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Spontaneous Recognition: Investigating the Role of Working Memory

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Abstract

In almost every aspect of life, focusing on a target and ignoring distractors effectively is very important. Alternative to the common view, distraction may aid recognition via triggering automatic responses. Spontaneous recognition (SR) can be defined as the unintentional recognition of target stimuli and is measured by the effect of familiarity to distractors on a recognition task. Research has indicated that previously-seen or not-seen (old/ new) distractors affect the recognition of targets. This research aimed to investigate the influence of working memory load on SR. A dual-task was designed to ensure engagement in two tasks, namely, memory Stroop task (recognition task) and n-back task (working memory task) at the same time. This design enabled to investigate the influence of working memory load and allow for further exploration of the influence of episodic memory load and the characteristics of n-back task. The results are in line with previous research; participants were more accurate when target and distractor were congruent vs. incongruent but only when WM load was high. This interaction was modulated by episodic memory load and n-back task trials (match/mismatch). It was concluded that many factors may contribute to the SR effect. This research demonstrated that the SR effect is determined by WM availability and recognition processes engaged in another task.

Keywords: Spontaneous recognition, Distraction, Working Memory, n-back task, memory Stroop

Spontaneous Recognition: Investigating the Role of Working Memory

The demands of modern 21st century life require juggling several tasks at the same time. Everyday tasks require both goal-related processes towards target stimuli and the ability to ignore irrelevant distractor stimuli. Unintentional distraction biases may therefore have an important influence on intentional target recognition. However, while there have been decades of research into intentional recognition, unintentional recognition has been neglected. Some research has focused on the effects of unintentional recognition on intentional recognition (Anderson et al., 2011; Bergström et al., 2016; Ste-Marie & Jacoby, 1993) which can also be termed as spontaneous recognition (SR) or distractor effect.

The SR effect has been found under divided attention conditions (simultaneously performing a secondary listening task) in young adults (Anderson et al., 2011; Ste-Marie & Jacoby, 1993). Ste-Marie and Jacoby (1993) investigated the SR effect using a Flanker task. In this task, a target word is presented centrally with a surrounding distractor word above or below the target. Recognition responses were made to the target word whilst ignoring the distractor. One group of participants completed the Flanker task with full attention devoted to the task whilst the divided attention group simultaneously performed a secondary listening task. The author's found that distractors affected both speed and accuracy performance but only under the divided attention condition.

Anderson, Jacoby, Thomas and Balota (2011) compared the SR effect for older and younger adults employing the memory Stroop task. The task involved learning words and pictures during a study phase and then making recognition judgements to a compound word-picture stimulus on a test phase. On some test blocks, the targets (old or new) were words and the distractors (old or new) were pictures whereas on other test blocks the targets were pictures and the distractors were words. In their first experiment older adults’ recognition judgements (hits and false alarms) to word targets were affected by the type of picture distractor (old or new). This distractor effect was not shown for younger adults or when pictures were targets. The authors reasoned that older adults were more likely to process the distractors unintentionally given their general depletion of attentional resources. Word distractors were less likely to affect performance on picture target judgements as pictures were thought to be more salient (possibly due to their larger size and complexity relative to words). In a second experiment, the authors provided young adults with a secondary listening task that divided attention as in Ste-Marie and Jacoby (1993). The listening task required participants to listen to a sequence of numbers whilst conducting the memory Stroop task and to respond when three odd numbers appeared consecutively. This time younger adults showed a distractor effect on both hits and false alarms. These results provide support that unintentional recognition can govern the intentional recognition under divided attention conditions.

Two different accounts have been suggested for the role of attention in distractor processing. Broadbent (1958) and Treisman (1969) suggested selective attention aids the limited capacity of perception for further cognitive processing. As a result, attention is involved in early stages of perception to select the attended stimuli, leaving unattended stimuli not being fully perceived. This mechanism (perceptual selection) passively excludes distractor stimuli. An alternative approach emphasizes the involvement of selective attention at later stages (e.g., Duncan, 1980). In contrast to the perceptual selection account, this view suggests perception is unlimited. Consequently, attentional involvement is needed in later stages, not in early perceptual processing. This late selection mechanism actively rejects irrelevant distractors employing attentional control after automatic perceptual processing.

A more recent account converges the two aforementioned mechanisms via perceptual load. Perceptual load refers to the both the quality (brightness, complexity etc.) and quantity of items to be perceived. A perceptual selection mechanism rejects distractor processing in an early stage in high perceptual load situations (e.g., 8-letter array), and a late selective mechanism rejects irrelevant distractors in low perceptual load conditions (e.g., 2-letter array whereby irrelevant distractors are perceived) (Lavie, 1995; Lavie & Tsal, 1994). The Load Theory of Attention and Cognitive Control (Lavie et al. 2004) focuses on the relationship between perceptual properties of the target (e.g., set size in a search task) and cognitive control of distractor processing (e.g., switching between the different types of trials). This theory aligns with the perceptual selection view whereby perception is limited and automatic unless the perceptual capacity is overloaded. If the perceptual load of the target stimulus requires more processing capacity (high perceptual load) then there would be no resources left for distractors to be processed. Such situations lead to automatic early selection and distractor rejection. In contrast, in low perceptual load settings any spare processing capacity would be used on distractor processing.

