the centre of the screen against a white background. Each of the ten experimental blocks comprised 100 face stimuli (50 targets and 50 distractors presented in random order for each block). Each face was presented for an unlimited period of time, or until the participant responded by means of a key-press ('c' for yes and 'n' for no), to confirm if the identity was someone they had seen in the previous day's learning phase. After making a response, the face stimulus disappeared, and a white background blank screen was presented randomly as either 1500 ms or 2000 ms, and this was then followed by the next stimulus until all 100 stimuli had been responded to per block. Participants were encouraged to rest between blocks of trials, and target-distractor assignment was counterbalanced as detailed in the previous phase, with the experiment lasting on average one hour.

Electrophysiological measures

These were exactly the same as detailed in the previous phase (see Experiment 8). Repeated measures analysis of variance (ANOVAs) were carried out for the factors electrode site for each ERP region (inferior-temporal and occipital, and mid-frontal), block (block 1 to 10), and identity (target or distractor), with a between-subjects factor of view type group (learned two-views of target identities, learned front-facing views only of target identities, or learned right-profile views of target identities), and EEG data were again (see Experiment 8) analysed for all trials.

4.3.3 Results

Behavioural data

The recognition phase included ten blocks of trials. However, because the first block was the only block that could be considered a test of true recognition, in that this was the first time that participants were exposed to the novel right three-quarter target-distractor views, analysis was carried out for block 1 only, and then all blocks together.

Recognition at block 1

Behavioural data were subjected to a one-way ANOVA, with view type group as the between-subjects factor and the percentage of correct matches (i.e., hits) was the dependent variable. Effect sizes were considered based on Cohen's (1988) recommendation of .02 for a small effect, .13 for a medium effect, and .26 for a large effect. It was observed that the between subjects main effect of view type group was significant, $F(2, 33) = 6.876$, $MSE = 207.283$, $p = .003$, $\eta_p^2 = 0.29$ (Observed power = .89), with pairwise comparisons revealing that mean hits for the two-view view type group were significantly greater than the right-profile view type group ($p = .009$; mean hits, 50.50% & 34.16% respectively), and front-facing view type group mean hits were significantly greater than the right-profile view type group ($p = .001$; mean hits, 54.83% & 34.16% respectively).

This represented low hit performance generally, and could be attributed to participants guessing, so it was important to confirm that participants were discriminating as instructed. Therefore, the same one-way ANOVA was carried out

for the dependent variable, correct rejections (i.e., correctly saying no to a mismatch), and it was found that the between subjects factor of view type group was not significant, $F(2, 33) = 1.131$, $MSE = 91.061$, $p = .335$, $\eta_p^2 = 0.06$ (Observed power = .23), revealing that participants were discriminating as instructed, and were not guessing. See Figure 9-1 for mean hit and correct rejection responses.

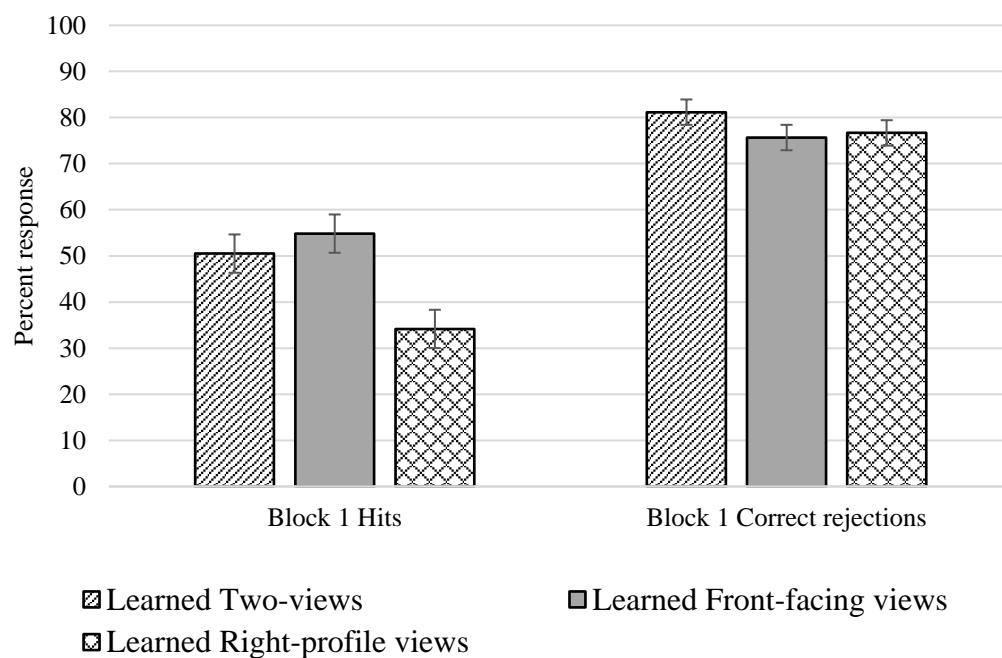


Figure 9-1. Behavioural Recognition Phase Results at block 1. Mean percent responses are plotted as a function of the between-subjects factor, view type group (two-views, front-facing view & right-profile view), for hits and correct rejections. Error bars represent standard error of the mean.

Recognition across all blocks

The percentage of correct recognition (hits) was analysed with a 3x10 mixed-factors design, with view type group as the between-subjects factor, and block as the

repeated-measures factor. Departures from sphericity were corrected using the recommendation of Girden (1992): for epsilon values greater than .75 the Huynh-Feldt correction was applied, and for epsilon values less than .75 the Greenhouse-Geisser correction was applied. Effect sizes were considered based on Cohen's (1988) recommendation of .02 for a small effect, .13 for a medium effect, and .26 for a large effect.

It was observed that the main effect of view type group was significant, $F(2, 33) = 4.462$, $MSE = 2362.816$, $p = .019$, $\eta_p^2 = 0.21$ (Observed power = .72), with pairwise comparisons revealing that mean hits for the two-view view type group were significantly higher than the right-profile view type group ($p = .041$; mean hits, 44.56% & 31.20%, respectively), and front-facing view type group mean hits were significantly greater than the right-profile view type group ($p = .007$; mean hits, 49.26% & 31.20%, respectively), repeating the pattern from block 1 analysis. The main effect of block was also found significant, $F(4.023, 132.749) = 8.795$, $MSE = 63.240$, $p < .001$, $\eta_p^2 = 0.21$ (Observed power = .99), with mean hits at block 1 greater than blocks 4 to 10 (all p 's $< .017$); block 2 mean hits greater than block 4 to 10 (all p 's $< .039$); block 3 mean hits greater than blocks 6, 8, 9 and 10 (all p 's $< .029$); block 4 mean hits greater than blocks 6, 9 and 10 (all p 's $< .019$); block 5 mean hits greater than block 10 ($p = .004$); block 6 mean hits greater than block 10 ($p = .017$); block 7 mean hits greater than block 6, 9 and 10 (all p 's $< .040$); and, block 8 mean hits were greater than block 10 ($p = .027$). However, view type group did not interact with block, $F(18, 297) = 1.114$, $MSE = 28.266$, $p = .337$, $\eta_p^2 = 0.06$ (Observed power = .77). See Figure 9-2 for mean hit responses.

Again, low hit performance over all ten blocks could be attributed to participants guessing, so the same mixed-factors design was applied to correct rejections (i.e., correctly saying no to a mismatch). It was found that the main effect of view type group was not significant, $F(2, 33) = 0.236$, $MSE = 1069.933$, $p = .791$, $\eta_p^2 = 0.01$ (Observed power = .08), revealing that participants were discriminating as instructed, and were not guessing. But, the main effect of block was significant, $F(4.489, 148.150) = 2.545$, $MSE = 66.353$, $p = .036$, $\eta_p^2 = 0.07$ (Observed power = .74), with block 1 mean correct rejections greater than B4 ($p = .007$), B5 ($p = .010$), B6 ($p = .001$), B7 ($p = .016$), B8 ($p = .002$), B9 ($p < .001$), and B10 ($p < .001$); block 2 mean correct rejections greater than B4 ($p = .038$), B5 ($p = .013$), B6 ($p = .001$), B7 ($p = .036$), B8 ($p = .002$), B9 ($p < .001$), and B10 ($p < .001$); block 3 mean correct rejections greater than B6 ($p = .004$), B8 ($p = .028$), B9 ($p = .006$), and B10 ($p < .001$); block 4 mean correct rejections greater than B6 ($p = .018$), B9 ($p = .016$), and B10 ($p < .001$); block 5 mean correct rejections greater than B10 ($p = .004$); block 6 mean correct rejections greater than B10 ($p = .017$); block 7 mean correct rejections greater than B6 ($p = .039$), B9 ($p = .016$), and B10 ($p < .001$); and, block 8 mean correct rejections greater than B10 ($p = .027$). However, view type group did not interact with block, $F(18, 297) = 1.282$, $MSE = 33.098$, $p = .198$, $\eta_p^2 = 0.07$ (Observed power = .84).

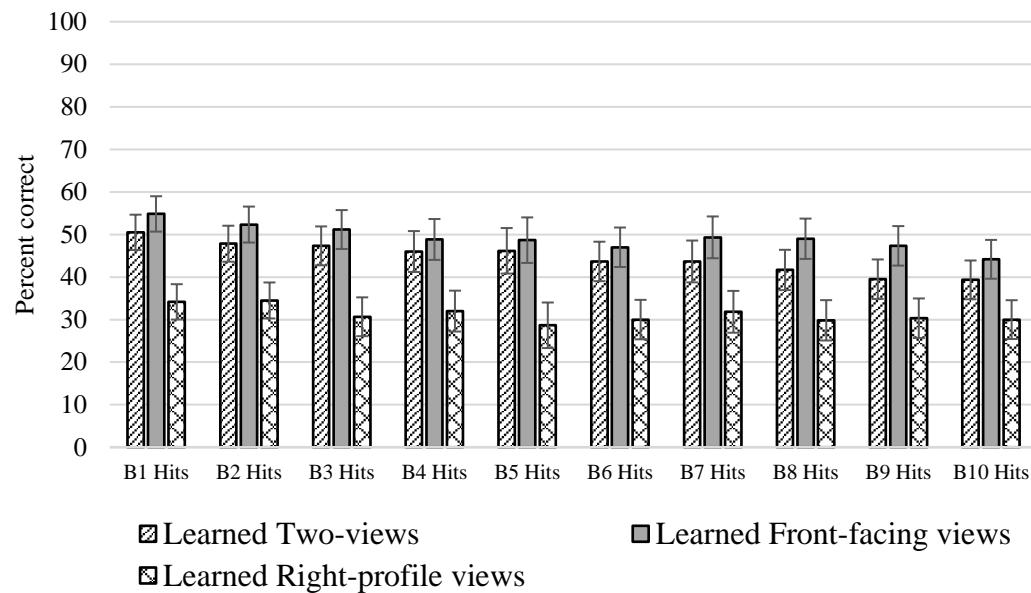


Figure 9-2. Behavioural Recognition Phase results for all blocks (1-10). Mean percent responses are plotted as a function of the between-subjects factor, view type group (two-views, front-facing view & right-profile view), for hits. Error bars represent standard error of the mean.

Electrophysiological data

Data was first analysed at block 1 between view type groups, as this was considered true first time recognition, in that this was the first time participants saw the novel views. After block 1 analyses, all recognition test blocks (1 to 10) were included to assess the impact of repetition. Departures from sphericity were corrected using the recommendation of Girden (1992): for epsilon values greater than .75 the Huynh-Feldt correction was applied, and for epsilon values less than .75 the Greenhouse-Geisser correction was applied. Effect sizes were considered based

on Cohen's (1988) recommendation of .02 for a small effect, .13 for a medium effect, and .26 for a large effect.

N250r (250-300ms ROI) at block one

Mean amplitudes were subjected to an 3x8x2 mixed-factors ANOVA with view type group (learned two-views, learned front-facing view, or learned right-profile view) as the between subjects' factor, and electrode site (P7, P8, PO7, PO8, PO9, PO10, O1 and O2) and identity (i.e., target-identities and distractor-identities) as repeated-measures factors. The main effect of view type group approached significance, $F(2, 33) = 2.895$, $MSE = 377.344$, $p = .069$, $\eta_p^2 = 0.14$ (Observed power = .52), with mean amplitudes larger when two-views had been learned than right-profile views ($p = .023$), but the main effect of identity was not significant, $F(1, 33) = 0.388$, $MSE = 12.744$, $p = .538$, $\eta_p^2 = 0.01$ (Observed power = .09). However, the main effect of electrode was significant, $F(3.162, 104.348) = 14.364$, $MSE = 58.051$, $p < .001$, $\eta_p^2 = 0.30$ (Observed power = 1), with mean amplitudes significantly lower at electrode P7 and P8 than all other electrodes (all p 's $< .002$), PO7 means lower than PO8, PO10 and O1 (all p 's $< .046$), and O1 means less than PO8 and O2 ($p = .037$ and $p = .027$, respectively). But, all interactions were found not to be significant, with all p 's $> .573$.

