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Are e-scooters active transport? Measured physical activity outputs of e-scooter riding vs walking

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ABSTRACT

Introduction: E-scooters have been adopted into the urban transportation network as a convenient, environmentally friendly, and low-cost mode of transportation intended to reduce vehicle dependence over short distances. However, there is a concern that e-scooters displace active modes of transport such as walking and therefore have the potential to negatively impact physical activity (PA), health and well-being. Currently, limited evidence exists to accurately quantify energy expenditure, and physiological and psychological responses to an acute bout of e-scooter riding.
Methods: This study compared a 15-minute bout of e-scooter riding to time-matched resting and walking conditions using a randomised crossover trial conducted in a controlled laboratory setting. The resting condition was performed in a supine position, and both e-scooter and walking were performed on a motorised treadmill. Cardiorespiratory measures were recorded for each condition using online gas analysis, and the metabolic equivalent of task (MET) minutes were used to determine energy expenditure. Subjective experience was also measured post-walking and e-scooter conditions.
Results: 15 minutes of walking yielded significantly greater MET minutes (55 ± 7 MET-min) compared to both resting (15 ± 4 MET-min, $P < 0.001$, $d = 7.38$) and e-scooter (24 ± 6 MET-min, $P < 0.001$, $d = 5.18$) conditions. Psychological well-being was significantly greater ($P < 0.001$, $d = 0.648$) following walking (19.2 ± 4.1) compared to e-scooter (17.1 ± 4.5). Psychological distress ($P = 0.40$) was significantly lower post-walking (5.0 ± 1.8) compared to e-scooter (5.8 ± 2.6).
Conclusion: In a controlled laboratory environment, riding an e-scooter resulted in significantly less energy expenditure and elicited an unfavourable psychological response compared to walking. Regular e-scooter use could displace PA participation and increase physical inactivity with resultant negative health consequences. PA engagement and health guidelines should be considered in the strategic development of electric micro-mobility transportation.

1. Introduction

Developments in transport technology make it possible to travel effortlessly over long distances and have displaced walking as the most common mode of transport (Pooley and Turnbull, 2000), encouraging governments to prioritise the expansion of infrastructure to accommodate these trends (Wardlaw, 2014). However, the dependency on motorised vehicles has led to cars becoming the principal mode of transport for journeys under 5 km (3.1 miles) (World Health Organization, 2002) prompting policymakers to re-evaluate urban design and explore more sustainable transport options, particularly across shorter urban journeys (Banister, 2007). Walking was encouraged, as it encompasses decreased air and noise pollution and promotes physical and psychological well-being (World Health Organization, 2002) and bike-sharing schemes were introduced to offer accessible and active transport solutions (Shaheen et al., 2020). However, technological determinism, sharing schemes, and low-cost private ownership have encouraged the launch of

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electric micro-mobility (EMM), designed to offer a sustainable transport solution over short distances with minimal physical effort (Hardt and Bogenberger, 2019; Bozzi and Aguilera, 2021).

Cities worldwide have implemented shared e-scooter schemes, intending to enhance mobility, provide first-last mile connectivity to existing public transport whilst decreasing private car use and consequently reducing road congestion and carbon emissions (Liao and Correia, 2022; Huang et al., 2024). Since their introduction in 2017, shared e-scooters (electric, two-wheeled vehicles with a standing deck and handlebars) have gained international popularity, with a consensus among users that e-scooters are time-efficient, cost--saving, environmentally friendly, and alleviate parking burdens (Bozzi and Aguilera, 2021; Zhu et al., 2020; Glenn et al., 2020). However, the perceived positive environmental impact of shared e-scooter schemes has been questioned, with evidence suggesting an energy-intensive manufacturing process, short lifespan (between 45 days and 2 years), and the need for additional transport for their redistribution and charging (Reis et al., 2023; Bozzi and Aguilera, 2021; Hollingsworth et al., 2019) results in a negative environmental impact.

In addition, reports have attempted to link e-scooters and active transport, forming a narrative they might align with some physical benefit (Glenn et al., 2020). However, such claims are unfounded, with the PA, health and well-being implications of e-scooters yet to be adequately explored. Pilot scheme evaluations report over 30% of the population have used an e-scooter, with around 9% considered regular users (Sanders et al., 2020). This is particularly pertinent as up to 51% of e-scooter users have been shown to use e-scooters as a feeder vehicle to link with public transport (Li et al., 2024), however numerous studies examining usage habits report that e-scooter users would have walked their journey if an e-scooter was unavailable (Chang and Miranda-Moreno, 2019; Christoforou et al., 2021; Glenn et al., 2020; Kopplin et al., 2021; Sanders et al., 2020). This highlights a potential conflict between EMM as a sustainable transport solution and promoting PA. The World Health Organisation (WHO) highlight an urgent need to address physical inactivity among adults (Bull et al., 2020), as more than a quarter of adults worldwide fail to meet the current PA guidelines of 150 min of moderate-intensity activity per week (Guthold et al., 2018), contributing to a global health phenomenon of 2.1 million preventable deaths per year (Forouzanfar et al., 2016). PA and health implications should therefore be considered in the continued development of e-scooters as an alternative transport option.

Prior health-based research in this field has addressed exposure to air pollution (Khreis et al., 2017), injury rates, and safety concerns (Trivedi et al., 2019). Injury rates and the severity of injuries have been a focus of research and accident data is typically associated with loss of balance during riding, due to rider inexperience (Singh et al., 2022), and riding under the influence of alcohol (Zube et al., 2022). Based on this, literature has suggested that rider reaction time, and balance could be compromised by electric motor acceleration (Zube et al., 2022). However, cognitive function and balance, specifically the impacts on these factors after a period of e-scooter riding, has not been explored.