Engaging in cognitive control, which requires working memory, could mitigate involuntary processing of the distractor (Lavie, 2010). Working memory (WM) is an important system for the maintenance and online manipulation of information and is a crucial cognitive mechanism that controls attention, prevents distractor processing and inhibits goal-irrelevant information (Logie et al., 2020). Several WM models have been proposed and supported by empirical studies. Reviewing the contributions of these models are beyond the scope of this paper, for a recent review see (Chai et al., 2018). Here, only the models that predict any influence of WM on distractor processing will be discussed.

According to the Multi-Component Model of working memory, the central executive (CE) sub-component is mainly responsible for guiding attention towards goal-related stimuli (Repovš, & Baddeley, 2006; Baddeley, 2000). In situations where CE is loaded, goal-related processing might be disrupted and consequently, attention might be misguided. An alternative account of WM portrays a more complex model and emphasises the contribution of the activated part of LTM (Cowan, 1999). The Embedded Processes model of WM suggests that the focus of attention and activated part of LTM forms WM. Irrelevant information can be processed in the activated part of LTM when the focus of attention is exceeded. Therefore, this model predicts that loading WM would allow distractor stimuli to be processed unintentionally (outside of focus of attention). A third model, focuses on individual differences on working memory span. In agreement with Baddeley and Cowan's models, this perspective emphasises the role of WM for maintaining activation of relevant information and suppressing distractors (Conway & Engle, 1994). As a consequence, the presence of irrelevant stimuli necessitates active maintenance of information in WM to prevent interference and to control response competition. This model also predicts individuals with a low working memory span would be more prone to distractor processing than individuals with a high working memory span. Taken together, the above WM models would have the same prediction: WM is required to control unintentional distractor processing. Lavie et al. (2004) conducted a series of studies to test the causal role of WM in control of interference with visual distractors. The authors found that loading WM in a selective attention task with a concurrent but irrelevant task reduced the focus of attention on the relevant stimuli with greater interference by distractors. Lavie and De Fockert (2005) used an attentional search task to demonstrate that the interference effect towards distractor stimuli is greater in high WM load conditions compared to low WM load conditions.

Following from the intertwined connection between attention and WM, it is possible to assume greater distractor processing when WM is loaded. Especially, in a paradigm like memory Stroop where distractor processing can be observed even with the low perceptual load (one distractor and one target) in divided attention conditions. On the other hand, it is not clear whether divided attention or WM is involved in the SR effect. Existing research (Anderson et al., 2011; Bergström et al., 2016) provides very little information on this subject. Therefore, we mainly aimed to understand the involvement of WM on the SR effect.

We have only come across the use of the memory Stroop task by Anderson et al. (2011) and Bergström et al. (2016). Therefore, the main aim of this study was to provide further evidence on SR, specifically the influence of unintentional recognition of distractors on the intentional target recognition. We also attempted to extend previous research by manipulating working memory load as well as strengthening the experimental procedure. In our research we (a) only used words as targets and pictures as distractors. This was done to provide a stronger test of the unintentional nature of the distractors. As Anderson et al. (2011) used pictures or words as targets in different blocks as a within-subject manipulation, it could be argued that when distractor effects were found for word targets the results may be contaminated by intentional memory. That is, checking both the attended and ignored modalities because on some blocks pictures were the relevant target modality. Studying pictures and words and then only testing words as targets with pictures as distractors should be a stronger test of any distractor effects that are driven by unintentional processes. (b) We also used a different secondary task to the one used by Anderson et al. (2011) and Bergström et al. (2016). An n-back task (1-back and 2-back) was used to tax working memory resources. N-back trials were alternated with memory Stroop trials. When n-back is larger than 1, two predictions can be made. First, the distractor effect will be more likely to appear when using the 2-back task during the test phase, as this task is more likely to divert attention away from the main memory Stroop task. Second, the higher working memory load for n-back >1 could deplete a common pool of attentional resources, thus allowing the distractor effect to break through. Furthermore, all values of “n” would require encoding and maintaining the information as well as matching (or mismatching) the current “n” with the maintained “n”. In addition to these processes, 1-back requires updating and replacing whereas 2-back requires updating, replacing as well as shifting the information (Chen et al., 2008). The additional information processing in the 2-back (shifting) condition would naturally make this task harder than 1-back condition. Additionally, there are more items to be maintained in 2-back than in 0- or 1-back versions and the order of the information should be preserved for the successful completion of the 2-back task (Chen et al., 2008).

Additionally, the n-back task allows the examination of whether the previous n-back decision (whether it is a match or a mismatch) would affect the distractor as an additional factor (Verhaeghen & Basak, 2005). A match trial in an n-back task requires the current stimuli to be congruent (the same) with the previous n-back stimuli. In contrast, a mismatch trial in n-back task requires the current stimulus to be incongruent (different) with the previous n-back stimulus. This factor will be called ‘congruency’ in the analysis. For instance, for the 1-back task, a match trial would require less WM resources than a mismatch trial which requires not only maintaining but also updating the memory record (where there is a requirement to replace old representations with new ones) compared to match trials. Alternatively, for 2-back task, both match and mismatch trials would require updating, maintaining, replacing, and shifting. Updating requires a flexible binding and unbinding of items for successful completion of the task

(Oberauer, 2009). Continuous updating of items in WM prevents strong binding of those items to their contexts in WM, and hence leads to an increased susceptibility to proactive interference (Szmalec et al., 2011).

