The next step: the influence of acute exercise on cognitive function during locomotive goal-directed behaviour

Submitted by

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MSc. (1st Class Hons)

January 2016

A thesis submitted in fulfilment of the requirements of the degree

Doctor of Philosophy

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ABSTRACT

In the performance of goal-directed behaviour, multiple attributes of cognitive function have been investigated. A core confounding factor, however, is that aspects of cognitive function have predominantly been evaluated employing seated or supine paradigms that are not representative of activities of daily living. Therefore the purpose of this PhD thesis was to evaluate differences in and the influence of acute bouts of exercise on cognitive function and gaze behaviour incorporating whole body movement and behaviour. In study 1, a locomotive task was designed and validated to evaluate differences in gaze behaviour during single- and dual-task performance. In study 2, the validated locomotive paradigm was utilised to evaluate differences in neural activity, specifically the N2 and P3 event-related potentials (ERPs) and in study 3, the effects of acute bouts of exercise (aerobic versus resistance) on single- and dual-task performance and neural activity (N2 and P3 ERPs) were evaluated using the locomotive paradigm. A unique aspect of these studies was capturing electroencephalographic (EEG) data during whole body movement and behaviour leading towards a more real world application. Results included: 1) validation of the locomotive paradigm and successful collection of gaze behaviour during single- and dual-task performance, with significant differences in time to complete the single- versus the dual-task, and significant differences in gaze behaviour being observed; 2) successful collection of neural activity using the validated locomotive paradigm, with significant differences in time to complete the single- versus the dual-task, but no significant task related differences in neural activity being observed; and 3) successful collection of behavioural (time to complete single- and dual-tasks) and neurophysiological (neural activity, specifically the N2 and P3 ERP components during single- and dual-task performance) before and after an acute bout of aerobic versus resistance exercise, with significant differences being observed in both

behavioural and neurophysiological measures relating to task difficulty and exercise intervention. An association was also observed between behavioural and neurophysiological measures and the influence of exercise and a significant difference in the effect of aerobic versus resistance exercise. The results are discussed within the context of current research that has examined visual attention and performance, neural activity focusing on single- and dual-task performance, the N2 and P3 ERP neural components and both behavioural and neurophysiological research that has investigated the influence of acute bouts of exercise on cognitive function. In conclusion, the body of work outlined provides evidence to support the use of the locomotive paradigm to evaluate measures of task-related differences in trial completion time, gaze behaviour, and neural activity. Further, behavioural improvements were associated with acute bouts of moderate intensity exercise; however, the underlying changes in the spatiotemporal patterns of neural activity differed as a consequence of the different exercise bouts. This is in specific reference to the enhanced allocation of attentional resources (aerobic) and neural efficiency (resistance).

DECLARATION

I, Shelley Jane Duncan, declare that the PhD thesis entitled “The next step: the influence of acute exercise on cognitive function during locomotive goal-directed behaviour” is no more than 100,000 words in length, exclusive of tables, figures, appendices, references and footnotes. This thesis contains no material that has been submitted previously, in whole part, for the award of any other academic degree or diploma. Except where otherwise indicated this PhD is my own work.

Signature Date 14 January 2016

ACKNOWLEDGEMENTS

This thesis would not have been possible to put together if it weren't for the help of many others. This part is an attempt to acknowledge and thank those people.

To my principal supervisor Prof Remco Polman, thank you for taking me on as a PhD student. Thank you for your unwavering support and belief in my ability and capacity to fulfil the requirements of my PhD, and enabling me to develop and pursue my passion within the Neuroscience field of research. Without you, I would not have had the opportunities I experienced throughout my PhD. To my co- supervisor Dr Derek Panchuk, words cannot fully articulate the gratitude I have for your ongoing support, guidance and faith you have had in me. You have provided at times a much needed calming influence and helped me keep my feet on the ground. Your guidance and ability to teach and help me develop my research skills, especially my writing skills was gentle, honest and I had complete faith and trust that you were pushing me in the right direction and helping me develop my academic self-confidence.

To Dr Jacqueline Williams, you were my colleague, friend and someone with whom I hold in the utmost regard. You have been my sounding board and mentor and I will continue to strive to be as ethical, professional and kind in the manner with which I will conduct myself as you have been. To Dr Angela Gosling, my neuroscience saving grace. I am eternally grateful for your generous nature and willingness to guide and teach me the ropes in terms of EEG data analysis, interpretation and write up. I don't know where I would be without you. To Rob Stokes and Rhett Stevens, Victoria Universities technical geniuses, without the two of you, my research design would not have been achievable. To my fellow office mates, Georgia, James, Ewout, Tim and Simone, I could not have asked for a better group of people to experience my PhD with. Thank you for your support, banter, laughs and willingness to help me with my research. To my fellow PhD's, Tom, Chris, Cian, Vicky and

Ramon words can’t express, how grateful I am for the support and help you have given me over the past four years and some fun times. To my two amazing research assistants Luca and Rachel, you made my data collection so much easier, thank you for being so supportive and reliable.

To all the participants throughout the three interventions in this thesis, thank you so much for your contribution, without you this PhD would have been impossible. To my family, particularly mum, Sara, Lucy, Jillian, Dave, the Corkin’s/Clark’s and Chandlers, thank you for all the support, kind words and encouragement throughout this time. Thanks for your patience, tolerance and comedy about the fact that you no longer understand my work. Everything you have done has made writing this thesis much easier. Last but not least I need to thank Agnes, who started off as the EEG equipment representative and became my sounding board and friend, thank you for all the constant support, problem solving and helping me remain sane throughout the past three years.

ABBREVIATIONS

BDNF	Brain derived neurotrophic factor
CNS	Central nervous system
SPL	Superior parietal lobule
HAROLD	Hemispheric asymmetry reduction in older adults
EEG	Electroencephalography
fMRI	Functional magnetic resonance imaging
MEG	Magnetoencephalography
EOG	Electrooculographic
EMG	Electromyographic
ECG	Electrocardiographic
ICA	Independent component analysis
PCA	Principal component analysis
LORETA	Low-resolution electromagnetic tomography
sLORETA	Standardised low-resolution electromagnetic tomography
ERP	Event-related potential
ISI	Inter-stimulus interval
QE	Quiet eye
GPS	Global positioning system
RPE	Rating of perceived exertion
HR_{max}	Heart rate maximum
VO_2 max	Maximum oxygen uptake
1 RM	One repetition maximum
10 RM	Ten repetition maximum

AT	Anaerobic threshold
W	Watts
$W.min^{-1}$	Watts per minute
n	Number
M	Mean
µV	Microvolts
kΩ.	Kiloohm
Hz	Hertz
m	Meter
m/sec	Meters per second
cm	Centre meters
mm	Millimetre
^{o}	Degree
s	Second
min	Minute
ms	Milliseconds
LMM	Linear mixed modelling
CI	Confidence interval

PUBLICATIONS AND PRESENTATIONS

This thesis is supported by the following publications and conference presentations:

Papers submitted for publication

1. *Duncan, S.*, Panchuk, D., & Polman, R.: "Validation of a new locomotive single-dual-task paradigm to evaluate task related differences in gaze behaviour and neural activity. Under review in the Journal of Psychophysiology
2. *Duncan*, S., Panchuk, D., & Polman, R.: "Comparison of acute aerobic and resistance exercise on brain mechanisms associated with single- and dual-tasks during locomotion". Under review in the Frontiers of Neuroscience Journal

Conference presentations

1. *Poster Presentation (awarded second prize)* - *Duncan, S.*, Panchuk, D., & Polman, R.C.J. (2014). Brain mechanisms associated with single and dual-tasks during locomotion. Institute of Sport, Exercise and Active Living (ISEAL) Higher Degree by Research Students Conference, December 2014, Melbourne, Australia
2. *Poster Presentation* - *Duncan, S.,* Panchuk, D., & Polman, R.C.J. (2014). Brain mechanisms associated with single and dual-tasks during locomotion. 12th International Conference on Cognitive Neuroscience, 27-31 July, Brisbane, Australia
3. *Oral Presentation* - *Duncan, S.*, Schneider, S., Panchuk, D., & Polman, R.C.J. (2015). The moderating effect of acute bouts of exercise and physical fitness on brain activity during locomotion" –20th Annual Congress of the European College of Sport Science (ECSS), Malmo, June 2015.

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Chapter One

Introduction

Over the course of the lifespan the human brain and body experience an array of changes. This includes the aging process, the influence of illness and disease and the impact of physical fitness and acute (single) bouts of exercise (Angel, Fay, Bouazzaoui, & Isingrini, 2011; Hogan et al., 2013; Wylie et al., 2009). A decline in the human brain is reported to occur from the third decade in life (Colcombe et al., 2006), which results over time, in the progressive loss of the ability to perform activities of daily living (Chou, Hwang & Wu, 2012). Consequently, a key focus of exercise physiology, psychology and neuroscience research has been to develop a better understanding of these changes and of normal development and aging to measure decrements in performance, and design interventions that will attenuate these decrements and improve overall physical and cognitive function (Colcombe et al., 2006).

Of specific interest is age-related decline in sensorimotor control and function, which have been linked to decrements in fine motor control, gait, and balance (Verbrugge & Jette, 1994). To obtain a more comprehensive insight into these differences and deficits, researchers have employed an array of paradigms to evaluate varying aspects of cognitive and motor performance. These include the study of differences in gait patterns during the performance of walking tasks of increasing difficulty. For example walking around a track (easy task) and walking around a track and avoiding obstacles along the route (complex task), which requires both locomotive navigation (primary task), and also pre-emptive strategies (secondary task) to avoid tripping or falling (Li, Lindenberger, Freund, & Baltes, 2001). This type of paradigm typically falls under the category of a dual-task, which incorporates the simultaneous execution of two tasks, for example a motor (primary) and cognitive (secondary) task. In the performance of activities of everyday function (e.g., driving and

navigation whilst walking), the capacity to dual-task is of primary importance (Li et al., 2001). Further, with the apparent dual-task costs associated with aging becoming more prominent (Mendelson, Redfern, Nebes, & Jennings, 2010), there is a drive to develop interventions to attenuate these deficits and improve overall cognitive and physical function (Córdova, Silva, Moraes, Simões, & Nóbrega, 2009; Forte et al., 2013). Therefore, for the purpose of this thesis, the two main concepts that will be discussed and manipulated are that of dual-tasking and the relationship between cognitive function and exercise, specifically of an acute nature.

Dual-tasking

A component fundamental to activities of daily living is cognitive processing, including visuomotor coordination (Goodale, 2010; Land & Hayhoe, 2001). For example, the reception, integration and processing of sensory information, that informs goal-directed behaviour. This includes processing of multiple stimuli at one time including a variety of exogenous and endogenous sources of information (Findlay, 2009). The integration of vision and motor performance is specifically pertinent in the efficient and effective hand-eye coordination and performance of time-stressed activities that require tight coupling between vision and action (Land & McLeod, 2000; Panchuk, Davids, Sakadjian, Macmahon, & Parrington, 2013) like catching a ball in flight or a falling glass before it hits the ground.

The difficulty in performing a dual-task is associated with the reduced capacity to maintain the continuous coordination and integration of visual, proprioceptive, and vestibular sensory information (Lindenberger, Marsiske, & Baltes, 2000). Another key factor of dual-task performance is the allocation of attentional resources to manage the simultaneous execution of both cognitive and motor tasks. With older, in comparison to younger, adults prioritising a motor task over a cognitive task, for example walking safely over engaging in a conversation (Li et al., 2001). This type of simple, compared to complex, task performance

has also been evaluated using brain functioning technology, which has shown that younger, compared to older, adults use more widespread regions of the brain for motor function, namely the prefrontal cortex (working memory) and basal ganglia (initiation/control of movement) networks (Seidler et al., 2010). With the advance in brain imaging technology (i.e., functional magnetic resonance imaging and electroencephalography), the complex nature of the brain's structure and function can be evaluated, including assessment of spatial (location of activity) and temporal (time course of information processing) patterns of activity and how these relate to goal-directed behaviour. Furthermore, differences between younger and older adult populations and how different interventions (e.g., pharmacological and exercise) can influence and alter the brain's function can be examined.

Cognitive function and exercise

The evidence relating to the positive influence aerobic exercise has on cognitive function is substantial. Exercise is reported to promote improvements in processing speed and executive functioning (Smith et al., 2010), and both structural and functional changes (Thomas, Dennis, Bandettini, & Johansen-Berg, 2012), including increases in brain activation (Colcombe et al., 2004), cerebral blood flow (Pereira et al., 2007), connectivity (Voss et al., 2010), and increases in brain volume, specifically in both the grey and white matter regions (Colcombe et al., 2006). These exercise-induced changes, specifically improvements in aspects of cognitive function, are also attributed to state arousal (Dietrich & Audiffren, 2011), which is reported to influence the allocation of attentional resources (Audiffren, Tomporowski, & Zagrodnik, 2008), consolidation of memory (McGaugh, 2006), and increases in neurochemicals such as epinephrine (Cahill & Alkire, 2003), and brain derived neurotrophic factor (BDNF) (Gomez-Pinilla, Vaynman, & Ying, 2008), which facilitate memory consolidation and learning (Roig, Skriver, Lundbye-Jensen, Kiens, & Nielsen, 2012).

Aerobic exercise is also suggested to be related to a neuro-protective mechanism, reducing the risk of age-related decline in cognitive function (Karp et al., 2006). However, a complicating factor in the use of exercise to promote changes in physical (i.e., muscle atrophy and bone fragility) and cognitive (i.e., perception, working memory and decision making) function is the multiple dynamics of any exercise intervention, which can be manipulated. These include the mode, intensity and duration of exercise. Consequently, multiple interventions have been employed to evaluate and measure exercise-induced changes in physical and cognitive function (e.g., Chang & Etnier, 2009b; Forte et al., 2013). Most research to date has evaluated the influence of both long-term and acute (single bout) interventions on cognitive function, employing aerobic exercise (e.g., Audiffren et al., 2008; Voss et al., 2010). There is also a growing body of research that has investigated resistance based exercise (e.g., Chang, Etnier, & Barella, 2009; Hsieh, Chang, Hung, & Fang, 2016). However, there is no research that has evaluated the influence of resistance based exercise on dual-task related spatial and temporal patterns of neural activity.

Two key aspects of any exercise intervention are that of intensity and duration, specifically in the context of acute bouts of exercise. Of note, is aerobic exercise of an acute, moderate sub-maximal intensity of 30–60 min, which is reported to have a positive effect on cognitive performance (Tomporowski, 2003). These findings are further supported in the assessment of acute bouts of resistance exercise, where a 45 min bout of moderate intensity (75% of the theoretical 1 repetition maximum (1RM) for 2 sets of 10 repetitions of 6 exercises) promoted improvements in both automatic cognitive processes, in particular executive function associated with Stroop task performance in middle-aged adults (Chang & Etnier, 2009a). From a behavioural perspective, such as assessments of reaction type tasks and ability to inhibit an incorrect response (modified flanker task), both aerobic and resistance exercise have proven to be beneficial in both attenuating decrements associated

with the performance of more cognitively demanding tasks (i.e., dual-tasks) and improving goal-directed behaviour (Chang, Tsai, Huang, Wang, & Chu, 2014; Pesce & Audiffren, 2011). However, from a neurophysiological perspective, specifically in relation to neural activity within the brain, only acute aerobic exercise has been examined (Kumar et al., 2012; O'Leary, Pontifex, Scudder, Brown, & Hillman, 2011).

The exercise-induced influence on cognitive functioning, in particular executive control processes, has mainly been demonstrated in a controlled laboratory environment. An important limitation of many of these assessment strategies is that they have been used in tasks that are stationary (supine or seated) and are not representative of many activities of daily living. Given that most tasks happen in environments far more dynamic than the laboratory, at some point we need to let people move freely so we can obtain a better understanding of cognitive processes that underlie how people perform in the real-world, with whole body movement, performing various tasks and processing multiple sources of information at the same time.

Purpose

There is a vast array of current literature that has individually investigated visual attention, dual-task performance, neural activity related to information processing, and the effects of acute exercise. There is however a need for a more holistic approach which incorporates the moderating effects of exercise upon cognitive function during goal-directed behaviour incorporating whole body movement. This research provides both a behavioural (i.e., task completion time) and neurophysiological (i.e., neural activity) assessment of determining the moderating effect of an acute bout of aerobic compared to resistance exercise on locomotive goal-directed behaviour. The key aims of this research were:

1. Design a locomotive single- and dual-task paradigm to evaluate gaze behaviour and neural activity in the performance of goal-directed behaviour.

2. Evaluate whether an acute bout of aerobic versus resistance exercise can influence single- and dual-task completion time and alter key aspects of neural activity related to sensory integration and decision making.

Chapter Aims:

Chapter 2: Literature review

This chapter provides a review of the existing literature which forms the basis of this thesis. The chapter will introduce an overview of cognitive function, specifically performing tasks of increasing difficulty and define and discuss the performance of single- and dual-tasks. Visuomotor coordination and the evaluation of gaze behaviour will be discussed, with specific focus on sensory information integration and goal-directed behaviour. Neural activity and measures employed to evaluate temporal patterns of neural activity in addition to event-related potentials will be outlined. The influence of exercise, specifically acute bouts of aerobic and resistance exercise on cognitive function will also be discussed. The final section of this chapter will highlight the limitations within the current literature and also discuss the overarching goals of this thesis.

Chapter 3: Study One – Validation of a new locomotive single- and dual-task paradigm to evaluate differences in gaze behaviour and neural activity

In order to begin to unravel the complex nature of cognitive function in a more real world application, a dual-task paradigm enabling whole body movement and behaviour was designed to measure both gaze behaviour and neural activity. The primary goal of this study was to design a locomotive, dual-task paradigm to examine task-related (single- and dual-task) differences in: 1) gaze behaviour, specifically differences in task-related fixations, location of gaze and quiet eye (onset, offset and duration), and 2) neural activity associated with the reception, integration and processing of sensory information during goal-directed behaviour.

Chapter 4: Study Two - Validating the use of EEG to examine neural activity associated with single- and dual-tasks during locomotion

The primary goal of this study was to determine whether tasks of increasing difficulty (single- and dual-tasks) would influence the temporal pattern of neural activity, specifically related to the reception, integration and processing of auditory stimuli in the performance of the locomotive single- and dual-task paradigm validated in study one. Event-related potentials (ERPs) are of specific interest as they represent the time course (i.e., temporal resolution) of neural changes and patterns of activity in response to a specific sensory, cognitive or motor event (Luck, 2005; Luck & Kappenman, 2012). Two key neural components of interest were that of the N2 and P3 ERP components. The two characteristics with regard to the N2 ERP are that of *latency*, which is an index of the timing of information processing during visual perception, with the *peak latency* representing the moment in time where sensory information is available to formulate the stimulus response decision (Schmitt, Münte, & Kutas, 2000; Thorpe, Fize, & Marlot, 1996), and the N2 *amplitude* which is associated with the neural activity (degree of effort and processes) required for response monitoring (Donkers & Van Boxtel, 2004; Yeung, Botvinick, & Cohen, 2004). The P3 ERP *latency* is related to the speed with which we can classify sensory stimuli and the *amplitude* which is representative of the allocation of attentional resources and working memory (Duncan-Johnson, 1981; Kutas, McCarthy, & Donchin, 1977; Polich, 1987).

Chapter 5: Study Three – Part A - Effect of acute exercise on neural activity associated with single- and dual-task performance during locomotion – aerobic versus resistance exercise

The dual-task paradigm in study one and two was refined to optimise the dual-task effect, specifically relating to engagement in the cognitive component of the dual-task. The primary goal of this study was to determine the influence of an acute bout of exercise on single- and dual-task related neural activity. Further, whether there would be a differential effect of aerobic compared to resistance exercise. In this study we utilized a novel paradigm

which allowed for the assessment of performance using different cognitive loads (single- versus dual-tasks) as well as the assessment of neural activity. In particular, this study examined the influence of aerobic compared to resistance exercise on the N2 and P3 ERP components (P3a and the early and late P3b). The P3a, and the early and late P3b, are associated with attentional and memory processing (P3a), retrieval, encoding and memory updating (early and late P3b) (Brookhuis et al., 1981; Kok, 2001; Morgan, Klein, Boehm, Shapiro, & Linden, 2008; Scisco, Leynes, & Kang, 2008).

Chapter 6: Study Three – Part B - Effect of acute aerobic exercise on neural activity associated with single and dual-task performance during locomotion

Due to the fact that key differences between the effects of an acute bout of aerobic compared to resistance exercise were not elucidated within the analyses performed within the previous chapter (chapter 5), it was the intention within chapters six and seven to examine the aerobic and resistance bouts of exercise independently in an attempt to obtain a more in-depth understanding as to the underlying mechanisms associated with differences in task-related performance identified in chapter five. Therefore, the purpose of this chapter was to evaluate neural activity (N2 and P3 ERP components) associated with the performance of both a single- and dual-task during locomotion before and after an acute bout of aerobic exercise.

Chapter 7: Study Three – Part C - Effect of acute resistance exercise on neural activity associated with single and dual-task performance during locomotion

The purpose of this chapter was to evaluate neural activity (N2 and P3 ERP components) associated with the performance of both a single- and dual-task during locomotion before and after an acute bout of resistance exercise.

Chapter 8: Overall discussion

This chapter will provide an overview of the research performed including: 1) a summary of the findings; 2) issues with electroencephalography data collection; 3) future

research directions; 4) practical implications of the research performed in this thesis; and 5) an overall conclusion of information provided within the studies performed.

Chapter Two

Literature Review

The human brain is a complex organ that has been extensively examined with the aim of obtaining a more comprehensive understanding of the role it plays in every day function. It is dynamic in nature and experiences changes in response to physiological (e.g., aging and illness), biological (e.g., aging and changes in brain chemistry) and environmental (e.g., social, educational and family) stimuli, and stressors an individual encounters throughout the lifespan (Daffner, 2010; de Lau & Breteler, 2006; van Dyck et al., 2008; Zahr, Rohlfing, Pfefferbaum, & Sullivan, 2009). These changes relate to both diminished cognitive function, such as that associated with age-related decline and in the occurrence of stroke, disease or head trauma, and improved cognitive function, such as enhanced attentional processing after exercise and an increase in the capacity to perform activities of daily living. These changes (e.g., physiological and biological) can be measured through the evaluation of the brain's structure and function from both behavioural (e.g., reaction times) and neural activity (e.g., event-related potentials) perspectives. The structure relates to the components of the brain, for example the different lobes (e.g., frontal, central and parietal lobes), regions (e.g., the motor, sensory and visual cortices), the divisions between the lobes and regions (e.g., sulci and gyri) and other areas of the brain (e.g., cerebellum, brain stem and corpus callosum). Knowledge of the brain's structure makes it possible to examine variations between different populations (e.g., younger compared to older adults, and healthy compared to neurologically impaired populations), and enables inferences to be made about the relationship between what areas of the brain are associated with both cognitive and physical function. Function, on the other hand, relates to the relationships between the production of neurotransmitters (e.g., dopamine, serotonin and norepinephrine), changes in the haemodynamic (e.g., cerebral oxygenation and glucose transport) and neuro-electric (e.g., event-related potentials)

responses to stimuli in the environment. Function is also described as a mechanistic process which is essential for the amplification of integrated behaviour and evolves over space and time (i.e., spatiotemporal patterns of activity). Having knowledge of the brain's function enables a better understanding of how these characteristics (i.e., electrical activity and haemodynamics) are altered throughout the lifespan and in the case of disease. It also provides a basis with which to evaluate the dynamic and malleable (i.e., neuroplastic) nature of the brain and makes it possible to assess how the brain communicates and influences both cognitive and physical function. Furthermore, it provides a platform with which to evaluate the influence of varying interventions (i.e., pharmaceutical and exercise) to improve cognitive function and overall quality of life (Kamijo et al., 2009; Molloy et al., 2006).

Our understanding of the complex nature of the brain has further been developed through the advancement in brain imaging technologies, such as functional magnetic resonance imaging (fMRI), magnetoencephalography (MEG) and electroencephalography (EEG). For example, differences in the brain's structure and function have been identified in cognitive tasks, requiring the performance of goal-directed behaviour between young and old adult populations and the influence of exercise on aspects of cognitive function, such as executive function and the allocation of attentional resources (Kamijo & Takeda, 2010; O'Leary et al., 2011).

Cognitive function is an umbrella term that relates to all mental abilities and processes incorporated in such things as perception, memory and working memory, judgement, reasoning, problem solving, decision making, comprehension and language (Ashcraft, 2002). The evaluation of cognitive function incorporates a broad spectrum of research from different disciplinary approaches (e.g., psychology and neuroscience) and is commonly examined from a behavioural and neurophysiological perspective. Where behavioural performance is associated with goal-directed actions, neurophysiological investigations look at different

areas of brain activation preceding and during the performance of the desired behaviour (e.g., Chou, Chen, & Madden, 2013; Gerloff et al., 1998; Pratt, Willoughby, & Swick, 2011). By employing a combined approach, researchers are able to elucidate the underlying mechanisms associated with the behaviours we can empirically observe and measure. Through the use of brain imaging technologies, differences in both spatial (i.e., location) and temporal (i.e., timing) patterns of activity, and how these change over time (i.e., hours, days, weeks and years) can be evaluated in the performance of varying goal-directed behaviour (e.g., Chang, Tsai, Chen, & Hung, 2013; Liu-Ambrose, Nagamatsu, Voss, Khan, & Handy, 2012). For example, aerobic exercise training over a six month period has been shown to promote an increase in both white and grey matter volume in an older adults (60 – 70 years) (Colcombe et al., 2006). Understanding the temporal and spatial relationships, enables a more comprehensive perspective of how these characteristics change over time and in response to a variety of manipulations. For example, differences in the characteristics of initiation and inhibition of actions, planning, working memory, monitoring and execution of a sequence of goal-directed actions (Coppin et al., 2006; Mendelson et al., 2010; Salthouse, Atkinson, & Berish, 2003), such as the simultaneous execution of both a motor and a cognitive task (dual-task).