Furthermore, research has yet to accurately quantify the physical demands of e-scooter riding. Literature suggests that the standing stance required during e-scooter use could contribute to low-level fitness benefits when compared to sedentary behaviour (Healy et al., 2015), but the physiological responses to e-scooter riding when compared to more active forms of transport such as walking are yet to be evidenced. Alternatively, studies have established walking as a mode of active transport that utilises sufficient energy demand to be beneficial to health and well-being compared to passive transport modes (Lee and Buchner, 2008; Audrey et al., 2014; Martin et al., 2014a). Nevertheless, energy expenditure (EE) during e-scooter use has been considered, via predicted METs (López-Dóriga et al., 2022) and using global positioning system (GPS) tracking (Sanders et al., 2022; Bretones et al., 2024) but the actual laboratory measurement of EE, alongside the relationship between e-scooter riding and cognitive control and balance, has yet to be explored. The primary aim of this study was to observe continuous cardiorespiratory responses to e-scooter riding with time-matched walking and a sedentary task (resting) in a controlled laboratory environment, and to use this data to quantify the energy cost of each task.

1.1. Research questions

To achieve the study's aims, the following research questions are addressed.

- How does the energy expenditure (measured as a metabolic equivalent of task) of an acute bout of e-scooter riding compare to walking and resting?
- What are the continuous cardiorespiratory responses associated with e-scooter riding compared to walking?
- How does e-scooter use affect psychological well-being, subjective fatigue, and balance, and how do these outcomes compare to walking?
- Does e-scooter riding influence cognitive performance compared to the effects of walking and resting?

2. Material and methods

2.1. Ethical approval

This study was approved by the School of Sport & Exercise Sciences (University of Kent) Research Ethics Advisory Group (Prop 15_20_22) and conducted in conformity with the Declaration of Helsinki. Written informed consent was provided by participants prior to their voluntary participation.

2.2. Participants

A convenience sample of forty-two healthy participants (25 males, 17 females; mean ± SD: age 29 ± 9 years; height 1.71 ± 0.1 m; body mass 72.5 ± 12.8 kg; body mass index 24.4 ± 3.3 kg/m 2) volunteered to participate in the study. Participants with impaired balance, a body weight ≥120 kg (maximum rider weight as per e-scooter manufacturer guidelines), a medical condition affecting the ability to be physically active, or any other medical condition or current pregnancy were excluded from the study. Before attending the laboratory, participants were instructed to avoid vigorous PA (24 h prior) and abstain from consuming food (3 h), alcohol (12 h) and caffeine (4 h), as these factors have been shown to influence EE.

2.3. Experimental overview

Participants reported to the laboratory (School of Sport and Exercise Sciences, University of Kent) for a single visit. After recording anthropometric data, participants completed baseline measurements of static balance (standing stork test) and cognitive control (Flanker Compatibility Task; see *"Report Instruments"*). Participants then completed 20 min of rest in a supine position, with measures of gas exchange and heart rate (HR) collected for the last 15 min of this period. Following this, participants received instruction on the procedures for mounting, riding, and dismounting the e-scooter (see *"E-scooter"*), and were familiarised with riding the e-scooter whilst mounted on a calibrated motorised treadmill (H-P Cosmos Pulsar treadmill, H-P Cosmos, Germany) with an incremental increase in treadmill speed up to 12 km/h. This approach allowed experimenters to ensure competence, confidence, and safety at lower speeds before reaching the trial speed of 12 km/h. Data was not collected during the familiarisation phase.

Participants completed two trials in a randomised and counter-balanced order, on the treadmill, separated by a 10 min rest period: 1) a walking trial consisting of 15 min of walking on the treadmill at 4.8 km/h, and 2) an e-scooter trial which consisted of 15 min of standing on the e-scooter mounted on the treadmill set at a speed of 12 km/h (See Fig. 1). This speed was selected based on average e-scooter research data, which reports typical speeds of 10–15 km/h in European cities (Gioldasis et al., 2024) and 7–13 km/h in U.S. cities (Huo et al., 2021). After completing each trial, participants dismounted the treadmill and completed the Subjective Exercise Experiences Scale (SEES) alongside tests for static balance and cognitive control. A schematic of the experimental design and protocol is outlined in Fig. 1.

2.3.1. E-scooter

The e-scooter (Pure Air Electric Scooter, 2nd Gen, 500W (maximum) motor, 25 km/h maximum speed, battery capacity 7800 mA-hours, weight 17 kg) was mounted on the treadmill and secured to its frame at the base and top of the handlebar stem using a slack tethered rope (Fig. 2a). Whilst on the e-scooter, participants were required to maintain a set posture for the duration of the trial (Fig. 2b). Participants were instructed to stand upright and facing forward, always keep their hands on the handlebar grips, and place one foot facing forward in a straight line, the other foot positioned behind with slight external rotation (Fig. 2c). Participants were able to determine which foot assumed the leading and rear positions during familiarisation.