Furthermore, n-back is considered a recognition task as well as a WM task (Jaeggi et al., 2010). N-back tasks involve cues and targets, therefore both recollection and familiarity processes may be engaged during the task (Campbell et al. 2012, Chen, Mitra, & Schlaghecken, 2008; Szmalec et al., 2011; Yaple, Stevens, & Arsalidou, 2019). Thus, it could be assumed that when n-back>1 recognition (both recollection and familiarity) is required to decide if the current stimulus matches the stimulus n-trials back. Match trials would also be easier compared to mismatch trials since they would possibly initiate an automatic familiarity response.

In sum, our first hypothesis was that participants would make more hits to old targets paired with old distractors compared to new distractors, and they would make more correct rejections to new targets paired with new distractors compared to old ones (SR effect). Our second hypothesis was that differences in accuracy (as defined in the first hypothesis) would be higher when the secondary task was a 2-back task (high WM load) compared to 1-back (low WM load). Moreover, we expect that SR effect would be higher in mismatch trials compared to match trials, since mismatch trials are thought to require more resources for working memory. To evaluate, we selected the memory Stroop paradigm described earlier as the recognition task to examine unintentional recognition indirectly.

This paper includes two different experiments using the same stimuli, only differing in the number of items encoded in the study phase. Initially, the aim was to investigate whether the change in the quantity of to-be encoded items would affect SR as well as the WM load. Accordingly, an experiment conducted with two episodic loads in different groups. Half of the participants encoded 12 pictures and 12 words whereas the other half encoded 6 pictures and 6 words. Later we combined all the data from the two groups and included episodic load as a factor. Participants were not randomly allocated to the two experiments, however, recruitment for the two studies took place during the same three-month period.

Methods

Participants

One hundred and two healthy young adults, undergraduate and postgraduate students from the school of Psychology recruited from the University of Kent. Participants were between 18-48 years old (77 females M_{age}=20.71, SD_{age}=4.40, 21 males M_{age} =24.48, SD_{age} =4.68). The participants were randomly assigned to the 1-back and 2-back conditions. Four participants were eliminated due to failure in their performance on the secondary WM task (below 50% accuracy).

Materials

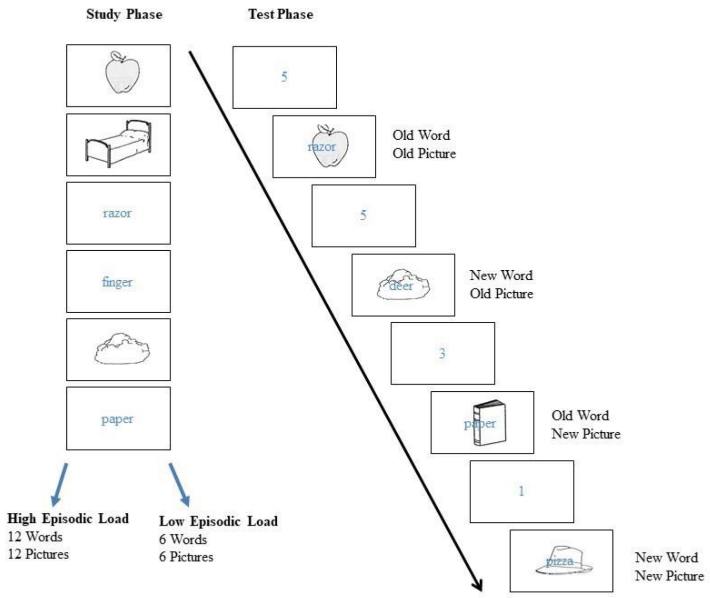
132 words and 132 pictures were used for stimuli. Pictures were single line, simple drawings in black and white and they were taken from Snodgrass and Vanderwart (1980) and Bonin et al. (2003) and words were selected from ELEXICON project database (Balota et al., 2007). The words selected were 3-6 letters in length and only nouns or concrete words. They were presented in blue 60- point Arial font. Pictures and words were randomly paired for the memory test with the restriction that the picture and word should not be semantically related.

Procedure

After giving information and having signed the informed consent participants were taken to a quiet room with a computer set up (Dell i5 computer with 15” square screen). The experiment started with a practice with two rounds (each of which included interleaved 10 n-back and 10 Memory Stroop trials) which were designed identical to the real experiment with different stimuli and continued until participants reached at least 80% success. The practice phase was followed by study and test phases. Test phase included the Memory Stroop Task (MST) interleaved with the working memory task. The instructions presented were written in blue on a white background whereas the words were in blue and images were black on white background. The experiment consisted of 5 rounds for high episodic load and 10 rounds for low episodic load conditions. This was done to achieve an equal number of trials for both groups. Each round included both study and test phases. Figure 1 shows the schema of the design and representative stimuli.

Figure 1.