N250r (250-300ms ROI) between all blocks

Mean amplitudes were subjected to an 3x8x10x2 mixed-factors ANOVA with view type group (learned two-views, learned front-facing view, or learned right-profile view) as the between subjects' factor, electrode site (P7, P8, PO7, PO8, PO9,

PO10, O1 and O2), block (1-10), and identity (i.e., target-identities and distractor-identities) as repeated-measures factors. The main between subjects' factor of view type group approached significance, $F(2, 33) = 2.812$, $MSE = 2622.601$, $p = .075$, $\eta_p^2 = 0.14$ (Observed power = .51), with mean amplitudes greater when two-views were learned than right-profile views ($p = .031$), and approaching significance over front-facing views ($p = .088$). The main effect of identity was not significant, $F(1, 33) = 0.869$, $MSE = 23.009$, $p = .358$, $\eta_p^2 = 0.02$ (Observed power = .14). However, the main effect of electrode was significant, $F(2.992, 98.735) = 15.376$, $MSE = 412.542$, $p < .001$, $\eta_p^2 = 0.31$ (Observed power = 1), with mean amplitudes lower at electrode P7 and P8 than all other electrodes (all p 's $< .032$), PO7 and PO9 means lower than PO8 ($p = .031$ and $p = .020$, respectively), and PO7, PO9 and O1 means lower than O2 (all p 's $< .024$). The main effect of block was significant, $F(6.862, 226.446) = 4.828$, $MSE = 34.975$, $p < .001$, $\eta_p^2 = 0.12$ (Observed power = .99), with block 1 mean amplitudes greater than all other blocks (all p 's $< .010$). The two-way interaction between electrode and block was also significant, $F(63, 2079) = 4.006$, $MSE = 2.183$, $p < .001$, $\eta_p^2 = 0.10$ (Observed power = 1), but was not analysed further as it did not include the factor of identity. All other interactions were not significant, with all p 's $> .270$.

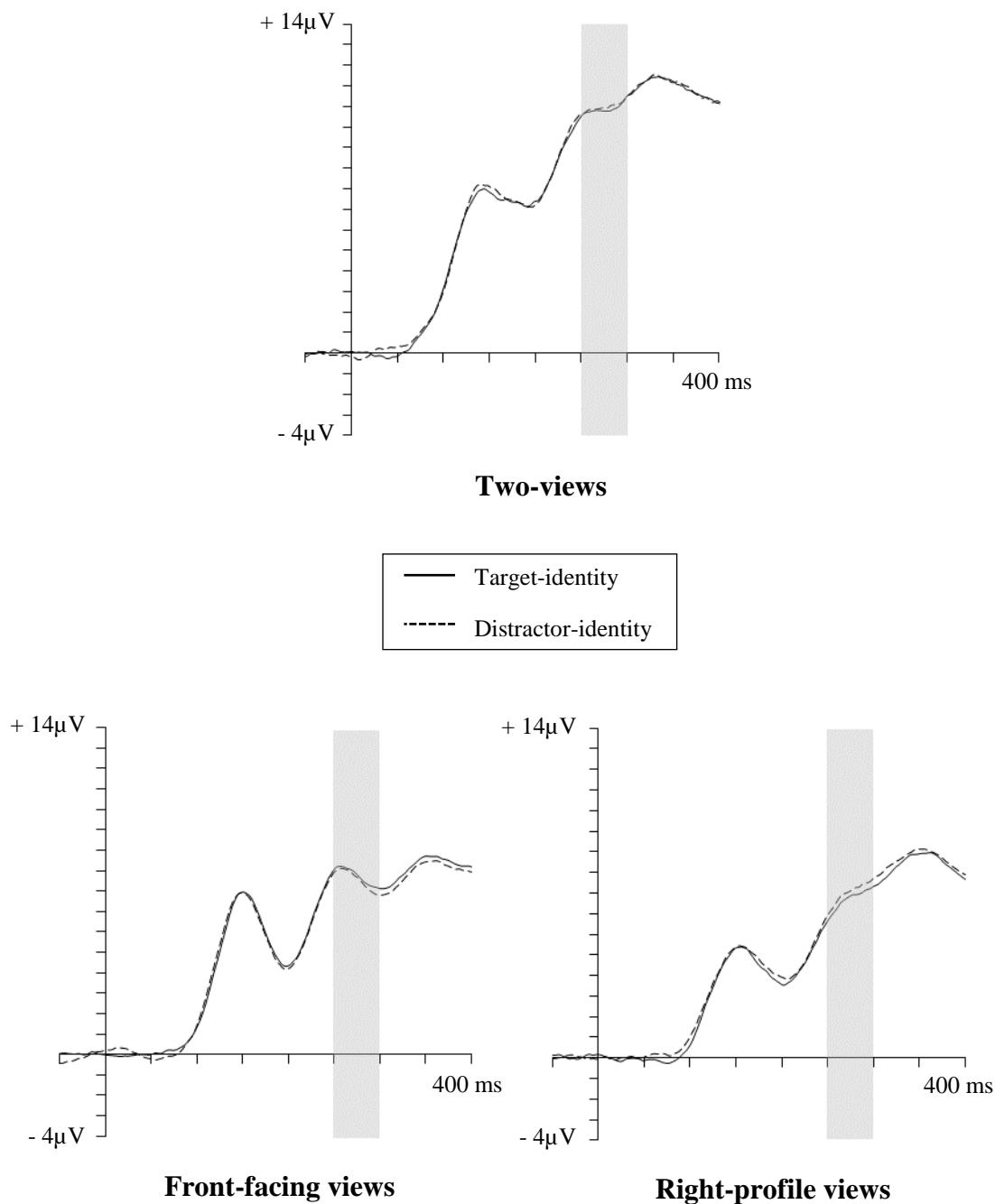


Figure 9-3. N250r (250-300 ms ROI highlighted) Grand averaged ERPs for each view type group, measured at inferior-temporal electrodes in the 400 ms interval (50 ms increments) for target-identity trials (solid line) and distractor-identity trials (dashed line), averaged across all experimental blocks and electrodes.

FN400 (300-500 ms ROI) at block one

Mean amplitudes were subjected to an 3x3x2 mixed-factors ANOVA with view type group (learned two-views, learned front-facing view, or learned right-profile view) as the between subjects' factor, and electrode site (F3, Fz and F4) and identity (i.e., target-identities and distractor-identities) as repeated-measures factors. The between-subjects main effect of view type group was not significant, $F(2, 33) = 1.898$, $MSE = 109.466$, $p = .166$, $\eta_p^2 = 0.10$ (Observed power = .36), but the main effect of electrode was significant, $F(2, 66) = 7.400$, $MSE = 2.791$, $p = .001$, $\eta_p^2 = 0.18$ (Observed power = .93), with mean amplitudes at electrode F4 greater than F3 ($p = .040$) and Fz ($p < .001$). However, the main effect of identity was not significant, $F(1, 33) = 0.056$, $MSE = 12.289$, $p = .814$, $\eta_p^2 = 0.002$ (Observed power = .05), and all interactions were not significant, with all p 's $> .235$.

FN400 (300-500ms ROI) between all blocks

Mean amplitudes were subjected to an 3x3x10x2 mixed-factors ANOVA with view type group (learned two-views, learned front-facing view, or learned right-profile view) as the between subjects' factor, electrode site (F3, Fz and F4), block (1-10), and identity (i.e., target-identities and distractor-identities) as repeated-measures factors. The main effect of view type group was not significant, $F(2, 33) = 2.392$, $MSE = 1026.544$, $p = .107$, $\eta_p^2 = 0.12$ (Observed power = .44), but the main effect of identity was, $F(1, 33) = 5.574$, $MSE = 13.141$, $p = .024$, $\eta_p^2 = 0.14$ (Observed power = .63), with target identity mean amplitudes greater than distractor identities (i.e., an FN400 ERP). The main effect of electrode was significant, $F(1.630, 53.796)$

$= 8.007$, $MSE = 14.020$, $p = .002$, $\eta_p^2 = 0.19$ (Observed power = .91), with mean amplitudes at electrode F4 greater than F3 ($p = .011$) and Fz ($p < .001$). The main effect of block was also significant, $F(8.367, 276.121) = 5.889$, $MSE = 22.014$, $p < .001$, $\eta_p^2 = 0.15$ (Observed power = 1), with block 1 mean amplitudes lower than all other blocks (all p 's $< .001$) and block 2 mean amplitudes lower than block 4 and 6 ($p = .032$ and $p = .013$, respectively). However, all interactions were not significant, with all p 's $> .109$.

Although identity did not interact with the other factors, because it was significant as a main effect, it was decided that, for investigative purposes, analysis would be carried out for each view type group, collapsed by block, to establish if the FN400 was present for one or more of the view type groups. Therefore, mean amplitudes were subjected to a 3x2 repeated-measures ANOVA within each view type group, with electrode site (F3, Fz and F4) and identity (i.e., target-identities and distractor-identities) as repeated measures factors.

It was found that when two-views had been learned, the main effect of identity approached significance, $F(1, 11) = 3.652$, $MSE = 0.884$, $p = .082$, $\eta_p^2 = 0.24$ (Observed power = .41), with target identity means greater than distractor identities (i.e., the FN400 ERP). However, the main effect of electrode was not significant, $F(1.220, 13.418) = 0.991$, $MSE = 2.652$, $p = .355$, $\eta_p^2 = 0.08$ (Observed power = .16), and the interaction between electrode and identity was not significant, $F(2, 22) = 0.060$, $MSE = 0.047$, $p = .942$, $\eta_p^2 = 0.005$ (Observed power = .05). When single front-facing views had been learned, the main effect of identity was not significant, $F(1, 11) = 2.010$, $MSE = 1.046$, $p = .184$, $\eta_p^2 = 0.15$ (Observed power = .25). But, the main effect of electrode was significant, $F(2, 22) = 3.806$, $MSE =$

$0.900, p = .038, \eta_p^2 = 0.25$ (Observed power = .63), with mean amplitudes at electrode F4 larger than Fz ($p = .016$). However, the interaction between electrode and identity was not significant, $F(2, 22) = 0.099, MSE = 0.092, p = .906, \eta_p^2 = 0.009$ (Observed power = .06). When single right-profile views had been learned, the main effect of identity was not significant, $F(1, 11) = 1.031, MSE = 2.012, p = .332, \eta_p^2 = 0.08$ (Observed power = .15). But, the main effect of electrode was significant, $F(1.140, 12.540) = 6.930, MSE = 1.598, p = .019, \eta_p^2 = 0.38$ (Observed power = .71), with mean amplitudes at electrode F4 larger than F3 ($p = .019$), and F4 mean amplitudes larger than Fz ($p = .001$). However, the interaction between electrode and identity was not significant, $F(2, 22) = 0.582, MSE = 0.202, p = .567, \eta_p^2 = 0.050$ (Observed power = .13). It can therefore be seen that, with the caveat that the present analysis was only based on a four-way main effect of identity, that the FN400 ERP only occurred when for the two-view view type group, although this only approached significance.