2.4. Measurements

2.4.1. Physical activity and cardiorespiratory measures

During the resting, walking and e-scooter trials, breath-by-breath measures of gas exchange were recorded by a calibrated online gas analysis system (Cortex Metalyser 3b, Leipzig, Germany). In addition, heart rate (HR) was recorded every 1 min (min) using a Polar FT1 HR monitor paired with a coded T34 transmitter (Polar HR Monitor, Kempele, Finland). The online gas analysis system was connected to a face mask (7450 V2; Hans Rudolph; Birmingham, UK) worn by the participant, and contained a volume-transducer and impeller turbine that measures the volume of air, with a port for a sample line to measure the content of air. This provided values for minute ventilation (V_E), oxygen uptake (VO_2; absolute and relative to bodyweight) and carbon dioxide production (VCO_2). All gas

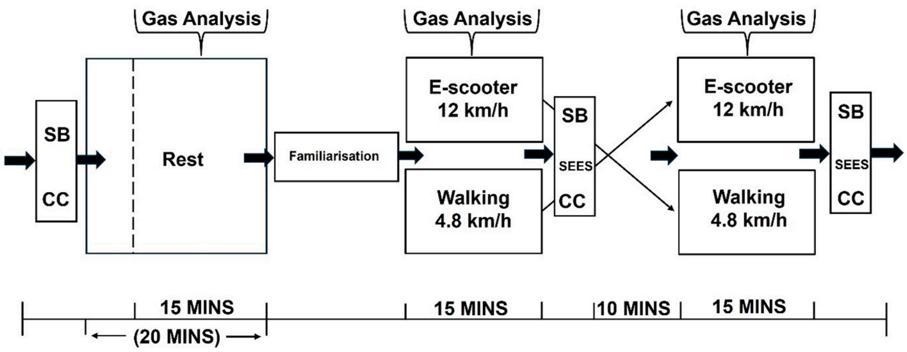

Fig. 1. Schematic overview of the experimental design and procedures. Static balance (SB), cognitive control (CC), subjective exercise experience scale (SEES).

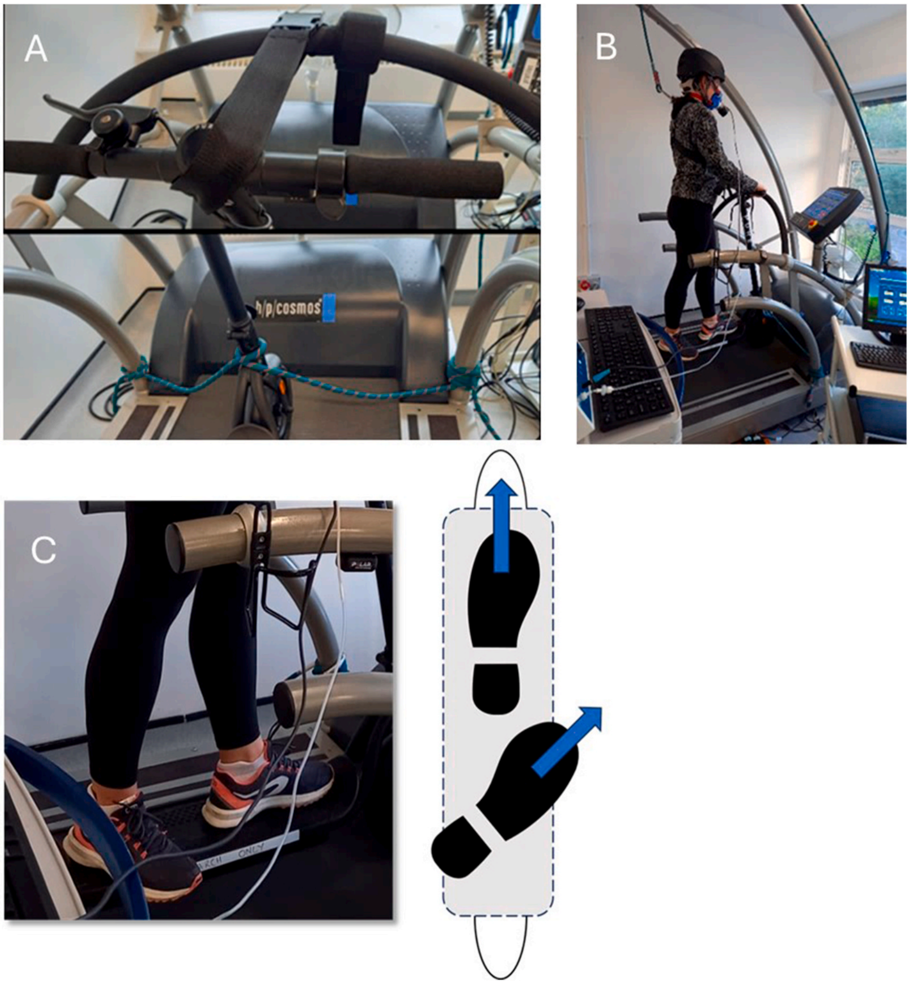

Fig. 2. (a) E-scooter tethered to treadmill frame, (b) Posture and body positioning, (c) Front and rear foot positioning, as chosen by participant during familiarisation.

exchange measurements were initially sampled every 5 s, followed by a moving average of 30 s to smooth and remove variations in the data. Analysis of gas exchange measures focused on 3-min segments across the 15 min of each trial. The Metabolic Equivalent of Task (MET) was calculated by dividing the mean relative VO_2 for each activity by 3.5 (rest = 1.0 MET, walking = 3.7 METs, e-scooter = 1.6 METs), with MET minutes (MET-mins) then determined by multiplying the MET factor computed for each activity by the duration of the activity (15 min) (Jetté et al., 1990; Liguori, 2020).

2.4.2. Static balance test

Participants were required to complete a standing stork test as a measure of static balance. Prior to commencing the test at baseline, the procedure was demonstrated, and the participants were allowed to practice the test. Participants then completed the test on the leg which assumed the rear position on the e-scooter (supporting foot), with the non-supporting foot placed against the inside knee of the supporting leg and hands placed on the hips (Fig. 3a). Participants then raised the supporting foot up onto the ball of the foot and held this position for as long as possible (Fig. 3b). Time measurement started as soon as this position was correctly adopted and stopped if either; the hands came off the hips, the supporting foot swivelled or moved in any direction, the non-supporting foot lost contact with the knee, or the heel of the supporting foot touched the floor (Johnson and Nelson, 1979). The longest (seconds) of three consecutive attempts were taken.