Illustration of the experimental procedure



Participants were shown 12 pictures and 12 words in high episodic load condition and 6 pictures and 6 words in low episodic load condition that were randomly mixed during study and presented individually. They were asked to memorize the words and pictures. The interstimulus interval (ISI) was 500ms and the duration of the stimulus was 2500ms. Participants were asked to switch between two tasks during the test phase (see Figure 1). The first task involved making a decision for the n-back task which comprised of numbers. The n-back task is generally used in the literature as a manipulation of working memory (Kirchner, 1958). We used the n-back (1-back/2-back) task in which participants were asked if the number on the current trial is the same with the number “n” (1 or 2) numbers before. The stimuli were single digits ranging from 1 to 9. A target was a single digit that was the same with the single digit presented 1 or 2 (1-back and 2-back, respectively) trials before. All other digits were referred to as non-targets. Target and non-targets were assigned pseudo randomly with the condition of maintaining the target/non-target ratio. Each of the blocks contained (50%) targets and (50%) non-targets. Participants were instructed to press the ‘S’ (for same) or ‘L’ (for different) keys. Behavioural outputs were reaction times and response accuracy (hits and false alarms). The second task, the memory Stroop task (MST), closely followed the design used by Anderson et al. (2011). In this task, participants are required to make recognition (old/new) judgements to the words when displayed simultaneously with the pictures. Pictures and words were randomly paired and pairings were different across all participants. Each test block included 24 trials for low episodic load condition and 48 trials for high episodic condition with a word superimposed on a picture and presented in a random order. Each test block was made up of an equal number of the four target/distractor item types: new words and new pictures (Nn), new words and old pictures (No), old words and new pictures (On) and old words and old pictures (Oo). In each of these four conditions there were 6 trials for low and 12 trials for high episodic memory load. Participants were instructed to ignore the pictures and make their recognition judgements only for the oldness of the words (did you see the word before in the study phase or not; S=old, L=new). The screen showing the test items was presented until response or for a maximum of 6000ms. After 500ms ISI, a single digit was presented for the n-back task. Participants were asked to respond as accurately as possible (S=same, L=different). Stimulus presentation and response collection was conducted with an open-source computer programme, PsychoPy 2.0 (Pierce, 2007).

Results

Analysis of N-Back task

The n-back performance accuracy and reaction times (RTs) were compared with 2 (episodic load; low, high) x 2 (WM load; high vs low) x 2 (congruency; match, mismatch) mixed factorial ANOVA with congruency as within and WM load and episodic load as between subjects factors. Analysis on accuracy (see Table 1) revealed that participants were less accurate in 2-back (*M*=0.88, *SD*=0.08) compared to 1-back task (*M*=0.94, *SD*=0.08; F (1, 94) = 11.29, p=0.001, η_p^2 = 0.11). However, there was no difference between high and low episodic load (F (1, 94) = 0.84, p=0.36, η_p^2 =0.009), and no interaction of WM load and episodic load conditions (F (1, 94) = 0.10, p=0.76, η_p^2 =0.001). The main effect of congruency was found significant (F (1, 94) = 47.99, p<0.001, η_p^2 = 0.34). Participants were more accurate on mismatch trials (*M*= 0.95, *SD*= 0.09) compared to match trials (*M*= 0.88, *SD*= 0.10). Interestingly, congruency and WM load interacted (F (1, 94) = 11.14, p=0.001, η_p^2 = 0.11). Independent samples t-test were separately conducted for match and mismatch trials. Analyses revealed that there was a significant difference between 1-back and 2-back conditions in match ($M_{1\text{-}back}$= 0.92, $SD_{1\text{-}back}$ = 0.09; $M_{2\text{-}back}$ = 0.84, $SD_{2\text{-}back}$ = 0.10; t (96) = 4.59, p<0.001, d=0.73) but not in mismatch trials ($M_{1\text{-}back}$= 0.96, $SD_{1\text{-}back}$ = 0.09; $M_{2\text{-}back}$ = 0.93, $SD_{2\text{-}back}$ = 0.09; t (96) = 1.26, p=0.21, d=0.40). In match trials, participants were more accurate in 1-back compared to 2-back task.

Analysis on RTs (see Table 1) revealed that participants were slower in 2-back (*M*=1534ms, *SD*=58ms) compared to 1-back task (*M*=864ms, *SD*=55ms; *F* (1, 94) = 70.46, *p*<0.001, η_p^2 = 0.43), also they were slower on high (*M*=1333ms, *SD*=61ms) compared to low (*M*=1041ms, *SD*=41ms) episodic load (*F* (1, 94) = 12.76, *p*=0.001, η_p^2 = 0.12) conditions. There was no interaction of WM load and episodic load conditions (*F* (1, 94) = 2.56, *p*=0.11, η_p^2 = 0.03). The main effect of congruency was found significant (*F* (1, 94) = 92.90, *p*<0.001, η_p^2 = 0.50). Participants were quicker on match trials (*M*= 1090ms, *SD*= 513ms) compared to mismatch trials (*M*= 1270ms, *SD*= 574ms). Interestingly, congruency and WM load interacted (*F* (1, 94) = 4.15, *p*=0.05, η_p^2 = 0.04). Independent samples t-test separately conducted for match and mismatch trials. Analyses revealed that there was a significant difference between 1-back and 2-back conditions in match ($M_{1\text{-}back}$= 788ms, $SD_{1\text{-}back}$ = 314ms; $M_{2\text{-}back}$ = 1421ms, $SD_{2\text{-}back}$ = 487ms; *t* (96) = 7.70, *p*<0.001, *d*=1.91) and mismatch trials ($M_{1\text{-}back}$= 931ms, $SD_{1\text{-}back}$ = 314ms; $M_{2\text{-}back}$ = 1638ms, $SD_{2\text{-}back}$ = 567ms; *t* (96) = 7.72, *p*<0.001, *d*=2.94. In both match and mismatch trials, participants were slower in 1-back compared to 2-back task.