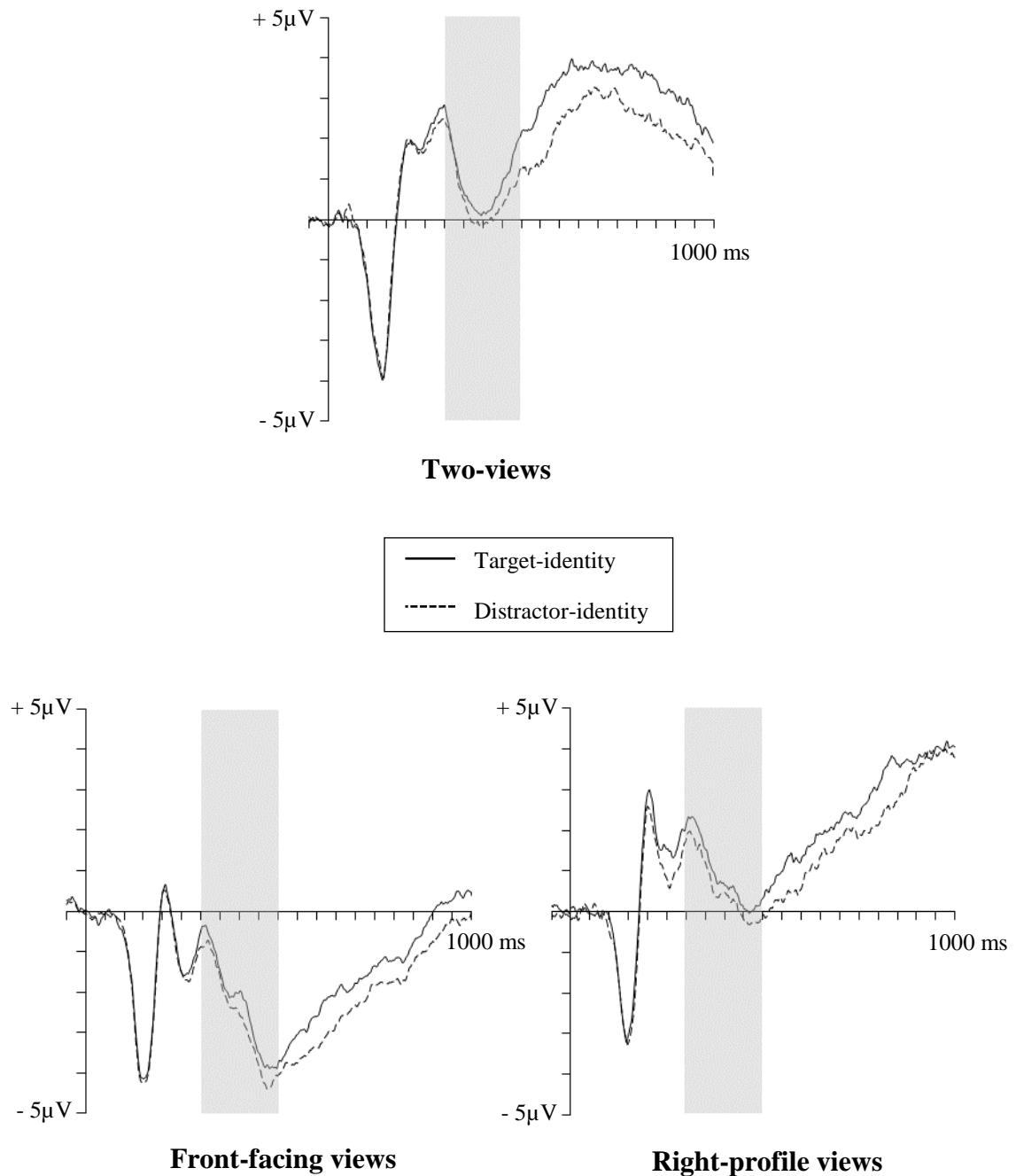


Figure 9-4. FN400 (300-500 ms ROI highlighted) Grand averaged ERPs for each view type group, measured at frontal electrodes in the 1000 ms interval (50 ms increments) for target-identity trials (solid line) and distractor-identity trials (dashed line), averaged across all experimental blocks and electrodes.

4.3.4 Discussion

The current recognition phase focused again on the N250r and FN400 identity-related ERP components at block 1, which was considered a true test of first-time novel view recognition, and across all blocks to establish whether these components were sensitive to stimulus repetitions. For the N250r ERP component, it was predicted that this ERP will be present for all view type groups (i.e., two-views, front-facing view, and right-profile view), but may have only emerged over repetitions (i.e., blocks 1 to 10), possibly representing ‘visual identity familiarity’. However, for the FN400 ERP, it was predicted that this would only occur for the two-view view type group, as it was thought to represent access to the theorised FRU. Furthermore, as was noted in the learning phase, the concern was that participants may have carried out the matching of different face views by simply recognising and responding based on the yes/no list structure provided, so this will need to be addressed when interpreting the recognition phase results.

First, the behavioural results indicated that accuracy when recognising a novel right three-quarter view at block one, which was the only true recognition block, were significantly greater when two-views (50.50%) and front-facing views (54.83%) had been learned, over learning right-profile views (34.16%). Across all blocks where repetition effects were tested, the same between view type groups advantage for two-views (44.56%) and front-facing views (49.26%) was present over right-profile views (31.20%), with accuracy tending to be significantly greater for the first block of trials over later blocks, indicating that targeting the first block as the only true recognition block seems to have been supported by the behavioural data. Although target recognition accuracy (i.e., hits) was generally low, it was clear that participants were discriminating accurately between targets and distractors, with

the main effect of view type group not significant for correct rejections, however the main effect of block was significant, with correct rejections tending to decrease as a function of block, across all view type groups, in turn meaning that false alarms (i.e., incorrectly saying ‘yes’ to distractors) increased as blocks proceeded. Therefore, the pattern of hits and correct rejections declining over blocks of trials (i.e., errors increasing over blocks of trials: misses and false alarms increasing) tends to suggest that overall accuracy decreased as a function of block, but note that this was the same for all view type groups and could therefore be possibly attributed to fatigue.

In contrast to the clear FRU effect reported in Experiment 1 (see Chapter 2), the current behavioural data did not find a recognition advantage from learning two-views over front-facing and right-profile single views, when tested on a novel right three-quarter view. As discussed in the learning phase (see Experiment 8), it was suggested that the reduced number of encounters may have led to insufficient learning of unfamiliar identities, and it is therefore likely that this caused an FRU behavioural effect to fail to emerge in the recognition phase. However, in summarising the current recognition phase behavioural results, it is suggested that when participants responded in block one, which was the first time they saw the novel views, that their subsequent increase in error responses from block two to block ten was possibly indicative of trying to remember how they had responded in block one, rather than a block-by-block novel-view target recognition accuracy effect. That is, repetition over the subsequent blocks of trials could have been based on whether they said yes or no to the novel view stimuli, and not necessarily based on stimulus by stimulus recognition or rejection, although it is accepted that this is speculative.

Moving on to the electrophysiological focus of the experiment, results indicated that at block 1, the N250r ERP component failed to emerge as a main effect of identity, and did not interact with the other factors. However, the main effect of view type group was significant, with mean amplitudes greater when two-views were learned than when right-profiles were learned, and the main effect of electrode was also significant, with mean amplitudes at electrode P7 and P8 lower than all other electrodes. When all blocks were considered, again the N250r ERP identity component failed to emerge as a main effect, and did not interact with the other factors. However, the main effect of view type group was again significant, with mean amplitudes greater when two-views were learned than when right-profiles (approaching) and front-facing views (significant) were learned. Again, the main effect of electrode was significant, with mean amplitudes at electrode P7 and P8 lower than all other electrodes, and block was significant, with block 1 mean amplitudes greater than all other blocks.

In terms of the stated hypotheses, clearly the N250r failed to emerge for any view type group, and therefore cannot be regarded as a marker of ‘visual familiarity’ of identity, at least in terms of the current experimental design. This may be explained by insufficient learning in the previous phase, but may more simply be due to the list structure of the recognition phase where exact identity image repetitions only occurred between blocks. In this way, the previous findings regarding the N250r ERP component repetition ‘identity’ effects reported by Zimmermann & Eimer (2013) may only become apparent when exact image or identity repetitions occur in a list structure that affords sequential repetitions, which the current list design did not provide. However, it cannot be stated categorically that such an effect may not become observable if sufficient learning takes place.

For the FN400 frontal ERP component, results at block 1 indicated that the main effect of identity (i.e., the FN400) was not significant and did not interact with the other factors, and the main effect of view type group was not significant, however the the main effect of electrode was, with mean amplitudes at F4 greater than those at Fz and F3, again indicating a left hemisphere effect. When all blocks were considered, again, the main effect of view type group was not significant, but the main effect of identity was (i.e., an FN400 ERP effect), but identity did not significantly interact with the other factors. It was again found that the main effect of electrode was significant, with mean amplitudes at F4 greater than those at Fz and F3, indicating a persistent left hemisphere effect across view type groups and blocks, and the main effect of block was significant, with early block mean amplitudes lower than later blocks.

Notably there were no significant interactions, but it was decided that due to the main effect of identity being significant, and in order to understand if there were any within view type group effects that might have been obscured by the overall between groups analysis, that an identity by electrode repeated measures analysis would be carried out within each learned view group (note that block was not included as a factor in this analysis). It was found that for the two-views learned view group the main effect of identity approached significance (i.e., an approaching significant FN400), but the main effect of electrode was not significant, and these two factors did not interact. For the front-facing learned view group the main effect of identity was not significant and did not interact with electrode, but the main effect of electrode was significant, with mean amplitudes at electrode F4 greater than Fz. Finally, for the right-profile learned view group, again the main effect of identity was not significant and did not interact with electrode, but the main effect of

electrode was significant, with mean amplitudes at electrode F4 greater than Fz and F3.

Based on this within-learned view group analyses it can therefore be concluded that learning two-views of identities led to an approaching FN400 ERP component identity main effect that was not present for the other two single-view learned view groups. Clearly this cannot be considered a strong effect, but is regarded as tentatively indicative of an effect of familiarity when two-views were learned, and provides at least a glimpse of a possible qualitatively different representation having been formed from learning two different views over learning either single view. Indeed, it has been found that this component distinguishes old (studied/familiar) items from new (distractor/unfamiliar) items (e.g., Curran & Cleary, 2003; Curran & Hancock, 2007; Schweinberger & Neumann, 2016), and may represent an index of familiarity based on implicit memory (e.g., MacKenzie & Donaldson, 2007; Rugg & Curran, 2007), with its effects lasting for up to 24 hours after initial learning (e.g., Wolk et al., 2006). However, as has been previously discussed, the FN400 mid-frontal component may also represent conceptual priming rather than familiarity per se (e.g., Paller, Voss and Boehm, 2007; Voss & Federmeier, 2011; Wiese & Shweinberger, 2015), but as this was a visual only task with no conceptual information included, apart from that which participants may have attributed in implicit and uncontrolled ways, it is much more likely to represent visual identity familiarity in this case, albeit only approaching significance when two-views were learned.

In conclusion, the current recognition phase has revealed that it is likely that insufficient unfamiliar face and identity learning occurred in the previous phase, and that this resulted in behavioural recognition of novel views being generally poor

compared to previous behavioural findings (see Experiment 1). However, the emergence of an approaching significant two-views within learned view group FN400 frontal ‘familiarity’ effect does provide somewhat supporting evidence that the representation formed from learning two-views may in fact be quantitatively (i.e., in terms of electrophysiological mean amplitude differences between targets and distractors) different to that produced from learning single views, and clearly needs to be investigated further. In terms of whether this two-view approaching significant FN400 familiarity effect represents access to an FRU would be speculative at best. In fact, one of the main problems of supporting the Bruce and Young (1986) FRU conceptualisation is that it is a somewhat ‘hidden’ operation that can only be inferred from indirect investigation. However, the current recognition results do provide some supporting evidence that learning two different views may produce a qualitatively different representation compared to single view learning, but arguably, more focused and measurable learning may be needed to fully test this finding.

4.4 General discussion

Applying the EEG/ERP method to the learning and recognition phases has in hindsight proved problematic. It was determined early in the design period for the current experiments that repeating the design of the previous behavioural experiments (see Chapters 2 and 3), and just applying the EEG/ERP method, would not work because there would be insufficient comparisons with which to carry out EEG/ERP analysis. It was therefore decided that the number of identities needed to be increased to a minimum of fifty for each view type group, and that three view type groups would need to be included so that all fifty identities could be seen in

each of the view types, without overloading the same participants with over three hours of learning.

Clearly the current behavioural learning phase results differ from those of Experiment 1. While single-view matching accuracy was comparable to Experiment 1, the pattern of matching accuracy over blocks for the two-view group was poor, and this did not change over blocks, with resulting knock-on effects apparent in the recognition phase behavioural analysis. The differences between the design of Experiment 1 and the current experiments have already been noted, and it is concluded that the different behavioural results found here are likely due to differences in list-structure and limited encounters. This can be characterised as a lack of similar two-view learning, compared to Experiment 1, but comparable single-view learning as Experiment 1, at least in terms of overall matching accuracy.

Clearly, further work will be required to fully understand if list-structure, and/or the number of encounters caused the difference in performance, but it can be concluded that based on the behavioural data alone, that insufficient explicit learning of two-views occurred.