2.5. Report Instruments

2.5.1. Subjective exercise experience scale (SEES)

Immediately after the walking and e-scooter trials, participants completed the Subjective Exercise Experiences Scale (SEES; Mcauley and Courneya, 1994). This 12-item scale is completed using a 7-point Likert-type scale (1 = not at all and 7 = very much so),

Fig. 3. (a) Standing stork balance test ready position, (b) foot raised commences test.

which assesses three general categories of subjective responses to PA stimuli: 1) positive well-being, 2) psychological distress, and 3) fatigue.

2.5.2. Flanker Task

At baseline, and following the walking and e-scooter trials, participants completed the Flanker Task on a computer tablet application (PsychLab101, Neurobehavioral Systems). The display for the task consisted of a fixation point, target zone, target and flanker presented concurrently. Participants were required to identify whether a square or a diamond (target) appeared within one of the four central circles (target zone) by tapping either on the left or right-hand side of the tablet screen, whilst ignoring any distractor shape (flanker) presented peripheral to the target zone (i.e., outside of the circles). The flanker was either compatible (same shape) with the target shape, incompatible (opposing shape) with the target shape, or not present (no flanker). Participants were instructed to respond as quickly and accurately as possible and remained blinded to the results throughout the visit. Measures of mean reaction time and response accuracy were collected for compatible, incompatible and no flanker trials for each condition (baseline, walking, e-scooter), with the compatibility effect (difference in mean reaction time between compatible and incompatible trials; an indicator of attentional capacity) also calculated for each condition.

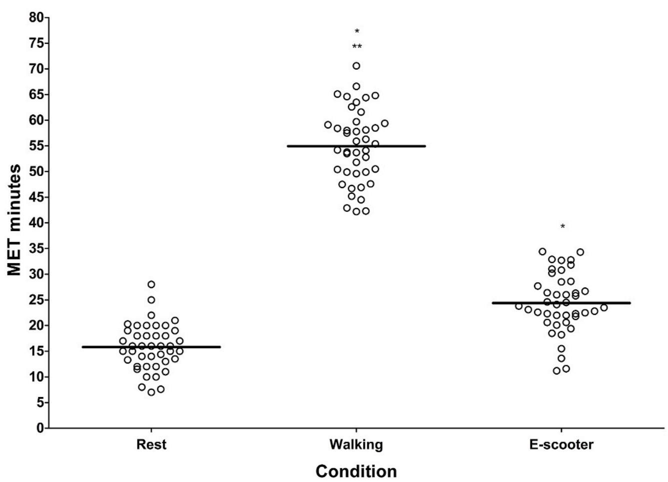

Fig. 4. Metabolic equivalent of task minutes (MET-mins) between conditions: Rest, walking, and e-scooter. Horizontal lines indicate the mean MET-min for each condition and standard deviation (SD). Dots represent per participant (n = 42). *Denotes significantly greater than rest ($P < 0.001$). **Denotes significantly greater than e-scooter ($P < 0.001$).

2.6. Statistical analysis

All data is presented as mean ± standard deviation (SD). Before statistical analysis, all data was checked for the assumptions required for performance of a paired samples *t*-test, a one-way ANOVA, and a repeated measures ANOVA as appropriate. Any data with missing values (HR) were automatically excluded. This ensured that the assumptions of a two-way ANOVA were met, and no outliers were present, as assessed by examination of studentised residuals for values greater than ±3. Data that did not satisfy the Shapiro-Wilk test of normality ($P < 0.05$) were either transformed by logarithm (balance time, no flanker reaction time, V_E, absolute VO_2, VCO_2VO2, VCO2, HR, psychological wellbeing) or were analysed with a non-parametric test (Wilcoxon's signed-rank or Friedman's test). Data that did not satisfy the Mauchly test of sphericity ($P < 0.05$) were analysed with a Greenhouse-Geiser correction. A two-way ANOVA with a treatment factor of three fixed levels (rest, walking trial and e-scooter trial) and a repeated measures time factor of five time-points was used to evaluate measures of gas exchange (V_E, VO_2, VCO_2) and HR recorded during each activity condition. If an interaction was observed, follow-up paired samples *t*-tests were performed with a Bonferroni correction applied. An alpha level of $P < 0.05$ was required for acceptance of statistical significance. All statistics were calculated using SPSS Statistics v28.0 (SPSS, IBM, New York, USA).

3. Results

3.1. Physical activity and cardiorespiratory measures

3.1.1. Metabolic equivalent of task

A one-way repeated measures ANOVA revealed a significant difference between conditions in MET minutes ($F_{2,82} = 1251.9$, $P < 0.001$, $\eta p^2 = 0.968$), with 15 min of walking yielding significantly greater MET minutes (55 ± 7 MET-mins) compared to both resting (15 ± 4 MET-mins) ($t_{41} = 47.8$, $P < 0.001$, $CI_{.95}$ 37.4–40.8, d = 7.38) and e-scooter (24 ± 6 MET-mins) ($t_{41} = 33.6$, $P < 0.001$, $CI_{.95}$ 28.7–32.4, d = 5.18) conditions (Fig. 4.). A difference was also observed between e-scooter and resting conditions ($t_{41} = 11.7$, $P < 0.001$, $CI_{.95}$ 7.1–10.0, d = 1.8).