1. Dual-task performance

A fundamental aspect of cognitive function that relates to the ability to perform activities of daily living is the capacity to integrate and process multiple competing sources of information and generate the desired goal-directed behaviour. For example, walking and talking is commonly categorised as dual-tasking. Fundamentally, a dual-task consists of both a primary (e.g., walking) and a secondary (e.g., talking) task. The ability to simultaneously integrate and process multiple task demands is affected by the degree of task demand (simple compared to complex task) and available cognitive resources to efficiently process the

information. This is specifically relevant in an older adult population where the inability to dual-task is a predictor of fall rates (Beauchet et al., 2009; Bessot et al., 2011), and altered gait patterns in the dual-task condition, which are used to compensate for the additional cognitive demand and attenuate dual-task costs (Ayers, Tow, Holtzer, & Verghese, 2014). This diminished capacity is reported to be related to a deficit in the attentional resource capacity (i.e., resource-based attentional framework), leaving fewer resources to distribute for the integration and processing of the competing tasks (e.g., walking and talking), resulting in dual-task costs (Neider et al., 2011). Hence, in the performance of a single-task, where there is only a primary task (e.g. walking), there are sufficient attentional resources with which to integrate and process the demands of the task and generate the desired goal-directed behaviour. However, with an increase in task difficulty, such as that associated with a dual-task condition (incorporating a secondary task, e.g., talking), there is a subsequent increase in demand on the attentional resources to integrate and respond accurately (Neider et al., 2011; Pratt et al., 2011). In this situation there may be insufficient attentional resources available to integrate and process all sources of information to carry out both tasks successfully. This may result in performance decrements, such as altered gait and inability to maintain a conversation (Ayers et al., 2014; Beauchet et al., 2009).

Over the past decade there has been a drive to create paradigms with greater ecological validity, to enable the evaluation of cognitive function from a behavioural perspective (e.g., walking gait and task performance) in a more real world context. For example, dual-task performance has been investigated within a total immersion, virtual reality environment (Neider et al., 2011) and in the performance of locomotive tasks incorporating whole body movement and behaviour (Lindenberger et al., 2000). The important difference between stationary (seated) and dynamic paradigms is that in a dynamic context, involving whole body movement, other aspects of cognitive function must be

accounted for, such as those associated with coordination of gait, maintenance of balance and negotiation of other environmental factors that may alter pattern or trajectory of movement. For example, changes in condition-related neural activity, specifically an observed reduction in the N2 ERP component in the walking compared to a seated condition and differences in the P3 ERP component responses (enhanced over fronto-central region and reduction over centro-parietal region) in the walking compared to a seated condition (De Sanctis, Butler, Malcolm, & Foxe, 2014). There is a wealth of research that has focused on the behavioural aspects (e.g., gait and speed of task performance), and a growing body of literature that has begun to elucidate the underlying mechanisms of dual-task performance and the associated costs. For example: hemispheric asymmetry reduction in older adults (HAROLD model), which relates to age-related changes in brain activity during cognitive performance (Cabeza, 2002). Specifically a reduction in lateralised prefrontal activity, potentially reflecting some compensatory function (Cabeza, 2002). The theory of compensation (or over-recruitment), suggests that older adults recruit more areas of the brain in the performance of a motor task in comparison to younger adults; this can lead to an additional reliance on areas of the brain involved in sensory information processing and integration (Heuninckx, Wenderoth, & Swinnen, 2008). Simply put, older adults compensate for age-related declines by recruiting additional areas of the brain to perform a given task (Heuninckx, Wenderoth, Debaere, Peeters, & Swinnen, 2005; Heuninckx et al., 2008). The functional consequence of this theory is an increase in the time taken to perform a given task (i.e., movement slowing), particularly in tasks with increasing difficulty. Another layer in the complex relationship between goal-directed behaviour and brain function is that of visuomotor coordination including the integration and processing of visual information and the subsequent coordination of goal-directed behaviour. Due to the fundamental importance of visuomotor coordination in the performance of goal-directed behaviour, and task-related differences in

this information processing loop, vision and neural activity will be discussed in more depth in the following sections.

2. Visuomotor coordination

Locomotion is an area in which visual attention and in particular gaze behaviour has been employed to establish the sequence of key determinants of movement (Grasso, Prévost, Ivanenko, & Berthoz, 1998; Hollands, Patla, & Vickers, 2002). The integration of visual and motor performance during locomotion is specifically pertinent in the efficient and effective co-ordination of both cognitive and motor skills, such as those associated with dual-task performance (e.g., crossing a busy street). Visual information provides a basis with which to regulate and guide locomotion both locally (step-by-step) and globally (route planning) and incorporates characteristics of visual perception and locomotor adaptive strategies (Patla, 1997). Visual perception encompasses visual sampling of the environment including visual feedback about body posture and movement. Locomotor adaptive strategies incorporate processing of information relating to the static and dynamic nature of the environment (Patla, 1997). In other words, adaptive strategies (altered step pattern or gait) are used to account for differences in the terrain or obstacle avoidance and maintenance of stability and balance. Visual information informs the initiation and termination of locomotion and helps to provide a rhythmic and coordinated sequence of movement to move in the desired direction (Patla, 1997).

Visual information is said to dominate over all other sensory system information received by the central nervous system (CNS), especially in situations where there is conflict between sensory information (Colavita, 1974; Posner, Nissen, & Klein, 1976). Consequently, it is the responsibility of the visual system to orient and process the most salient perceptual cues within the visual field to determine the correct course of action to achieve a given task (Mann, Coombes, Mousseau, & Janelle, 2011). The fundamental importance of vision in

motor performance is specifically pertinent for the efficient and effective hand-eye coordination and fast reflexes required in many activities of daily living. There is a wealth of research that has examined the integration and processing of visual information in the performance of goal-directed behaviour, for example gaze behaviours associated with catching a ball (Stone et al., 2014).

In the course of our daily lives we unconsciously account for, process and respond to a variety of sources of information (Findlay, 2009). A fundamental aspect of the capacity to do this is that of perception-action coupling, which incorporates three central processing mechanisms and are thought to manage all sensory information. These include perception, decision and effector mechanisms (Abernethy, 1986). The perception mechanism receives information from various receptors (e.g., retina for visual information). The decision mechanisms processes what action is required and the effector mechanisms, manages the temporal and sequential aspects of desired movements (Abernethy, 1986). In a situation requiring the integration and processing of multiple sources of stimuli, resulting in an increased demand on the allocation of attentional resources, perception-action coupling is negatively affected, specifically in the form of voluntary and reflexive saccadic eye movement (Meyer, Gauchard, Deviterne, & Perrin, 2007). Visuomotor information is therefore one important area of focus that has the potential to provide us with a better understanding of the associated motor performance decrements associated with performing tasks of increasing difficulty.

2.1 Evaluating visuomotor coordination

To enable the evaluation of differences in gaze behaviour, research has employed eye tracking technology that includes head-mounted, monocular eye-tracking systems that use corneal reflection to measure eye-line-of-gaze with respect to the field of view and a scene camera to simultaneously track both pupil dynamics and location of gaze within the

environment (see Figure 2.1). Parameters of interest are those of saccadic eye movements, fixations, and the quiet eye (QE). Saccadic eye movements enable optimal processing of multiple visual targets through the use of rapid changes of fixation from one target to another. These movements are ballistic in nature and are defined by two basic characteristics, latency and direction (Findlay, 2009). The latency of a saccade relates to the time that elapses between the presentation of a stimulus and the onset of the saccadic eye movement (Findlay, 2009; Halliday & Carpenter, 2010) and is used as a non-invasive means of examining mechanisms of decision making (Halliday & Carpenter, 2010). Humans typically perform two to three saccades a second (Halliday & Carpenter, 2010; Morrillo, Di Russo, Pitzalis, & Spinelli, 2006) and these saccades can be influenced by cognitive processes, including attention, working memory, learning, long term memory and decision making (Hutton, 2008). Further, in tasks of increasing difficulty, a reduced capacity to inhibit short latency reflexive saccades and an increase in error rates has been reported and is said to represent diminished working memory capacity (Mitchell, Macrae, & Gilchrist, 2002).

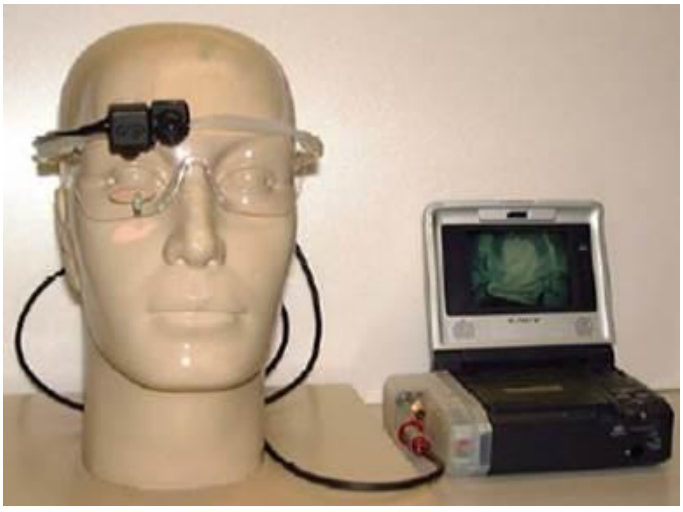

Figure 2. 1: ASL Mobile Eye Unit

Gaze behaviour also includes fixations, which are periods of time between saccadic eye movements where gaze is held steady, during which time information about the environment is obtained. For example, in a locomotive context, visual information relates to a new direction of desired movement and is reported to precede body rotation by as much as 1.5 s (Land, 2006; Reed-Jones, Hollands, Reed-Jones, & Vallis, 2009). Gaze behaviour, and in particular focus of attention, is reported to be negatively affected under a dual-task context, resulting in the narrowing of attention of the functional field of view and longer gaze shift latencies (Lamers & Roelofs, 2011; Pak, Rogers, & Fisk, 2006). Further, there is an association between inefficient search (gaze) patterns and dual-task performance, which are suggested to be a result of the increase in cognitive load and effort required to manage the dual demands of the goal-directed behaviour (Perez-Moreno, Conchillo, & Recarte, 2011). The QE, which is a sub-category of fixation, is the final fixation that occurs before a critical movement during task performance (Panchuk & Vickers, 2011). The QE has three parameters of interest, the onset, offset of the fixation and the duration. The onset represents the time where the final fixation prior to initiation of the critical movement begins, whereas the offset is representative of the time point at which sufficient visual information has been obtained to perform the correct goal of the motor-task (initiation of a change in direction of travel) (Panchuk & Vickers, 2011). QE duration is the length of the final fixation prior to the initiation of movement, and is thought to be associated with the time needed to obtain information from the fixation cue/target and plan a movement (Mann et al., 2011). Increased accuracy and efficiency of goal-directed behaviour is associated with an earlier occurring QE of a longer duration compared to less successful movements (Harle & Vickers, 2001; Janelle et al., 2000; Vickers, 1996a, 1996b).

3. Neural activity

There has been an exponential growth in our understanding of various aspects of neurological activity over the past two decades in the context of the brain's structure and function. In the evaluation of dual-task costs from a neurophysiological perspective, changes in spatial and temporal patterns of neural activity have been observed. For example, a decrease in the allocation of attentional resources as indicated by a reduction in the magnitude of neuro-electric activity and reduced activation within the supplementary motor area, cingulate cortex, insula and post-central gyrus in the performance of more complex tasks (dual-task) (Johansen-Berg & Matthews, 2002). Of specific interest are decrements in task performance which have been associated with the capacity to engage inhibitory processes to prevent the occurrence of an incorrect response. It is well documented that, as we age, our ability to integrate and respond to a dual-task scenario becomes diminished, with older adults typically prioritising the motor compared to the cognitive component of a task to maintain balance and reduce the risk of falling (Hall, Echt, Wolf, & Rogers, 2011; Schaefer & Schumacher, 2011). This decrement in performance is associated with a mismatch between the task-related cognitive load required to perform the task accurately and efficiently and the attentional resources available. Further support for this mismatch is the age-related reduction in the P3 ERP component characteristics, specifically an increase in *latency* (1.36 ms per year) and decrease in *amplitude* (at a rate of 0.18 μV per year) (Picton, Stuss, Champagne, & Nelson, 1984). This indicates that it takes longer for older adults to categorise a sensory stimulus (P3 *latency*) and there is a reduction in the available attentional resources (P3 *amplitude*) with which to process the requirements of goal-directed behaviour (Duncan-Johnson, 1981; Kutas et al., 1977; Polich, 1987). Dual-task costs have also been observed in a young healthy population, where deficits are reported to be associated with impairments in executive control (Meyer et al., 2007).

3.1 Evaluating neural activity

Measuring the dynamics of sensory information integration, processing and goal-directed behaviour provides a basis with which to determine when the brain is most active during the performance of a cognitive task and the efficiency of the pathways involved in the generation of a response (e.g., Dai, Chang, Huang, & Hung, 2013; Pasalar, Ro, & Beauchamp, 2010; Voss et al., 2010). This means that we can obtain a better insight and understanding of how the brain changes in structure and function, and how it can be manipulated to promote neuroplasticity.

There is a range of neuroimaging technologies that have been employed to evaluate differences in cognitive function associated with changes throughout the lifespan (e.g., Angel et al., 2011; Chou et al., 2013), including fMRI and EEG. Whereas fMRI reflects changes in regional cerebral blood flow and has high spatial resolution (i.e., ability to identify location of neural activity), EEG is an electrophysiological recording technique, which is able to measure voltage fluctuations over time and has high temporal resolution (i.e., changes in neural activity over time) (Friedman, Cycowicz, & Gaeta, 2001). Another fundamental difference between these technologies is that fMRI data can take several seconds due to the timing (seconds) of the haemodynamic response, EEG can assess neural changes within a 1 ms time frame, hence the high temporal resolution (Luck, 2005). As the focus of this literature review and thesis is related to the use of EEG, only this technology will be discussed further.

EEG is able to measure inhibitory and excitatory post-synaptic activity that results in the generation of extracellular loop currents (Gramann et al., 2011). These loop currents travel along the apical dendrite of excitatory (i.e., pyramidal) cortical neurons, and when these are orientated perpendicular to the cortical surface (e.g., within the gyri) neural activity can be recorded using EEG at the scalp. A limitation of EEG is that transversely orientated neural activity (e.g., within the sulci), which represents the bulk of cerebral cortex is more

difficult to record. The neocortex is reported to produce most of the electric potential measured at the scalp, and has a thickness of between 0.2 – 0.3 cm (see Figure 2.2, Nunez & Srinivasan, 2006). Therefore in the use of EEG, any neural activity must travel through this cortical layer, the implication being that the resulting neural activity recorded at the scalp is diffused. One of the key issues around the use of EEG is that of spatial resolution. A single electrode provides an estimation of synaptic action averaged over a tissue mass containing between 100 million and 1 billion neurons (Nunez & Srinivasan, 2006). This presents three core issues with regard to spatial resolution: 1) The ability to identify the origin of the neural activity is problematic, as the neural activity observed in the EEG signal trace is the summation of activity of this area and does not represent the origin of the activity; 2) The EEG signal is representative of the summation of cortical voltage fluctuations at the scalp, however, is not capable of measuring activity in deep structures of the brain, for example the hippocampus, thalamus or brain stem (Kandel, Schwartz, Thomas, Siegelbaum, & Hudspeth, 2013); and 3) The pattern of activity observed over this broad mass (100 million – 1 billion neurons) may, in fact, differ from the pattern observed over a smaller mass (e.g., that contains 10 million neurons) (Nunez & Srinivasan, 2006). A means by which researchers have attempted to overcome the low spatial resolution of EEG is by using 1) source reconstruction software, such as low-resolution electromagnetic tomography (LORETA), which is used to analyse and localise the multiple distributed sources of EEG activity in a three-dimensional space (Pascual-Marqui, Michel, & Lehmann, 1994); and 2) larger electrode configurations to enable the collection of voltage fluctuations over more areas of the scalp thereby enhancing the ability to better identify the spatial location of neural activity (Nunez & Srinivasan, 2006) (see Figures 2.3 and 2.4). However, a key factor to consider in the use of a larger channel montage is the risk of cross bridging (electrical bridging) between electrodes, which can result from electrolyte gel spreading or the production of perspiration, which in effect links

the two electrodes. This can cause a distortion of the neural activity recorded at the involved electrodes and subsequent inability to accurately determine and evaluate neural activity of interest arising from the involved electrodes (Alschuler, Tenke, Bruder, & Kayser, 2014).

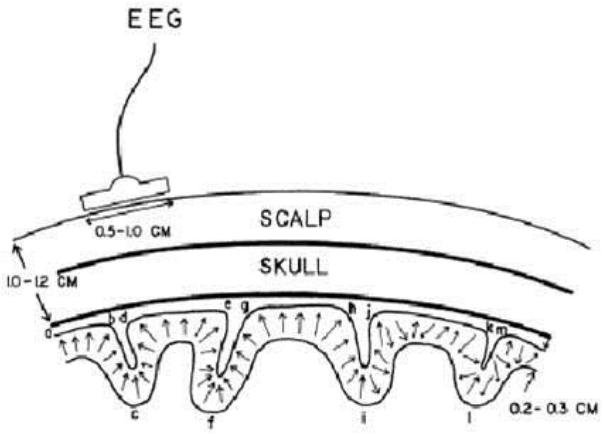

Figure 2. 2: EEG recording – the electrode is placed on the scalp and measures neural activity within the cortical level of a depth of 0.2 – 0.3 cm (adapted from Nunez & Srinivasan, 2006).

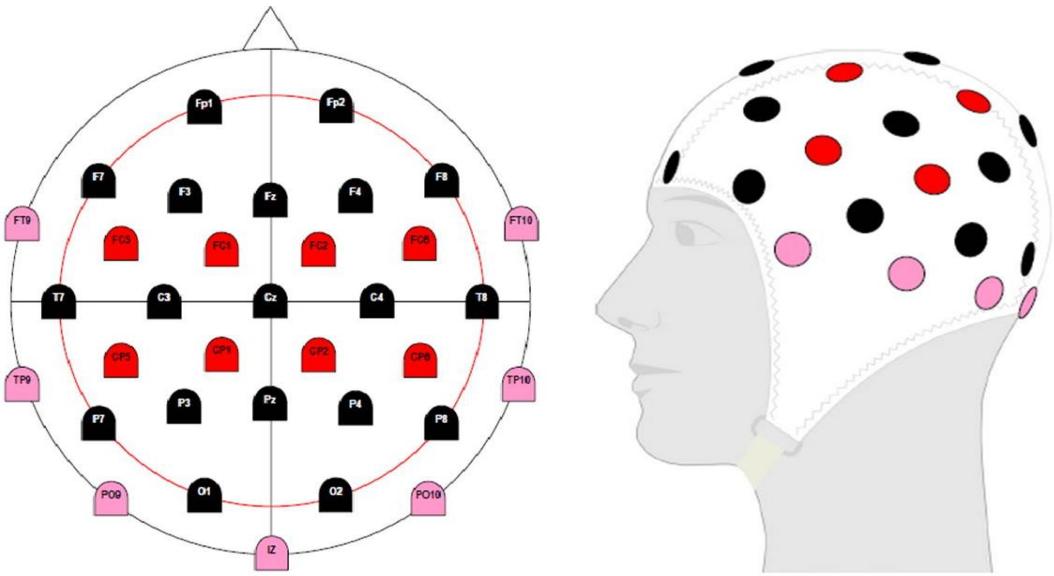

Figure 2. 3: 32 Channel montage representing a 10/20 electrode configuration (Brain Products, 2009).

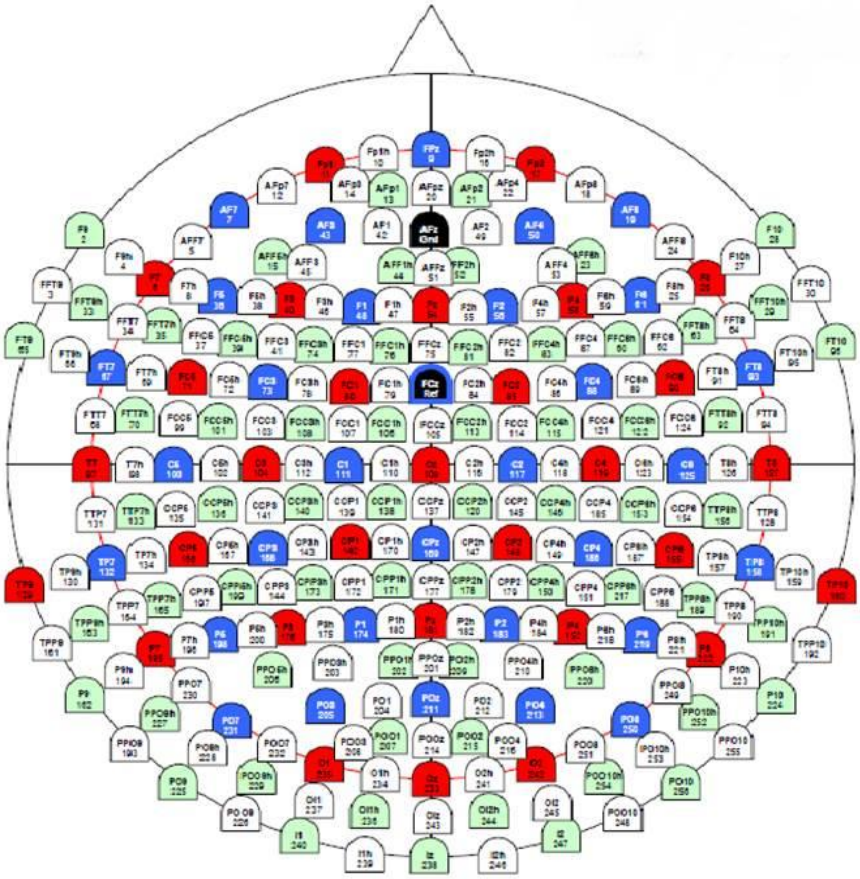

Figure 2. 4: 250 Channel montage representing a 10/5 electrode configuration (Oostenveld & Praamstra, 2001)

Similar to fMRI, EEG has the capacity to measure neural activity over the whole brain through the use of multiple electrode configurations (32 – 250 electrode montages) with larger numbers of electrodes improving spatial resolution (although not to the degree of fMRI) (Nunez & Srinivasan, 2006). The differences in these configurations are defined as 10/5, 10/10 and 10/20 montage/system, with the first figure (10) representing the percentage difference from the anatomical reference points (nasion, inion and ear channel opening) and the electrode directly above the point, whereas the second figure (5, 10 and 20) represents the percentage difference between each electrode (see Figure 2.5, BrainProducts, 2009). The parameters of each of these montages/systems are calculated in respect to two key factors: 1) the connection lines between each of the anatomical reference points, specifically between

the nasion and inion (longitudinal line) and between the opening to each ear channel (lateral line), with each line representing 100%; and 2) the circumference of the base of the cap around the head (hat line) (see Figure 2.5, BrainProducts, 2009). Having these measures, specifically relating to the use of anatomical reference landmarks, enables replicable measures to be obtained over time, which is a valuable attribute within research, allowing examination of changes before and after an intervention over different periods of time/days/months.

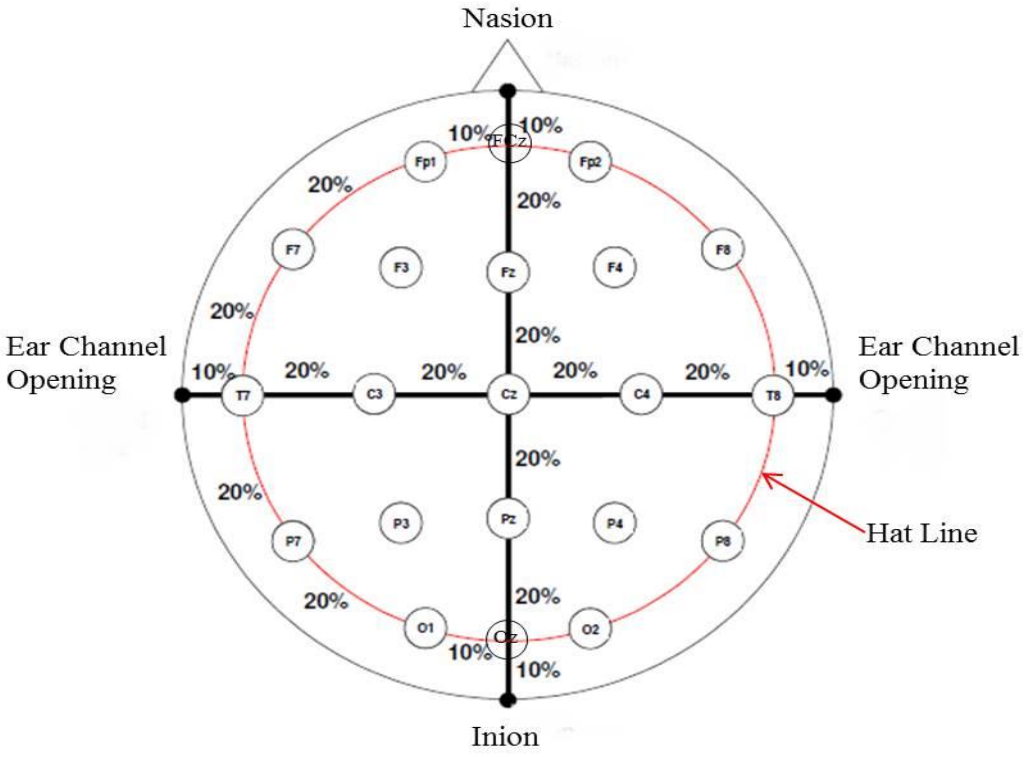

Figure 2. 5: EEG Electrode System Montage (Brain Products, 2009)

Two main aspects of neural activity obtained through the use of EEG are those of patterns of neural oscillations, for example alpha (8 – 12 Hz) frequency, and ERPs. Whereas oscillations are stimulus-induced, ongoing EEG activity (Zhao et al., 2014), ERPs are stimulus dependent, meaning that to generate this evoked potential there needs to be some

form of stimulus (Cohen, 2011). As the focus of this literature review and thesis is related to task- and exercise-related differences in ERPs only these will be discussed further.