However, the main focus of the two phases was to understand identity sensitive ERPs in relation to matching by view type and novel-view recognition, analysed for all trials. It was found that the N250r was not present in the learning phase or the recognition phase. This lack of an N250r was attributed to participants possibly responding to the yes/no list structure in the learning phase rather than matching by identity, and in the recognition phase, the list structure was again implicated because exact identity image repetitions only occurred between blocks, and therefore repetition of same images for same identities was too remote to produce the N250r effect.

For the FN400 ERP component in the learning phase, it was suggested that the effects reported may represent early onset familiarity effects, which was inferred by the later frontal effect reported by Henson et al. (2003), but this was speculative. Furthermore, the perceptual matching evidence for FN400 effects associated with recognition phase word to learned target associations (Griffin, DeWolf, Keinath, Liu & Reder, 2013) did suggest that the FN400 effects may represent access to an established representation in memory, although again this was speculative. However, the recognition phase results for this component were much more promising, finding an approaching significant main effect of identity within the two-view view type group, and not the other two single view type groups, but this was far from conclusive.

In summary, the current EEG/ERP experiments were an attempt to quantify, electrophysiologically, the processes that participants undertake in matching and recognising previously unfamiliar faces/identities, and while it is accepted and acknowledged that insufficient learning may have occurred, there was a tantalising glimpse of an advantage when two-views were learned over learning single-views, when tested on a novel view, that requires further investigation. In terms of the stated aim of investigating the FRU account of face learning, the current results are inconclusive, and the evidence provided does not allow a distinction to be made between the type of encoding taking place in the matching phase, or the type of representation accessed to recognise a novel view in the recognition test phase. Clearly, potential issues relating to maintaining participant attention on the by-identity matching task may have reduced the overall effect of this investigation, but it was an ambitious attempt to resolve the previous behavioural experiments by applying the EEG method, and in hindsight was a necessary first step in

understanding the pitfalls associated with such an endeavour. Future research can apply the lessons learned here in an attempt to answer these crucial face learning questions to a greater degree than the current experiments were able to achieve.

Chapter 5: Conclusions and future directions

5.1 Learning unfamiliar faces

In this thesis I set out to investigate how exposure to different views of an unfamiliar face during learning influences recognition performance of novel views. This is important for practical face learning purposes, but may also indicate something about the nature of the representations that are built during unfamiliar face learning, and the type of information necessary to learn such faces. For example, Bruce and Young's (1986) model proposed that learning unfamiliar faces involves the interlinking of abstracted structural codes from different experiences of a face to build a Face Recognition Unit (FRU) for each identity, describing the face in a manner that goes beyond the specific pictorial features of single episodic encounters. In contrast, a representation based on pictorial codes alone (i.e., a 'pictorial' account) would only allow limited generalisation to novel views (e.g., Liu & Ward, 2006; Longmore et al., 2017; Longmore, Liu, & Young, 2008; Megreya & Burton, 2006), and it would arguably need many more encounters and variations in view to achieve familiar face recognition on this account.

Using a one-back face identity matching task, participants in my experiments learned unfamiliar faces as a single-view, or two different views. During a later recognition test phase, participants were asked to recognise each face as either an identity that they had seen before or had not. Critically, along with testing the learned viewing angles, participants were also tested at a novel viewing angle. The results of the behavioural experiments in Chapters 2 and 3 showed some evidence that recognition of a novel view benefitted from learning two different views than

having only learned a single view. However, there were at least two factors that affected the robustness of this effect. First, it was critical that these two views were truly different views. That is, when two views were created by simply mirror reflecting one view (i.e., Experiment 4, mirrored profile-views), this conferred no ‘two-view advantage’. The second factor found to be critical in the robustness of the representation formed, and therefore ability to recognise a novel view, was that of ‘view type utility’. It was found that the information contained and able to be extracted from each of the two views learned as single-views as well as two-views, directly impacted recognition ability of a novel test view.

To further clarify and provide detail to these broad findings, the following sections will first summarise the behavioural and electrophysiological findings, and will then go on to bring these together to understand how the experimental results allow a clearer understanding of how faces are learned and become familiar. Then, the following sections will discuss practical applications of the current experimental findings, possible future directions, with the final section addressing overall conclusions.

5.2 Summary of the main findings

5.2.1 Behavioural findings

Chapter Two reported three experiments that were designed to first test a sequential identity matching procedure that was based on empirical findings that were considered important for rapid visual unfamiliar face learning, and subsequent recognition. Unfamiliar faces were learned as either one of two single-views (front-

facing or profile), or both of these views, and subsequently tested on the same single view learned, the other single view not learned, or a completely novel view (right three-quarter). Specifically, the learning/matching procedure included cropping static face images so that matching of the images was focused on the internal features, providing multiple exposures, and encouraging consolidation of any representations formed by including a period of sleep between learning and test (i.e., Experiments 1 and 3), which was compared to an almost immediate recognition test (Experiment 2).

Chapter Two therefore intended to first establish whether the learning procedure resulted in approximately equivalent and accurate matching for the three view types (single front views, single right-profile views, or two-views), and how matching performance differed between these view types over blocks of trials, ultimately testing the efficacy of the learning/matching paradigm. During the recognition phase, the focus was on view-invariance effects. That is, whether learning two-views would result in equivalent (i.e., non-significant) recognition accuracy across all test views, as well as significantly better recognition performance on a novel view (right three-quarter), when compared to having learned each of the single-views. A secondary focus was on how learned single-views would transfer to the other novel single view not learned, as well as the novel right three-quarter view, as this would help to identify the type of encoding (i.e., ‘pictorial’ versus ‘structural’) for single-views, and if this differed from that of learning two-views. Therefore, the main theoretical focus for Chapter 2 was to understand how face learning occurred, by primarily testing the predictions of the functional model of Bruce and Young (1986).

Critically, based on the Bruce and Young (1986) account, true face learning should only occur when more than one view was learned, as a key component of the

FRU account is that of ‘interlinking’ of abstracted structural codes (i.e., the two-view condition). If this does not occur when two-views are learned, then the opposing ‘pictorial’ account of face learning (e.g., Longmore, Lui and Young, 2008) would be supported. That is, that face learning only occurs through an accumulation of episodic encounters, with each stored representation being compared to the novel view in an ‘on-line’ manner. In other words, this account of face learning would predict that the more visually similar a test view is to a learned view, the better recognition accuracy will be, and conversely, the more dissimilar the test view is to a learned view, the poorer recognition accuracy would be.

The results of Experiment 1 indicated that learning two-views, after affording a period of overnight consolidation, produced a significant recognition advantage on the novel three-quarter test view, compared to when only single-views had been learned, and that learning two-views resulted in non-significant differences between each test view type, resulting in view-invariance. However, when a period of overnight consolidation was not included (i.e., almost immediate test, Experiment 2), learning two-views still produced a significant recognition advantage of the novel three-quarter test view, compared to having learned front-facing views, but not right-profile views, and performance when two-views had been learned was significantly different between the test views, indicating a lack of view-invariance. It could therefore be concluded that the FRU-effect reported in Experiment 1 was not reproduced in Experiment 2, as the two-view advantage was not present over both single learned views. Analysis between Experiments 1 and 2 highlighted that a period of consolidation was not strictly necessary to produce a significant advantage from learning two-views, when tested on a novel-view, but did produce view-invariant effects across all test-views in Experiment 1, but not in Experiment 2. So, it

can be concluded from these first two experiments that affording overnight (sleep) consolidation of formed representations did not significantly aid recognition performance when two-views were learned, indicating that any advantage gained from learning two-views was fast acting.

For Experiment 3, consolidation was again included because although not providing a significant advantage between Experiments 1 and 2, it was thought that affording a period of overnight consolidation would at least not harm any representation formed. For this experiment, now the critical novel test view was external in rotation to those views learned (i.e., a left three-quarter view when a front-facing and right-profile view had been learned), to test whether the representation formed from learning two-views was limited to just novel views between those views learned. Results indicated that again, learning two-views produced a significant advantage over learning either of the single-views, and as found in Experiment 1, when a period of overnight consolidation was afforded, learning two-views produced view-invariant effects, even when the novel view was outside the rotation of those views learned. Clearly then, recognition of an externally rotated novel view was possible, and it was suggested that this was due to the approximately symmetric nature of faces. It was further suggested that the type of views learned and the information that each conveys (i.e., their ‘view type utility’), determined the effectiveness of the FRU representation formed and its ability to answer other novel recognition test views, rather than recognition accuracy being limited to an internal rotation interpolation between those views learned. Finally, when a between experiments analysis was carried out for this first chapter, it was found that mean hit differences between experiments when two-views had been learned and tested on the novel three-quarter view (i.e., internal and externally

rotated novel views), were not significant. This indicated that affording overnight consolidation or not, and providing internally or externally rotated novel test views, had no effect on recognition accuracy of a novel test view when two-views were learned.

In order to further understand the ‘view type utility’ that different view types might afford, Chapter 3 reported four experiments that systematically varied the types of view learned, which again included a period of overnight consolidation, and all learned view types were tested on the same novel front-facing view type. Experiments 4 and 5 tested mirrored and true profile views respectively, which were chosen to test the prediction that FRUs require at least two-views that varied, but without knowing if variance between the views required only view direction (i.e., Experiment 4, mirrored profile views), or more visually discernible and useful within-identity visual variation (i.e., Experiment 5, true profile views). It was found that view direction alone (i.e., Experiment 4, mirrored profiles) did not produce the same pattern of learning/matching found in the previous experiments, with two-view matching accuracy not changing over blocks, indicating that learning did not improve over time. In the recognition test phase, no significant advantage was found when two-views had been learned over learning single-views, on the novel test view, and this was interpreted as demonstrating that an FRU representation required more than view direction variation to be formed. However, to confirm this interpretation, it was necessary to also test true profile views in the same manner.

Therefore, Experiment 5 tested true profile views, and found that learning both views produced the same pattern of increasing matching accuracy over blocks in the learning phase, as found in Chapter 2, as well as a significant advantage in the test phase on the novel view when two-views had been learned, over learning the

single left-profile view, but not the right-profile single view. Learning two-views also produced significantly better recognition on the same left and right-profile test view than when single profile views had been learned and tested on the same views. It was reported that any firm FRU conclusions for performance on the novel front-facing test-view were contradictory and therefore inconclusive, and it was also noted that learning two-views did not produce view-invariant recognition. Initially, it was thought that the two-view advantage over learned single-views, when tested on the same profile test views, could simply be accounted for by overall poor performance for single profile view learning. But importantly, learning two-views did seem to benefit recognition accuracy overall, and this instead suggested that a different type of representation may have been formed from learning two-views compared to only learning single-views (i.e., a qualitative difference). It was further found that when an analysis was carried out between Experiments 4 and 5, that learning two-views that were true profiles provided a significant advantage over learning two-views that were mirrored profiles. It was also revealed that single-profile view hits between experiments in the recognition phase were not significantly different from each other, so the advantage gained from learning two true profile views in Experiment 5 could not be accounted for by worse single view performance in Experiment 5.

As it was unclear whether learning two-views that were true views (i.e., not mirrored), but were the same view type, may have produced inconclusive results on the novel front-facing test view, due the ‘view type utility’ of profile views, it was decided to test three-quarter views, as it was thought that such views might provide greater ‘view type utility’ than profiles. Therefore, Experiment 6 tested true three-quarter views, and the same increasing pattern of matching accuracy was found in the learning phase when two-views were matched, as well as a significant advantage

when two-views were learned over learning single-views, on the critical novel test view, as well as a view-invariant effect between all test views in the recognition phase. Further analysis was carried out between these three same-view experiments (Experiments 4, 5 and 6), finding that when three-quarter views were learned as single-views or two-views, that this view type provided a significant advantage over learning mirrored and true profile views, and profile views between Experiments 4 and 5 were not significantly different from each other.

Based on these results, it was concluded that profile views did indeed provide less ‘view type utility’ than three-quarter views, with three-quarter views affording a more powerful or useful representation when learned as two-views, but importantly, single three-quarter views could not overcome the advantage gained from learning two of these views (i.e., significant over left three-quarter learned single views, and approaching significance over the learned right three-quarter learned single views). However, although this suggested that the type of information represented in each view learned was relevant for the representation formed, it was unclear to what extent this information needed to vary to produce a representation that was able to provide a significant advantage over learning only single-views, on a novel test view. So, it was decided that views would be chosen that overlapped considerably in their informational utility, to test if the information contained in a particular view type (i.e., its ‘view type utility’) affected the type of representation formed, and thus, its utility in answering a recognition test of a novel view.