3.1.2. Minute ventilation (V_E)

A Two-way repeated measures ANOVA highlighted a significant effect of condition ($F_{2,80} = 444.7$, $P < 0.001$, $\eta p^2 = 0.917$) but not

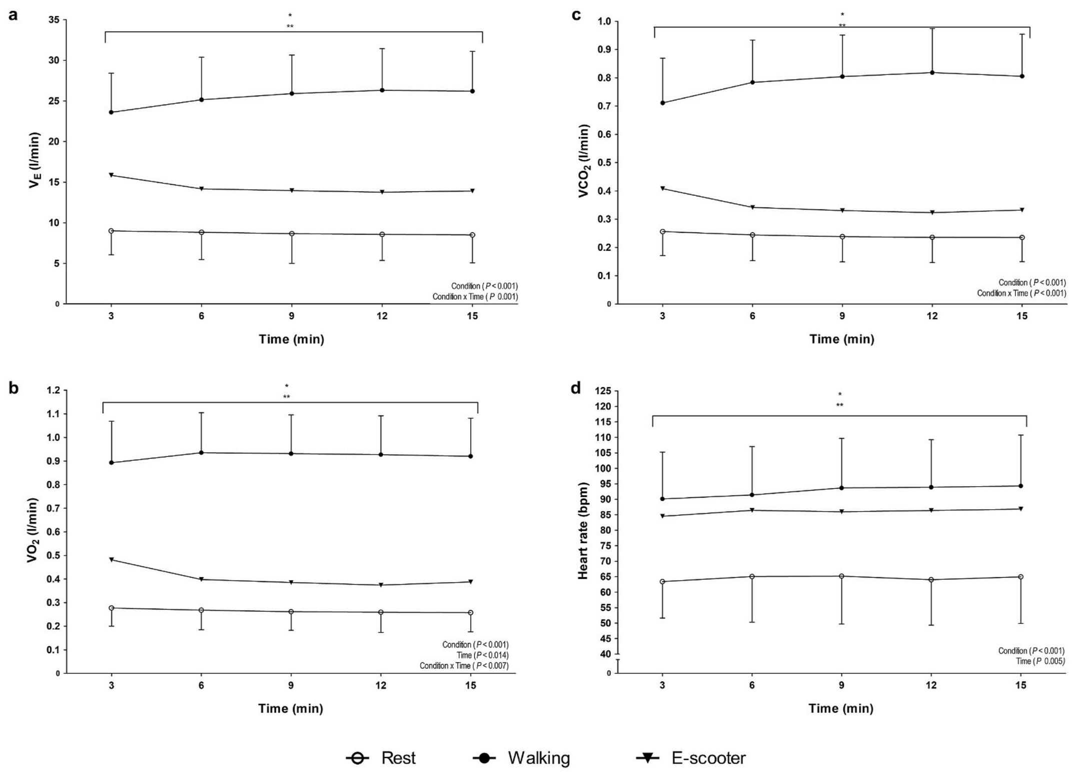

Fig. 5. Cardiorespiratory differences between conditions. Differences in minute ventilation (V_E; **a**), Oxygen uptake (VO_2; **b**), carbon dioxide production (VCO_2; **c**) and heart rate (HR; **d**) over time between conditions. *Denotes significantly greater during walking compared to both e-scooter and rest. **Denotes significantly greater during e-scooter compared to rest.

time ($F_{4,\ 160} = 0.891$, $P = 0.471$, $\eta p^2 = 0.022$) for V_E (Fig. 5a). A significant interaction effect for V_E over time between conditions was also observed ($F_{6,\ 240} = 4.3$, $P < 0.001$, $\eta p^2 = 0.099$). Follow-up simple main effects testing of condition revealed that V_E was significantly greater during walking than resting and e-scooter activity at all time points ($P < 0.001$). V_E was also significantly higher during e-scooter activity compared to rest across all time points ($P < 0.001$).

3.1.3. Absolute oxygen uptake (VO_2,)

A 3 × 5 (condition × time) two-way repeated measures ANOVA highlighted a significant effect of condition ($F_{1.6,\ 62.5} = 686.7$, $P < 0.001$, $\eta p^2 = 0.946$) and time ($F_{3.1,\ 123.1} = 3.614$, $P < 0.014$, $\eta p^2 = 0.085$) for absolute VO_2 with a significant interaction effect also observed ($F_{5.1,\ 200.7} = 3.266$, $P < 0.007$, $\eta p^2 = 0.077$). Follow-up simple main effects testing of condition revealed that VO_2 was significantly greater during walking than resting and e-scooter activity at all time points ($P < 0.001$). VO_2 was also significantly higher during e-scooter activity compared to rest at all time points ($P < 0.001$) (Fig. 5b).