3.2 Event-related potentials

ERPs provide a dynamic means of examining the time course of voltage fluctuations and patterns of activity in the brain in response to a specific sensory, cognitive or motor event (stimulus) (Luck, 2005; Luck & Kappenman, 2012). These fluctuations are associated with different components which are representative of various sensory, cognitive and motor processes (Friedman et al., 2001). This type of stimulus-induced neural activity provides a picture of differences in neural responses that precede any subsequent observable behavioural response such as reaction time and are present even in the absence of a behavioural response (Kutas et al., 1977; Luck, 2005). The differences in these voltage fluctuations lead to inferences about both the nature and location of brain function, specifically around the underlying short latency and more complex long latency components such as the N1 and P3 ERPs (Duncan et al., 2009). As ERPs are quite small (1 – 30 millionths of a volt) a number of trials are required to enable the extraction of the desired component of interest. This is achieved through a process of signal-averaging, with more trials representing a better signal-to-noise ratio and the ability to delineate the component wave form and background EEG artefact (Friedman et al., 2001). The core characteristics of an ERP include: *polarity (N and P), latency (ms), amplitude* (μV) (see Figure 2.6), *scalp distribution and experimental variables* (Friedman et al., 2001; Luck, 2005). *Polarity* refers to the direction of the stimulus-driven voltage deflection, specifically negative or positive, whereas *latency* refers to the time course of processing activity within milliseconds and order in which it occurs after stimulus onset (Luck, 2005). For example, the N2 ERP component indicates that this is a negative (N) going component that occurs within approximately 200 ms (2) after stimulus onset and is the second negative going voltage deflection observed after stimulus onset (Luck, 2005). The

ERP *amplitude* is representative of the cognitive effort involved in the reception, integration, and processing of sensory stimuli with which subsequent goal-directed behaviour is generated (Duncan et al., 2009; Key, Dove, & Maguire, 2005). *Scalp distribution* of the stimulus-driven ERP relates to the location of the neural activity (as identified by electrode scalp placement) and can provide a basis with which to determine the functional association of the pattern of voltage fluctuations in response to a given stimulus (e.g., visual or auditory) (Luck, 2005). The last characteristic is that of the *experimental variable*, for example the different neural responses associated with the use of an auditory compared to a visual sensory stimulus (Duncan et al., 2009). The use of an ERP methodology is multifaceted and includes the evaluation of a vast array of different neural components and is an effective and informative means of evaluating differences in neural activity between population groups and/or interventions, such as younger and older adults and the influence of physical fitness and acute bouts of exercise. For example, Kamijo et al. (2009) found that after an acute bout of moderate intensity aerobic exercise, there was an enhanced P3 ERP *amplitude* in the younger (19 – 25 years) compared to older (60 – 74 years) adults, indicating an improvement in the allocation of attentional resources and working memory.

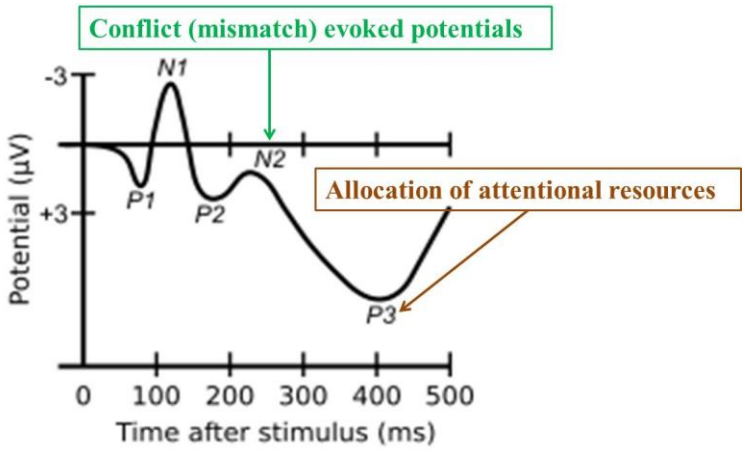

Figure 2. 6: Event-related potential diagram showing the N2 and P3 ERPs of interest.

There are also some limitations to using ERPs to evaluate differences in neural activity and formulating inferences of correlations between this activity and behaviour are related to: 1) the low spatial resolution as highlighted previously, specifically identifying the internal ERP generators, direction of neural activity (apical compared to transversely orientated activity and the diffused activity measured at the scalp; 2) due to the small voltage of ERPs a large number of trials (e.g., 50-1000) are required to enable an accurate measure of the neural response to a stimulus (Luck, 2005). The need for a large number of trials relates to signal averaging, which is a process that assumes that the ERP waveform is identical in each trial, whereas extraneous noise (non-cerebral artefact) is not. Therefore, the more trials that can be performed, the clearer the resulting ERP waveform will be (Luck, 2005); and 3) Accounting for potential overlap in the ERP waveforms, which occurs when the neural response to the previous stimulus has not ended and the next stimulus is presented. This is problematic as it can cause a jittering or smearing effect of the neural data, and can lead to the data being misinterpreted. As an ERP can last several seconds the inter-stimulus interval (ISI) must account for this to minimise the risk of overlap occurring (Luck, 2005).

For the purpose of this literature review and thesis focus will be on task- and exercise-related differences in ERPs, specifically the N2 and P3 ERP component *latencies* and *amplitudes*. The N2 ERP component is the second negative going voltage deflection after stimulus onset and occurs within a time window of 150 – 400 ms after sensory stimulus onset (Falkenstein, Hoormann, & Hohnsbein, 1999; Gajewski & Falkenstein, 2012) and is reported to be most prominent over fronto-central and posterior scalp sites (Luck, 2005; Van Veen & Carter, 2002). The N2 component is reported to be related to the process of response monitoring and/or response inhibition (Donkers & Van Boxtel, 2004; Falkenstein et al., 1999; Schmitt et al., 2000). The fundamental difference between response monitoring and response inhibition is that response monitoring occurs before the response, whereas response inhibition

refers to the ability to deliberately suppress a habitual response (Donkers & Van Boxtel, 2004; Yeung et al., 2004). The two main characteristics of the N2 component are *latency*, which is an index of the timing of information processing during visual perception, with the *peak latency* representing the moment in time where sensory information is available to formulate the stimulus response decision (Schmitt et al., 2000; Thorpe et al., 1996), and *amplitude* which is associated with the neural activity (i.e., degree of effort and processes) required for response monitoring and/or response inhibition (Donkers & Van Boxtel, 2004; Yeung et al., 2004).

The P3 component is a positive going waveform and includes both the P3a and P3b, which represent different phases of information processing. The P3a (or novelty P3) subcomponent of the P3 is a large, positive deflection with a fronto-central and anterior frontal distribution and is associated with involuntary attention shifts to changes within the environment (Friedman & Simpson, 1994; Jongsma, Meeuwissen, Vos, & Maes, 2007; Spencer, Dien, & Donchin, 1999). It has a *latency* of approximately 250 – 350 ms and is an indicator of automated, bottom-up aspects of attention (Debener, Kranczioch, Herrmann, & Engel, 2002; Escera, Alho, Winkler, & Naatanen, 1998). This includes attentional processes (Scisco et al., 2008) and aspects of stimulus evaluation in tasks requiring some form of action (Hohnsbein, Falkenstein, & Hoormann, 1995). The P3b is a positive deflection that has a posterior-parietal distribution with a longer *latency* compared to that of the P3a. In tasks incorporating complex perceptual and conceptual processing the P3b *latency* is approximately 300 – 600 ms (Comerchero & Polich, 1999; Kok, 2001), and is associated with processes of memory access triggered by the presentation of a stimulus requiring action (i.e., covert or overt response) (Kok, 2001). This subcomponent of the P3 reflects voluntary, top-down attributes of attention (Debener et al., 2002). This includes, memory updating (Scisco et al., 2008), and response selection (Christensen, Ivkovich, & Drake, 2001;

Hohnsbein et al., 1995). The P3b is further defined into two key aspects, that of the early and late P3b, which are representative of modulation of working memory load on the encoding and retrieval phases of information processing (Brookhuis et al., 1981; Jongsma et al., 2007; Morgan et al., 2008; Scisco et al., 2008).

These subcomponents have two main characteristics, the *latency* which is related to the speed with which we can classify sensory stimuli and the *amplitude* which is related to the allocation of attentional resources and working memory (Duncan-Johnson, 1981; Kutas et al., 1977; Polich, 1987). The P3a and P3b are elicited in the performance of tasks requiring an inhibitory response, specifically related to processing of additional stimuli (such as in a dual-task context), and the subsequent updating of neural stimulus representation in working memory (see Figure 2.6).

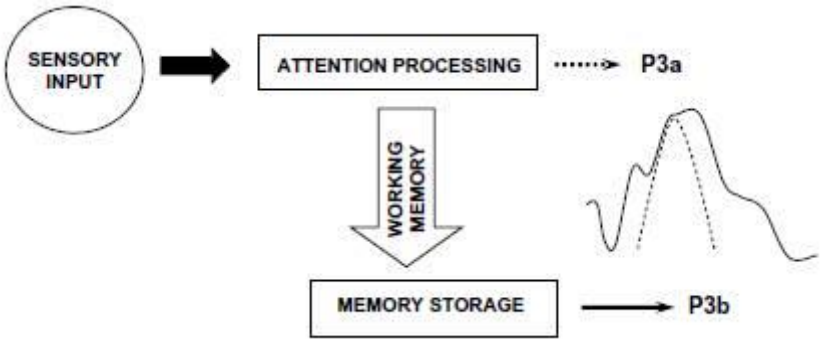

Figure 2. 7: "Sensory input is processed, with frontal lobe activation from attention-driven working memory changes (P3a) and temporal/parietal lobe activation from memory updating operations (P3b)" (Polich, 2003).

A core contributor to the generation of the P3 ERP component is the engagement of working memory, which is reported to be a critical factor in the maintenance of attentional focus and conflict resolution (Pratt et al., 2011). Both working memory and attention have a reciprocal relationship, in that maintenance of active attentional preparation of an event involves storing of the representation of the event within working memory (Kok, 2001). For example, an event may require the performance of a right button press when a red light is

presented; the representation (red light = right button press) is accessed from working memory to enable the performance of the correct goal-directed behaviour. In a dual-task scenario, where there are task-related differences in attention (multiple event representations in working memory), there is a reported graded effect of primary and secondary task difficulty on the P3 *amplitude* (Isreal, Chesney, Wickens, & Donchin, 1980a; Isreal, Wickens, Chesney, & Donchin, 1980b). In other words there is an association between an increase in task difficulty (e.g., engaging an inhibitory response to prevent an error occurring) and a reduction in the attentional capacity resulting in a decrease in the P3 *amplitude* (Hahn, Wild-Wall, & Falkenstein, 2011; Kramer, Sirevaag, & Braune, 1987; Polich, 2007; Pratt et al., 2011; Strayer & Kramer, 1990).

There is strong evidence from both a behavioural and neurophysiological perspective to support the association between the increased demands on working memory and attention with more complex and cognitively demanding tasks (i.e., within a dual-task context) and a decrease in the P3 ERP *amplitude* (representative of the allocation of attentional resources) (Morgan et al., 2008; Pratt et al., 2011). Further, this decrease in attentional capacity is linked to fall rates in older adults (Ayers et al., 2014; Beauchet et al., 2009). The functional repercussions of this risk may include a reduced capacity to perform activities of daily living, impaired quality of life and the resultant financial burden. Therefore, a common goal within research has been to obtain a better understanding of why these decrements occur and how we can attenuate this decline and improve overall cognitive and physical function.

4. Cognitive function and exercise

One of the key goals within exercise physiology and cognitive neuroscience research is to evaluate and obtain knowledge of interventions to improve cognitive function in various populations (e.g., older adults and those with a neurological impairment). One such intervention is that of exercise, with growing evidence to show exercise-induced changes

which include enhanced neural efficiency and allocation of attentional resources to process and manage tasks requiring interference control (Huang, Lin, Hung, Chang, & Hung, 2014). When evaluating the optimal exercise-stimulus to promote improvements in cognitive function, however, consideration must be given to the core attributes of any exercise intervention (i.e., intensity, mode, and duration).

The intensity of exercise bouts includes the differential influence of continuous low, moderate and high intensity aerobic exercise on cognitive function. Evidence to date suggests that there is an inverted-U relationship between exercise intensity and cognitive performance (Kashihara, Maruyama, Murota, & Nakahara, 2009). The greatest improvement in cognitive function appears to result from moderate intensity (e.g., as defined by the anaerobic threshold; AT) compared to low and high intensity exercise (see Figure 2.7, Kashihara et al., 2009). Moderate intensity exercise has also been linked to an increase in the P3 ERP *amplitude*, which relates to the magnitude of cognitive effort involved in the allocation of attentional resources in the performance of goal-directed behaviour (see Figure 2.8, Kamijo, Nishihira, Hatta, Kaneda, Wasaka, et al., 2004). In contrast to these results, high intensity aerobic exercise (a graded exercise test to VO_2max) has also been shown to improve cognitive function, specifically learning and memory (Griffin et al., 2011). However, improvements in cognitive function, specifically enhanced allocation of attentional resources (represented by an increase in the P3 ERP *amplitude*) has been linked to light and moderate (RPE of 11 and 13 respectively) aerobic exercise, whereas there was no improvement after the hard (RPE of 15) bout of exercise (Kamijo, Nishihira, Higashiura & Kuroiwa, 2007).

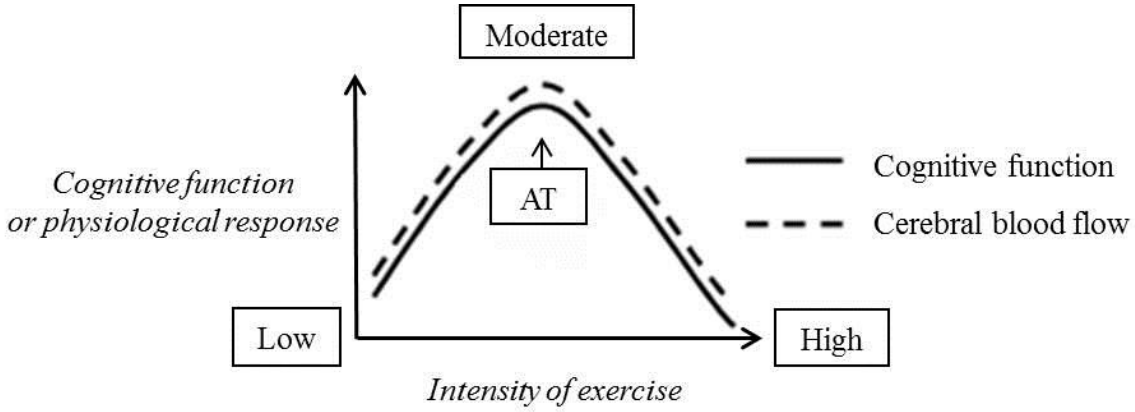

Figure 2. 8: Inverted U - physiological response corresponding to cognitive function (adapted from Kashihara et al., 2009).

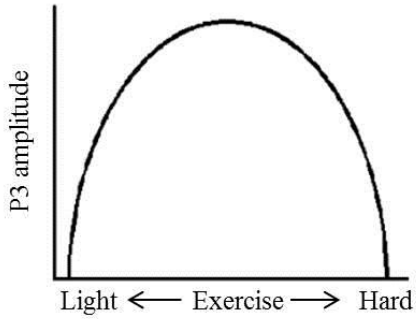

Figure 2. 9: Inverted U – exercise intensity corresponding to an increase in the P3 ERP amplitude (Kamijo et al., 2009).

Mode of exercise also varies between research interventions and includes aerobic and resistance-based exercise (e.g., Pesce & Audiffren, 2011; Weinberg, Hasni, Shinohara, & Duarte, 2014). Continuous aerobic exercise is the main form of exercise where exercise-induced enhancements in cognitive function have been observed, both as a result of long-term (e.g., Colcombe et al., 2006) and acute (e.g., Audiffren et al., 2008) interventions. For example, long-term (e.g., 12 months) participation in an exercise regime promoted cortical plasticity, specifically resting functional connectivity within the frontal, posterior, and temporal cortices, which was associated with an improvement in executive function (Voss et al., 2010). Further, improvements in reaction time in both younger and older adults have been observed after a single 20 min bout of moderate (50% VO_2max) cycling (Kamijo et al.,

2009). Whereas there is a wealth of research relating to the influence of aerobic exercise there is a lack of research on resistance exercise of a long-term or acute nature.

Research that has investigated the influence of resistance exercise on cognitive function, specifically the P3 ERP component, suggests that, similar to aerobic exercise, this type of exercise promotes an improvement in neural activity, namely a *latency* decrease and an *amplitude* increase in the P3 ERP component (Chang et al., 2013). When assessing these exercise modes the core attributes and differences between protocols must be considered to obtain an understanding of both behavioural and neurophysiological exercise-induced changes. For example, a basic difference between aerobic and resistance exercise being that aerobic exercise such as jogging or cycling would be classified as repetitive in nature and requires less cognitive engagement to perform the simple and rhythmic movement patterns on a stationary cycle ergometer or treadmill. Resistance exercise in contrast requires more complex movement patterns and is dynamic by nature incorporating a higher cognitive load than aerobic exercise, thus requiring more active engagement and allocation of attentional resources which is crucial for the controlled and fluid performance of exercise (Best, 2010; Chang et al., 2013; Dai et al., 2013).

A final consideration is that of one off acute compared to long term exercise interventions. A growing number of studies have observed exercise-induced enhancements in cognitive processes, including improvement in plasticity of the aging brain (Colcombe, et al., 2004) and increases in brain volume, specifically in both the grey and white matter regions after short term aerobic exercise training interventions in older adults (Colcombe, et al., 2006). Further, a single acute bout of exercise has been linked to an immediate and transient improvement in cognitive function (Griffin et al., 2011; Schneider, Brümmer, Abel, Askew, & Strüder, 2009) including an increase in the P3 ERP *amplitude* in the performance of an executive function test (e.g., modified flanker task). This is indicative of an increase in the

allocation of attentional resources during stimulus engagement (O'Leary et al., 2011). In light of the fact that this thesis is focused on the effects of a single acute bout of exercise the following sections will discuss research relating to acute bouts of both aerobic and resistance exercise.

4.1 Acute aerobic exercise

Acute aerobic exercise has been reported to have a beneficial effect on reducing task-related deficits in performance. For example, exercise-induced enhancement in cognitive flexibility and reduction in complex switch-task costs has been observed (Pesce & Audiffren, 2011). In young, healthy populations acute exercise appears to have a positive effect on cognitive functioning including executive functioning and cognitive processing speed (Griffin et al., 2011). Improvements in reaction times have also been reported after moderate intensity exercise (50% VO_2max) compared to baseline and light intensity (30% VO2max) exercise, in younger and older adults (19 – 25 and 60 – 74 years respectively). From a neurophysiological perspective these behavioural improvements were correlated with changes in neural activity, specifically the P3 ERP *latency* and *amplitude* (Kamijo et al., 2009).

In reviewing the literature, which included the use of PubMed, Scopus, Medline and PsychInfo search engines the process outlined in Figure 2.10 was followed. Sixteen studies were identified that have examined exercise-induced influence on neural activity, namely the N2 (5 studies) and P3 (14 studies) ERP components (see Table 2.1). Four of these studies evaluated multiple exercise intensities on the P3 ERP component before and after exercise (Barak et al., 2007; Kamijo et al., 2009; Kamijo, Nishihira, Hatta, Kaneda, Kida et al., 2004; Kamijo et al., 2007). Changes in P3 *amplitude* are equivocal, and include an increase after a moderate (i.e., RPE 12 – 14 and 75% HR_{max}) bout of cycling exercise, no difference or a decrease following high intensity aerobic exercise bouts (90% HR_{max}, RPE 15 and volitional

exhaustion), and a variation in results after a light bout of exercise (RPE 7 – 11 and 60% HR_{max}). Findings with regard to the P3 *latency* have also been equivocal with three studies not finding differences irrespective of exercise intensity (Barak et al., 2007; Kamijo et al., 2004; Kamijo et al., 2007). Kumar et al. (2012), on the other hand observed faster P3 *latencies* after a 20 min moderate exercise bout (60 – 80% HR_{max}). The ten studies that evaluated only a moderate bout of exercise on the N2 (x 4) and/or the P3 (x 9) ERP components, also reported a variation in results including no change in either component, an increase and decrease in P3 *amplitude*, decrease in N2 *amplitude* and *latency* and either no change or decrease in P3 *latency* (Chu, Alderman, Wei, & Chang, 2015; Drollette et al., 2014; Kumar et al., 2012; Magnié et al., 2000; O'Leary et al., 2011; Pontifex, Parks, Henning, & Kamijo, 2015; Scudder, Drollette, Pontifex, & Hillman, 2012; Stroth et al., 2009; Yagi, Coburn, Estes, & Arruda, 1999). The variety of findings may be related to: 1) the different exercise intensities and definitions employed (e.g., the use of HR_{max} or RPE to quantify exercise intensity); and 2) the different durations (between 5 min – 20 min) of exercise employed. The duration of a single bout of exercise is suggested to be an important factor in exercise-induced changes in cognitive function, with exercise sessions longer than 11 min having been reported to achieve significant differences in cognitive function after exercise (Chang, Labban, Gapin, & Etnier, 2012). In summary, the effect of aerobic exercise on cognitive function is varied, and to date no research has examined the acute effects of exercise on dual-task related neural activity.

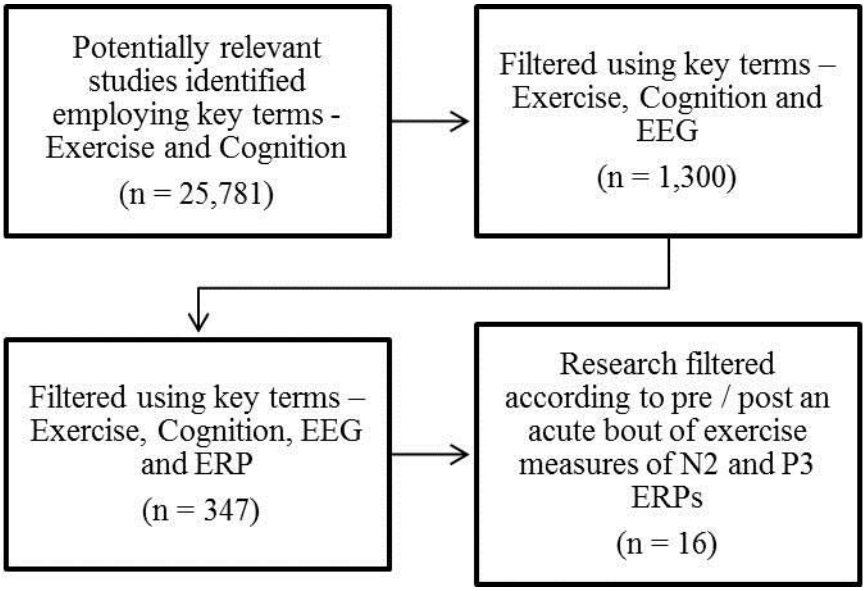

Figure 2. 10: Article review filter process.

Table 2. 1: Articles evaluating acute exercise-related influences on the N2 andP3 ERP components

Authors	Sample	Exercise intervention	Cognitive task	Pre Post Exercise Measure	Neural Activity Evaluated	Findings
Kumar et al., (2010)	34 males and 26 females 15 – 30 years	Moderate Aerobic	Auditory oddball paradigm	Yes	N100, P200, N200 ERP components	Exercise-related decrease in the N1, N2 & P2 ms in both genders and decrease in the N2 – P3 interpeak ms in males.
Magnie et al., (2000)	20 participants 18 – 30 years	Maximal Aerobic	Auditory oddball paradigm	Yes	P300 and N400 ERP components	Exercise-related increase in the P3 and N4 μV and ms decrease in all subjects even after body temp and HR returned to pre exercise values.
Yagi et al., (1999)	12 males and 12 females 20 ± 2 years	Moderate Aerobic	Auditory and visual oddball paradigm	Yes	P3 ERP component	Decrease in the P3 ms and μV during exercise, suggestive of faster cognitive information processing, but decreased attention and increase in errors during exercise.
O'Leary et al., (2011)	18 males and 18 females 18 – 25 years	Moderate Aerobic	Modified flanker task	Yes	P3 ERP component	An increase in the P3 μV following treadmill exercise relative to rest, suggestive of an increase in allocation of attentional resources during stimulus engagement.
Kumar et al., (2012)	60 sedentary males and females, 18 – 30 years	Moderate Aerobic	Auditory Oddball Paradigm	Yes	P3 ERP Component	Exercise-related reduction in the P3 ms.
Stroth et al., (2009)	35 adolescents 14.2 ± .05 years	Moderate Aerobic	Modified flanker task	Yes	N2 and P3 ERP components	Higher fit individuals showed higher CNV and decreased N2 μVs. No change in P3 μV and no substantial influence on cognitive processing with an acute bout of exercise.