To test this, Experiment 7 used left three-quarter views and left-profile views as single or two-views, as the previous profile and three-quarter view experiments had indicated good performance for three-quarter views and poor performance for profile views. It was therefore thought that including both view types in this

experiment would allow any advantage from learning two-views to be assessed based on the relative ‘view type utility’ that each view type afforded when tested on a novel view. It was again found that learning two-views produced the same pattern of increasing matching accuracy over blocks in the learning phase, and that learning two-views produced significantly greater recognition on the critical novel front-facing view than when a single left-profile view had been learned, but not when a single left three-quarter view had been learned, and view-invariance between test views was absent. Again, view type and the information each conveyed (i.e., ‘view type utility’) was found to be a critical factor in recognition accuracy performance, whether learned as two-views or single-views, with single profile views performing poorly compared to single three-quarter views.

When further analysis was carried out between Experiments 6 and 7 for single learned views only, when tested on the same view, the other view, or the novel front-facing view, it was again found that the three-quarter view provided a significant advantage over learning profile views. Finally, an analysis was carried out between all four experiments in Chapter 3 when two-views had been learned and tested on the novel front-facing view, finding that Experiment 6 (left and right three-quarter views) and Experiment 7 (left-profile and left three-quarter views) mean hits were significantly greater than Experiments 4 and 5 (mirrored and true profile views respectively), but differences between Experiments 4 and 5, and Experiments 6 and 7, were not significantly different.

Overall results from Chapter 3 revealed that the ‘view type utility’ of profile views was significantly worse than that of three-quarter views, however, single three-quarter views were still unable to overcome the advantage from learning two of these views, although this only approached significance when compared to the

learned right three-quarter single views. It was also found that in Experiment 7, where profile and three-quarter views were learned as two-views, that the contribution from each of these views was found to be unequal. That is, it was suggested that the three-quarter view provided greater ‘view type utility’ than the profile view when recognising a novel front-facing view, and this indicated that both views learned were separately available. It was further suggested that the finding of unequal summation in Experiment 7 might be better accounted for by an operation whereby exemplars are stored separately and combined only when a recognition decision was required. It was therefore concluded that if this operation was applicable to all experiments carried out so far, this would mean that the FRU account proposed by Bruce and Young (1986) must receive much less support as it is defined, and based on the present evidence, requires some adjustment and reappraisal.

In addition to the recognition phase of the seven experiments discussed so far, while the learning phases of each has been discussed briefly, an overall consideration of the learning patterns between experiments was held over until all experiments were completed. It was found that a pattern emerged of significant single view matching accuracy decline between block 1 and block 7 for Experiments 1, 2 and 7, and it was noted that this only occurred in matching lists that contained two different views, although Experiment 3 also contained two different views, single view matching accuracy did not change over blocks. It was concluded that cognitive control and selective attention mechanisms (e.g., Park, Kim & Chun, 2007; Minamoto, Shipstead, Osaka & Engle, 2105) associated with the match-mismatch two view list structure could account for this decline, as well as the other patterns of matching found throughout all behavioural experiments. It would therefore seem to

be the case that the declining pattern of matching accuracy cannot be accounted for by view type or frequency effects, as the other experiments mentioned also contained these views, had the same list structure frequency, but importantly differed in view type list structure.

In summary, over seven behavioural experiments that set out to test the Bruce and Young model (1986) of face learning, and by systematically varying the types of views learned as single-views and two-views, which was informed by the findings of each previous experiment, it has been possible to show that the types of view and information each view conveys plays a critical role in novel view recognition.

Furthermore, it was found that the two-views learned did not always afford significant recognition of a novel view, and that view-invariance was only present for Experiments 1, 3 (i.e., front-facing views and right-profile views) and 6 (i.e., true three-quarter views). It was further proposed from detailed discussion of all seven experiments that rather than these effects being dependent on ‘pictorial’ and ‘structural’ codes as Bruce and Young suggested, that the ‘bar code’ perceptual encoding and recognition evidence (e.g., Dakin & Watt, 2009; Goffaux & Dakin, 2010; Pachai, Sekuler & Bennett, 2013) provided a better account of the effects reported. It was also revealed in Experiment 7 that unequal contribution of the two-views learned was observed, and that apparent online summation of these views indicated that each view learned appeared to be separately available when a recognition decision was required. These findings and possible explanations for the effects reported in relation to the Bruce and Young account will be discussed in greater detail in section 5.3, ‘How do unfamiliar faces become familiar’.

5.2.2 Event related potential (ERP) findings

To further understand the cognitive processes highlighted in the behavioural experiments (see Chapters 2 and 3), in terms of their temporal operation, Chapter 4 investigated electrophysiological event related brain potential (ERP) correlates of the learning and test phases, focusing on two identity sensitive ERPs (N250r and FN400).

It was found that the N250r ERP inferior-temporal and occipital component was not present in the learning and test phases. Its absence was particularly surprising in the learning phase when matching same-views, as this component has been extensively found to represent a robust effect of same-view face repetitions (e.g., Schweinberger, Huddy & Burton, 2004; Schweinberger and Neumann, 2016; Schweinberger, Pickering, Jentzsch, Burton & Kaufmann, 2002; Trenner, Schweinberger, Jentzsch & Sommer, 2004). It was suggested, based on the behavioural results from the learning phase and the lack of improvement over blocks when two-views were learned, that insufficient learning may have occurred. It was further suggested that although all trials were included in the ERP analysis, participants may have experienced the stimuli but may not have matched these by identity, as there was a concern that the list structure could have been used to respond to each one-back stimulus occurrence (i.e., match-mismatch).

However, for the FN400 ERP component, interesting effects were obtained in both the learning phase and matching phase. In the learning phase, the FN400 was targeted because, although it has been identified as a marker of familiarity in recognition memory paradigms (e.g., Curran & Cleary, 2003; Curran & Hancock, 2007), it has also been found to reflect conceptual and/or perceptual priming (e.g.,

Paller, Voss & Boehm, 2007; Rugg & Curran, 2007; Wiese & Schweinberger, 2015), so it was included in the learning phase as a marker of perceptual repetition.

However, results indicated that it was present when two-views were learned at block 4, present as a main effect for right-profile single views, and not present at all when front-facing views were learned. It was suggested that these effects were likely to represent access to established representations in memory (e.g., Griffin, DeWolf, Keinath, Liu & Reder, 2013), but it was further suggested that this conclusion was speculative based on the observed learning phase concerns mentioned previously.

For the test phase however, and accepting that learning may not have proceeded as intended, an approaching significant FN400 was found for the two-views view type group only, when analysis was carried out within each group. It was considered again speculatively that the approaching significant FN400 effect may in fact represent a marker of ‘familiarity’, and that the representation formed from learning two-views may in fact be quantitatively (i.e., in terms of electrophysiological mean amplitude differences between targets and distractors) different to that produced from learning single views. However, it was cautioned that although this two-view approaching significant FN400 familiarity effect may represent access to an FRU, this requires much more investigation.

5.3 How do unfamiliar faces become familiar?

This thesis intended to test the Bruce and Young functional model (1986) by cropping unfamiliar face view stimuli of their external features to promote internal feature processing, providing single-views and two different views of unfamiliar identities and subsequently testing participants on the same view learned, the other

view not learned, and a novel view that had not been seen before. At the heart of the model was the proposition that each identity is represented by Face Recognition Units (FRUs), which were suggested to be produced from the accumulation of abstracted visual ‘structural’ code information that represented the ‘arrangement of features’, with these becoming ‘interlinked’ to form FRUs for each identity.

However, how structural encoding led to an FRU was not clarified by Bruce and Young, and was left for future researchers to investigate.

The FRU account and resulting findings from these experiments were also to be tested against alternative accounts which instead proposed that ‘pictorial’ codes (which Bruce and Young also defined) could account for face learning (e.g., Liu & Ward, 2006; Longmore et al., 2017; Longmore, Liu, & Young, 2008; Megreya & Burton, 2006). On this account, being exposed to a greater number of varied episodic traces which were ‘pictorially’ encoded, would lead to better recognition of novel encounters, based on similarity to, and some degree of interpolation between, the ‘pictorial’ representations encoded and the novel view to be recognised.

Therefore, the crucial comparison appeared to be between identifying the types of encoding taking place during the learning phase (i.e., ‘structural’ or ‘pictorial’), and relating this to, or inferring this from, performance in the recognition test phase, which would in turn support one account or the other. It was decided that the critical test of the FRU account would be significantly better recognition of a novel view when two-views had been learned, compared to either of the single views, with a further caveat that FRU formation should produce equal recognition of all views, and therefore view-invariance should be evident when two-views were learned. But, if learning two-views did not produce these effects, then it could be concluded that the ‘pictorial’ account would receive support. However, it was

unclear if the FRU account was to be supported, whether it could be concluded that single-view matching would be predominantly ‘pictorial’ in nature, and thus recognition of other views would be harmed by these image-based representations, or whether single-view matching would also be ‘structural’ in nature, but just lacking within-identity variation (i.e., a second different view), with which to form an FRU.

First, note that consideration of the pattern of matching in the learning phase for all experiments, especially when single-view matches decrease between block 1 to block 7 in Experiments 1, 2 and 7, has been extensively discussed in section 3.6 and 5.2.1, finding that cognitive control and selective attention mechanisms associated with list structure could account for these effects (e.g., Park, Kim & Chun, 2007; Minamoto, Shipstead, Osaka & Engle, 2105). Therefore, as the focus of this section needs to be on the theoretical accounts of face learning and perceptual codes that enable learning and recognition, the learning phase patterns of responding will not be covered in any more detail here.

It was found in Experiment 1, that included a period of overnight consolidation between the learning and test phases, that when participants learned front-facing views, right-profile views, or both of these views, that a significant view-invariant FRU-effect resulted from learning two-views, when tested on the novel right three-quarter view, in comparison to learning single-views that were not significantly different from each other, and this therefore supported the Bruce and Young account. However, it was noted that with the FRU account ‘interlinking’ process being a ‘hidden’ memorial operation, that it was not possible to confirm or disconfirm its predictions from a single study, and therefore the FRU account could not be fully supported yet, even though its main prediction was met.

In terms of addressing the type of encoding evident in Experiment 1, it was first important to clarify that the original ‘pictorial’ learning account of Longmore, Liu, & Young (2008), where no advantage was gained from learning two-views over single-views, when tested on a novel view, was subsequently put in doubt by a later study that used the same learning procedure but now used cropped face view stimuli (i.e., Longmore et al. 2015). In this later study an advantage was gained from learning two-views, and this was reported as being due to, “the integration of information across different study views of a face, leading to enhanced generalization of recognition to a previously unstudied view” (p. 258). Notably, this later Longmore et al. study used the same view types as those used in Experiment 1, but their account of why this occurred was not entirely explicit in terms of the codes used to achieve this. However, if one assumes that they again attribute their outcome to ‘pictorial’ encoding and ‘pictorial’ effects during recognition, then one would also have to infer from this that the two views learned were available at test and were ‘integrated’ in an online fashion.

However, to be able to distinguish between ‘pictorial’ and ‘structural’ encoding as accounting for their (i.e., Longmore et al., 2015) ‘integration’ interpretation and the FRU-effect stated contention, then one would need to clearly find evidence for one or the other form of encoding being explicitly used during recognition. It was argued that a ‘structural’ encoding account better characterised the effects of ‘integration’ referred to by Longmore et al. (2015), because according the Bruce and Young definition of ‘pictorial’ codes, these should only allow recognition of the same view, and not allow as successful a transfer to other views, which was clearly not the case in the Longmore et al. (2015) study. Furthermore, it was observed in Experiment 1 that decrements in single-view learned recognition of

another view appeared to be dependent on something more than the properties of the image (i.e., ‘pictorial’ codes’), and instead suggested that the structure and arrangement of features of a particular view type influenced its ability to transfer to another view.

Interpreting what constitutes ‘pictorial’ encoding, and how this is distinguishable from ‘structural’ encoding, depends on how much one infers from the recognition effects in relation to the theoretical predictions and definitions provided by the Bruce and Young model (1986), with the subsequent inference depending on seemingly inaccessible FRU formation and how this is theorised to have been produced. Based on the Bruce and Young (1986) definitions of these codes, if it is found that transference from single or two-views to a novel view are not significantly different from each other, then a ‘pictorial’ account should be supported (e.g., Longmore et al., 2008). However, if it is found that transference from two-views to a novel view is significantly better than that of single-views, then an abstracted ‘structural’ encoding FRU account should be supported (i.e., Experiments 1 and 3 in the current thesis, and the results of Longmore et al., 2015). Although these effects seem straight forward to interpret, it would appear that the boundary between ‘pictorial’ and ‘structural’ encoding effects is somewhat blurred, as approaching significant effects, for instance, cannot be easily ascribed to one or other account. Therefore, it was decided that an alternative encoding explanation was to be sought that might be able to accommodate both of these types of encoding, without losing the critical memorial effect of ‘interlinking’ (i.e., an FRU) or alternative ‘separateness’ of representations in memory accessed online when a recognition decision is required.