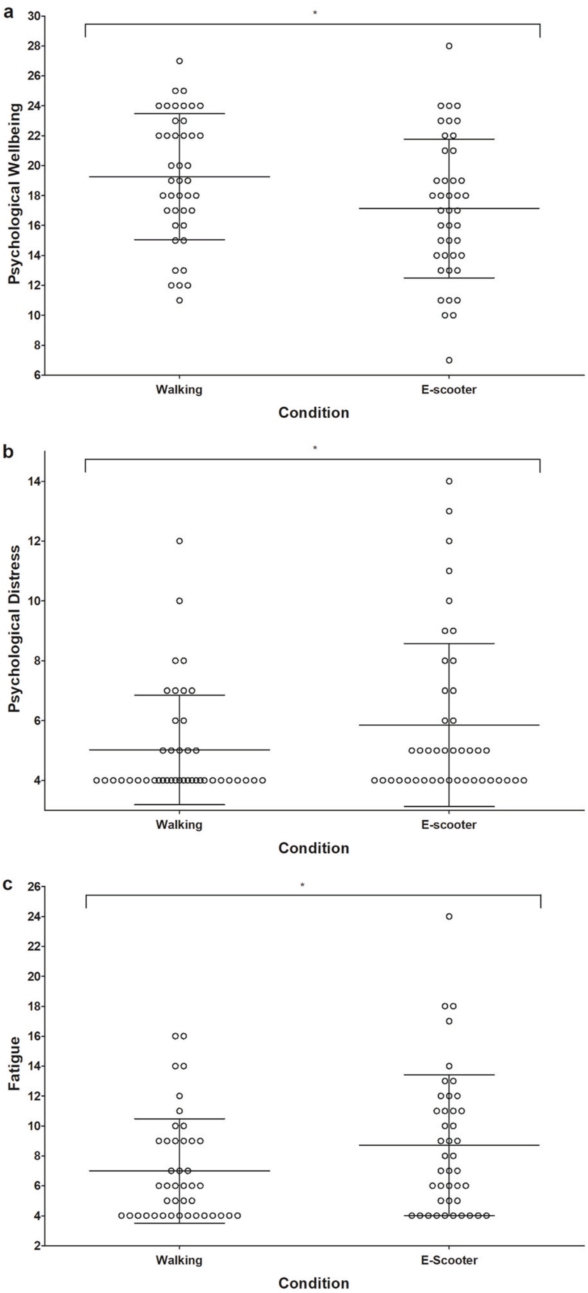

Fig. 6. Subjective Exercise Experience Scale for conditions: Walking and E-scooter trials. Horizontal lines indicate the mean for each condition and standard deviation (SD). Dots represent per participant (n = 42). *Denotes difference between conditions ($P < 0.05$).

3.1.4. Volume of carbon dioxide (VCO_2)

The 3 × 5 (condition × time) repeated measures ANOVA demonstrated a significant effect of condition ($F_{1.4,\ 55.7} = 385.5$, $P < 0.001$, $\eta p^2 = 0.908$) but not time ($F_{3.1,\ 122.1} = 2.203$, $P = 0.088$, $\eta p^2 = 0.053$) for VCO_2 with a significant interaction effect observed ($F_{8,\ 312,} = 16.638$, $P < 0.001$, $\eta p^2 = 0.299$). Follow-up paired-sample t-tests revealed that VCO_2 was significantly greater during walking than resting and e-scooter activity at all time points ($P < 0.001$), with VCO_2 also significantly higher during e-scooter activity compared to rest at all time points ($P < 0.001$) (Fig. 5c).

3.1.5. Heart rate

The 3 × 5 (condition × time) repeated measures ANOVA demonstrated a significant effect of condition ($F_{1.651,\ 49.5} = 94.619$, $P < 0.001$, $\eta p^2 = 0.759$) and time ($F_{2.385,\ 71.5} = 5.305$, $P = 0.005$, $\eta p^2 = 0.150$) for HR. No significant interaction effect was observed ($F_{3.406,\ 102.1} = 1.186$, $P = 0.320$, $\eta p^2 = 0.038$). Pairwise comparisons revealed that walking (93 ± 16 bpm) was significantly greater than baseline resting (65 ± 14 bpm, $P < 0.001$) and e-scooter (86 ± 18 bpm, $P = 0.002$). The pairwise comparison also revealed e-scooter was significantly greater than baseline resting ($P < 0.001$) (Fig. 5d).

3.2. Static balance

A Friedman's ANOVA revealed no significant difference between baseline resting, walking and e-scooter conditions ($\chi^2_F(2) = 1.762$, $P = 0.414$).

3.3. Subjective Exercise Experiences Scale

A paired sample *t*-test revealed significantly greater psychological well-being ($t_{41} = 4.20$, $P = 0.001$, $CI_{.95}$ 1.1–3.1 $d = 0.648$) post walking (19.2 ± 4.1) compared to e-scooter (17.1 ± 4.5) trial (Fig. 6a). A Wilcoxon Sign-Rank test indicated that psychological distress ($Z = -2.058$ $P = 0.040$) was significantly lower post-walking (5.0 ± 1.8) compared to e-scooter (5.8 ± 2.6) (Fig. 6b). A Wilcoxon Sign-Rank test also revealed that fatigue ($Z = -2.2$, $P = 0.023$) was significantly greater after e-scooter (8.7 ± 4.6) compared to walking (7.0 ± 3.4) (Fig. 6c).

3.4. Cognitive

A Friedman's ANOVA test showed there was a significant difference in compatible accuracy (χ^2_F (2) = 10.42, $P = 0.005$) and reaction time (χ^2_F (2) = 24.8, $P = 0.001$). Pairwise comparisons were performed with a Bonferroni correction for multiple tests. They demonstrated no significant differences between conditions for accuracy ($P > 0.05$), but significantly faster compatible reaction times after walking (542 ± 106 ms) compared to baseline resting (630 ± 150 ms, Z = 4.9, $P < 0.05$), walking compared to after e-scooter (561 ± 119 ms, Z = 2.5, $P = 0.031$), and after e-scooter compared to baseline resting (Z = 2.4, $P = 0.049$).