Hillman et al., (2003)	10 males (20.5 ± .05) and 9 females 20.2 ± 1.0	Graded maximal exercise test	Eriksen flanker task	Yes	P3 ERP Component	Post-exercise related increase in the P3 μV. Suggestive of an exercise effect on neuroelectric processes underlying executive control through an increase in the allocation of neuroelectric resources, cognitive processing and stimulus classification speed.
Themanson & Hillman (2006)	14 males and 14 females 18 – 23 years	Vigorous but submaximal Aerobic	Eriksen flanker task	Yes	N2 ERP component	Higher fit adults exhibited a reduced error-related negativity μV, increased error positivity μV, and increased post-error response slowing compared to lower-fit adults.
Kamijo et al., (2007)	12 males 22 – 30 years	Light and Moderate Aerobic	Modified Flanker Task	Yes	P3 ERP Component	Increase in the P3 μV across light and moderate conditions but not hard.
Kamijo et al., (2009)	24 males 12 x 60 – 74 years and 12 x 19 – 25 years	Light and Moderate Aerobic	Modified Flanker Task	Yes	P3 ERP Component	Increase in the P3 μV after moderate exercise for the younger group only. Decrease in P3 ms after both light and moderate exercise for both groups.
Kamijo et al., (2004)	12 males 22 – 33 years	Low, Medium and High Aerobic	Go/No Go Reaction Time Task	Yes	P3 ERP Component	Reduced P3 μV after high-intensity exercise and an increase in the P3 μV after moderate-intensity exercise.
Drollette et al., (2014)	13 males and 27 females 9.7 ± 0.7 years	Moderate Aerobic	Modified flanker task	Yes	N2 and P3 ERP components	Exercise-related increase in the P3 μV and a reduction in the N2 μV and P3 ms, suggestive of an overall facilitation in response conflict and the speed of stimulus classification.
Pontifex et al., (2015)	21 males and 16 females 19.3 ± 0.9 years	Moderate Aerobic	Three-stimulus oddball task	Yes	P3, P3a and P3b ERP component	Exercise-related attentional processing was sustained (as indexed by the P3b) relative to pretest whereas prolonged sitting resulted in attentional decrements.

Scudder et al., (2012)	19 males and 18 females 19.7 ± 1.3 years	Moderate Aerobic	AX-continuous performance task	Yes	N2 and P3 ERP components	Exercise-related increase in the P3 μV within midline-parietal sites for both target and non-target trials.
Chu et al., (2015)	21 participants 19 – 24 years	Moderate Aerobic	Stop signal task	Yes	N1 and P3 ERP components	Exercise-related increase in the P3 μV and ms, however no effect on the N1 component.
Barak et al., (2007)	17 adults 21.6 ± 1.07 years	60, 75 and 90% max pulse Aerobic	Reaction time task	Yes	P3 ERP Component	Increase in P3 μV seen at 70% max pulse. No change in P3 ms.

4.2 Acute resistance exercise

Resistance exercise has been predominantly advocated in the attenuation of sarcopenia (muscle loss) and bone degeneration (osteoporosis), with resistance exercise increasing serum concentrations of bone ratio markers suggestive of increased bone turnover and bone formation (Karabulut et al., 2011). The few studies which have been conducted suggest that high intensity resistance training (100% 10 RM) improves cognitive processing speed, whereas moderate intensity resistance training (70% 10 RM) is associated with enhanced processing speed and executive functioning immediately following exercise (Chang & Etnier, 2009b; Chang et al., 2014). These exercise-induced improvements have also been reported in relation to automatic cognitive processes, such as speed of processing in executive function tasks (e.g., Stroop colour – word) and a trend towards improvements in the performance of tasks requiring shifting of an habitual response (Chang & Etnier, 2009a).

An improvement in episodic memory performance has also been observed after lower body resistance exercise (e.g., one-leg knee extension/flexion task) (Weinberg et al., 2014). Further, Hsieh et al. (2016) reported an improvement in working memory in both young (21 – 30 years) and older (65 -72 years) adult males after exercise. These authors suggested that the improvements in task performance support the beneficial effects of an increase in exercise-induced arousal and improved processing speed in the working memory task. They further suggested that these improvements may be related to exercise-induced changes in cortisol, which is believed to modulate cognitive function (Hsieh et al., 2016). Of note, is that changes in serum levels of cortisol has previously been reported to be associated with differences in electrophysiological performance, such as the P3 *amplitude*, an indicator of the degree of allocation of attentional resources recruited to perform a cognitive task (Tsai, Wang, et al., 2014).

In summary, from the limited research that has examined the influence of acute bouts of resistance exercise on cognitive function, suggest a positive effect. However, there is no research that has evaluated the influence of an acute bout of resistance exercise on neural activity, and more specifically dual-task related neural activity.

4.3 Additional factors in assessing cognitive function and exercise

The cognitive task employed must also be considered, due to the differences in behavioural tasks available and the areas of cognitive function of interest. The modified flanker and oddball paradigms require participants to respond to a form of sensory stimuli (e.g., auditory or visual) through the execution of a button push in response to the stimulus. These paradigms are examples of cognitive tests that promote the use of executive control, specifically interference control in the evaluation of the P3 ERP component response. This response has been observed to be more prominent when performing tasks that require an inhibitory response. For example, in the use of a modified flanker task, participants are presented with a set of visual stimuli to assess their ability to suppress an incorrect response. The participant is required to identify the direction of the central target which is flanked by distractor stimuli by pressing the left or right key on a computer. The inhibitory response in an incongruent trial (e.g., central arrow facing in the opposite direction of the flanker arrows) is reported to increase the P3 *latency*. In other words an inhibitory response takes longer to perform, hence the increase in P3 *latency* (Hahn et al., 2011).

Timing of testing, both time of day and period between cessation of exercise and cognitive function testing are also parameters to be considered. Current evidence relating to the time of day, suggests that testing in the morning is the optimal time to perform cognitive tests opposed to the afternoon (Chang et al., 2012). Finally, time of administration of the cognitive exercise is reported to be of fundamental importance. This is due to the short lasting effect of exercise on cognitive function (e.g., executive function). Chang et al. (2012)

concluded within their meta-analysis, that exercise-induced improvement in cognitive performance where negligible in the first 10 min after exercise, negative between 11 – 20 min post exercise, and positive 20 min post exercise, with larger effects seen in measures of executive function as opposed to other categories of cognitive function.

5. Summary

This literature review highlights the complex nature of performing activities of daily living and the importance of visuomotor function, including visual coordination and neural function. The equivocal nature of current research relating to the influence of acute bouts of exercise on cognitive function has also been explored, and provides a basis with which to justify the studies performed in the completion of this thesis. In further support of this, although there are numerous studies that have assessed brain function from a behavioural perspective (e.g., Barella, Etnier, & Chang, 2010; Córdova et al., 2009; Tseng, Munro Cullum, & Zhang, 2014), there is a paucity of neurophysiological research that has investigated the relationship between acute exercise and cognitive function, specifically in the context of dual-task performance and the underlying neural mechanisms (neural activity), for example the N2 and P3 ERP components.

Another fundamental limitation of many of the assessment strategies employed within the literature outlined in this review, is that cognitive function has been assessed in a stationary (supine or seated) context, and are not representative of many activities of daily living. Given that most tasks happen in environments far more dynamic than the laboratory, at some point we need to let people move freely so we can obtain a better understanding of cognitive processes that underlie how people perform in the real-world, with whole body movement, performing various tasks and processing multiple sources of information at the same time. Therefore, the overarching goal of this research was to examine whether an acute bout of exercise (aerobic compared to resistance) could influence the ability to perform tasks

of increasing difficulty in a more real world application. To achieve this, a locomotive dual-task that incorporated a secondary task appropriate for measuring neural activity (EEG) had to be designed.

The objective of this research was to provide both a behavioural and neurophysiological assessment for determining the moderating effect of an acute bout of aerobic compared to resistance exercise on dual-task performance. The key aims of this research were:

1. Design a locomotive dual-task paradigm to evaluate gaze behaviour and neural activity in the performance of goal-directed behaviour.
2. Evaluate whether an acute bout of aerobic versus resistance exercise can influence single- and dual-task completion time and alter key aspects of neural activity related to sensory integration and decision making.

Chapter Three

Study 1 – Validation of a new locomotive single- and dual-task paradigm to evaluate differences in gaze behaviour and neural activity

1. Introduction

In the course of our daily lives we are required to integrate and respond to multiple sources of information to successfully navigate our way around our environment. This ability requires the coordinated interaction between visual perception and action to perform a task safely and efficiently. For example, crossing a road has both visual perceptual (e.g., watching for other pedestrians and oncoming cars) and motor (e.g., walking) components. The coordination of these perceptual (cognitive) and locomotive (motor) aspects are classified as a dual-task because they require the execution of the cognitive and motor task simultaneously. There is a wealth of research that has examined dual-task capacity (e.g., simultaneous performance of walking and memory encoding) throughout the lifespan. This shows that dual-task costs become more pronounced with age, specifically decrements in memory encoding capacity (Lindenberger et al., 2000). This understanding is important because decrements in dual-task capacity have been linked to an increase in fall rates in older adults (Ayers et al., 2014; Lundin-Olsson, Nyberg, & Gustafson, 1997). Dual-task costs have also been associated to older adults altering their gait pattern (e.g., reduced walking speed), and taking longer to evaluate traffic patterns and initiate movement when crossing a road (Hall et al., 2011; Neider et al., 2011).

In an attempt to create dual-task paradigms that have greater ecological validity, laboratory-based walking tasks and immersive virtual environments have been designed (Lindenberger et al., 2000; Neider et al., 2011). These paradigms have measured dual-task costs from a behavioural (e.g., change in movement time and changes to gait and walking

speed) perspective, but we have yet to understand the underlying neurophysiological differences associated with these dual-task costs, such as task-related differences in visual perception and neural activity. Therefore, the purpose of this research was to develop a locomotive paradigm that would enable the collection of both gaze behaviour and neural activity (EEG) associated with performing tasks of increasing difficulty (single- and dual-tasks).

Visuomotor coordination and efficiency are fundamental to the acquisition of information from the environment and provide a basis from which motor tasks are performed. Because of the association between eye movement and attention (Land, 2009; Land & Hayhoe, 2001), eye tracking has frequently been employed as a means of investigating how changes in physiological function, such as the influence of exercise intensity, affect visual function (Middlebrooke, Stephenson, & Unnithan, 1999), and the effect of fatigue on saccadic eye movement. Fatigue, in this context, results in a reduction in saccade velocity and accuracy (Duncan, 2011). From a practical perspective these changes may influence the precision and efficiency of perception-action coupling. This could result in delays in reaction times associated with stimulus response (e.g., tracking and catching a ball in flight) (Stone, et al.,2014). Further, visual fixations precede whole-body rotation by as much as 1.5 s when changing direction of travel during locomotion (Reed-Jones et al., 2009). Therefore, any delay in perception-action coupling may result in faltering in gait (e.g., in older adults) and increased risk of falls. An increase in cognitive load, such as in a dual-task scenario, where there is an increase in attentional demands, is also associated with a reduction in visuomotor performance (e.g., voluntary and reflexive ocular movement) (Meyer et al., 2007). An underlying aspect of these behavioural differences in performance associated with perception-action coupling is how cognitive load influences visuomotor performance at a neural level (e.g., changes in the spatial and temporal aspects of neural activity).

Numerous aspects of brain function have been examined with the goal of obtaining a more comprehensive understanding of the mechanisms that underpin behavioural outcomes. This includes the costs associated with carrying out dual-tasks. The brain has an amazing capability to perform various tasks and process multiple sources of information at the same time (e.g. dual-task capability) with efficiency and precision in healthy functioning individuals. Numerous aspects of neurological function have been examined with the goal of obtaining a more comprehensive understanding of the mechanisms that underpin behavioural outcomes, such as those associated with aging and dual-task costs. Over the past few decades, research employing imaging technology such as fMRI and EEG, have provided significant insights into spatial (fMRI) and temporal (EEG) alterations in brain function in response to cognitive tasks in a variety of populations. Of note is research that has observed an age-related decline in neural activity, specifically smaller parietal P3 amplitudes with increasing age, associated with the classification of sensory stimuli and allocation of attentional resources during dual-task performance (Hahn et al., 2011). This study like many others (e.g., Bisiacchi, Schiff, Ciccola, & Kliegel, 2009), however, employed a paradigm where participants were required to perform a dual-task in a seated position, therefore negating whole body movement and negotiation of locomotion within the environment. Given that most tasks happen in environments far more dynamic than the laboratory, at some point we need to let people move freely so we can obtain a better understanding of cognitive processes that underlie how people perform in the real-world, with whole body movement, performing various tasks and processing multiple sources of information at the same time.

The challenge with previously employed dual-task walking paradigms like the aperiodic and oval tracks designed by Lindenberger et al. (2000) is that they lack fundamental attributes required for the collection of ERP neural activity data. ERPs are stimulus dependent, meaning that this type of neural activity requires some form of stimulus

(e.g., auditory or visual) to generate the ERP response. Therefore, key attributes of a walking paradigm must include: 1) the flexibility to enable the collection of sufficient trials that can be performed in a consecutive manner, and 2) sufficient trial length to enable the collection of ERP data. The need for a large number of trials specifically relates to signal averaging, which is a process that assumes that the ERP waveform is identical in each trial, whereas extraneous noise (non-cerebral artefact) is not. Therefore, the more trials that can be performed, the clearer the resulting ERP waveform will be due to the reduction of the non-cerebral artefact. A smoother looking trial averaged ERP waveform will allow for better identification of the ERP characteristics of interest. In the evaluation of ERP neural activity the length of a trial is also important because an ERP can last for several seconds (epoch). If one epoch overlaps another this can distort (smear) the data, increasing the risk of the data being misinterpreted and making it difficult to identify neural activity of interest (Luck, 2005). Therefore, a dual-task walking paradigm needs to account for these two considerations (trial duration and number) to enable the collection of task-related neural activity.

In light of the need to develop paradigms that enable more naturalistic movement and behaviour, this study sought to design a locomotive dual-task paradigm to examine task-related (single- and dual-task) differences in: 1) gaze behaviour, specifically difference in task-related fixations, location of gaze and quiet eye (onset, offset and duration). The quiet eye is defined as the final fixation location and duration prior to the performance of the behavioural response (e.g., change in direction of travel) (Panchuk & Vickers, 2011). The quiet eye is an important factor in terms of this paradigm as it has been presumed to play a role in motor planning during goal-directed locomotion and shown to be related to expertise during these tasks (Panchuk & Vickers, 2011), and 2) neural activity, specifically the N2 and P3 ERP component *latencies* (ms) and *amplitudes* (μV). For the N2 ERP, *latency* is an index of the timing of information processing during visual perception, with the *peak latency*

representing the moment in time where sensory information is available to formulate the stimulus response decision (Schmitt et al., 2000; Thorpe et al., 1996), and the N2 *amplitude* is associated with the neural activity (degree of effort and processes) required for response inhibition (Jodo & Kayama, 1992; Sasaki, Gemba, Nambu, & Matsuzaki, 1993). The P3 ERP *latency* is related to the speed with which we can classify sensory stimuli and the *amplitude* is related to the allocation of attentional resources and working memory (Duncan-Johnson, 1981; Kutas et al., 1977; Polich, 1987). For this study it was hypothesized that: 1) the dual- compared to single-task will take longer to perform; 2) there would be a greater fixation count associated with dual-task performance; 3) the duration of fixations would be shorter in association with dual-task performance; 4) there would be a longer quiet eye period associated with dual-task performance; 5) there would be an increase in the N2 and P3 *peak latencies* associated with dual-task performance, and 6) there would be a decrease in the P3 *mean amplitudes* associated with dual-task performance.

2. Methods

2.1 Participants

Prior to participation in the screening and experimental session, participants were provided with an overview of the experiment (see Appendix 1), engaged in preliminary screening, and asked to provide informed consent (see Appendix 2). Suitability to participate in the study was assessed by a health history and demographics questionnaire (see Appendix 3). Seven males (n = 7) and eight females (n = 8) (*M* age = 25.7 years; range 20 – 34 years) were recruited to participate in this study. All participants were healthy and reported being free of any neurological disorders and any medication that would influence central nervous system function. The study was reviewed and approved by the Human Research Ethics Committee, Victoria University, Melbourne, Australia.

2.2 Apparatus

2.2.1 Walking grid:

A walking grid (21 m x 14 m) was created within a laboratory space by placing 48 mm wide tape on the ground. The grid was partitioned into 3.5 m sections allowing for a number of directional changes at each intersection. During the study task, a trial was defined as a 3.5 m section of track ending in a 90° left/right turn at each intersection (see Figure 3.1). Marks were placed on the grid to provide a visual prompt (1 m from the intersection) at which point the auditory stimulus was triggered. The size of each section was based on the following factors: 1) the flexibility to enable the collection of sufficient (150) trials to be performed in a consecutive manner; 2) to reduce the risk of overlapping ERP components; and 3) this track was designed to enable the future evaluation of an older adult participant group, who travel at approximately .8 - .9 m/sec (Studenski et al., 2011), and to account for the deceleration and acceleration phases of performing a turn at each of the intersections.

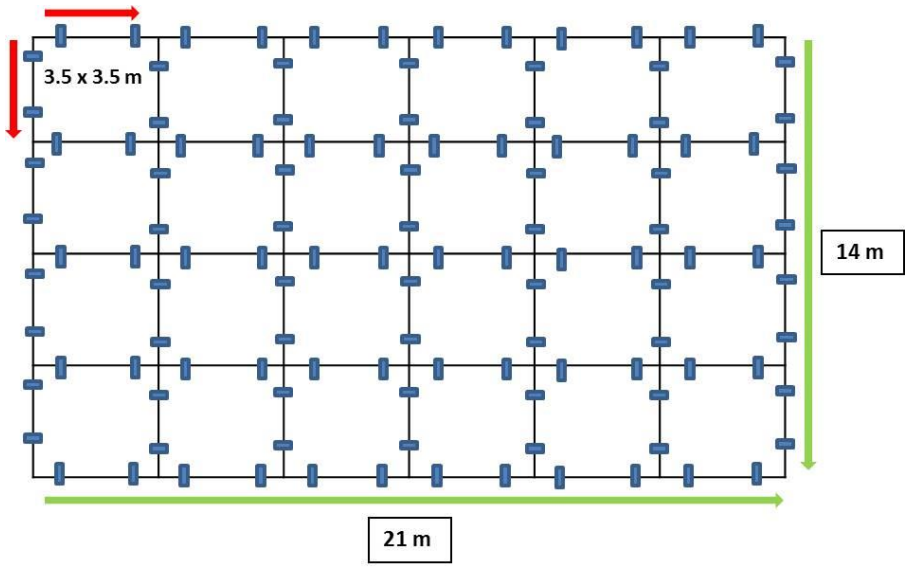

Figure 3. 1: Walking Track ▮ = 1 m marker before the intersection, where the directional auditory command tone (1000 or 2000 Hz tone) was triggered.

2.2.2 Gaze recording

To assess visual attention, participants were asked to wear an eye tracking device to measure gaze behaviour during the study task. The Mobile Eye (Applied Science Laboratories, Bedford, MA) is a head-mounted, monocular eye-tracking system that uses corneal reflection to measure eye-line-of-gaze with respect to the field of view with an accuracy of 0.5° and resolution of 0.1° of visual angle. Pupil position from the eye camera was used to calculate point-of-gaze and a cursor overlay was generated on video from the scene camera. The eye tracker permitted full range of movement to participants during performance of the study tasks. The video image recorded from the scene camera was synchronized and combined with a video image of the participants' transition around the walking grid to enable an accurate determinant of gaze location throughout the duration of each trial (3.5 m) (see Figure 3.2).

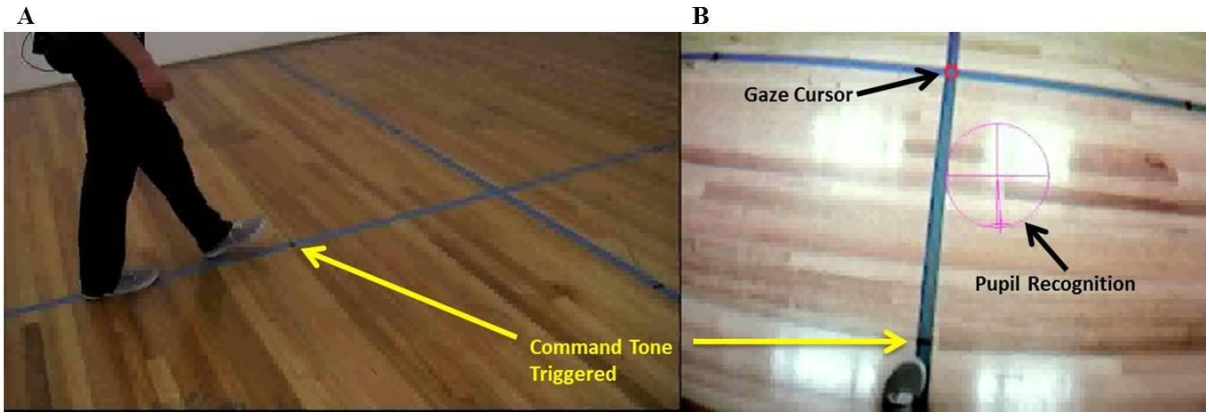

Figure 3. 2: A) External camera and B) Scene camera.

2.2.3 Neural activity

Continuous EEG data were recorded using an elastic ActiCap with 32 channel Ag-AgCl active electrodes (reducing the signal to noise ratio), electrical activity was then transmitted as a digital signal via the MOVE wireless system via Bluetooth to the receiver and subsequently amplified by the ActiCHamp active amplifier component and recorded using PyCorder 1.0.7 software (Brain Products, GmbH). As the intention is to employ this

study design in the subsequent study, which will evaluate the influence of acute exercise on neural activity, only a 32 channel montage was employed. This was for the primary reason of reducing the risk of signal distortion occurring as a result of perspiration induced cross bridging (electrical bridging) between electrodes (Alschuler et al., 2014). Electrodes were placed in accordance with the international 10/20 system (Klem, Lüders, Jasper, & Elger, 1999; Pontifex & Hillman, 2007). A ground electrode was positioned above the forehead (Fpz), and all electrodes were referenced during recording to TP10. Additional electrodes were placed above and below the left orbit, and the outer canthus of each eye to monitor bipolar electrooculargraphic (EOG) activity. Heart rate electrocardiographic (ECG) activity was recorded through placement of electrodes below the collar bone on the mid and lateral aspect of the left side of the body on a 45º angle. In addition a reference electrode for the MOVE Wireless System was placed in the position of AFz. Data were sampled at 1000 Hz and electrode impedances were checked pre and post each phase of testing and remained < 3 kΩ.

2.2.4 Stimuli

Turn direction at each intersection was indicated to participants using an auditory stimulus. For the delivery of the auditory tone to the participant, including accounting for the parameters of sound propagation (approximately 343 m/sec), a tone generation system that had that capacity to send a tone wirelessly to the participant within a 10 ms time frame was constructed. Auditory command stimuli were triggered by way of a wireless control and presented to participants 1 m prior (see Figure 3.2) to each intersection to indicate which direction they were to turn (left or right) in two of the study conditions (single- and dual-task). The stimuli consisted of a ramped based (2 ms increase, plateau of 5 ms at 60 dB and 2 ms decrease) tone system, including low-pitch (1000 Hz) and high-pitch (2000 Hz) tones. Auditory stimuli were presented via Logitech in-ear noise-isolating earphones (Logitech -

UE200vi); with the 1000 and 2000 Hz tones indicating the need to perform a left and right hand turn at the intersection respectively.

3. Procedure

Participants attended a single testing session consisting of: 1) screening measures and initial health assessments to determine suitability for further participation; and 2) the experimental task. Once the eye tracker and EEG equipment were fitted and calibrated, participants performed testing in four *phases* including: 1) *Baseline condition*: Participants were required to walk around the grid system and instructed to turn left or right at each of the intersections (participant's choice) for a total of 100 trials (one x 3.5 m section of track = 1 trial). The auditory tones (low and high pitch) were generated when the participant's leading foot passed over a mark 1 m from the intersection (see Figure 3.2), however participants were instructed to ignore the tone; 2) *Tone training*: Participants received tone training to learn which tone was associated with each of the directional commands. Once the participant was confidently able to identify each respective tone command they progressed to either the single- or dual-task condition, which was randomised between participants; 3) *Single-task condition*: Participants repeated the same task as outlined in the baseline condition for a total of 150 trials with the inclusion of a directional (1000 or 2000 Hz) command tone or, if no tone was presented, the participant was instructed to walk straight ahead (no turn) at the intersection (50 trials each direction, randomised); and 4) *Dual-task condition*: Participants were shown a list of 15 concrete nouns representative of a shopping list (e.g., almonds, pizza, wine and onions), with each word being presented one at a time for two seconds. Participants were asked to memorise as many words as possible and then asked to travel around the walking grid performing the same task as outlined in the single-task condition. At the completion of the walking trial, participants were asked to recall as many of the 15 words as possible.

4. Data processing and analysis

Due to ongoing technical issues with the EEG equipment and signal contamination that only became apparent post data collection, all EEG data were lost. Therefore, for the purpose of this study only the behavioural and gaze behaviour data will be presented.

4.1 Behavioural data

Time to complete each trial was defined as the time it took a participant to walk through a 3.5 m section of track ending at each of the intersections. In order to determine the difference in time taken to perform the single- versus the dual-task trials, pairwise comparisons were employed. For all analyses data is reported using standard error of the mean.