It was found that the work on visual perceptual ‘bar codes’ perhaps offered a possible solution to the ‘pictorial-structural’ encoding account incongruity (e.g., Dakin & Watt, 2009; Goffaux & Dakin, 2010; Pachai, Sekuler & Bennett, 2013). It was discussed previously (see section 2.2.3) that such codes could account for the effects reported that could not otherwise be separated by the ‘pictorial-structural’ encoding accounts. It was therefore concluded for this first experiment that ‘bar code’ perceptual encoding could account for the matching and recognition effects reported, and that although this constituted a departure from the Bruce and Young model, the FRU-account of face learning could still be supported over an image based ‘pictorial’ account of face learning. However, it remained to be seen if in subsequent experiments this conclusion would remain supported. Interestingly though, although ‘bar codes’ seemed to provide an overarching perceptual account of how faces might be encoded and recognised, it could again be argued that these are ‘image’ effects.

Experiment 2 then used the same view types as Experiment 1, but carried out the test phase almost immediately after the learning phase, finding that consolidation afforded in Experiment 1 was not necessary to produce an advantage for two-views, although this time learning two-views did not provide view-invariance and the recognition advantage over learning single views was not equally significant, with the FRU-effect inconsistent. However, what was taken away from this experiment was that although the differences between Experiments 1 and 2 were not significant but were noticeably numerically different, that a lack of consolidation may have harmed all representations formed. It was therefore decided that for all of the following experiments, a next day test phase would be included. For Experiment 3, which used the same learned view types as Experiments 1 and 2, but this time

changed the novel test view to an externally rotated novel left three-quarter view, the FRU-effect was repeated, as well as view invariance being present when two-views had been learned.

The first three experiments revealed that the FRU predicted recognition accuracy effect was present in Experiment 1, inconclusive in Experiment 2, and present again in Experiment 3. However, because these experiments used the same view types and novel test view type (i.e., three-quarter view), it was not possible to determine whether these particular view types produced the FRU-effect by virtue of their informational properties, so it was decided to test mirrored profile views, which it was thought would not produce the FRU-effect due the images being identical apart from view direction, with this hypothesis being confirmed (Experiment 4). Then, to test if low-level visual variation was necessary between two-views to produce the FRU-effect, true mirrored profiles were used (Experiment 5). Results at first glance seemed not to support the FRU-account, as learning two-views did not convey an advantage over both single views on the novel view, and view-invariance was absent. However, on closer inspection and analysis between the profile experiments, it was found that learning two true profile views did provide a significant advantage over learning single views, and that single view recognition performance between these two experiments were not significantly different. This therefore suggested that the prediction from the FRU account that learning two-views would provide a recognition advantage over a novel view was not met, but two-views did provide an advantage over single views on the same and other learned view tested. That is, by providing two different views that were the same view but differed in low-level visual variation, it was argued that within-identity visual variation produced the effects reported, and somewhat supported an FRU-account

for at least an advantage from learning two-views over single-views, just not when tested on a novel view.

It was further suggested that the true profile effects reported over those of mirrored profiles might be explained by the work of Burton, Kramer, Ritchie and Jenkins (2016). That is, the ‘dimensionality’ of a face for a particular person may be represented by idiosyncratic statistical within-identity differences, with such idiosyncratic statistical constraints allowing other visual examples of the same identity to be incorporated. On this account, the representational space for each identity was suggested to be separate to every other representational space for every other identity, with person-based statistical constraints that allows occurrences of only that person to be categorised as being the same identity.

On one hand, this proposal could be regarded as similar to the FRU proposal put forth by Bruce and Young (1986), but it differs in an important way by proposing a superordinate set of statistical constraints for each identity, rather than the FRU account which instead suggests that many FRUs exist for the same identity. This was also discussed in an earlier paper that specifically addressed the Bruce and Young model (1986) and the type of representation formed (Burton, Jenkins & Schweinberger, 2011). In this they discussed how both ‘structural’ and ‘pictorial’ codes might provide the within-identity variability necessary to produce an FRU for each identity, and acknowledged that the theorised FRU was still an important theoretical concept.

From the findings of Experiments 4 and 5, it was clear that profile views were unable to produce a two-view recognition advantage over single-views, on a novel test view, so this time it was decided to use true three-quarter views

(Experiment 6). It was found that the FRU-effect was repeated, but not equally over both single views, and view invariance was present between test views. Furthermore, when this experiment was compared to Experiments 5 and 6, it was confirmed that the ‘view type utility’ of the three-quarter view learned as single-views and two-views was significantly better during recognition than both mirrored and true profile views. Taking these results into the final experiment (Experiment 7), left-profile and left three-quarter views were used to try to tease apart the relative contributions of each when learned as two-views. It was found that the two-view advantage only occurred over learning single profiles and not single three-quarter views, on the novel test view, and view-invariance was absent. It was observed therefore that the three-quarter view part of the two-view condition was likely to have unequally contributed to the recognition advantage observed.

Further analysis between Experiments 6 and 7 for single views on the same, other or novel test view confirmed that three-quarter single views did indeed provide significantly greater ‘view type utility’ than profile views, but importantly, single three-quarter views in the two three-quarter view experiment (Experiment 6) could not overcome the recognition advantage gained from learning two-views. When analysis was carried out between Experiments 4, 5, 6 and 7, when two-views had been learned and the test was a novel view, it was found that two-view three-quarter views (Experiment 6) and left-profile / left three-quarter two-views (Experiment 7) provided significantly better recognition of a novel view than either profile view experiment (Experiments 4 and 5), and Experiments 4 and 5 were not significantly different from each other, and Experiments 6 and 7 were not significantly different from each other.

Finally, an electroencephalography (EEG) investigation of event related brain potentials (ERPs) associated with face learning and recognition was carried out over two experiments (Experiments 8 and 9 respectively) to test for the N250r and FN400 identity related ERP components. It has been previously discussed and acknowledged in the relevant section (see Chapter 4) that the learning paradigm, which was different than that of the previous behavioural experiments, may have produced unwanted consequences which may have affected the overall results, and this will not be discussed further here. However, the critical identity related findings from the two phases both concerned the emergence of an FN400 ERP component in the learning and recognition phases. In the learning phase, an FN400 was present when two-views were learned at block 4, present as a main effect for right-profile single views, and not present at all when front-facing views were learned. It was suggested that these effects likely represented access to established representations in memory (e.g., Griffin, DeWolf, Keinath, Liu & Reder, 2013), and in the recognition test phase, an approaching significant FN400 was found for the two-views view type group only, when analysis was carried out within each group. It was suggested that this may in fact represent a marker of ‘familiarity’ (e.g., Curran & Cleary, 2003; Curran & Hancock, 2007; Paller, Voss & Boehm, 2007; Rugg & Curran, 2007; Wiese & Schweinberger, 2015), but it was suggested that both of these conclusions must be regarded as speculative based on the observed learning phase concerns mentioned previously. However, both of these FN400 ERP effects do seem to warrant further investigation, as they are both suggestive of access to representations in memory that were retrieved when a matching and recognition decision was required.

Throughout the seven behavioural experiments discussed, it is clear that the original definition of what constituted support for the Bruce and Young (1986) FRU account was only fully met in Experiments 1 and 3. That is, a significant recognition advantage from learning two-views over learning both single-views, when tested on a novel view, with the result being view-invariance. Notably, both of these experiments included learning exactly the same view types, both included a next day test, and only differed in terms of the novel test view, with these being a right three-quarter and left three-quarter novel test view respectively. Based on these experiments alone, it might have been appropriate to say that full support had been gained for the FRU account over a ‘pictorial’ account, however, as the other experiments have demonstrated, and that was their purpose, accounting for how faces were learned using the current paradigm is far from that simple.

First, it must be accepted that learning two different views and single-views in laboratory settings is not representative of everyday face learning, and it may take many more encounters, and/or many more examples of a face for them to become truly visually familiar (e.g., Burton, Jenkins & Schweinberger, 2011). It must also be realised that the test for supporting an FRU account may be too stringent. That is, is it enough to show a two-view advantage over single-views that is not dependent on a novel view and does not require view-invariance? After all, the experimental learning phase provided a relatively limited and highly constrained set of parameters with which to achieve a level of visual familiarity that would arguably require greater variation, and perhaps more numerous occurrences. If this ‘softer’ approach was to be taken in judging these experiments against the FRU account, then one might consider a two-view advantage ‘trend’ as enough to support an FRU account, and therefore all experiments (apart from Experiment 4 which used mirrored

profiles) could be regarded as supporting this view of face learning. However, there were too many other inconsistencies, alternative accounts and effects of view type along the way to simply accept this approach.

As has been discussed throughout this thesis, critical differences between ‘pictorial’ and ‘structural’ encoding have been used by Bruce and Young (1986) to account for differences between unfamiliar and familiar recognition effects, however, they themselves were unclear about how these codes might lead to FRU formation, and left it to other researchers to remedy. Others (e.g., Liu & Ward, 2006; Longmore et al., 2017; Longmore, Liu, & Young, 2008; Megreya & Burton, 2006) have also used the Bruce and Young code definitions to explain their experimental findings, supporting a ‘pictorial’ account of face learning. However, as Burton, Jenkins and Schweinberger (2011) discussed in their paper, ‘pictorial’ codes represent, “information highly specific to the image viewed” (p. 944), while ‘structural’ codes are more abstract and give rise to FRUs that are, “entirely visual, but not tied to a particular *instance* of a viewed face” (p. 944).

So, it would seem to be the case that for an FRU to be identified ‘in action’, this needs to be demonstrated by seeing another example of a known face and being able to accurately recognise it, not necessarily over single views. In other words, seeing a known face activates the FRU for that identity, and then all stored visual information about that identity is accessed from memory and available to be utilised, whether it be image-based or ‘structural’. In this way, and as Burton et al. (2011) stated, “the incorporation of variability into an FRU seems to require that pictorial, as well as structural codes are processed *specifically for each individual*” (p. 954). So, on this account, distinguishing between ‘structural’ and ‘pictorial’ codes may be missing the point, instead, all information that is relevant to an identity becomes

stored and accessed visually by activation of its FRU. The question then arises, do the current experimental results provide any evidence for this?

The pattern of results across all behavioural experiments indicated that learning two-views that were not mirrored views (i.e., Experiment 4), produced an advantage over at least one of the single views. Additionally, investigation of single-view effects in the recognition phase indicated that all view types were not equally capable of successful recognition of other views, and this was described by the phrase, ‘view type utility’ effects. In particular, profile views did not transfer well to other views, noting that in Experiment 3 which used a novel left three-quarter view, when the single view was in the opposite direction (i.e., right-profile), performance was significantly worse than the single front-facing learned view, which was not the case in Experiment 1 where the novel view was in the same direction as the single profile-view.

This ‘view type utility’ effect was also demonstrated in Experiment 7, which extended the findings from Experiments 4, 5 and 6, when the two views used were profile and three-quarter views, finding that these two views provided apparent unequal contribution to the two-view advantage. That is, two-views were significantly greater than the profile-view and not the three-quarter view, on the front-facing test view, indicating that the three-quarter learned single-view was as good on the novel test view as two-views, and that the profile single-view was significantly worse than two-views. It was suggested that this represented evidence of unequal contribution from the two views, characterised as online summation between the two views learned that could not overcome the advantage gained from only learning a single three-quarter view.

Therefore, over seven behavioural experiments, it can be seen that the original model of Bruce and Young (1986) cannot be fully supported as a route to unfamiliar face learning. The critical distinction that ‘structural’ encoding is necessary for an FRU to be formed is not supported by the evidence. In fact, it seems more likely that something similar to perceptual ‘bar code’ visual information is used as a route to successful matching in the learning phase (e.g., Dakin & Watt, 2009; Goffaux & Dakin, 2010; Pachai, Sekuler & Bennett, 2013). In addition, there is also little evidence to support that these percepts were ‘interlinked’ at the encoding stage, or that ‘interlinking’ confers an advantage for two-views over single views in the recognition stage. So, on this account, it would seem that all visual examples of an identity are stored as individual percepts.