Table. 1. ANOVA results for n-back accuracy and reaction times

	Accuracy			Reaction Times		
Source	*F* (1,94)	*p*	η_p^2	*F* (1,94)	*p*	η_p^2
C	47.97	<0.001	0.34	92.90	<0.001	0.50
C*E	0.53	0.47	0.006	2.73	0.10	0.03
C*WM	11.14	0.001	0.11	4.15	0.05	0.04
C*E*WM	3.31	0.07	0.03	2.21	0.14	0.02
E	0.84	0.36	0.009	12.76	0.001	0.12
WM	11.29	0.001	0.11	70.46	<0.001	0.43
E*WM	0.10	0.76	0.001	2.56	0.11	0.03

C=Congurency, WM=Working Memory load, E=Episodic load

The difference between 1-back and 2-back WM load conditions on accuracy and RTs show that manipulations for WM load have been implemented. Furthermore, the results indicated that match and mismatch trials affected the n-back accuracy and RT performances differentially. Participants were more accurate in match trials for 1-back task compared to 2-back task, but the accuracy in mismatch trials were similar for 1-back and 2-back tasks. In comparison, reaction times showed that participants were quicker on match trials in 1-back compared to 2-back task, this difference was found to be less on mismatch trials compared to match trials.

Analysis of Memory Stroop task

Mean accuracy scores and standard deviations were calculated for oldness (new and old) of target and distractors at each WM load, episodic load and congruency conditions (see Table 2).

Table 2. Mean and (Standard deviation) of hit and correct rejection scores for episodic load, working memory load and congruency conditions.

Episodic Load	WM load	Congruency	Old Target		New Target	
			Old Distractor	New Distractor	Old Distractor	New Distractor
High	1-back	Match	0.79 (0.15)	0.76 (0.18)	0.84 (0.16)	0.90 (0.17)
		Mismatch	0.75 (0.18)	0.74 (0.22)	0.88 (0.13)	0.89 (0.12)
	2-back	Match	0.80 (0.17)	0.67 (0.19)	0.77 (0.18)	0.87 (0.11)
		Mismatch	0.76 (0.15)	0.74 (0.20)	0.81 (0.15)	0.82 (0.16)
Low	1-back	Match	0.86 (0.13)	0.84 (0.16)	0.96 (0.09)	0.96 (0.08)
		Mismatch	0.86 (0.14)	0.84 (0.18)	0.96 (0.07)	0.97 (0.11)
	2-back	Match	0.85 (0.19)	0.84 (0.14)	0.89 (0.15)	0.94 (0.10)
		Mismatch	0.88 (0.14)	0.83 (0.19)	0.88 (0.17)	0.92 (0.13)

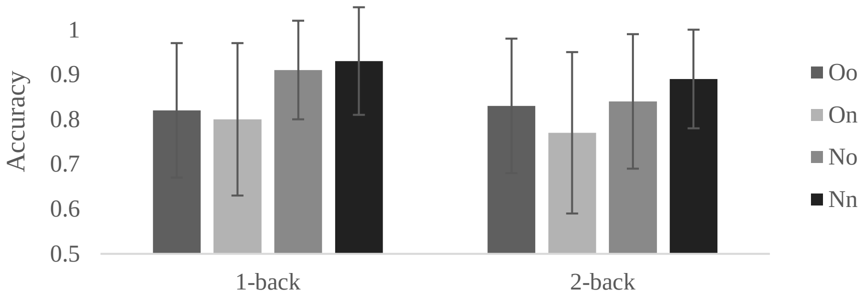
The design of the statistical analysis was a 2 (target type: old, new) x 2 (distractor type: old, new) x 2 (congruency: match, mismatch) x 2 (working memory load: 1-back, 2-back) x 2 (episodic load: low, high) mixed factorial ANOVA with target type, distractor type and congruency were within-subjects and working memory load and episodic load were between-subjects factors (See Table 3).

First, there was a significant main effect of target type (*F* (1, 94) = 28.52, $p<0.001$, η_p^2 =0.23). Participants were more accurate to new targets (*M*=0.89, *SD*=0.12) compared to old targets (*M*=0.80, *SD*=0.15). Furthermore, the interaction of target type and distractor type (*F* (1, 94) =21.62, $p<0.001$, η_p^2 =0.19) was significant. This was due to responses being more accurate on Oo trials (*M*= 0.82, *SD*= 0.15) compared to On trials (*M*= 0.79, *SD*= 0.18; *t*(97)= 2.87, *p*=0.005, *d*=0.29) and Nn trials (*M*= 0.91, *SD*= 0.12) compared to No trials (*M*= 0.88, *SD*= 0.13; *t*(97)= 4.32, $p<0.001$, *d*=2.31).

As predicted, target type and distractor type interacted with WM load (*F* (1, 94) = 4.24, *p*=0.04, η_p^2 =0.04), see figure 1. To understand the three-way interaction, two separate ANOVAs were conducted. For the 1-back condition, the target type x distractor type interaction was not significant (*F* (1, 49) = 3.44, *p*=0.07, η_p^2 =0.07). However, this was significant for the 2-back condition (*F* (1, 45) = 22.03, $p<0.001$, η_p^2 =0.33) and was due to higher accuracy for trial Oo (*M*=0.83, *SD*=0.15) compared to On (*M*=0.77, *SD*=0.18; *t* (46) = 2.68, *p*=0.01, *d*=0.39), and trial Nn (*M*=0.89, *SD*=0.11) compared to No (*M*=0.84, *SD*=0.15; *t* (46) = 4.27, $p<0.001$, *d*=0.62).