4.2 Gaze behaviour data

Each trial was broken into three motor phases, identified by the following parameters (see Figure 3.3): 1) The approach phase was defined as the period between 1 m after the beginning of each intersection to the 1 m mark before the next intersection (i.e., where the auditory stimulus was triggered); 2) the stimulus onset phase was defined as the period between the end of the approach phase to the initiation of a change of direction of travel (identified by change of direction of foot placement); and 3) the turn phase was defined as the period between the end of the stimulus onset phase to the beginning of the next approach phase (1 m after the intersection). Gaze behaviour was assessed in relation to the motor phases of the walking task. Gaze behaviour parameters were: fixations, location of gaze and QE (onset, offset and duration) recorded throughout the duration of each motor phase. A fixation was defined as gaze behaviour where the cursor remained still (within 3^{o} of visual angle) for a period of at least 100 ms (or 3 frames of video). The QE relates to the extraction of information from the environment and is essential for perception-action coupling (Panchuk

& Vickers, 2011). For the purpose of this study the QE was defined as the final fixation prior to the stimulus onset phase (Panchuk & Vickers, 2011).

Each dependent variable was analysed separately using linear mixed modelling (LMM) with single- and dual-tasks as fixed factors, average of trials, and participant as random factors. The fit of the model was adjusted by inclusion of random intercepts and slopes, changing the variance structure, and removing non-significant effects. Goodness of fit between models was compared using Akaike Information Criterion. LMM provides an alternative to traditional statistical techniques for analysing repeated measures effects (e.g., repeated measures ANOVA) as it does not rely on the assumptions of parametric statistics (i.e., normality and homoscedasticity), is able to account for individual and group changes over time, and can handle unequal data sets with randomly missing values (Baayen, Davidson, & Bates, 2008; Gueorguieva & Krystal, 2004).

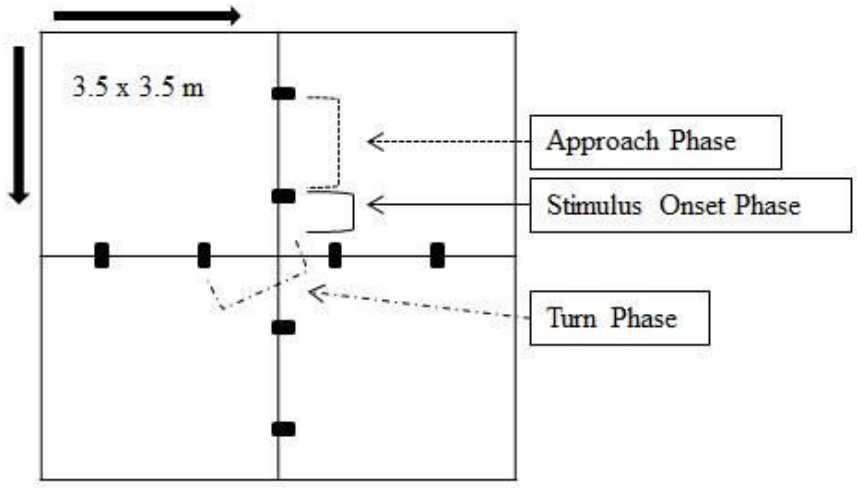

Figure 3. 3: Key motor phases for analysis of gaze behaviour.

5. Results

5.1 Behavioural data

Comparison of trial completion time revealed a main effect for task (t (14) = - 4.85, p < .001, d = 0.79) with faster times in the single- compared to the dual-task (4.02 ± .46 s and 4.45 ± .56 s respectively; see Figure 3.4). On average the participants recalled 9 ± 4 out of 15 words.

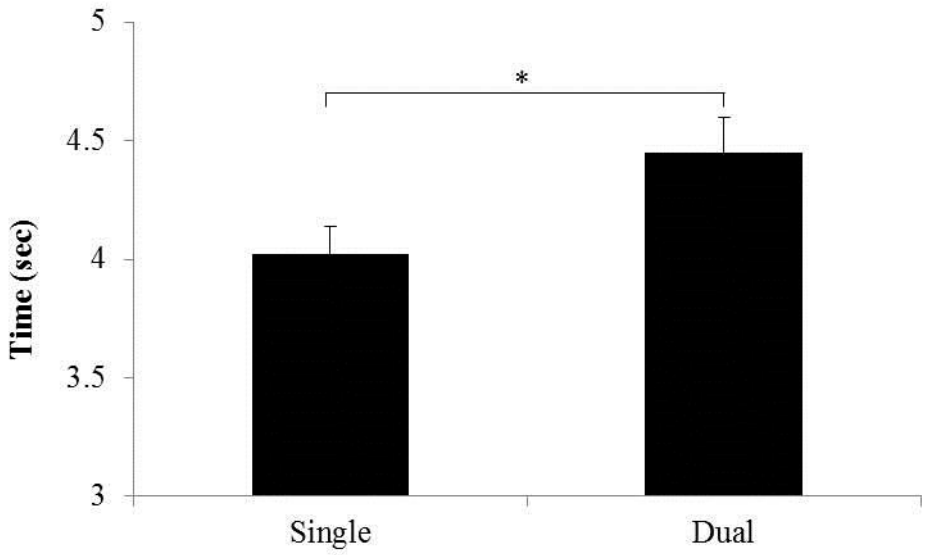

Figure 3. 4: Comparison of trial completion time between single- and dual-task conditions (* represents p < .05). Data is presented as mean ± SE.

5.2 Gaze behaviour data

One participant's data was discarded from the analysis due to technical faults and calibration issues leaving a total of 4500 trials (of 4800).

Overall fixation count revealed a significant difference between conditions (p = .01; 95% CI [-1.12, -0.17]) with more fixations occurring in the performance of the dual- compared to the single-task (7.40 ± .37 and 6.76 ± .37). There was also a significant difference in fixation location (p = .01; 95% CI [0.15, 0.81]) with more fixations in the direction opposite the direction of travel in the single- compared to the dual-task (0.48 ± 0.16 0.00 ± .00) (see Table 3.1). Gaze was also assessed relative to the different motor phases.

Participants spent relatively more time looking straight ahead during the approach phase ($p <$ .01; 95% CI [1.44, 6.45]) in the single- (35.66 ± .59%) compared to the dual-task condition (31.72 ± .80%). In contrast, participants spent relatively more time looking in the direction of the turn ($p <$ .01; 95% CI [-3.73, -1.40]) in the dual- (3.57 ± .80%) compared to the single-task (1.00 ± .59%) condition (see Table 3.1). Results also revealed a significant effect for the relative QE offset (p = .01; 95% CI [-4.31, -0.49]), with the single-task offset occurring earlier than that observed in the dual-task (58.49 ± 1.10% and 60.89 ± 1.13% respectively).

Table 3.1: Percentage of fixations to each location for the three motor phases

Phase	Location	Single-task (%)	Dual-task (%)
Approach	Straight Ahead	35.34	31.27
	Direction of subsequent turn	1.82	5.08
	Opposite direction of subsequent turn	0.67	0.73
	Other	1.09	0.29
Stimulus Onset	Straight Ahead	4.29	1.92
	Direction of subsequent turn	4.54	8.33
	Opposite direction of subsequent turn	0.41	0.35
	Other	0.29	0.11
Turn	Straight Ahead	0.19	0.00
	Direction of subsequent turn	16.89	19.68
	Opposite direction of subsequent turn	0.06	0.30
	Other	0.29	0.22

6. Discussion

The purpose of this study was to design a locomotive dual-task paradigm to enable the collection of both gaze behaviours in task-related fixations, location of gaze and QE (onset, offset, and duration) and neural activity by means of the N2 and P3 ERP component *latencies* and *amplitudes*. However, due to ongoing technical issues with the EEG equipment and signal contamination that only became apparent post data collection, all EEG data were lost. Therefore, for the purpose of this study only the behavioural and gaze behaviour data were presented. The behavioural results of this study show an increase in time taken to perform a dual- compared to a single-task. Further differences in task-related gaze behaviour were identified, specifically: 1) fixation count, with more fixations occurring in the dual- compared to the single-task; 2) differences in gaze location between the single- and dual-task; and 3) difference in QE offset phase was observed.

Navigation through the environment involves the coordinated recruitment of visual (cognitive) and motor (head and body movement) resources in response to various cues and stimuli (Reed-Jones et al., 2009). In the performance of tasks of increasing complexity (e.g., dual-tasking), the ability to process visuomotor information may become impaired due the increased demand on the attentional resources (Meyer et al., 2007). This proposed impairment in task-related allocation of attentional resources is highlighted within the behavioural results of this study, which show an increase in time taken to perform a dual- compared to a single-task, consistent with previous research (Capizzi, Correa, & Sanabria, 2013).

This difference in task-related activity is also represented in some of the key parameters of gaze behaviour. More fixations occurred in the dual- compared to the single-task suggesting a less efficient pattern of visual search as a consequence of increasing task demands. Furthermore, during the approach phase (i.e., the period prior to the onset of the

directional auditory stimulus) of the single-task condition, participants spent relatively more time looking in the direction of travel, whereas in the dual-task condition they looked in the direction of the subsequent turn (to the right or left while walking straight ahead) for a greater proportion of time prior to the turn. Simply put, in the single-task condition participants focused their attention in the direction they were heading. Whereas, in the dual-task condition participants appeared to anticipate the direction of travel prior to the onset of the auditory command stimulus. The latter might indicate a compensatory measure to circumvent the increased attentional demands required to perform the task successfully under dual-task conditions. In other words, participants tried to predict what the next directional change would be before the presentation of the auditory stimulus, thereby reducing the cognitive load required to simultaneously manage both the memory recall task and recalling what direction to turn at the onset of the auditory stimuli. Finally, a significant difference in QE offset phase was observed. This offset is representative of the time point at which sufficient visual information has been obtained to perform the correct goal of the motor-task (initiation of a change in direction of travel) (Panchuk & Vickers, 2011). In the single-task condition, participants had an earlier QE offset compared to the dual-task condition. This suggests that there may be a delay in visual information processing due to the increase in dual-task attentional demand. In other words, the time point that participants had sufficient information with which to perform the change in direction of travel was delayed due to the attentional resources having to simultaneously manage both the primary (walking around the grid and responding to the sensory stimulus) and secondary (words from the shopping list) task.

There are a few limitations in this study, these included: 1) ongoing technical and EEG signal contamination issues that resulted in the complete loss of neural data within this study. These problems resulted from the limitations of the EEG system used, specifically the restricted signal transmission range which allowed for data to be recorded within a 6 m radius

only. Further, the EEG transmitter and receiver had to be in direct line of sight at all times to reduce the risk of loss of signal; and 2) EEG signal contamination occurred as a consequence of the wireless auditory system. Specifically, the hardware components, being in close proximity to the EEG hardware and the use of electrode TP10 (mastoid placement), resulting in significant movement-related artefact that could not be removed or attenuated in the offline analysis.

This novel, locomotor dual-task paradigm was designed to examine potential task-related differences in gaze behaviour and neural activity. The use of this type of paradigm was successful for collection of valid and reliable gaze behaviour data within a replicable experimental paradigm. Gaze behaviour findings, specifically less efficient and anticipatory fixations and delay in visual information processing (QE offset) may contribute to the significant difference seen in trial completion time between the single- and dual-task conditions. However, differences in gaze behaviour are only part of the changing dynamics associated with performing tasks of increasing difficulty. To further understand the underlying mechanisms responsible for behavioural changes (trial completion time) further investigation is required, specifically how we integrate and process sensory information in response to changing cognitive load. It was therefore the intention to adjust the auditory hardwired components and change the online reference electrode to prevent the contamination of the EEG signal and employ this dual-task paradigm within the next study to examine whether this paradigm is suitable for measuring task-related differences in neural activity using electroencephalography.

Chapter Four

Study 2 - Validating the use of EEG to examine neural activity associated with single- and dual-tasks during locomotion

1. Introduction

A fundamental component of everyday function is the ability to simultaneously execute both cognitive and motor tasks. For example driving requires the integration of both visual (watching for environmental cues such as cars, cyclists and traffic lights) and motor (controlling the motor aspects of driving such as steering and gear changes) function to successfully accomplish this goal-directed behaviour. Our capacity to simultaneously carry out a cognitive and motor task has been examined widely from a behavioural and biomechanical approach using computer-based and virtual reality tasks (Li et al., 2001; Neider et al., 2011). However, a key component that must be understood is what the task-related differences in neural activity are with increasing cognitive demands. Therefore, the purpose of this research was to examine whether the paradigm validated in study one would be suitable for measuring neural activity associated with performing tasks of increasing cognitive load while performing whole-body movements.

The brain has an amazing capability to perform various tasks and process multiple sources of information at the same time with efficiency and precision in healthy functioning individuals. This capability has been widely examined with the goal of obtaining a better understanding of both the structural and functional differences in the brain of healthy, aging and diseased populations. For example, numerous studies have assessed brain function from a behavioural perspective by examining cognitive performance related to aging and the influence of exercise and disease (Barella et al., 2010; Córdova et al., 2009; Tseng et al., 2014). In addition, more neurophysiological assessment methods such as EEG and fMRI

techniques have been developed to examine brain functioning during task performance. Two key parameters examined within a neurophysiological approach are that of spatial and temporal resolution. Spatial resolution refers to the identification of areas of the brain that are most active (e.g., differences in cerebral oxygenation during the performance of a cognitive, motor or visual task), while temporal resolution refers to the time course of activation in the brain (e.g., neural response to a sensory stimuli). In other words spatial and temporal resolution relate to the ability to identify neural events in space and time. Over the past few decades, research employing imaging technology such as fMRI (which has good spatial resolution) and EEG (which has good temporal resolution) have provided significant insights into alterations in brain function in response to cognitive tasks in a variety of populations. From these assessment measures a wealth of knowledge relating to brain function and how different populations perform laboratory-based cognitive tasks has been reported (e.g., Chou et al., 2013; Heuninckx et al., 2008; Kamijo et al., 2009). An important limitation of many of these assessment strategies, however, is that they have been primarily used in tasks that are stationary (supine or seated) and are not representative of many activities of daily living. To evaluate how engaging in activities of daily living influences patterns of neural activity, there is a need to develop paradigms that enable whole-body movement and behaviour.

Technological developments, including mobile EEG systems, have made it possible to assess neural activity in an 'unconstrained' and dynamic environment (Lin, Wang, Wei, & Jung, 2014). The compact and portable wireless transmitter and receiver configurations replace the leads and cables that would normally be used with a hardwired system (e.g., amplifier and computer), in effect, untethering the participant and enabling more naturalistic human movement and behaviours. The validity of mobile EEG systems is yet to be determined, however, an important question needs to be addressed; that is whether valid data can be obtained when employing paradigms that permit natural head/body movement,

specifically in context of minimising and treating movement-related artefact? In the following section, these issues will be addressed.

Minimising the occurrence of movement-related artefact involves the strategic design of testing paradigms and the treatment of data in offline analyses. Multiple steps can be employed to minimise extraneous noise, such as that caused by electrode and cable movement. For example, they can be minimized by the use of a tubular bandage to secure the cap and electrodes to the head. Furthermore, modern brain computer interface EEG systems (e.g., ANT Neuro) use a combination of central references and grounds (e.g., electrode Cz – central midline placement) and active shielding strategies to minimise movement-related artefact. There are a few offline processes proposed in the management of artefact such as that observed with electromyographic (EMG), EOG, and ECG activity. Two processes that are utilised for identifying extraneous artefact include principal component analysis (PCA) and independent component analysis (ICA; Makeig, Jung, Bell, Ghahremani, & Sejnowski, 1997). Whereas PCA is a statistical procedure that uses an orthogonal transformation to identify linearly, unrelated components, ICA is a class of blind source separation that uses both linear and non-linear relationships to separate the raw EEG signal into underlying informational components that are statistically independent and is able to exploit non-Gaussian features of the signal (Luck, 2005; Stone, 2004).

The use of ICA in the identification and attenuation of signal contamination such as that observed with EMG and ECG is supported within the literature (Gramann, Ferris, Gwin, & Makeig, 2014; Gramann, Gwin, Bigdely-Shamlo, Ferris, & Makeig, 2010; T. P. Jung et al., 2000). However, unlike ECG artefact, that is rhythmical in appearance and can be identified and removed, EMG artefact is neither rhythmical nor constant and can have a similar appearance to that of neural activity, making it difficult to remove without compromising the underlying neural activity. In tasks that are more representative of the real-world, the

challenge that remains is how to effectively and reliably identify and attenuate EMG artefact during movement. Treatment of data has included the use of filters such as 50 Hz notch filters and high and low-pass filters (e.g., 0.5 to 60 Hz). Low pass filters of 50 Hz are also used to account for any potential extraneous environmental artefact such as 50 Hz electrical artefact (Reis, Hebenstreit, Gabsteiger, von Tscharner, & Lochmann, 2014). With more research occurring within this field including data collection whilst walking and running on a treadmill and cycling (Gwin, Gramann, Makeig, & Ferris, 2010; Schneider, Rouffet, Billaut, & Strüder, 2013), clearer topographies, signal time and amplitude variances have begun to emerge. For example, the identification and removal of movement-related artefact such as eye blink and saccadic eye movement topographies (see Figure 4.1, Plank, 2013). These developments are promising in the ongoing endeavour to obtain more reliable and valid strategies for the identification and attenuation of non-cerebral movement-related artefact.

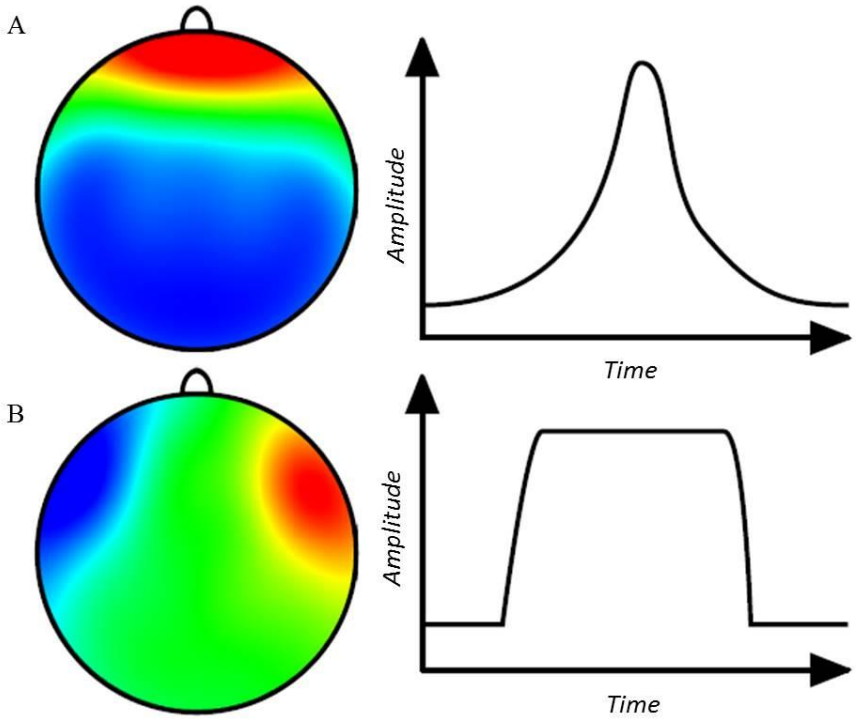

Figure 4. 1: Eye blink (A) and saccadic eye movement (B) topographies (Plank, 2013).

For the field of cognitive neuroscience to advance further it is important to explore whether results obtained from well-defined and controlled laboratory studies can be generalised to dynamic conditions where participants are required to engage with the environment and perform whole body movement. The current evidence suggests that differences exist between laboratory and more naturalistic settings which include whole body movement. Debener et al. (2012) found differences in the P3 ERP component responses between an indoor seated condition and an outdoor walking condition, specifically a reduction in the P3 *amplitude* in the outdoor compared to the indoor seated condition. It was suggested that the reduction in the P3 *amplitude* outdoor condition resulted from a distraction from the primary task (e.g., reduced allocation of attentional resources). It could be further postulated that differences may be related to the physical demands of a seated stationary position and a dynamic locomotor task where the participant is required to coordinate both a motor and cognitive task simultaneously. These findings are further supported by De Sanctis et al. (2014), who found that the N2 and P3 ERP components, in a seated compared to walking (treadmill-based) dual-task were significantly different. These differences included a significant reduction in the N2 *amplitude*, and both a decrease and increase in P3 *amplitude* over different regions of the brain and a decrease in P3 *latency* in the walking compared to the seated position. This pattern of activity is believed to be related to differences in the underlying generator configuration of the P3 ERP component activity, specifically the topography in the seated compared to the walking condition was maximal over the central scalp compared to fronto-central scalp position in the walking conditions respectively (De Sanctis et al., 2014).

In light of the need to develop paradigms that enable more naturalistic movement and behaviour, we used the locomotor dual-task paradigm, validated for the evaluation of gaze behaviour in study one to examine task-related (single- and dual-task) differences in neural

activity, specifically the N2 and P3 ERP component *latencies* (ms) and *amplitudes* (µV). N2 *latency* is an index of the timing of information processing during visual perception, with the *peak latency* representing the moment in time where sensory information is available to formulate the stimulus response decision (Schmitt et al., 2000; Thorpe et al., 1996), and *amplitude* is associated with the neural activity (degree of effort and processes) required for response inhibition (Jodo & Kayama, 1992; Sasaki et al., 1993). The P3 *latency* is related to the speed with which we can classify sensory stimuli and the *amplitude* is related to the allocation of attentional resources and working memory (Duncan-Johnson, 1981; Kutas et al., 1977; Polich, 1987). In the evaluation of the P3 ERP, the different attributes of this component were included. These incorporate the P3a and the early and late P3b. These are associated with attentional and memory processing (P3a), retrieval, encoding and memory updating (early and late P3b) (Brookhuis et al., 1981; Kok, 2001; Morgan et al., 2008; Scisco et al., 2008). The final aim of this study was to identify strategies for managing, identifying, and attenuating movement-related artefact. It was hypothesised that: 1) there would be task-related differences in trial completion time; 2) there would be an increase in the N2 and P3 *peak latencies* associated with dual-task performance; and 3) there would be a decrease in the N2 and P3 *mean amplitudes* associated with dual-task performance.

2. Method

2.1 Participants

Prior to participation in the screening and experimental session, participants were provided with an overview of the experiment (see Appendix 4), and engaged in preliminary screening, and asked to provide informed consent (see Appendix 5). Suitability to participate in the study was assessed by a health history and demographics questionnaire (see Appendix 3). Twelve male and female (n = 12) (*M* age = 25.7 years; range 20 – 34 years) were recruited

to participate in this study. All participants were healthy and reported being free of any neurological disorders and any medication that would influence central nervous system function. The study was reviewed and approved by the Human Research Ethics Committee, Victoria University, Melbourne, Australia.

2.2 Apparatus

2.2.2 Walking grid and stimuli

For the walking grid and auditory stimuli configurations please see study one (Chapter 3).

2.2.3 Neural activity

EEG parameters are identical to those outlined in study one (see Chapter 3), in addition, electrode Cz (central midline placement) was employed as an online reference to reduce the risk of movement-related contamination, as observed in the use of the standard mastoid (TP10) reference placement employed in study one (see Figure 4.2).

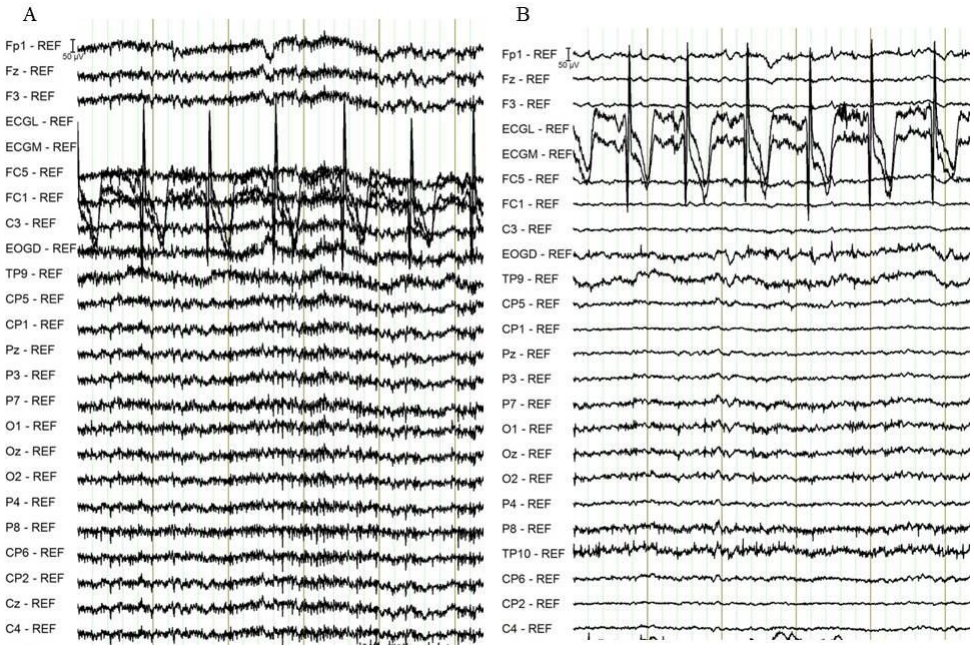

Figure 4. 2: A) Movement related artefact contamination using TP10 (mastoid placement) as the online reference. B) Signal comparison using Cz (central midline placement) as the online reference.

2.2.4 Apparatus configuration

Two further problems encountered in study one were the EEG signal loss during data collection and signal contamination as a result of proximity of the EEG and auditory system components. The signal loss issue was a result of the limited transmission range of the Brain Products system, which only allowed for data recording within a 6 m radius, and the EEG transmitter and receiver having to be in direct line of sight to reduce the risk of loss of signal. To resolve both the signal loss and contamination issues, equipment was secured to a moveable trolley, which was pushed behind the participant, whilst they travelled around the walking grid. This enabled the continuous collection of neural activity data and sufficient separation of the EEG and auditory system components to reduce the risk of contamination. The apparatus (see Figure 4.3) included both the placement of the hardwired and wireless components. The hardwired components included the EEG power pack, amplifier, wireless MOVE system, aerials, notebook computer and auditory system transmission components, which were secured to the moveable trolley. While the EEG transmitter and wireless auditory receiver components were secured to the participant by way of a global positioning system (GPS) harness. The use of the GPS harness also reduced the risk of movement of both leads and transmitter components in addition to reducing the risk of excessive tension on the electrode leads (see Figure 4.4).