It was also not possible, until Experiment 7, to establish whether these individual percepts were combined only after overnight consolidation, however this experiment provided evidence that in fact online summation of the individual contributions of the views learned seemed to occur when a novel view was seen, supporting the conclusions reached by Longmore et al. (2015), that found that ‘integration of learned views’ occurred during recognition. However, critically, it cannot be stated categorically that FRU ‘interlinking’ as an associated memory phenomenon doesn’t exist. Tantalisingly though, the approaching significant FN400 found in the recognition stage (Experiment 9) would seem to provide speculative evidence of a qualitatively different type of memorial representation that was not present for either single learned view, and this could be the fabled FRU.

It is also not possible to provide strong support for the within-identity FRU account put forward by Burton, Jenkins and Schweinberger (2011), although it does seem that within-identity variation had a greater role in the learning phase than did

‘structural’ or ‘pictorial’ encoding accounts. So, perhaps it is more accurate to characterise the current evidence as inconclusive with regards to FRUs, but somewhat supporting the action of within-identity variation as a route to face learning. It was also found that ‘view type utility’ effects differed between view types seen as single-views and two-views, and while the ‘bar code’ (e.g., Dakin & Watt, 2009; Goffaux & Dakin, 2010; Pachai, Sekuler & Bennett, 2013) perceptual visual encoding account doesn’t explicitly state how differences in view type might be encoded and represented, it does seem that such visual stability between view types that share the same vertically aligned horizontal structure may be able to incorporate such information.

Finally, it has been shown that it is not necessary for individual face view percepts in the current experiments to be ‘interlinked’ (i.e., Bruce & Young, 1986), or associated by their ‘idiosyncratic’ dimensions in memory (i.e., Burton, Jenkins & Schweinberger, 2011), to account for the recognition results reported. In fact, it may take many more examples of faces and more extensive testing to fully understand if such memorial effects are present, and it is proposed that this could be achieved using the EEG/ERP method and further investigation of the FN400 component during learning and recognition. Characterising all of the evidence considered in this thesis, it can be summarised as follows. All face image views were encoded as individual percepts in the learning phase, and this is suggested to be primarily based on their visual perceptual commonalities such as their ‘bar codes’. Then, upon recognition testing, these were compared to the test image in an online manner, with the ‘view type utility’ of each individual representation compared based on their visual perceptual ‘bar code’ commonalities, with an advantage gained from two-views learned over single-views, only if their ‘integrated’ information or

‘summation’ exceeded that of the particular single-view(s) ‘view type utility’. Notice that this characterisation does not require memorial ‘interlinking’ (i.e., FRUs) to account for the evidence, and could easily be attributed to ‘image-effects’ (i.e. ‘bar codes’), but importantly, not ‘pictorial’ or ‘structural’ encoding as defined by the Bruce and Young model (1986).

5.4 Practical applications from the current research

The conclusions and findings of the current thesis promise to extend our knowledge of how faces are learned and become familiar. Although not the focus of this body of work, such theoretical understanding of how ‘normal’ face learning might occur is an essential tool that can be used when trying to understand difficulties in face learning, such as people with developmental prosopagnosia that present as having severely impaired face recognition abilities and no history of brain damage (see Duchaine & Nakayama, 2006, for a review). For instance, the ‘normal’ stages of perceptual learning that relies on within-identity variation, offers an opportunity for researchers to test if people with developmental prosopagnosia can distinguish and thus learn faces by their within-identity variation. It may even be the case that some other dysfunction or just different process or processes are observable for this group, but it is important to be able compare this to how ‘normal’ face learning might occur, and the current research and others can only help to further this understanding.

It is also possible that the learning procedure itself could be used to rapidly learn many unfamiliar faces in a relatively short period of time, in areas such as: teachers/lecturers learning new students, business people learning their staff, or

prison officers rapidly becoming familiar with their inmates etc. As has been demonstrated here, participants learned twenty-seven new identities in approximately one hour, with approximately 85% matching accuracy, so learning a class cohort would only involve the teacher spending this time before term started to familiarise themselves with the visual representation of their students in perhaps three main view types (i.e., profile, three-quarter, and front-facing), which could also have the added advantage of associating names to faces much easier, as arguably names can be assigned to already established visual representations of identity.

5.5 Future directions

The current research has identified four main areas for future research. However, it must be noted that these are not considered the only areas of interest for research into face learning, but are rather considered the most pressing in terms of formulating an up-to-date theory of face learning. Therefore, the following four areas of research are suggested to represent the core questions that it is suggested should engage face learning researchers in the future.

5.5.1 Multiple encounters of within-identity variation

As has been demonstrated, matching two different examples of unfamiliar faces led to relatively rapid familiarisation (i.e., Chapters 2 and 3). So, it is reasonable to expect that providing more exemplars of the same identity should elicit a more robust representation, as previous studies have demonstrated that within-identity variation leads to more robust representations being formed (e.g., Andrews,

Jenkins, Cursiter & Burton, 2015; Bindemann & Sandford, 2011; Bruce, 1994; Burton, Jenkins & Schweinberger, 2011; Burton, Kramer, Ritchie & Jenkins, 2016; Dowsett, Sandford & Burton, 2016; Kramer, Ritchie & Burton, 2015). And, although it is suggested that the representation formed can be updated over time with new information (Young & Bruce, 2011), it has also been found that once a robust representation has been formed, the representation can become so ‘overlearned’ that performance can become asymptotic (Tong & Nakayama, 1999). So, it seems sensible that, from a purely visual point of view, research should directly test the uptake and effect of learning within-identity related variations to establish which elements of visually represented faces are diagnostic of a robust representation. That is, what visually derived perceptual components and/or configurations are at the core of such representations, and to what extent do different forms of variation (e.g., hair style, make-up, spectacles, facial hair etc.) help or harm recognition. Critically, for any theory of face learning, it is important to test and understand what constitutes a ‘representation’. For example, is the system that allows the construction of a robust representation automatic when exposed to more than one exemplar, or is it restricted to, as Bruce and Young (1986) suggest, only the structural aspects of a face, with image and lower level visual differences peripheral to its construction?

To simplify this point further with an example of everyday experience, we can learn faces that have make-up on them, but we can sometimes struggle to recognise the same person immediately if they are not wearing similar make-up on a given day, unless the link with the same identity is maintained in time or in context (e.g., this is person A with make-up, and also person A without make-up). This example would seem to imply that the visual system encodes all the information available at the time, even if it is not strictly configural or structural, but is instead a ‘camouflaged’

representation. In other words, it is important to test and clarify whether the visual system encodes all the information available in a ‘dumb’ way, or prioritises diagnostic information over time and encounters, and whether this is sensitive to or dependent on the type of task demands of a particular paradigm (e.g., matching by identity versus matching by gender, age, category, etc.).

5.5.2 Attention to internal features

The current research has also demonstrated that matching unfamiliar faces based on their internal features aided rapid acquisition of multiple identities, which was based on previous research that found an ‘internal-feature advantage’ that favoured familiar faces (e.g., Clutterbuck & Johnston, 2002; Meinhardt-Injac, Meinhardt & Schwaninger, 2009), and learned unfamiliar faces (Longmore, Liu & Young, 2015). Clearly, the ‘internal-feature advantage’ would therefore seem to suggest that encoding the arrangement of facial features is necessary for true face and identity learning. So, to build a new or revised model of face learning, it will be necessary to understand the relative importance of ‘stable’ and diagnostic elements, such as the structure of the face and configuration of features, compared to arguably ‘transient’ elements such as: hair style and colour, make-up, piercings, facial hair, tattoos, etc. This will help the researcher to clarify and understand, not only what is diagnostic of a face, but to what extent (if at all) such ‘transient’ elements may have in interfering with or aiding this process. For example, it may be that such ‘transient’ elements interfere with true face learning, primarily because they offer a much simpler route to recognition based on image-based encoding (e.g., ‘iconic’ image effects reported by Carbon, 2008), rather than identity. However, it is far from clear

if this is the case, or whether ‘transient’ elemental variation provides just one within-identity exemplar with which the representation becomes associated, and it is an accumulation of all information available from a face that is important for true familiarity to become established (e.g., Andrews, Jenkins, Cursiter & Burton, 2015; Bindemann & Sandford, 2011; Bruce, 1994; Burton, Jenkins & Schweinberger, 2011; Burton, Kramer, Ritchie & Jenkins, 2016; Dowsett, Sandford & Burton, 2016; Kramer, Ritchie & Burton, 2015). Clearly, this topic is closely linked with that of within-identity variation, but is distinguishable by its focus on the internal features of a face, which have been found to be diagnostic of familiar and learned unfamiliar face recognition.

5.5.3 View type utility

The third area of interest is what has been termed here, ‘view type utility’. Clearly, and has been demonstrated in this thesis, different view types afford different information, and with the main finding of within-identity variation in mind, it is argued that research be carried out to more clearly delineate what is important about each view type. For example, the current research highlighted that profile views learned singularly or as two-views, did not provide sufficient ‘view type utility’ to recognise a view change. However, when combined with a front-facing view, profiles seemed instrumental in producing successful recognition of a novel view that exceeded that of either single view. It is therefore proposed that research needs to be carried-out which tests every combination of learned view type and novel test view type, which could be initially restricted to the main five view types (i.e., left-profile view, left three-quarter view, front-facing view, right three-quarter

view, and right-profile view). In this way, a better understanding of ‘view type utility’ could be more firmly established, which would provide knock-on advantages to real-world applications such as human passport control and even machine learning and recognition.

Indeed, it is suggested that the ‘bar code perceptual visual encoding and recognition field of study (e.g., Dakin & Watt, 2009; Goffaux & Dakin, 2010; Pachai, Sekuler & Bennett, 2013) needs to be extended and form one of the main focuses of research. That is, while the matching and recognition of different views in the current thesis have been suggested to be accounted for by this body of work, it is still unclear how views that were the same views (i.e., true profiles), could demonstrate a two-view advantage over that of the same single views learned and tested. The question from this evidence that arises concerns, how do perceptual visually derived ‘bar codes’ include subtle within-identity variation (as is suggested by the evidence), and how is this manifest in terms of spatial frequencies. For example, are there finer grained ‘bar codes’ within or between a set of more widely distributed and represented gross structures, or is it an entirely different perceptual mechanism that achieves this? It is suggested that these are the kind of questions that must be pursued in future research.

5.5.4 ERPs associated with face learning and recognition

The fourth and final area is that of ERPs associated with face learning and recognition. While it is accepted that insufficient learning of two-views may have occurred, the fact that an FN400 ERP ‘familiarity’ effect approached significance, and perhaps represented access to an FRU in the recognition phase from learning

two-views only, does suggest that the ERP method offers the promise of understanding face learning at an electrophysiological level. Furthermore, finding that the FN400 was observable during perceptual matching, and may represent access to established representations in memory during matching, also presents an opportunity to study the memorial representation aspects of face learning. However, one of the problems of learning and recognition ERP research is that of true recognition. In other words, it is important that designs find some way of testing ‘first-time-seen’ recognition associated ERP effects. That is, providing a design whereby participants EEG data is limited to only the first time an identity is seen again in the recognition test phase, rather than relying on repetition, which may not represent recognition per se, but rather remembering what response was provided to each image in the first block. Clearly this is a problem, as ‘one-shot’ recognition requires many identities to have been learned, as well as a sufficient number of participants to find an effect.

One approach that may be used to increase the number of data points for each participant would involve providing many examples of each identity at test in many viewpoints (to avoid image-based repetition effects), counterbalanced by distractor identities in many viewpoints. For example, participants could learn a front-facing view and a profile-view as two-views (as well as these views singularly for different identities), and would then be tested on 15-degree rotation variation views that are novel. In other words, this would result in five views within the rotation of those views learned (avoiding repetition of the profile mirror), and five views in external rotation of those views learned, which would result in ten novel views of each identity that are not exact image repetitions. In this way, as all views would be novel views, but with some closer to the ones learned than others, an analysis could be

made purely on identity (i.e., target versus distractors). This would also mean that the number of encounters at learning could be increased, while at the same time allowing one to reduce the number of identities. But importantly, every identity would be seen again at test ten times (counterbalanced by distractors), resulting in 270 data points for each participant by identity, rather than the current fifty times. This design would also allow a comparison to be made based on within-identity variation, as ten occurrences of a target identity that had been learned could be compared to ten occurrences of distractor identities that had not. However, it remains to be seen if this would provide better ‘one-shot’ recognition ERP data. But, techniques such as the one suggested (and others) must be attempted to be able to clarify if the ERPs under investigation represents true recognition, or simply repetition effects that may be representative of, ‘remembering the response given in the first block’.