A Friedman's ANOVA test revealed no significant difference in incompatible accuracy (χ^2_F (2) = 2.51, $P = 0.285$), but there was a significant difference in incompatible reaction time (χ^2_F (2) = 13.65, $P = 0.001$). Pairwise comparisons were performed with a Bonferroni correction. They demonstrated significantly faster incompatible reaction times after walking (584 ± 109 ms) compared to baseline resting (735 ± 435 ms, Z = 3.2, $P = 0.004$), and after e-scooter (588 ± 119 ms) compared to baseline resting (Z = 3.1, $P = 0.005$). There was no significant difference between walking and e-scooter (Z = 0.55, $P = 1.000$).

A Friedman's ANOVA test showed a significant difference in accuracy with no flanker (χ^2_F (2) = 6.54, $P = 0.038$). Pairwise comparisons were performed with a Bonferroni correction for multiple tests. They demonstrated no significant differences in conditions for accuracy with no flanker ($P > 0.05$). An ANOVA revealed a significant difference between conditions in reaction time with no flanker ($F_{1.5,61.7} = 14.4$, $P < 0.001$, $\eta p^2 = 0.261$). Follow-up paired sample t-tests with a Bonferroni-adjusted alpha level revealed no significant difference in non-flanker reaction times after e-scooter compared to walking ($P > 0.05$). There was a significant difference in non-flanker reaction times after baseline resting (598 ± 158 ms) compared to e-scooter (531 ± 94 ms) ($t_{41} = 4.028$, $P = 0.01$, CI_{95} 0.21–0.65, $d = 0.621$) and baseline resting compared to walking (529 ± 88 ms) ($t_{41} = 4.173$, $P = 0.01$, CI_{95} 0.023–0.68, $d = 0.64$).

A Friedman's ANOVA test revealed no significant difference in compatibility effect accuracy (χ^2_F (2) = 5.05, $P = 0.081$) and reaction time (χ^2_F (2) = 3.964, $P = 0.138$) between conditions.

4. Discussion

This is the first study to monitor the continuous physiological responses to e-scooter riding in a controlled laboratory setting to accurately quantify the energy cost of this activity. Our analysis of gas exchange measures and continuous HR monitoring has revealed that e-scooter riding requires significantly less energy demand and has lower cardiorespiratory output compared to active transport in the form of walking. In addition, the study measured no effect of acute e-scooter use on static balance and cognitive tests revealed no adverse effects from e-scooter use. However, an unfavourable psychological response was revealed in comparison to walking. These findings suggest that the activity of riding an e-scooter should not be considered to elicit the same magnitude of physiological and psychological benefits associated with PA.

METs were used to assign an intensity value for each activity (walking and e-scooter), with MET minutes calculated as a measure of total EE. PA guidelines recommend that to maintain and enhance health, a combination of both moderate (3.0–6.0 METs) and vigorous intensity (6.0 METs) activities should be performed to accumulate an EE of 600–1200 MET-mins per week (López Sánchez et al., 2022).

Studies that have examined the physical contribution of e-scooter riding have proposed riders are required to balance and maintain a fixed upright posture (López-Dóriga et al., 2022). Others have raised concerns about the potential health risks associated with whole-body vibrations experienced within the static stance during riding (Cano-Moreno et al., 2021). Therefore, it is plausible that e-scooter use carries some physiological demand greater than seated, inactive forms of transport, however proposals that e-scooter use elicits a similar MET value to active forms of transport (i.e. walking; López-Dóriga et al., 2022) are discredited.

The present study revealed that walking at a pace of 4.8 km/h on a treadmill without incline expended 3.7 METs (a moderate intensity activity, >3.0 METs), the equivalent of 55 MET-mins. Riding an e-scooter on a treadmill at 12 km/h expended 1.6 METs (a light intensity activity, <3.0 METs), equivalent to 24 MET-mins, and laying down resting expended 1.0 MET, the equivalent to 15 MET-mins. This suggests riding an e-scooter expends fractionally greater METs than driving a car and riding public transport (1.3 METs, Ainsworth et al., 2011) but less than conventional cycling (8 METs) and e-bike riding (4–7 METs) (Berntsen et al., 2017; Gojanovic et al., 2011; Haskell et al., 2007). The calculated MET value for a bout of e-scooter riding presented here, under laboratory conditions, is significantly less than the 3.5 MET value assigned by López-Dóriga et al. (2022), highlighting that, contrary to previous estimations, e-scooter riding and walking do not elicit equivalent EE. As a further comparison, cardiorespiratory values (V_E, VO_2, VCO_2) were lower across all time points when riding the e-scooter compared to walking. However, it is acknowledged that whilst the laboratory-based trial in the present study allowed for good experimental control, a field-based test might provide values more reflective of natural e-scooter usage and would therefore have greater ecological validity.

López-Dóriga et al. (2022) conducted a health impact assessment of EMM and considered PA (via predicted METs), air pollution, and morbidity and mortality outcomes including road traffic fatality records. The study predicted that adoption of EMM to replace seated motorised travel would reduce morbidity-associated fatalities, by increasing PA. However, an increase in fatalities is predicted in shifting from active transport to EMM (López-Dóriga et al., 2022). If the MET value of e-scooter riding measured within the present study (1.6 METs) was applied to a revised health impact assessment, there could be an increase in health-related predicted fatalities and increased potential health disparity between e-scooter usage compared with active modes of transport. Whilst our research examines an acute bout of walking or e-scooter riding, intended to emulate an average journey undertaken, the view that e-scooter use does not incur an energetic cost comparable to active transport is supported by Sanders et al. (2022) and Bretones et al. (2024). Their longitudinal study used GPS activity trackers to compare EE of different transport modalities (e.g., walking, electric bicycle, bicycle, e-scooter, automobile, public transport) and determined that e-scooter use was approximately as active as automobile trips. Taken together and considering the scale of uptake in some cities (Sanders et al., 2020) there is further rationale to apply caution against overestimating energetic cost of EMM travel.