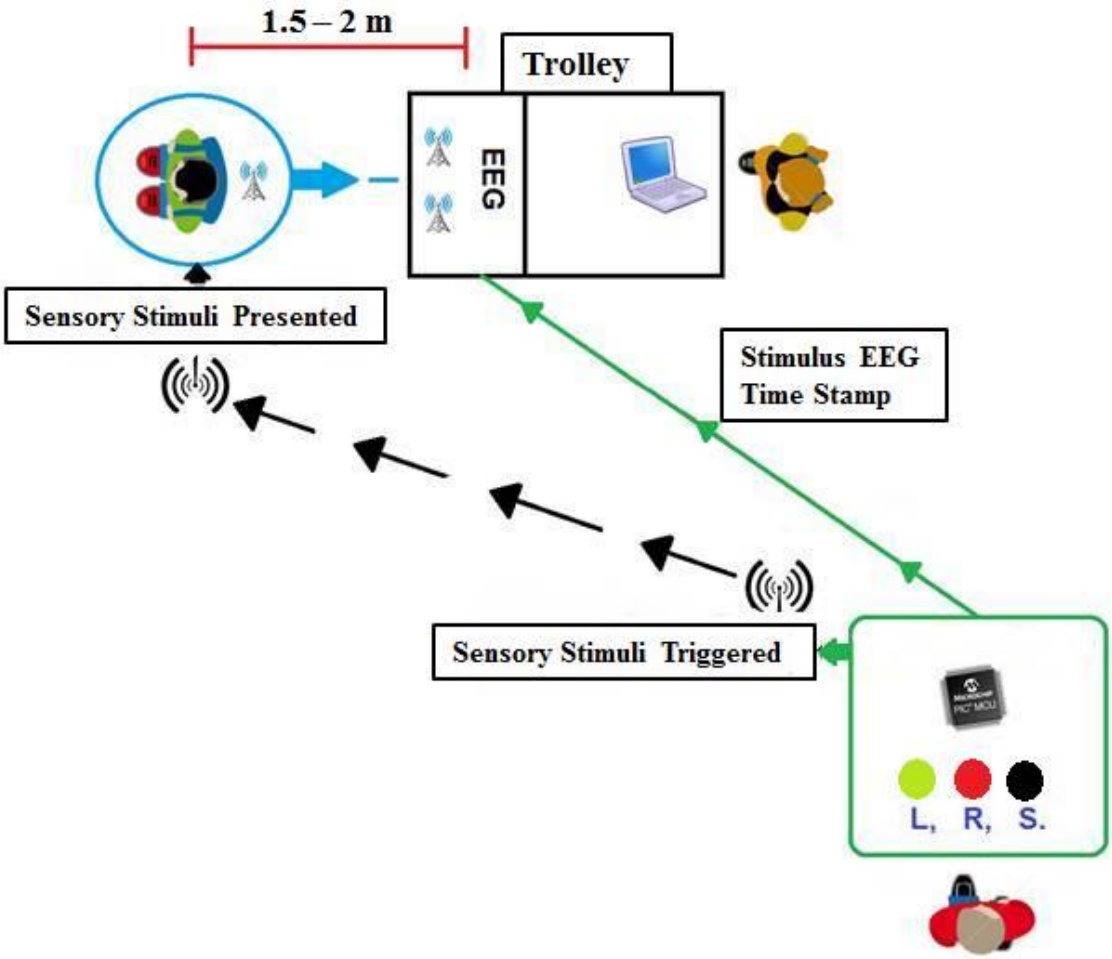

Figure 4. 3: Schematic representation of equipment configuration and direction of signal transmition.

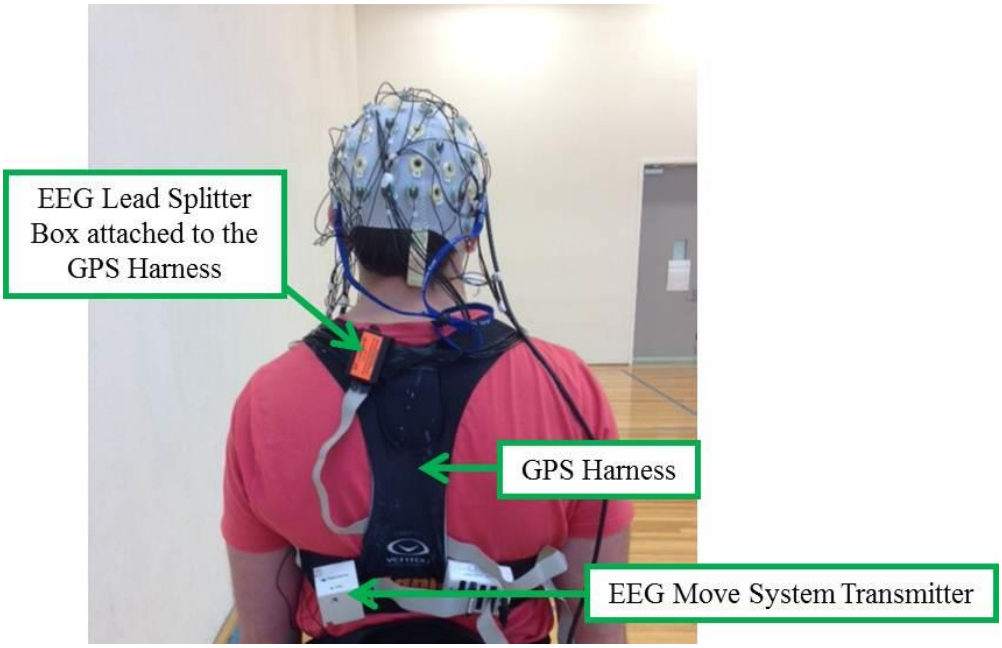

Figure 4. 4: EEG Move System Transmitter, secured to a GPS harness.

3. Procedure

Participants attended a single testing session consisting of: 1) screening measures and initial health assessments to determine suitability for further participation; and 2) fitting of the EEG equipment to enable neural activity data to be collected. Once the equipment was fitted and prepared, participants performed the locomotor task in three conditions (baseline, single- and dual-tasks) as outlined in study one (see Chapter 3).

4. Data processing and analysis

4.1 Behavioural data

Time to complete each trial was defined as the time it took a participant to walk through a 3.5 m section of track ending at each intersection. In order to determine the difference in time taken to perform the single- versus the dual-task trials, pairwise comparisons were employed. For all analyses data is reported using standard error of the mean.

4.2 Neural activity data

Working memory is a core component of the cognitive dual-task paradigm employed within this research. Based on the review by Kok (2001) and research by Jongsma et al. (2007), and the temporal topographical pattern of activity, the key EEG epoch of interest relating to the P3 is that of 300 – 600 ms. In defining a larger epoch (300 – 600 ms) to evaluate the *mean amplitude*, in effect combining the P3a, and early and late P3b attributes, there is a risk of blurring these three unique aspects of cognitive function together (Brookhuis et al., 1981; Kok, 2001; Scisco et al., 2008). To reduce the risk of this occurring, and to optimise the identification of potentially important temporal patterns of activity (Alperin, Tusch, Mott, Holcomb, & Daffner, 2015; Mecklinger, Ullsperger, Mölle, & Grune, 1994; Rozenkrants & Polich, 2008) the 300 – 600 ms epoch was segmented into three time

windows (100 ms per window and defined by the topographical pattern identified within the grand averaged data) (McEvoy, Smith, & Gevins, 1998). The *mean amplitude* for each window was calculated to evaluate temporal and topographic differences in association with information processing (Alperin et al., 2015; Morgan et al., 2008), specifically the P3a (attention, stimulus evaluation and memory processing) and the early and late P3b attributes (modulation of working memory load on the encoding and retrieval phases of information processing) (Brookhuis et al., 1981; Jongsma et al., 2007; Morgan et al., 2008; Scisco et al., 2008). The last aspect of this P3 component analysis is that of differences in spatial patterns of activation, therefore separate analysis of EEG data were completed for midline and bilateral hemisphere electrodes (Kayser, Bruder, Tenke, Stewart, & Quitkin, 2000).

4.2.1 EEG data reduction

Using the Brain Analyzer 2 software (Brain Products), EEG data from each condition were corrected offline using the following EEG data reduction process:

1) Visual check of raw data, removal of trials where signal drop out occurred.

2) Application of low and high cut-off filters (0.1 and 30 Hz respectively with a time constant of 1.59 s and a slope of 49 db/oct for each filter).

3) Independent component analysis, resulting in the removal of electrodes TP9 and TP10 (mastoid placement) due to movement related artefact.

4) Ocular correction using Gratton and Coles (Gratton, Coles, & Donchin, 1983) bipolar channel correction for both horizontal (saccadic – electrode placement on the outer orbit of the left and right eyes) and vertical (blink – electrode placement above the brow and below on the cheek bone of the right eye) eye movement.

5) Data re-referenced to a global average reference.

6) Combined left, right and straight trial segmentation of data with an epoch of -100 ms pre stimulus onset (presentation of the auditory stimulus) to 600 ms post stimulus onset.

7) Artefact rejection using a) Gradient - maximum allowed voltage step 50 µV/ms with bad segments being marked 200 ms pre and post event, b) Maximum and minimum difference of values in intervals 200 µV and 200 ms bad segments being marked 200 ms pre and post event and c) Maximal and minimal amplitude 100 and -100 µV respectively, with bad segments being marked 200 ms pre and post event.

8) Baseline correction of -100 pre stimulus onset.

9) Grand averages computed for single- and dual-tasks.

10) Grand averaged data used for peak identification and topographic scalp maps used to identify key electrodes with regard to activity associated with the N1 and P3 ERP components (see Figure 4.6).

11) Parameters identified from the grand averages utilised and applied to the individual participant trial analysis.

12) N1 and P3 ERP component data exported for *peak latency* (ms) analysis. For the purpose of this study the *peak latency* is defined as the time point in which these components were observed, specifically, between 180 and 220 ms (N2) and 300 – 600 ms (P3) post stimulus onset.

13) *Mean amplitude* epochs for the N2 ERP component (time window – 180 to 220 ms) and P3 ERP component (time window one – 300 to 400 ms – P3a, time window two – 400 to 500 ms – early P3b and time window three – 500 to 600 ms – late P3b), post stimulus onset were exported for *mean amplitude* data analysis (see Figure 4.7 and 4.8).

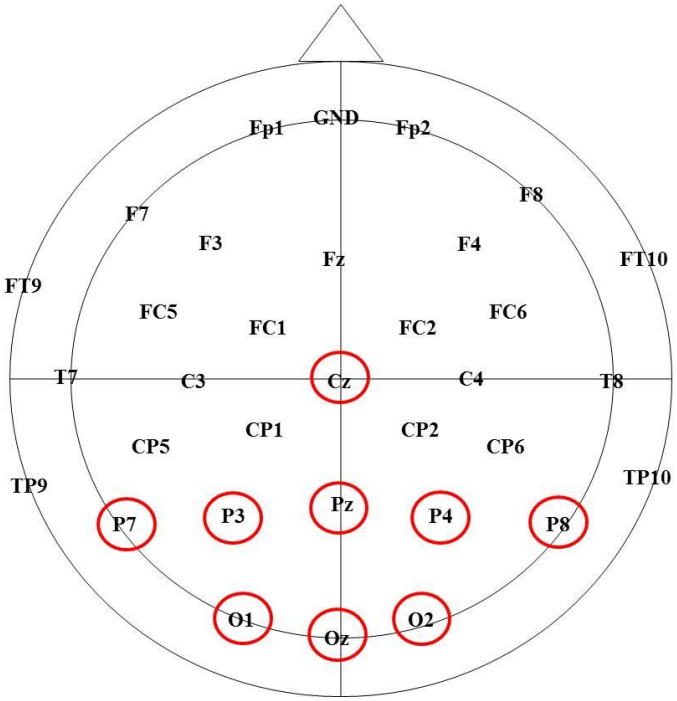

Figure 4. 5: 32 Channel Montage with key channels examined circled.

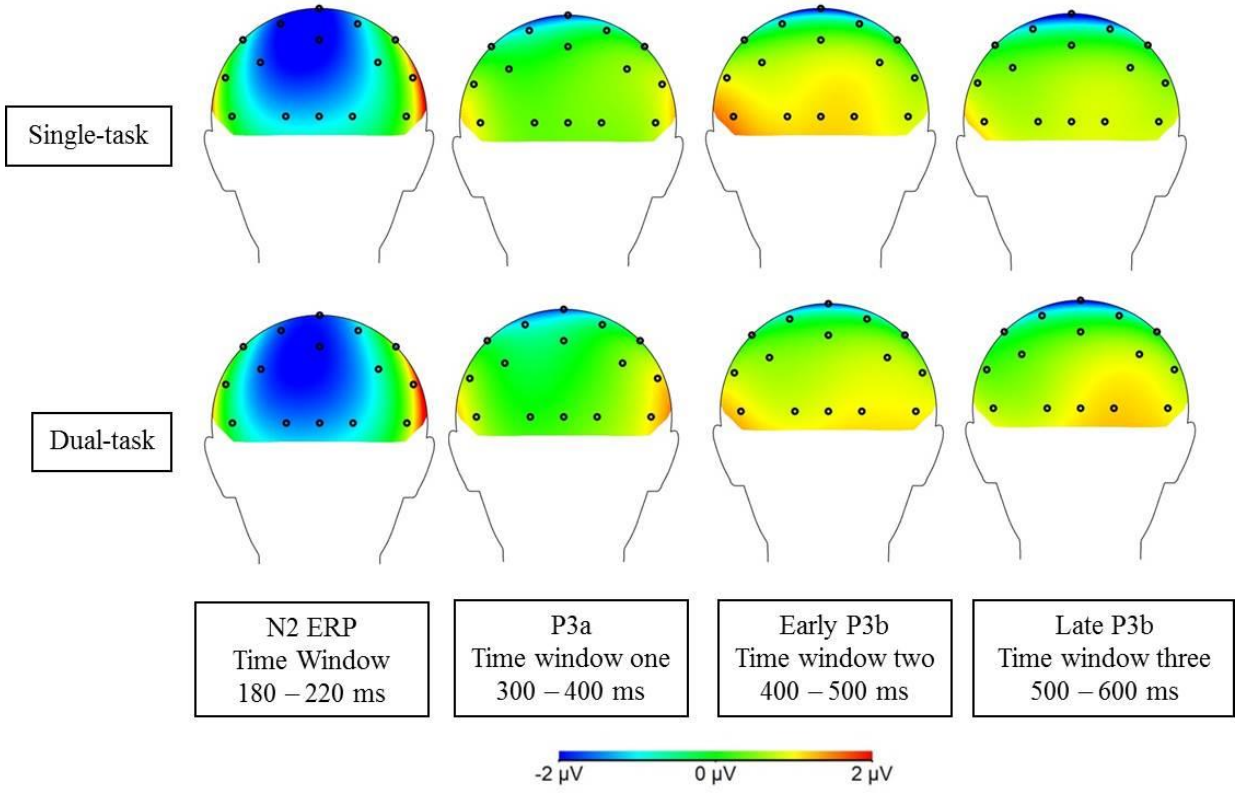

Figure 4. 6: Topographical scalp map comprising the key ERP *mean amplitude* time windows analysed comparing single- and dual-task neural activity.

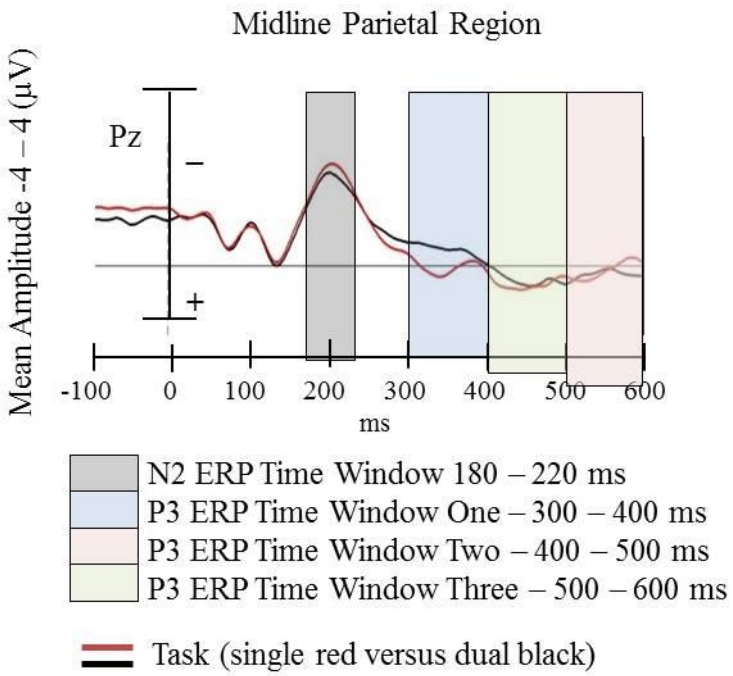

Figure 4. 7: Example of the grand averaged N2 and P3 *mean amplitude* response time windows employed to examine the difference in the neural activity over time in response to task difficulty.

4.2.2. Event-related potential analysis

Due to the analysis of this data involving the use of averaged data sets, one-way ANOVA was used to determine whether single- and dual-task neural activity waveforms in the time windows of interest (see Figure 4.7) were significantly different between tasks. The analyses specifically focused on:

1) N2 ERP component *peak latency* (ms) and *mean amplitude* (µV) for the one time window (*time window – 180 – 220 ms)* following stimulus onset. The data were measured from *lateral* electrodes including parietal (P3, P4, P7 and P8) and occipital (O1 and O2) regions, and *midline* electrodes including central (Cz), parietal (Pz) and occipital (Oz) regions.

2) P3 ERP component *peak latency* (ms) and *mean amplitude* (µV) for three time windows (*time window one – 300 – 400 ms – P3a, time window two ms – 400 – 500 – early*

P3b and time window three – 500 - 600 ms – late P3b) following stimulus onset. The data were measured from *lateral* electrodes including parietal (P3, P4, P7 and P8) and occipital (O1 and O2) regions, and *midline* electrodes including parietal (Pz) and occipital (Oz) regions.

For all non-significant data see the attached appendices for a breakdown of results means and standard deviations and statistical summary tables (see Appendices 9 and 10).

5. Results

5.1 Movement related topographic map identification

During data processing and analyses, a movement related artefact topography was identified using independent component analysis (ICA; see Figure 4.7). This topography was only present during the performance of the walking task (regardless of condition) and was not present in any of the stationary data. Moreover, this movement related topography was only present in the electrodes TP9 and TP10 (left and right mastoid electrode placement). When these components were removed the noisy signal was attenuated in these electrodes with no effect on the surrounding electrodes. Consequently both TP9 and TP10 were removed from the overall analysis of the EEG data prior to applying the global averaged reference.

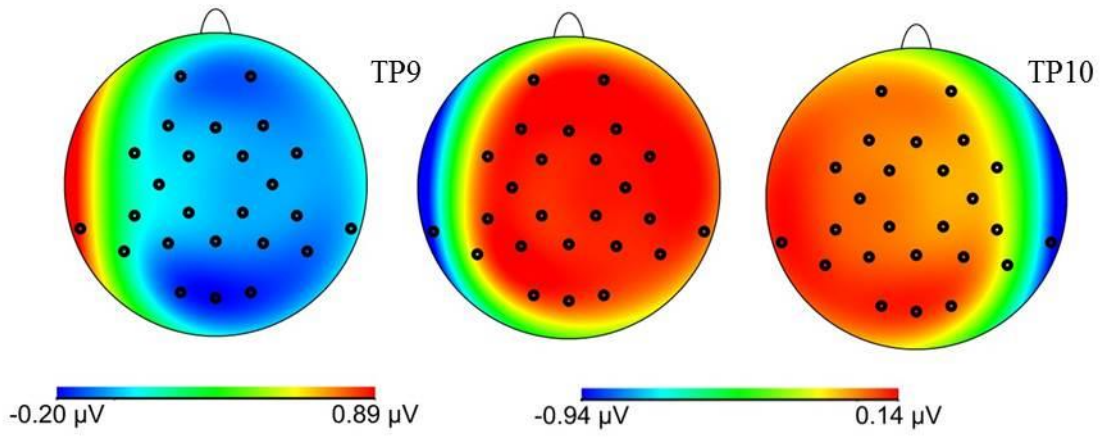

Figure 4. 8: Movement related topographies observed in electrodes TP9 and TP10.

5.2 Behavioural data

Results revealed a main effect for task (t (14) = -2.82; p = .02, d = 0.60). Participants had a quicker mean trial completion time in the single- compared to the dual-task (3.20 ± 0.35 s and 3.30 ± 0.37 s respectively; see Figure 4.9). On average the participants recalled 9 ± 3 out of 15.

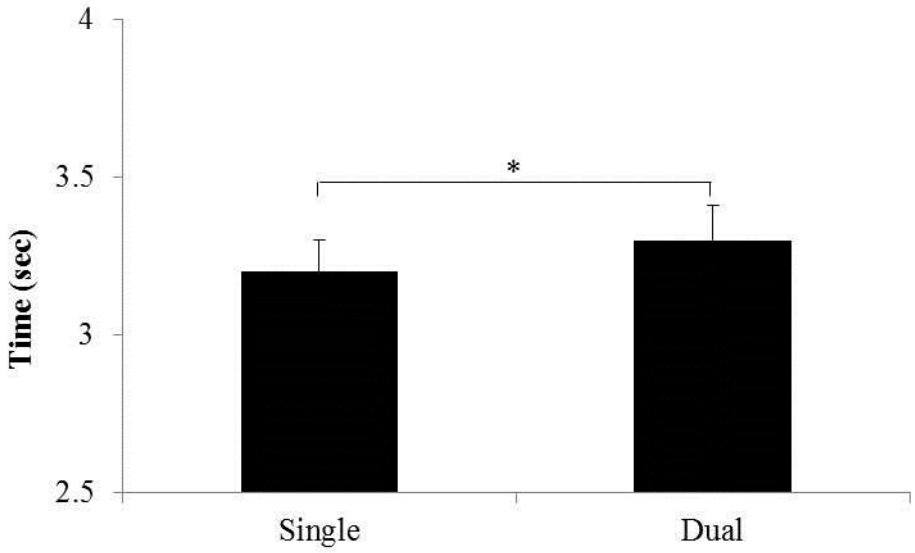

Figure 4. 9: Comparison of trial completion time between conditions. (* denotes p < .05). Data is presented as mean ± SE.

5.3 Neural activity data

Due to issues of signal loss during data collection and artefact rejection, a total of 3637 trials (of 3665; < 1% dropout) were used for the subsequent ERP analyses. Impedances were checked at the beginning and upon completion of testing and remained < 3 kΩ.

5.3.1 N2 ERP component

N2 *peak latency* and *mean amplitude* - There was no significant effect of task for either the N2 *peak latency* or *mean amplitude* in the *lateral* or *midline* electrode analyses.

5.3.2 P3 ERP component (P3a and early and late P3b)

P3 *peak latency* and *mean amplitude* - There was no significant effect of task for either the P3 *peak latency* or *mean amplitude* in the *lateral* or *midline* electrode analyses.

6. Discussion

The purpose of study two was to determine whether the dual-task paradigm designed and validated in study one would be suitable for measuring dual-task related neural activity using EEG. Task completion times for study two were consistent with those found in study one and results from previous studies (Capizzi et al., 2013). Despite the lack of significant findings associated with task-related differences in neural activity, valid EEG data were obtained. This was primarily related to: 1) the flexibility of the grid design to enable the collection of sufficient trials (150 per single- and dual-task conditions) in a consecutive manner, and 2) the length of trials (3.5 m) which enabled the collection of valid ERP data minimising the risk of overlapping ERP data.

The lack of a dual-task effect in respect to the neural activity may be a consequence of an insufficient cognitive load. Anecdotal feedback from participants suggested that, in the performance of the dual-task, they put aside the memory component of the task to focus on the walking component, thereby negating the cognitive component of this task. Due to the nature of the data being collected (EEG) a limitation of this paradigm was how to ensure that participants were engaged with the cognitive component of this task without requiring verbal feedback, which was necessary to control for facial movement related-artefact. A potential solution to this issue would be the development of a dual-task paradigm that enables shorter periods of performance. This could include, for example, using three blocks of 50 trials as opposed to one block of 150 trials, presenting the shopping list to the participant at the beginning of each block, giving the participant three key words to be remembered at the beginning block, and having the participants recall the key words at the end of each block.

Another potential factor relating to the lack of task-related differences in neural activity, as seen in previous research, is that the evaluation of these differences has predominantly been performed in a seated position (Hahn et al., 2011) or controlled treadmill

(with railing to support balance) (De Sanctis et al., 2014) settings. Whereas the paradigm employed within this study, although similar to previous research employing dual-task paradigms, also included a walking component. This additional requirement may have altered the task-related neural response due to the increased demand on the allocation of attentional resources with which to perform the task accurately and efficiently. Consequently, altering the neural pattern of the task-related activity, for example potentially reducing the magnitude of neural activity due to the need to spread what resources are available over a broader context to simultaneously manage both cognitive and locomotive motor tasks.