Figure 1

The effects of target type, distractor type and Working Memory load on accuracy in the memory Stroop task.

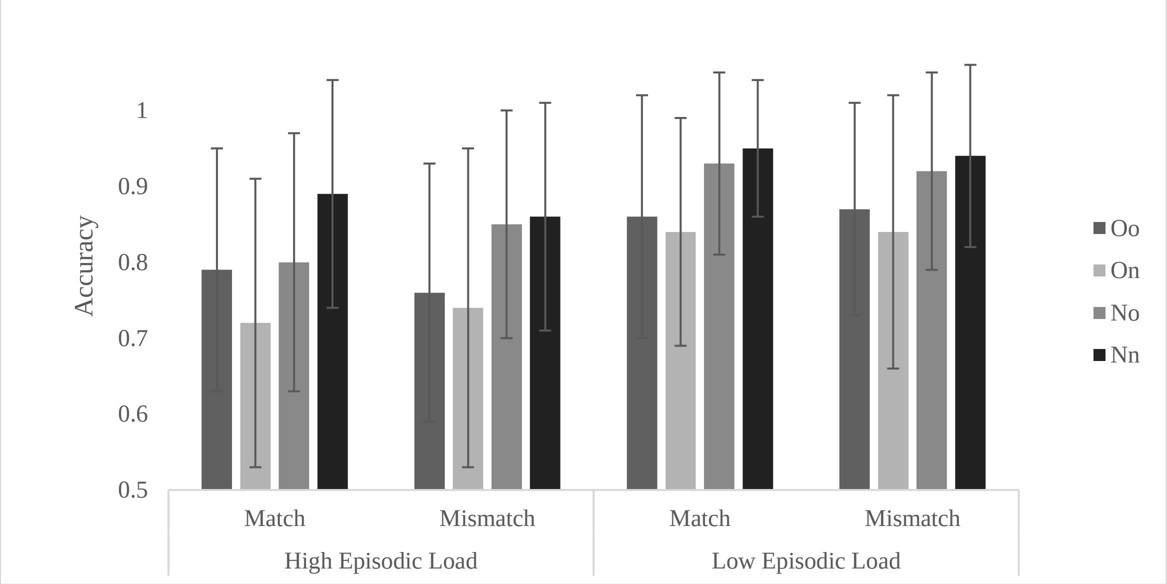


Note: Oo: Old Target- Old Distractor pair, On: Old Target- New Distractor pair, Nn: New Target- New Distractor pair, No: New Target- Old Distractor pair. Error bars show standard errors.

Interestingly, the target x distractor x congruency x episodic load interaction (F (1, 94) = 7.81, p=0.006, η_p^2 = 0.08) was significant (see figure 2). To investigate, a 2 (target type) x 2 (distractor type) x 2 (congruency) repeated measures ANOVA was conducted separately for high and low episodic load conditions collapsed for WM load conditions. The target type x distractor type x congruency interaction was not significant in the low episodic load condition (F (1, 50) = 0.43, p=0.52, η_p^2 = 0.008) but was significant in the high episodic load condition (F (1, 46) =8.59, p=0.005, η_p^2 =0.16). Further, within the match trials the target type x distractor type interaction was significant, (F (1, 46) =23.75, p<0.001, η_p^2 =0.34), but was not significant in mismatch trials, (F (1, 46) =0.90, p=0.35, η_p^2 =0.02). In match trials, there were more hits in Oo trials (M=0.79, SD=0.16) compared to On trials (M=0.72, SD=0.19; t (46) = 3.62. p=0.001, d=0.53) and more correct rejections in Nn trials (M=0.89, SD=0.15) compared to No trials (M=0.80, SD=0.17; t (46) = -4.11. p<0.001, d=0.60). See Table 3 for results of ANOVA.

Figure 2

The effects of target type, distractor type episodic load and congruency on accuracy in the memory Stroop task.



Note: Oo: Old Target- Old Distractor pair, On: Old Target- New Distractor pair, Nn: New Target- New Distractor pair, No: New Target- Old Distractor pair. Error bars show standard errors.

Table 3. ANOVA results for Memory Stroop recognition accuracy

Source	*F* (1,94)	*p*	η_p^2
T	28.52	<0.001**	0.23
T * E	0.14	0.71	0.002
T * WM	1.95	0.17	0.02
T * E * WM	0.04	0.85	<0.001
D	0.04	0.85	<0.001
D * E	0.06	0.81	0.001
D * WM	0.04	0.85	<0.001
D * E * WM	1.20	0.28	0.01
C	<0.001	0.98	<0.001
C * E	0.005	0.94	<0.001
C * WM	0.03	0.85	<0.001
C * E * WM	0.12	0.73	0.001
T * D	21.62	<0.001**	0.19
T * D * E	2.81	0.10	0.03
T * D * WM	4.24	0.04*	0.04
T * D * E * WM	0.35	0.56	0.004
T * C	<0.001	0.98	<0.001
T * C * E	0.93	0.34	0.01
T * C * WM	2.98	0.09	0.03
T * C * E * WM	0.19	0.66	0.002
D * C	0.55	0.46	0.006
D * C * E	0.06	.802	0.001
D * C * WM	0.12	0.74	0.001
D * C * E * WM	1.31	0.26	0.01
T * D * C	3.88	0.05	0.04
T * D * C * E	7.81	0.006*	0.08
T * D * C * WM	0.81	0.37	0.01
T * D * C * E * WM	1.74	0.19	0.02