5.6 Conclusions

Behavioural and electrophysiological measures were applied in order to understand how unfamiliar faces become familiar, primarily testing the functional model of Bruce and Young (1986). This model proposed that face learning occurs through the abstraction of ‘structural codes’ which become ‘interlinked’ for the same identity, forming a face recognition unit (FRU) for each identity, and that upon presentation of a face, the FRU’s ‘signal’ to the cognitive system would depend on the degree to which the stored representation (FRU) matched or resembled that provided by structural encoding of the presented stimulus. This account of face learning was also tested against an alternative, ‘pictorial’ account (e.g., Liu & Ward,

2006; Longmore et al., 2017; Longmore, Liu, & Young, 2008; Megreya & Burton, 2006), which instead proposed that face learning occurred through the ‘pictorial’ encoding of episodic traces of faces, that could also include some degree of abstraction, but would only allow limited generalisation to novel views. Therefore, from a ‘pictorial’ account perspective, learning two views should not provide a significant advantage over learning either single-view because each of the two-views should match the performance of the single-views, as they are separately stored exemplars and were defined as not transferring to other views very well.

When considering the results of all seven behavioural experiments together, the main finding was that the Bruce and Young FRU account of face learning could not be fully supported, and the ‘pictorial’ account could not be fully supported either. That is, it was difficult to reconcile ‘pictorial’ encoding and its stated limitations with the apparent advantage for some views over others, without attributing these effects to ‘structural’ encoding. In other words, the difference between ‘pictorial’ and ‘structural’ codes and their relative attributes and advantages or disadvantages over the other, and how this could or could not account for the effects observed, was becoming somewhat blurred and unhelpful.

Although Experiment 1 provided a pattern of recognition results that was completely aligned with an FRU account prediction, and the findings of Experiments 2 and 3 seemed to support this, as well as support from the work of Longmore, Liu, & Young (2015) who also cropped their stimuli, it was still possible to envisage an online summation and/or interpolation between the two-views that could produce an advantage over single-views, so this left open the possibility that a ‘pictorial’ explanation may still be able to account for these results. Furthermore, this later Longmore et al. (2015) finding seemed to raise doubts about the conclusions of their

earlier study (Longmore et al., 2008) which used full head images and concluded a ‘pictorial’ account of face learning. That is, if their earlier stimuli had also been cropped, different recognition results and subsequent conclusions may well have been reached. Nevertheless, Longmore et al. (2015) concluded that their effect was likely due to the ‘integration of information’ afforded by the internal feature processing of their stimuli.

While they made no claims about the types of codes that might have achieved this result, it did leave open the possibility that ‘pictorial’ codes could also have been deemed responsible for their effect, with such representations being integrated in an online fashion when a novel view was presented. However, as stated previously, this again meant that the finer detail of each code’s definition in terms of the Bruce and Young model, and how this is interpreted by researchers, allowed for circular and difficult to resolve disagreement with unsatisfactory outcomes. It was therefore decided that an alternative perceptual encoding account was to be sought that would allow both ‘pictorial’ effects and ‘structural’ effects to be either encompassed into one overarching perceptual ‘code’, or to allow a clearer distinction to be made between these codes.

The perceptual visual ‘bar code’ account of face matching and recognition (e.g., Dakin & Watt, 2009; Goffaux & Dakin, 2010; Pachai, Sekuler & Bennett, 2013) seemed to offer a solution to this predicament, and its operation was applied to the results, providing a convincing accounting of the effects reported. However, the results of Chapter 3 which varied the types of view learned, but tested all on a novel front-facing view indicated that such ‘bar codes’ could not as described account for the effects reported, without also including within-identity variation that was

particularly evident between mirrored and true profile views (i.e., Experiments 4 and 5).

The work of Burton, Kramer, Ritchie and Jenkins (2016), seemed to suggest an alternative approach to the Bruce and Young FRU account by proposing that it was within-identity visual variation that produced the idiosyncratic representational space for each identity, rather than distinguishing between ‘pictorial’ and ‘structural’ codes as accounting for FRU formation. And earlier work (Burton, Jenkins & Schweinberger, 2011) also suggested that both ‘structural’ and ‘pictorial’ codes might in fact provide the within-identity variability necessary to produce an FRU. So, based on these accounts, it would seem that the ‘bar code’ perceptual visual route to face learning and recognition was still a good explanation for the effects reported, but further work was needed to establish if such ‘bar codes’ could also include finer grained visual variation leading to idiosyncratic within-identity visual variation to fully support the ‘idiosyncratic representational space’ account.

In relation to the overall conclusions of the seven behavioural experiments, perhaps the most telling experiment was the last one. In Experiment 7, it was decided that profile and three-quarter views would be used, as evidence from the previous experiments had shown that both provided disadvantages and advantages as single views and two-views respectively, so using both here would allow these differences to be compared when learned as two-views. Indeed, it was found that an unequal contribution from the two views was apparent, and this suggested that online summation and integration at the point of recognition was the most likely explanation for these findings. This result therefore indicated that it was not necessary for face views to become ‘interlinked’ during encoding (i.e., an FRU,

Bruce & Young, 1986), nor was it necessary for them to be associated by their ‘idiosyncratic representational space’ (Burton, Kramer, Ritchie & Jenkins, 2016).

Instead, recognition seemed to be based purely on the information available from memory and its particular ‘view type utility’ to answer the different test views. In fact, learning two-views could not overcome having learned only a single three-quarter view (Experiment 7), but in the previous experiment (Experiment 6), where two-views were three-quarters, a single three-quarter view could not overcome the advantage of learning two of these views. So, it can be seen, with the benefit of hindsight from Experiment 7, that in Experiment 6, the effect of learning two three-quarter views can be seen again as summation and integration in online fashion when a recognition decision was required, that is directly affected by the ‘view type utility’ of the views learned. Applied to Experiment 5 that used true profiles, the same advantage was seen from learning two-views over single views on the same test views, and in Experiments 1, 2 and 3, the advantage from learning two-views was dependent on the ‘view type utility’ of the two views learned (front-facing and profile), that seemed to work particularly well.

That being said, it is not being claimed based on this evidence alone that memorial representations of learned face views are not associated in memory by FRUs (Bruce & Young, 1986), or encoded and restrained by their ‘idiosyncratic representational space’ (Burton, Kramer, Ritchie & Jenkins, 2016). Finding evidence of either of these accounts has not been possible behaviourally, but the behavioural effects do seem to clearly indicate that all effects of learning two-views and single-views are accounted for by the ‘view type utility’ afforded to particular view types and the information they provide in aiding recognition of another view. This seemed not to be dependent on whether ‘pictorial’ or ‘structural’ codes were used, and could

in fact be based on ‘bar codes’, and there was no evidence of a qualitatively different type of representation being formed from learning two views, as much of the resulting behavioural effects could be accounted for by online summation and integration or interpolation between the views learned.

However, and in relation to representations in memory, it was interesting to find in the EEG/ERP analysis that the FN400 was present in both phases. It was regarded as speculative due to the stated problems with the learning phase, but the FN400 in the learning phase was suggested to represent a marker of access to an established representation (e.g., Griffin, DeWolf, Keinath, Liu & Reder, 2013), and a marker of familiarity in the recognition phase (e.g., Curran & Cleary, 2003; Curran & Hancock, 2007; Paller, Voss & Boehm, 2007; Rugg & Curran, 2007; Wiese & Schweinberger, 2015). With the stated EEG/ERP learning issue caveat in mind, the speculative and only approaching significant FN400 for two-views in the recognition phase supported the view that this represented access to a ‘familiar’ representation in memory, that was not present for single-views, so it could not simply be related to access to any encoded representation, and it was speculated that this may in fact represent access to an FRU.

In summarising all of the behavioural and EEG/ERP evidence reported in this thesis, it is suggested that all face images were encoded based on their visual ‘bar codes’ that did not require a distinction to be made between ‘pictorial’ and ‘structural’ codes, and were separately stored in memory and accessed individually when a recognition decision was required, with their particular ‘view type utility’ instrumental in successful recognition of a different view to that learned. It is argued that different recognition success was attributable to the ‘view type utility’ of single views and two views, with the two-view advantage being due to the integration

and/or summation of the two stored views, in an online manner. This did not require FRUs to be formed from learning two-views, but the admittedly weak FN400 recognition effect for two-views did seem to suggest that the representation that was accessed at least seemed to represent a ‘familiar’ representation over that for single views, so it may be that some association in memory is evident and might support an FRU conceptualisation, but clearly this needs more work.

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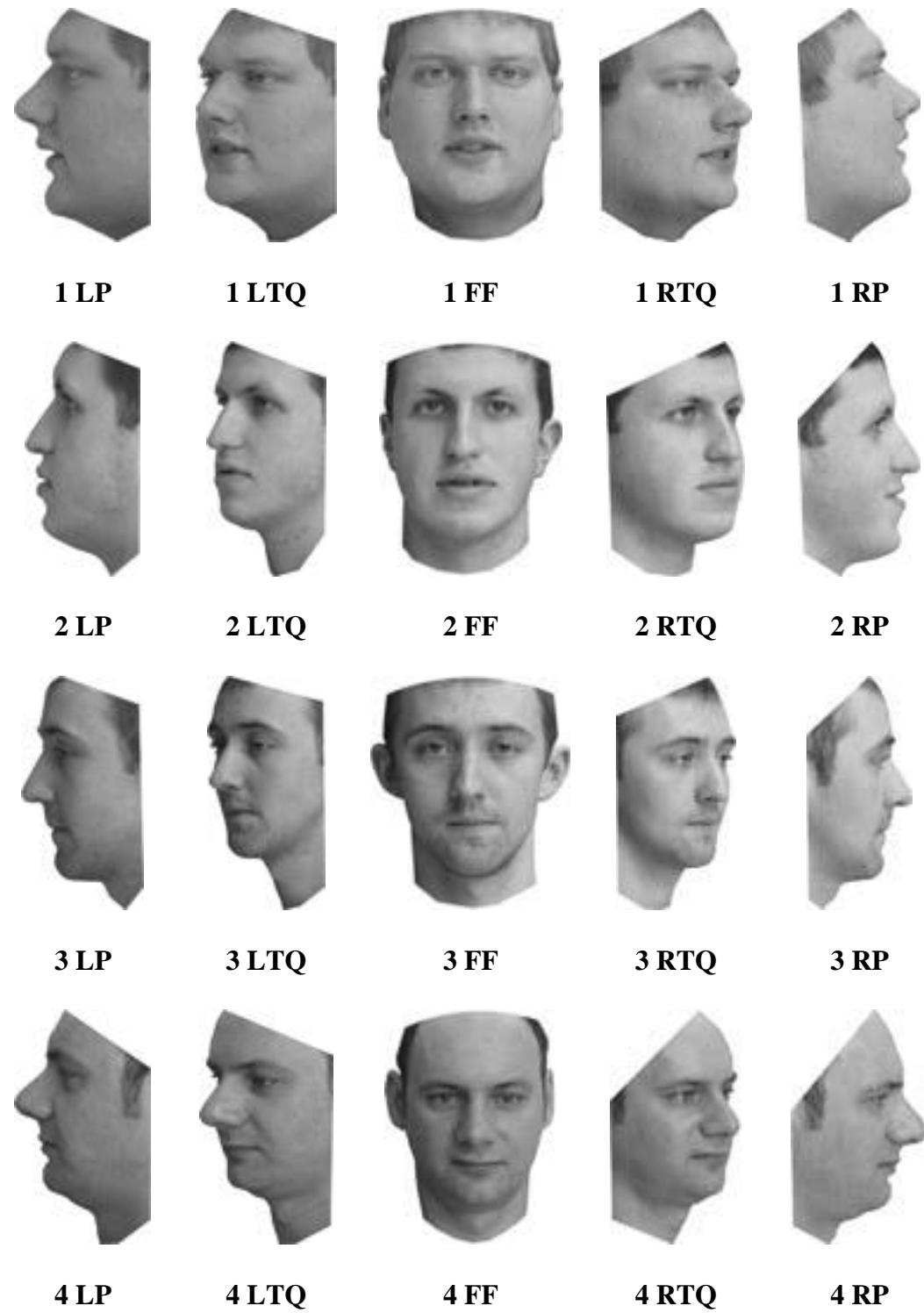
Appendix

Figure 10. Examples of each view type for four identities used in all experiments.