The methodological design developed in this study provides two important advancements over existing dual-task paradigms, specifically in context of the analysis of neural activity. First, this method maintains functionality by engaging the participant in cognitive dual-task performance requiring whole body movement, which has greater applicability to how we interact and function in everyday activities. Second, it provides practical strategies for minimising environmental and equipment movement-related artefact during data collection and the attenuation of other non-cerebral artefact. For example, attenuation of EMG activity observed in TP9 and TP10 (mastoid placement) in the offline analysis. Strategies also included the use of a tubular bandage to secure the cap and electrodes to the head and the EEG transmitter being fixed to a GPS harness, thereby removing extraneous noise created by lead tension and movement during walking. Offline processes included in the management of artefact such as that observed in EMG, EOG and ECG activity included the use of ICA in the identification and attenuation of signal contamination (Gramann et al., 2014; Gramann et al., 2010; Jung et al., 2000).

This study is not without limitation. For example, as previously discussed, the dual-task might not have been cognitively demanding for participants. A solution would be the use of a paradigm that enables shorter periods of performance as described above. Having shorter

periods (blocks) of performance would enable the participant to provide verbal feedback on words remembered between the end and start of each block, maintaining active cognitive engagement during the walking task, without compromising the EEG signal due to facial movement related artefact.

The methodological approach that has been presented in this chapter provides a means to bridge the gap between static and dynamic dual-task testing paradigms and demonstrated a valid method for the collection of neural activity in a paradigm that permitted natural head/body movement, while minimising and treating non-cerebral artefact. As this is the first study of this type it is recommended that further research be performed to determine whether the current findings can be replicated, specifically in context of the observed ICA analysis and identification of EMG artefact topographies and to provide further validation that wireless systems can reliably be used in a more dynamic environment that incorporates whole body movement and behaviour. The use of this paradigm provides an important advancement over existing dual-task paradigms that have evaluated task-related differences in neural activity, specifically this paradigm maintains functionality by engaging the participant in dual-task performance requiring whole body movement and behaviour, which has greater applicability to how we interact and function in everyday activities.

Chapter Five

Study 3 – Part A

Effects of acute exercise on neural activity associated with single- and dual-task performance during locomotion – aerobic versus resistance exercise

1. Introduction

It is well established, from a behavioural perspective, that physical fitness and exercise have a positive influence on cognitive function. Specifically, improvements in reaction time tasks (i.e., time from stimulus onset to the execution of a behavioural response e.g. pressing of a button) and executive functioning (e.g., the ability to inhibit an incorrect response) (Guizani et al., 2006; Rattray & Smee, 2013; Sibley, Etnier, & Le Masurier, 2006) have been observed following an acute bout of aerobic exercise. Higher levels of fitness are also associated with improved executive control and a reduction in effort required to resolve conflict (Stroth et al., 2009). Exercise therefore, seems to have both a long- and short-term benefit on cognitive function.

Most research to date has examined the role of acute aerobic exercise on cognitive performance with few studies exploring the role of resistance exercise. Under certain conditions acute aerobic exercise facilitates response speed and accuracy as well as goal-oriented actions (Pontifex, Hillman, Fernhall, Thompson, & Valentini, 2009; Sibley et al., 2006). This includes improvements in executive functioning (planning and inhibition) (Hung, Tsai, Chen, Wang, & Chang, 2013). A recent review by McMorris & Hale, (2012) found a relationship between exercise and cognitive functioning with speed of processing specifically being enhanced after moderate intensity aerobic exercise. In one of the rare studies examining the role of resistance exercise on cognitive performance, it was found that high intensity resistance training (100% 10 RM) improved cognitive processing speed whereas moderate

intensity resistance training (70% 10 RM) was associated with enhanced executive functioning immediately following exercise (Chang & Etnier, 2009b). Acute exercise is also associated with an immediate and transient improvement in cognitive performance (Griffin et al., 2011; Schneider et al., 2009). These improvements in cognition have been found to be associated with changes in neural activity. In particular, increases in the P3 ERP neural component *amplitude* (μV) have been observed during the performance of an executive function test (modified flanker task). This finding is reported to be associated with an increase in the allocation of attentional resources during stimulus engagement (O'Leary et al., 2011).

A limitation of research in this area is that cognitive function has predominantly been examined in controlled laboratory environments using tasks which have relatively little in common with activities of daily living. In everyday life we engage with our environment in a more complex manner and are continuously adjusting and reacting to multiple stimuli we encounter. This would suggest that many laboratory tasks where participants are required to be stationary (i.e., supine or seated) are not representative of many activities of daily living. There is therefore a need to develop a better understanding of cognitive processes and neural activity that are associated with how people in the real-world, with whole body movement, perform various tasks and process multiple sources of information at the same time.

Numerous aspects of neurological function have been examined with the goal of obtaining a more comprehensive understanding of the mechanisms that underpin the ability/ inability to perform activities of daily living and how we can improve this. The neural system is sensitive to change (e.g., cortical plasticity), for example, there is an association between increases in cardiovascular fitness and increased functioning of the attentional networks of the brain has been observed (Colcombe et al., 2004). The potential of exercise to promote cortical plasticity, specifically with regard to attentional networks is further

evidenced in improvements in reaction times (Kamijo et al., 2009) which is accompanied by an increase in the *amplitude* of ERPs associated with stimulus evaluation and categorization after an acute bout of aerobic exercise.

ERPs are of specific interest as they represent the time course (i.e., temporal resolution) of neural changes and patterns of activity in response to a specific sensory, cognitive or motor event (Luck, 2005; Luck & Kappenman, 2012). Two key neural components of interest are that of the N2 and P3 ERP components. The N2 ERP component is reported as the most negative going peak after stimulus onset occurring within a time window of 150 – 400 ms post sensory stimulus onset (Falkenstein et al., 1999; Gajewski & Falkenstein, 2012). There are two theories around the N2 ERP component and what aspect of cognitive function it represents. The first is that it is associated with response inhibition (i.e., inhibiting a habitual response). The second is that it is related to response monitoring (i.e., monitoring for conflict between competing responses) such as the ability to discount erroneous (secondary) stimuli to respond to the primary stimuli such as that involved in dual-task performance (Donkers & Van Boxtel, 2004; Falkenstein et al., 1999; Schmitt et al., 2000). The fundamental difference between response monitoring and response inhibition is that response monitoring occurs before the response whereas response inhibition refers to the ability to deliberately suppress a habitual response (Donkers & Van Boxtel, 2004; Yeung et al., 2004). The two basic characteristics with regard to the N2 ERP are that of *latency*, which is an index of the timing of information processing during visual perception, with the *peak latency* representing the moment in time where sensory information is available to formulate the stimulus response decision (Schmitt et al., 2000; Thorpe et al., 1996), and the N2 *amplitude* which is associated with the neural activity (degree of effort and processes) required for response monitoring (Donkers & Van Boxtel, 2004; Yeung et al., 2004).

Exercise-related differences in the N2 ERP component are varied, with a reduction in N2 *amplitude* being linked to an improvement in cognitive performance, specifically an improvement in neural processes associated with response monitoring and allocation of attentional resources (Drollette et al., 2014; O'Leary et al., 2011). Other findings suggest that a reduction in N2 *amplitude* is related to lower global costs, specifically an enhancement in processing resources associated with retrieval and maintenance of multiple task sets in memory. In contrast, an increase in N2 *amplitude* is reported to be related to a reduction in switch costs (lower local costs). In other words, a process of proactive interference occurs based on previously presented stimuli, resulting in an increase in focused attentional demands on a specific outcome as opposed to dividing attentional resources towards multiple potential outcomes (Gajewski & Falkenstein, 2012). There appears, however, to be no research that has investigated the effect of acute aerobic exercise compared to resistance exercise on the N2 ERP component. Nor has there been any research that has looked at the effect of acute exercise on the N2 ERP component while performing a locomotive task involving whole body movement.

The P3 ERP component has the most positive-going peak after stimulus onset occurring within a time window of 300 – 750 ms (Kamijo et al., 2009; Kamijo, Nishihira, Hatta, Kaneda, Wasaka, et al., 2004). This ERP has two basic characteristics, the *latency* which is related to the speed with which we can classify sensory stimuli and *amplitude* which is related to the allocation of attentional resources and working memory (Duncan-Johnson, 1981; Kutas et al., 1977; Polich, 1987). In the evaluation of the P3, the different attributes of this component must be considered. These incorporate the P3a, and the early and late P3b, which are associated with attention, stimulus evaluation and memory processing (P3a) and modulation of working memory load on retrieval and encoding phases and memory updating (early and late P3b) (Brookhuis et al., 1981; Jongsma et al., 2007; Kok, 2001; Morgan et al.,

2008; Scisco et al., 2008). To date no research has evaluated these individual attributes of the P3 component. However, the overall P3 (encompassing one epoch that combines all attributes of the P3) component was investigated by O'Leary et al. (2011) in relation to the influence of an acute bout of exercise. O'Leary et al. proposed that an increase in the P3 *amplitude* resulting from an acute bout of exercise may indicate an increase in the capacity to allocate the necessary attentional resources to successfully perform a given task. What remains unclear is what the optimal mode and/or intensity of exercise is necessary to improve neural activity, specifically in the context of performing dual-tasks.

To-date results pertaining to the P3 ERP component in the context of dual-tasking and exercise studies are equivocal. Studies employing a measure of dual-task performance have found an age-related decline in the ability to differentiate between primary and secondary stimuli, with greater *amplitudes* in a single- compared to a dual-task condition being observed in young compared to older adults (Hahn et al., 2011). Exercise-related research has found an increase in the P3 *amplitude* and no change in *latency* after an acute bout of aerobic exercise (Kamijo, Nishihira, Hatta, Kaneda, Kida et al., 2004). Others have found no change in the *amplitude* and a decrease in *latency* (Kumar et al., 2012). Further, there appears to be no research to date that has evaluated the influence of an acute bout of resistance exercise upon the different attributes of the P3 ERP component, specifically in relation to the comparison of different modes of exercise (e.g., aerobic versus resistance).

To further explore the relationship between acute exercise and cognitive functioning, more representative and interactive testing environments need to be developed. Specifically in relation to developing a better understanding of cognitive processes related to the P3 ERP component during whole body movement and behaviour. There is no research that has investigated the effect of acute aerobic exercise compared to resistance exercise on the P3 ERP component. Nor has there been any research that has examined the effect of acute

exercise on the P3 ERP component while performing a locomotive task involving whole body movement and behaviour.

In this study we utilized a novel paradigm (validated in study one) which allowed for the assessment of performance using different cognitive loads (single- versus dual-tasks) as well as the assessment of neural activity. In particular, this study examined differences in behaviour and neural activity associated with the performance of both a single- and dual-task during locomotion before and after an acute bout of aerobic versus resistance exercise in young adults. It was predicted that: 1) quicker trial completion time would be observed following both exercise protocols; 2) dual- compared to single-task will take longer to perform, irrespective of exercise; 3) shorter global N2 *peak latencies* and a reduction in *mean amplitude* for both single- and dual-tasks, following both exercise protocols; 3) shorter global P3 *peak latencies* and an increase in *mean amplitudes* for both single- and dual-tasks, across all time windows following both exercise protocols; 4) overall longer N2 and P3 *peak latencies* in the dual- compared to the single-task, irrespective of exercise; and 5) greater N2, P3 *mean amplitudes* in the single- compared to the dual-task.

2. Method

2.1 Participant

Sixteen healthy males (n = 8) and females (n = 8) (*M* age = 27 ± 7 years; range 20 – 34 years) were recruited to participate in the study. Data from one male participant was discarded due to voluntary withdrawal. Thus, all analyses were conducted on the data from fifteen participants (7 males and 8 females).

2.2 Participant screening

Prior to participation in the screening and experimental sessions, participants were provided with an overview of the study (see Appendix 6), and engaged in preliminary

screening, and asked to provide informed consent (see Appendix 7). Participants were asked to complete screening questionnaires to assess risk factors in addition to a physical activity questionnaire to provide information about their recent physical activity (see Appendix 8). Only those participants deemed low risk were accepted into the study. All participants were healthy and reported being free of any neurological disorders and any medication that would influence central nervous system function. The study was reviewed and approved by the Human Research Ethics Committee, Victoria University, Melbourne, Australia.

3. Measurements

Participants came to the laboratory on four separate occasions (M = 6.4 ± 7.7 days apart). Below follows a description of each session.

3.1 Session one: Maximal oxygen uptake testing and strength testing familiarisation

During the initial screening session each participant performed an incremental VO_2max test on an electromagnetically braked cycle ergometer to exhaustion (Lode bike, ExCalibur Sport, 2005). For all participants the workload started at 20 watts (W), with an increase by 20 W.min^{1}. The test lasted no longer than 20 min. Expired respiratory gases were collected through a mixing chamber connected to gas analysers (COSMED Quark CPET, Italy). Expired gas analysis data was integrated for each 15 s interval, and the mean values for VO_2 ml/min/kg, were used for that interval. The gas analyser was calibrated immediately before each test using gases that had been calibrated at alpha standard. Heart rate was measured at rest and during the incremental test using a Polar heart rate monitor (Polar RS400). VO_2max was determined when heart rate reached 80% of the participant's age-predicted maximum (220 – age), a respiratory exchange rating of > 1.1, a participant's rating of perceived exertion (RPE) reached "very very hard" (Borg scale = 19 - 20, Borg, 1982),

volitional exhaustion and/or a VO_2max plateau was obtained. The test was terminated earlier if clinical signs or symptoms of metabolic or cardiorespiratory abnormalities appeared.

Muscle strength testing familiarisation: This session provided participants with the opportunity to become familiar with the 1RM strength testing using three different exercises including two upper (latissimus pull down & bench press) and one lower body exercises (inverted leg press). During the familiarisation session, correct lifting and breathing technique were taught and practiced using submaximal and near maximal loads.

3.2 Session two: Strength testing

Muscle strength testing (1RM); 1RM is defined as the heaviest weight a participant is able to lift once, using a proper lifting technique, without compensatory movements. 1RM strength was assessed for three different exercises including two upper (latissimus pull down and bench press) and one lower body exercises (inverted leg press). The tests commenced after a light warm-up on a stationary cycle. The maximal strength test protocol included one set of 12 repetitions at a relatively light load (50% 1RM) that served as a specific warm-up, followed by a gradual increase in load until 1RM was achieved. The rate of the increase was dependent on the participant's self-perceived capacity (Levinger et al., 2009). A two-to-three minute rest period was provided between each attempt.

3.3 Sessions three and four: Study protocol

3.3.1. Walking grid and apparatus configuration

For the walking grid and apparatus configurations please see studies one and two respectively (Chapters 3 and 4).

3.3.2 Visual stimuli

A key difference in this study compared to studies one and two was the change from an auditory to a visual stimulus. This was done due to ongoing technical problems

experienced with the wireless auditory system that were not resolvable. Consequently, a wireless and portable visual stimulus system was developed and employed.

The visual stimuli consisted of a LED light, which was attached, by way of an optic cable, to a lightweight plastic glasses frame (see Figure 5.1). The LED light was placed in a central position within the visual field and at a distance of 11 cm from the nasion. Light stimuli were triggered using a wireless control and presented to participants at the same time intervals as that described for the auditory tone, with the inclusion of a no light condition, indicating that the participant was required to walk straight ahead at the intersection. The stimuli consisted of a green (left hand turn) and red (right hand turn) light (0.955 milli candela), and a no light condition (walk straight ahead at the intersection) which were triggered via wireless control (time delay between button press, light display and EEG time stamp = 1ms). The receiver box attached to the participant then sent a signal to the LED light attached to the glasses via an optic cable.

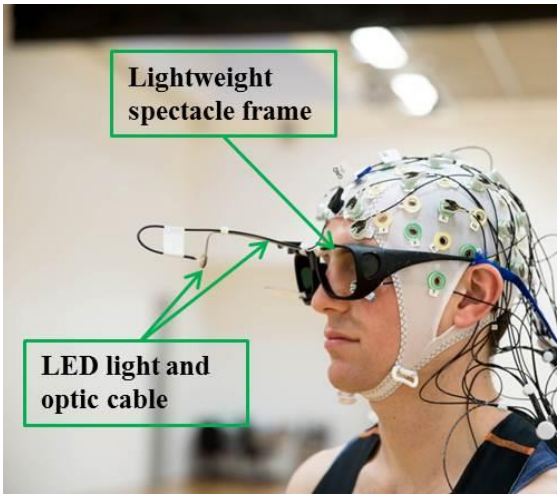

Figure 5. 1: Visual Stimuli Configuration

3.3.3 Neural activity

For the EEG parameters and configuration please see studies one and two respectively (Chapters 3 and 4).

4. Procedure

Participants came to the laboratory on two occasions with testing always being performed between 8 – 11am. Sessions three and four were identical with the exception of the mode of the exercise performed, which were: 1) moderate continuous aerobic (45 min at 50 – 60% VO_2max), and 2) a 45 min bout of muscle strength-based exercise, which included a five minute warm up on a stationary cycle, a warm up circuit of the two upper and one lower body exercises at 50% of the 1RM followed by three sets of 12 reps of each exercise at 60 - 70% of the 1RM. The order of exercise was randomised across participants (Rognmo, Hetland, Helgerud, Hoff, & Slørdahl, 2004). Prior to testing, participants were fitted with the EEG equipment to record continuous neural activity data. Once the EEG was calibrated participants performed the single- and dual-task locomotive paradigm, as validated in study one (Chapter 3). The paradigm was amended due to on-going issues with the auditory stimuli generation system and the lack of significant task-related neural activity observed in study two. These amendments included the removal of the collection of gaze behaviour data to enable the use of a light as opposed to the auditory stimulus and the reconfiguration of the dual-task condition (outlined below):

1. Phase 1. Baseline performance required the participants to walk around a grid based track (employed in studies one and two) performing left and right hand turns in addition to a straight ahead condition at each of the intersections (direction of turn was the participants choice). In order to obtain a baseline neural response to the visual stimuli during performance of the walking task, light stimuli (green, red and no light – 50 for each randomised) were generated upon the transition of the participants leading

foot over a 1 m mark from the intersection, however participants were instructed to ignore the light.

2. Phase 2. Participants received instructions as to the directional commands associated with the presentation of the light stimuli. Once the participant was confident in being able to accurately identify each respective light command they progressed to either the single- or dual-task phases of testing (phases 3 and 4 were randomised across participants).
3. Phase 3. Single-task performance that required participants to walk around the walking grid performing a directional response at each intersection according to the visual stimuli presented. Participants completed three blocks of 50 turns, (direction of turn randomised within each block for a total of 50 trials per direction) with a one minute break between each block. The one minute break was incorporated to enable time matching with the dual-task performance where a memory task was performed at the end of each block.
4. Phase 4. Dual-task performance was the same as in the single-task condition with the inclusion of a memory task. Due to a lack of significant results in study two, specifically in relation to the non-significant neural activity findings, presentation structure of the dual-task was altered as follows: To control for movement related artefact, specifically facial movement resulting from talking/moving the mouth, a memory task (secondary task) was designed that required the participant to engage in the active mental recall (working memory) of key words representative of a shopping list. This task involved participants being shown a list of 15 concrete nouns (e.g., almonds, pizza, wine) prior to the beginning of each of the three blocks, with each word being presented one at a time at a rate of one word per two seconds. Prior to presentation of the 15 word list, participants were instructed to memorise three

specific words (e.g., the 1st, 5th and 14th word), which differed for each subsequent block. In block one participants were instructed to remember the 3rd, 9th and 14th word (presentation time = 1 min). In block two they were asked to remember the 1st, 5th and 13th words, and in block three the 2nd, 7th and 11th words. At the end of each block, the participant was requested to repeat the three key words they were instructed to remember.

5. Performed exercise (either aerobic or resistance).
6. Repeated baseline, single- and dual-task measures.

5. Data processing and analysis

For behavioural and base neural activity data reduction please see study two (Chapter 4).

5.1 Additional EEG data reduction

For the pre- and post-exercise EEG data on average 2 ± 1 and 5 ± 2 % respectively was removed due to the issues of signal drop-out during data collection and the artefact rejection processes. Impedances were checked before and after each phase of testing and remained < 3 kΩ. In addition to the EEG data reduction process outlined in study two (Chapter 4) the following steps were added:

1. After the visual check, channels TP9 and TP10 (mastoid placement) were removed due to movement artefact originating from the neck muscles and head movement.
2. After the individual data were averaged, grand averages were computed for pre- and post-aerobic and resistance exercise.
3. Grand averaged data used for peak identification and topographic scalp maps used to identify key electrodes with regard to activity associated with the N2 and P3 ERP components (see Figure 5.2).

4. Parameters identified from the grand averages utilised and applied to the individual participant trial analysis.
5. N2 and P3 ERP component data exported for *peak latency* (ms) analysis. For the purpose of this study the *peak latency* is defined as the time point in which these components were observed, specifically, between 180 and 220 ms (N2) and 300 – 600 ms (P3) post stimulus onset for both the aerobic and resistance exercise protocols.
6. *Mean amplitude* epochs (based on presentation of the light stimulus) for the N2 ERP component (time window – 180 to 220 ms) and P3 ERP component (time window one – 300 to 400 ms – P3a, time window two – 400 to 500 ms - early P3b and time window three – 500 to 600 ms – late P3b) post stimulus onset for both the aerobic and resistance exercise, were exported for *mean amplitude* data analysis (see Figures 5.3 – 5.5).

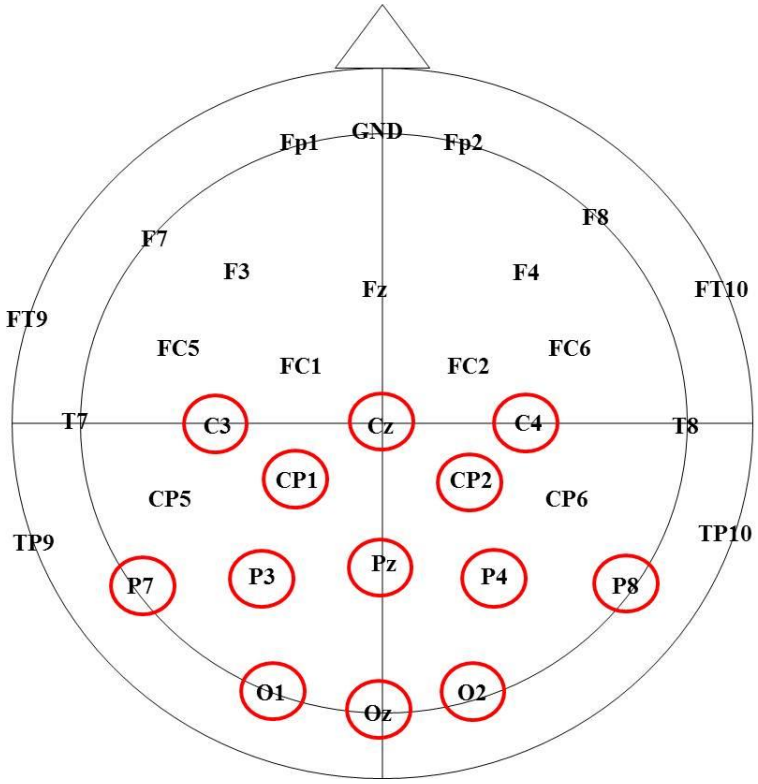

Figure 5. 2: 32 Channel Montage with key channels examined circled in red.

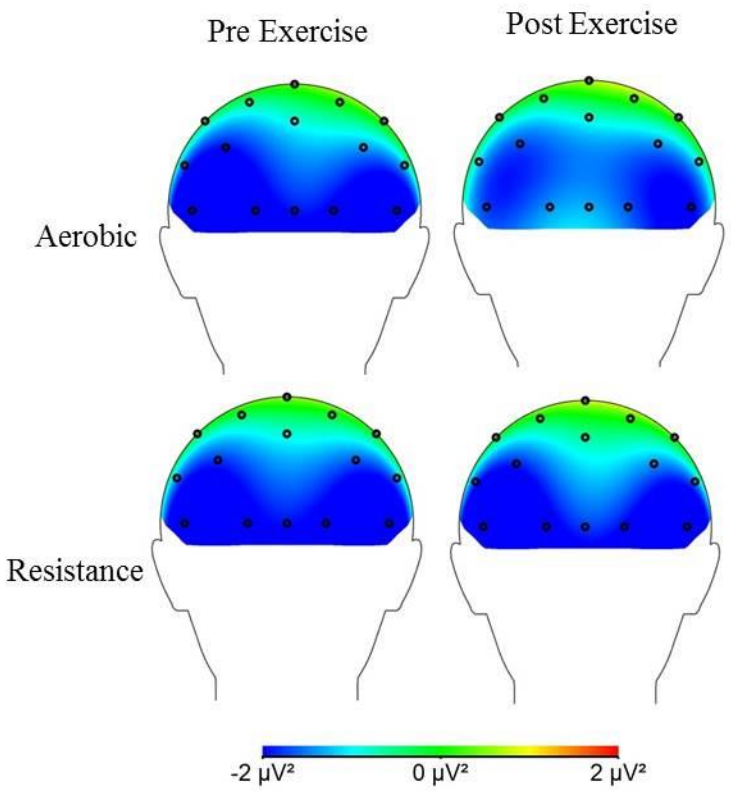

Figure 5. 3: Aerobic and Resistance Exercise - Time window (180 – 220 ms post stimulus onset) employed to examine the difference in the N2 ERP component *peak latency* and *mean amplitude*.