T= Target type, D=Distractor type, C= Congruency, WM= Working Memory Load, E= Episodic Load, $*p<0.05$, $**p<0.001$

Discussion

We are often surrounded by distractor stimuli alongside intentionally processed target stimuli that are important for our goals. This ability to ignore distractor stimuli and focus on goal-directed stimuli is essential for completing everyday tasks. Here, we have reported a combination of two experiments on the effects of WM on SR of a distractor item. Both experiments investigated SR in a memory Stroop task and examined WM load, congruency and episodic memory load. The aim of the research was to extend the results of Anderson et al. (2011) using the memory Stroop task to determine how distractor images (old vs. new) influence recognition of old and new word targets. Our study is in line with previous research investigating the influence of old compared to new distractors on target recognition (Ste- Marie & Jacoby, 1993; Anderson et al., 2011; Bergström et al., 2016). Specifically, we found participants were more accurate at recognising old targets paired with old distractors compared to new distractors, and better at correctly rejecting new targets paired with new distractors compared to old distractors.

In contrast to Anderson et al. (2011) who employed pictures as targets and words as distractors to show an SR effect, we used pictures as distractors and words as targets. This is motivated by neuropsychological findings that show differences in pictorial and verbal processing in studies of modality-specific aphasias, priming in semantic access dyslexia, and modality-specific aspects of semantic memory disorders (McCarthy & Warrington, 1988; Paivio, 1971; 1991; Shallice, 1988; Warrington & Shallice, 1984). These findings indicate a superiority of pictorial over verbal processing. As such, in our paradigm picture distractors potentially acted as stronger distractors for the target words as they were directly accessible from semantic memory.

Extending previous research, we provide evidence for the involvement of WM on the SR effect, as the interaction between target and distractor was modulated by WM load. In instances where the secondary task was less cognitively demanding (i.e., low WM load task: 1-back condition), participants did not show the SR effect even though their attention was divided. In contrast, when the secondary task was more cognitively demanding (i.e., high WM load task: 2-back condition) attention was sufficiently divided and allowed unintentional recognition of distractors to influence target recognition. The results suggest that WM resources are required to avoid unintentional Stroop-like effects of distractors. More specifically, high WM-related cognitive demand reduces the ability to actively reject distractors.

According to the Embedded Processes Model of working memory (Cowan, 1999; Cowan et al., 2020), there are two types of mechanisms that are involved in WM: the activated long-term memory that holds previously learned information (i.e., old items) and active information (i.e., new items) during the trial, and the limited focus of attention. In our experiment, compared to the 1-back task, the 2-back task requires individuals to actively hold both more information (i.e., two items rather than one) and the order of the numbers. This potentially creates additional load on activated LTM. In fact, we observed the influence of WM load on n-back accuracy and reaction time, with participants displaying more errors and slower reaction times in the 2-back compared to 1-back task. Moreover, focused attention was reduced to a greater extent in the 2-back compared to 1-back task, suggesting dividing attention between the two different tasks (i.e., holding the items and the sequence of items) constrains the focus of attention.

Contrary to our predictions on the n-back task, we saw a speed-accuracy trade-off, with participants displaying more errors but shorter reaction times for matched compared to mismatched trials. Moreover, the difference in accuracy between 2-back and 1-back trials was more pronounced in match trials compared to mismatched trials. This difference may have emerged from the discrepancy of cognitive processes involved in 1-back and 2-back tasks, respectively. More specifically, following a 1-back match trial replacing and updating the number held in WM is not necessary as the number on the current trial matches the previous one. In contrast, in the 2-back task both match and mismatch trials require multiple cognitive processes (i.e., encoding, maintaining, matching, updating, shifting and replacing; Chen et al., 2008). It has been suggested that the n-back task also includes recognition processes, such as familiarity in matched trials (Jaeggi et al., 2010; Redick & Lindsey, 2013). This suggests that familiarity responses may assist participants to give accurate answers in matched trials of the n-back task. However, in dual task conditions like our paradigm, a concurrent recognition task may have disrupted this process and conflicted with match trials more in 2-back than 1-back task. As a result, participants were less accurate in n-back decisions for matched compared to mismatched trials.

In the presence of two competing tasks, conflict is unavoidable due to the limited focus of attention. Conflict occurs when two sets of items are held in WM even when the modalities are different (Cowan et al., 2011, 2014), and when storage and processing occur at the same time (Doherty et al., 2019; Rhodes et al., 2019). The dual task used in our experiment included such processes and conflicts. According to Cowan et al. (2020) conflicts may be avoided if information can be transferred from attention to activated long-term memory in order to reduce interference between two tasks. It is thought that suppressing distractors can be achieved through various control processes, such as moving items into the focus of attention, and updating the contents of focused attention and of long-term memory. However, our results suggest such preventive mechanisms can be utilized to a certain degree as the SR effect was not present when the secondary task was 1-back. Instead, it was observed only when the secondary task required more cognitive resources (i.e., 2-back task).