The requirement to maintain balance was also considered due to the static riding position and the potential for whole-body vibrations to cause fatigue, discomfort, and impaired postural stability (Cafiso et al., 2022; Cano-Moreno et al., 2021). Although discomfort was not measured within this study, the 15-min continuous bout of e-scooter riding did not induce a loss in static balance as measured by the standing stork test, indicative that the demands of riding an e-scooter within the measured usage duration were no more fatiguing to participant balance than the time-matched period of walking. Further research using surface electromyography to monitor the activation of the muscles involved in maintaining e-scooter posture is required to offer a more conclusive comparison to other activities.

Regular active travel and active commuting has a positive effect on wellbeing and is viewed more favourably than public transport (Martin et al., 2014a). Existing e-scooter research has suggested enjoyment as a key benefit for habitual users, and a primary reason for using an e-scooter (Kopplin et al., 2021). However, the findings presented here demonstrate a significant difference in SEES scores (Mcauley and Courneya, 1994) following walking and e-scooter activities in a laboratory setting. Higher psychological well-being and lower psychological distress following walking compared to e-scooter riding supports established acute psychological health benefits associated with being active (Friman et al., 2017). It is well acknowledged that regular PA is associated with chronic psychological well-being (World Health Organization, 2019), a notion that should be considered in promoting a transportation solution that could potentially reduce PA levels and associated mental health benefits.

Milakis et al. (2020) suggested elevated perception of safety risk could also negatively influence mood. Although mood was not directly measured in the present study, a significantly lower psychological well-being post e-scooter trial could be related to perceptions of safety, in that 73% of participants were novice e-scooter users. Combined with the environmental constraints during the e-scooter trial in a controlled laboratory setting, this may have negatively affected subjective well-being compared to the walking trial. Kopplin et al. (2021) indicated that non-owners can be more sensitive to the safety risks of riding e-scooters in comparison to e-scooter owners, suggesting that increased experience and confidence in riding an e-scooter may reduce perceived safety concerns. When a sample ($n = 8$) of regular e-scooter users were required to avoid using a scooter, 75% of users said they did not enjoy travelling as much (Sanders et al., 2022), suggesting enjoyment of the activity could develop over time, or that riders who did not enjoy or feel safe during the activity, did not tend to adopt regular usage habits. Further exploration into the acute psychological effects of e-scooter use, perceived risks, and comparison between habitual and novice users is needed.

E-scooter riders use public highways and cycle paths, yet in contrast to motor vehicle licence requirements, there is no requisite for users to demonstrate cognitive capabilities to use the road, such as reaction time or hazard perception. Therefore, reaction time was measured at baseline and following walking and e-scooter trials, to determine if e-scooter riding and the associated continuous concentration influenced cognitive ability compared with after walking and baseline. Results revealed no negative effects of e-scooter use on accuracy and reaction times compared to baseline, suggesting that following an average usage period riders maintain normal cognition.

5. Conclusion

This laboratory study has enabled the controlled measurement of energy expenditure for the activity of e-scooter riding, an activity which has been estimated yet not quantified prior to this study. Unique to the laboratory is the ability to standardise terrain and other variables, however it is acknowledged that findings of the present study may not be fully representative of authentic e-scooter use in an outdoor environment. For example, variables such as weather and terrain could result in different outcomes, whilst the laboratory setting may not be able to adequate capture the cognitive and psychological responses typically experienced with the more natural and complex outdoor conditions. However, any variations in EE outdoors are likely negligible, and the potential EE from walking would still exceed that evidenced through e-scooter use.

Based on the findings presented here, we support the notion that acute e-scooter use cannot be considered to elicit health benefits and is not active travel. As such, prolonged and frequent use of e-scooters as an alternative to active transport could result in a decline in PA, be detrimental to long-term public health and therefore not be recommended (López-Dóriga et al., 2022; Sanders et al., 2022). PA is associated with reduced risk of non-communicable diseases, as well as psychological health benefits (World Health Organization, 2019), yet 36.8% of people in high-income countries remain insufficiently active (Guthold et al., 2018), and physical inactivity is a globally acknowledged health concern (Bull et al., 2020).

Governments worldwide have implemented policies to promote health-enhancing PA (Breda et al., 2018), however, this has occurred during a time when e-scooters have been shown to predominantly replace active modes of transport (Chang and Miranda-Moreno, 2019; Christoforou et al., 2021; Glenn et al., 2020; Kopplin et al., 2021; Sanders et al., 2020). Increasing EMM transport infrastructure appears counterproductive within a health agenda, especially as recognised active transport has been linked to Health-enhancing PA for over twenty years (Oja et al., 1998; WHO, 2002). The gap between existing transport provision and the first-last mile, connecting traditional public transport to end destination, presents an ideal opportunity to promote active transportation. This could include the strategic placement of shared EMM to encourage walking as part of the user experience, as well as a responsibility of shared EMM providers and local authority to notify users of the activity implications of their transport choices. Collectively, transport policy and provision should focus investments on creating safe, sustainable, appealing environments for an inclusive travel experience (Oja et al., 1998; Kazemzadeh and Sprei, 2024).

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CRediT authorship contribution statement

Christopher Payne: Writing – review & editing, Writing – original draft, Project administration, Investigation, Formal analysis, Data curation. **Samuel A. Smith:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Ashleen Sappal:** Writing – original draft, Project administration, Investigation, Data curation. **Rushil Boorgula:** Writing – original draft, Project administration, Investigation, Data curation. **Katrina A. Taylor:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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