More broadly, our results are consistent with the load theory of selective attention. In low perceptual load settings, attentional control mechanisms actively reject distractors and depend on higher cognitive processes such as WM (Lavie et al., 2004). In this experiment when WM was under a higher load (i.e., 2-back task), attentional control was reduced and was insufficient to avoid the unintentional processing of the distractor. In contrast to the 1-back task, the 2-back task divided attention and resulted in participants being less able to resist distractor effects and retrieve relevant information encoded in the study phase. This finding supports earlier studies investigating the role of WM on distractor effects (de Fockert et al., 2001; Kane & Engle, 2003; Lavie et al., 2004). Further, Barrett et al., (2004) emphasized the general ability to deploy attentional resources to actively manage ongoing cognition. They suggested two resources, those that maintain goal-relevant information and/or those that disengage from irrelevant information. Accordingly, disengagement may depend on cognitive inhibition, memory updating, and tagging items in episodic memory to prevent retrieval (Mashburn et al., 2020). While attentional allocation between these processes is required, in our paradigm some of the resources were occupied by the more cognitively demanding 2-back task that requires maintenance. Therefore, participants likely failed to disengage from the recognition of distractor pictures, leading to the SR effect.

Contrary to the predictions, unintentional recognition of distractors influenced target recognition if the previous n-back trial was a match, but only in the high episodic load condition. The finding that high episodic load influences SR effect only in matched trials is particularly interesting because it suggests the combination of high episodic memory load and the cognitive processes required for a match response creates a stronger SR effect, similar to the effect of high WM load. Indeed, Kim et al proposed that “the efficiency of selecting a target and inhibiting a distractor depends on the relationship between the contents of WM and how it overlaps with target or distractor processing” (Kim et al., 2005, p. 16529). There is the possibility that the recognition processes underlying n-back task (especially in match trials) conflicted or competed with the memory Stroop task, leading to a stronger influence of unintentional distractor processing. However, an additional episodic load might be necessary for this competition to emerge. Alternatively, according to the Signal Detection Theory, decisions on accepting or rejecting studied items forms a response criterion that might change according to participants' or the task properties (Yonelinas et al., 1996). A strict response criterion would increase the probability of rejecting items, whilst a relaxed response criterion would increase the probability of accepting items, leading to an increment of false alarms. Research has shown that shifts in response criterion affects familiarity more than recollection (for a comprehensive review see Yonelinas, 2002). To our knowledge such a shift in response criterion has not been reported using the n-back task. However, considering the recognition processes underlying the n-back task it is plausible for response criterion on match decisions might have been relaxed, resulting in more false alarms as indicated by the lower accuracy in matched compared to mismatched n-back match trials. In turn, this shift might have carried over to the memory Stroop target decisions. However, our current experimental procedure is insufficient to test these assumptions and future research is needed to clarify this complex interaction.

In our experiment, the SR effect was seen only in the high episodic load condition where the to-be-encoded items was greater than in the low episodic load condition. Observing such an interaction in only the high episodic load condition could partially be explained by the Embedded Processes Model of WM; as activated LTM is loaded with more items in high episodic load condition, less resources are available for control of distractor processing. According to Cowan (1999), the activated part of LTM is part of WM and the number of items to be recalled is related to the capacity of WM. Therefore, asking participants to recognize an item amongst 12 encoded items is naturally harder than recognizing an item amongst 6 encoded items. Alternatively, global matching models of recognition (Clark & Gronlund, 1996) argue that to make a decision it is necessary to evaluate and combine the strength of each related item stored in memory. Therefore, this kind of recognition decision with more items to be matched in episodic memory might be more error prone. Furthermore, according to the Search Model of Recognition Memory (Atkinson and Juola, 1974), making a serial search prolongs the response time and as a result, more items would require longer search time.

The methodology of the studies reported in this research specifically allowed us to investigate concurrent WM load on the SR effect. In contrast to previous research, using an n-back task as the secondary task ensured the continuous maintenance of the n-back stimuli in WM. The WM task had the same load in each trial with the exception of the difference between matched and mismatched trials. However, in Anderson et al’s (2011) study, participants heard a string of digits in which they were asked to respond when they detected three consecutive odd numbers. This could lead to discrepancies in WM load in each trial. For instance, participants might hold only one or two digits in WM depending on the location of the number in the sequence.

Moreover, the main manipulation in the Anderson et al. (2011) study was the mere presence of the secondary task, which was only included in the divided attention condition, but not in the full attention condition. Consequently, the divided attention condition required participants to complete a dual task paradigm compared to the single task in the full attention condition in which they only completed the recognition task. In contrast, our dual task paradigm required participants to divide their attention between two tasks in both WM load conditions. Our results are consistent with Lavie and De Fockert (2005) who showed that the interference from distractors is greater under dual-task conditions compared to single-task conditions. These findings suggest that the availability of WM is an important determinant of the distractor interference effects and these are more pronounced in dual-task compared to single-task conditions.

It is important to note that several questions remain unanswered in the current experiments. For instance, we believe future research should focus on the specific processes related to executive functions involved in distractor processing in a recognition task. Overall, our results strongly support the unintentional nature of the distractor effect, as even when words were used as targets the picture distractors still affected performance. This effect was not present when participants' attention was divided. SR of a distractor item influenced the correct recognition of targets only when WM was sufficiently loaded.

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