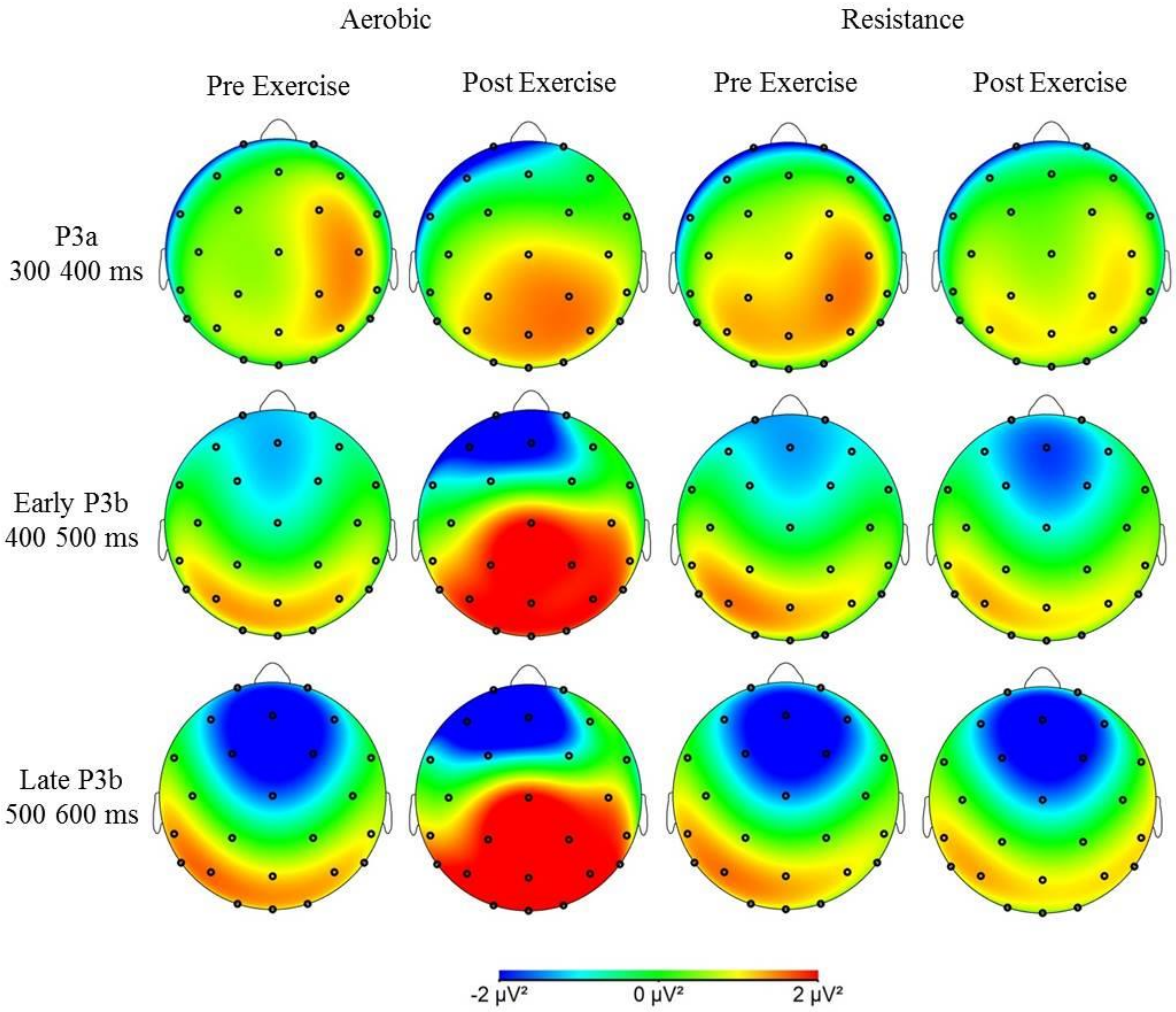

Figure 5. 4: Aerobic and Resistance Exercise – Time windows employed to examine the difference in the P3 ERP component *peak latency* and *mean amplitude*.

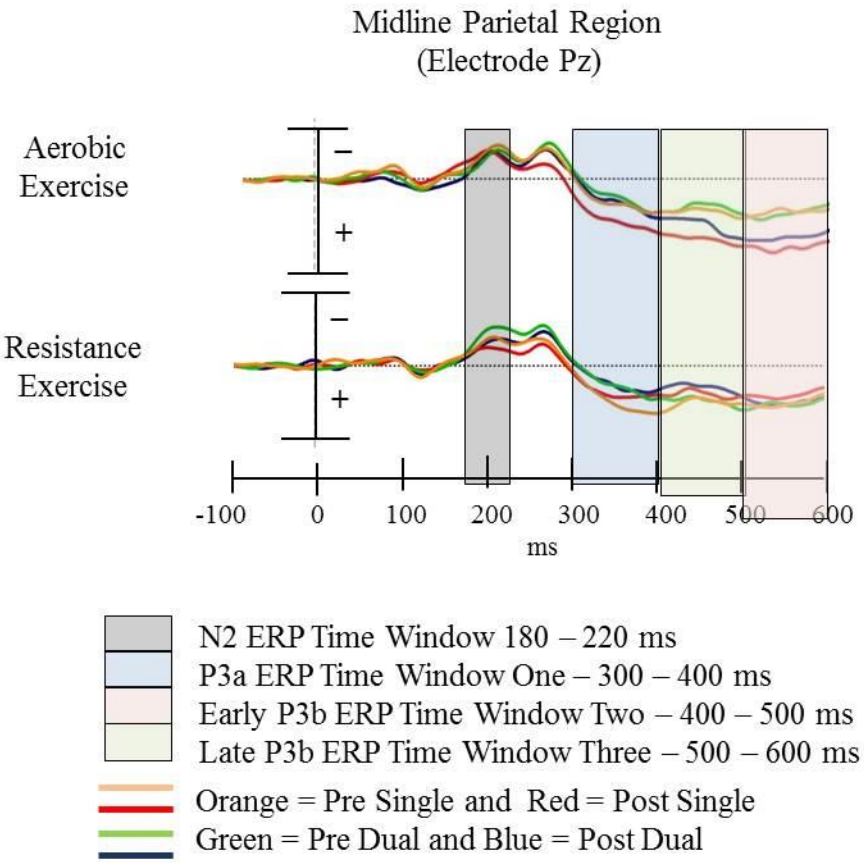

Figure 5. 5: Example of the grand averaged N2 and P3 *mean amplitude* response time windows employed to examine the difference in the neural activity over time in response to task difficulty and exercise type.

6. Data analysis:

6.1 Behavioural data

To determine the difference in time taken to perform the single- compared to dual-task trials for the aerobic and resistance exercise, a 2 (exercise: aerobic vs resistance) x 2 (task: single vs dual) x 2 (time: pre vs post) within-subject, repeated measures analysis of variance (ANOVA) was employed. For all analyses data is reported using standard error of the mean. For all analyses data is reported using standard error of the mean.

6.2 Neural activity data

Due to the analysis of these data involving the use of averaged data sets, repeated measures ANOVA was employed.

Lateral analyses of the N2 ERP component peak latency and mean amplitude (time window 180 – 220 ms post stimulus onset):

The N2 *peak latency* (ms) and *mean amplitude* (μV) differences were analysed from posterior parietal and occipital electrode sites using a 2 (exercise: aerobic versus resistance) x 2 (task: single versus dual) x 3 (recording site: parietal P3/P4 versus P7/P8 versus occipital O1/O2) x 2 (hemisphere: left versus right) x 2 (time: pre versus post) within-subject repeated measures ANOVA.

Midline analyses of the N2 ERP component peak latency and mean amplitude (time window 180 – 220 ms post stimulus onset:

The N2 *peak latency* (ms) and *mean amplitude* (μV) differences were analysed from midline electrode sites from posterior parietal and occipital electrode sites using a 2 (exercise: aerobic versus resistance) x 2 (task: single versus dual) x 2 (recording site: parietal Pz and versus occipital Oz) x 2 (time: pre versus post) within-subject repeated measures ANOVA.

Lateral analyses of the P3 ERP component peak latency and mean amplitude (time window one – 300 – 400 – P3a, time window two – 400 – 500 – early P3b and time window three – 500 - 600 ms – late P3b, post stimulus onset):

P3 *peak latency* (ms), *mean amplitude* differences were computed from central, central parietal, parietal and occipital electrode sites using a 2 (exercise: aerobic versus resistance) x 2 (task: single versus dual) x 6 (recording site: central C3/C4 versus central

parietal CP1/CP2 versus CP5/CP6 versus parietal P3/P4 versus P7/P8 versus occipital O1/O2) x 2 (hemisphere: left versus right) x 2 (time: pre versus post) within-subject repeated measures ANOVA.

Midline analyses of the P3 ERP component peak latency and mean amplitude (time window one – 300 – 400 – P3a, time window two – 400 – 500 – early P3b and time window three – 500 - 600 ms – late P3b, post stimulus onset):

P3 *peak latency* (ms), *mean amplitude* differences were computed from central, parietal and occipital electrode sites using a 2 (exercise: aerobic versus resistance) x 2 (task: single versus dual) x 3 (recording site: central Cz versus parietal Pz versus occipital Oz) x 2 (time: pre versus post), within-subject repeated measures ANOVA.

For all analyses - statistical data is reported using Greenhouse-Geisser corrected *p* values and standard error of the mean. Only those main effect results showing large effect sizes (.14 = large) in reference to the partial eta squared (η_p^2) measure of magnitude of a treatment effect (Cohen, 1988) which are theoretically meaningful (Kayser et al., 2000) and interactions that remained significant after post-hoc comparisons using pairwise *t*-tests are reported. For all other data see the attached appendices for a breakdown of results means and standard deviations and statistical summary tables (see Appendices 11 and 12).

7. Results

7.1 Behavioural data

Single- and dual-task trial completion:

Analyses revealed no main effect of exercise but there were main effects for time (F (1,14) = 15.43; p = .002, η_p^2= .52) and task (F (1,14) = 5.55; p = .03, η_p^2= .28) and no interaction effects (see Figure 5.5). Participants completed the single-task faster than the

dual-task and they completed both the single- and dual-task faster following the completion of exercise. On average from the nine words (3 words x 3 blocks) participants were asked to recall, 6 ± 3 and 7 ± 2 (before and after aerobic exercise respectively) and 7 ± 1 and 8 ± 1 (before and after resistance exercise respectively) were correct.

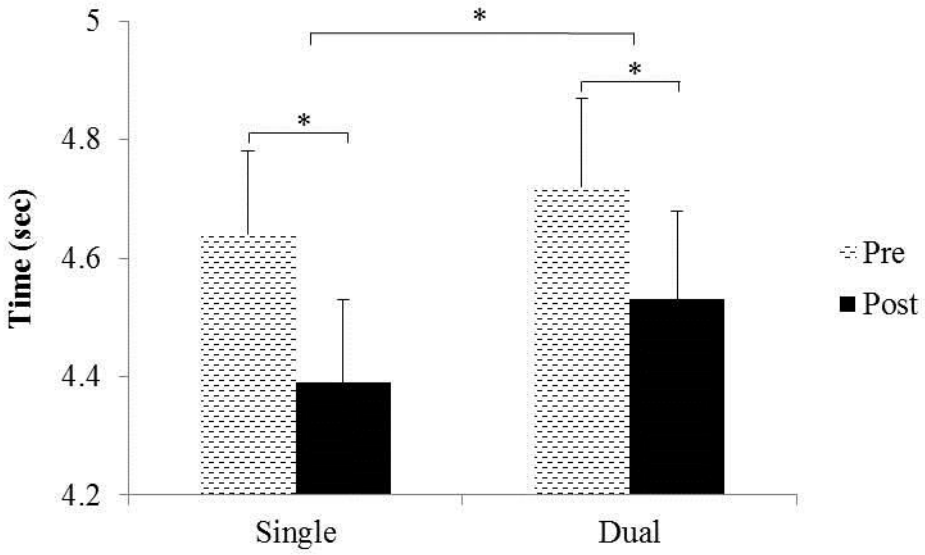

Figure 5. 6: Comparison of trial completion time between pre and post exercise and condition (* represents $p < .05$). Data is presented as mean ± SE.

7.2 Neural activity data

7.2.1 Lateral analysis

Exercise comparison in the N2 peak latency

There was a significant main effect of time (F (1,14) = 11.69; $p < .001$, $\eta_p^2 = .46$) but not task (see Figure 5.7), nor were any of the interactions significant. However, large effect sizes were obtained for the interaction between exercise, task, and time (F (1,14) = 3.20; p = .10, $\eta_p^2 = .19$), showing shorter *peak latencies* after exercise.

Exercise comparison in the N2 mean amplitude (180 – 220 ms post stimulus onset)

There was no effect of exercise, time or task, for N2 *mean amplitude* analysis, nor were any of the interactions significant.

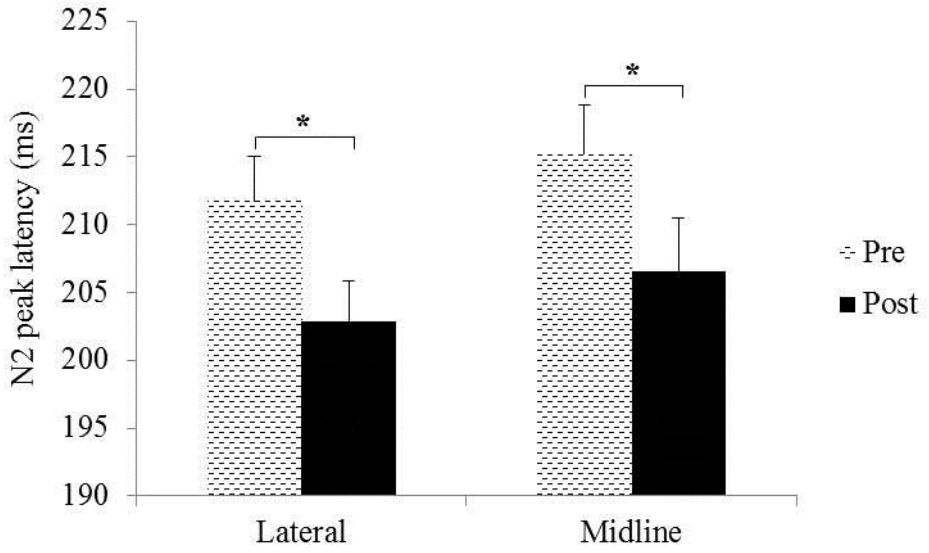

Figure 5. 7: Comparison of the N2 *peak latency* between pre and post exercise (* represents $p < .05$). Data is presented as mean ± SE.

Exercise comparison in the P3 peak latency

There were no significant main effects for P3 *peak latency* for exercise conditions, time or task, nor were any of the interactions significant.

Exercise comparison in the P3a mean amplitude, time window one – 300 – 400 ms

Analysis of the P3a *mean amplitude* during this first time window (see Figure 5.4) showed a significant interaction between exercise and time (F (1,14) = 4.80; p = .05, η_p^2 = .26) (see Figure 5.8). Post-hoc comparisons showed a significant difference in the pre- compared to post-aerobic exercise *mean amplitude* (t (14) = -2.61, p = .02, d = 0.57) but not the resistance bout (see Figure 5.9). There was also a significant main effect of time (F (1,14) = 5.56; p = .03, η_p^2 = .28), but not exercise or task type.

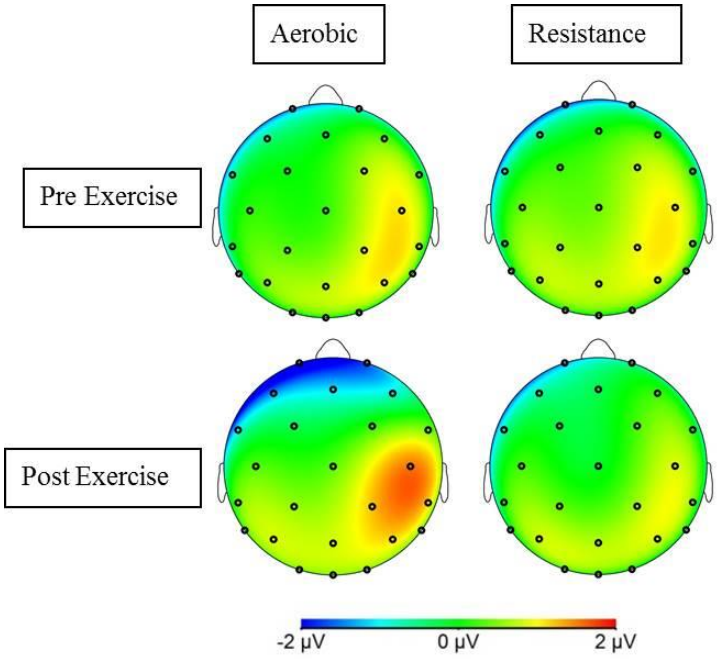

Figure 5. 8: Topographic scalp map comparison of time window one (300 – 400 ms) *lateral* P3a *mean amplitude* aerobic and resistance exercise.

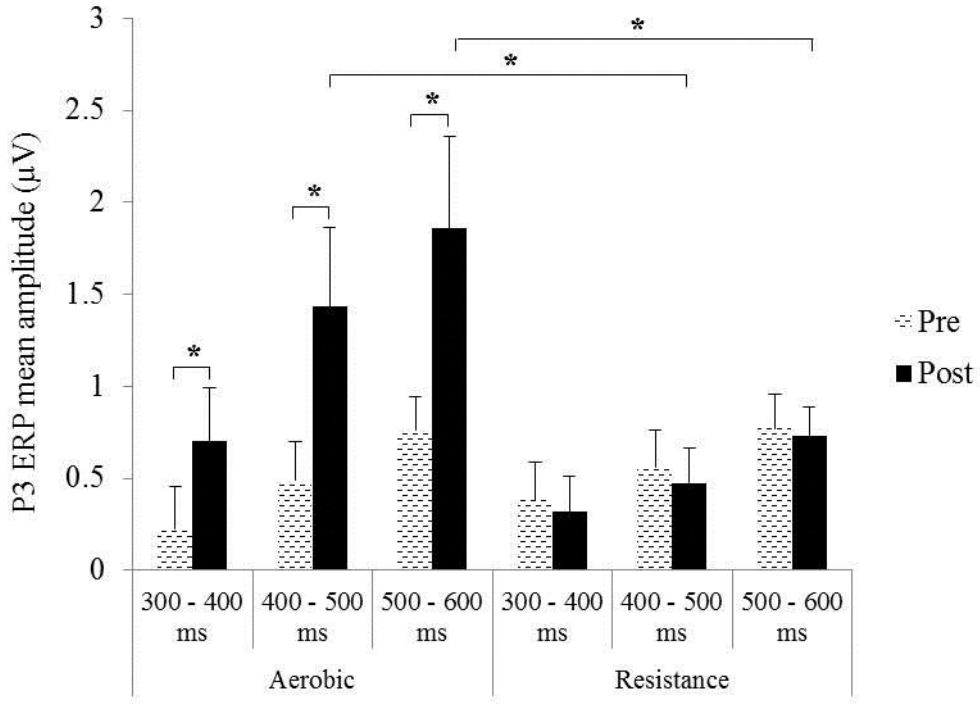

Figure 5. 9: Comparison of the *lateral* P3 *mean amplitude* across all time windows before and after aerobic and resistance exercise (* represents $p < .05$). Data is presented as mean ± SE.

Exercise comparison in the early P3b mean amplitude, time window two – 400 - 500 ms

Analysis of the early P3b *mean amplitude* during this second time window (see Figure 5.4) showed a significant interaction between exercise and time (F (1,14) = 5.57; p = .03, η_p^2 = .29). Post-hoc comparisons showed a significant difference in the pre- compared to post-aerobic exercise *mean amplitude* (t (14) = -2.78, p = .02, d = 0.60) and significant differences between aerobic and resistance post exercise *mean amplitude* (t (14) = 2.43, p = .03, d = 0.54) (see Figure 5.9).

There was a significant main effect of exercise (F (1,14) = 5.06; p = .04, η_p^2 = .27) and time (F (1,14) = 9.78; p = .01, η_p^2 = .41), but not task. This showed a mean increase in *mean amplitude* after the aerobic bout of exercise (0.944 ± 0.09 µV) compared to the resistance exercise which showed a decrease in *mean amplitude* (-0.087 ± 0.09 µV) (see Figure 5.10).

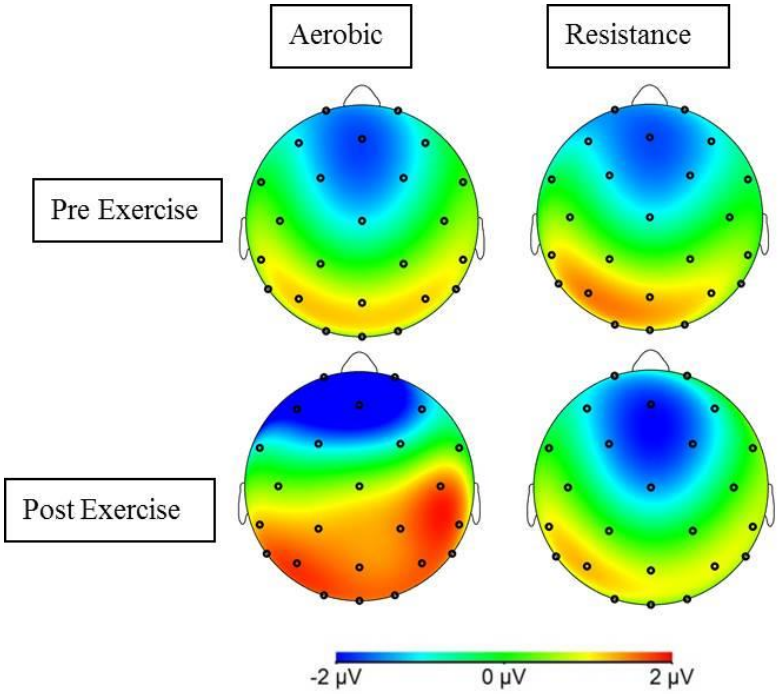

Figure 5. 10: Topographic scalp map comparison of time window one (400 - 500 ms) *lateral* early P3b *mean amplitude* aerobic and resistance exercise.

Exercise comparison in the late P3b mean amplitude, time window three – 500- 600 ms

Analysis of the late P3b *mean amplitude* during this third time window (see Figure 5.4) showed a significant interaction between exercise and time (F (1,14) = 5.57; p = .03, η_p^2 = .29). Post-hoc comparisons showed a significant difference in the pre- compared to post-aerobic bout of exercise *mean amplitude* (t (14) = -2.52, p = .03, d = 0.56) and significant difference between aerobic and resistance post-exercise *mean amplitude* (t (14) = 2.43, p = .03, d = 0.54) (see Figure 5.9).

There was also significant main effect of exercise (F (1,14) = 6.35; p = .02, η_p^2 = .31) and time (F (1,14) = 8.39; p = .01, η_p^2 = .38), but not task. This showed an increase in *mean amplitude* after the aerobic exercise (1.094 ± 0.11 µV) compared to the resistance exercise which showed a *mean decrease* in amplitude (-0.039 ± 0.11 µV) (see Figure 5.11).

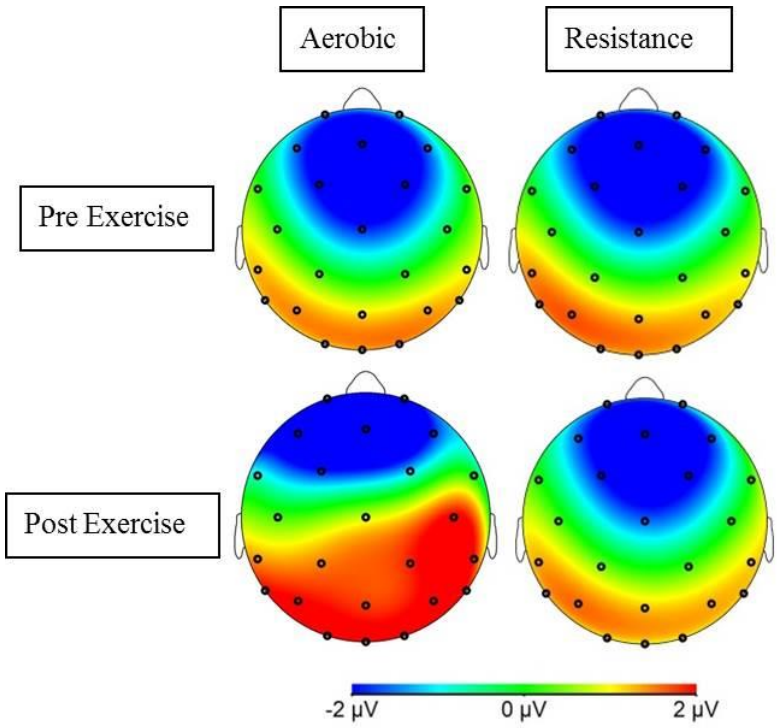

Figure 5. 11: Topographic scalp map comparison of time window one (500 - 600 ms) *lateral* late P3b *mean amplitude* aerobic and resistance exercise.

In summary, there were shorter overall N2 *peak latencies* after exercise, but no differences in N2 *mean amplitude* or P3 *peak latency.* There was however, interactions between exercise mode and time for P3 *mean amplitude* across all time windows examined. This showed an overall increase in *mean amplitude* associated with the aerobic exercise and either no change or a decrease in *mean amplitude* after the resistance exercise.

7.2.2 Midline analyses

Exercise comparison in the N2 peak latency

There was a significant main effect of time (F (1,14) = 7.66; p = .02, η_p^2 = .35) but not task (see Figure 5.7), nor were any of the interactions significant. However, a large effect size was obtained for the interaction between exercise, task and time (F (1,14) = 2.47; p = .14, η_p^2 = .15), showing shorter *peak latencies* after exercise.

Exercise comparison in the N2 mean amplitude (180 – 200 ms post stimulus onset)

There was a main effect of time (F (1,14) = 13.89; p = .00, η_p^2 = .50), with a greater *mean amplitude* before exercise compared to after (-1.318 ± 0.23 and -1.111 ± 0.25 µV respectively).

Exercise comparison in the P3 peak latency

There were no significant main effects in the P3 *peak latency* for exercise, time or task. The interactions were also not significant. However, there was a large effect size for the exercise, time and task interaction (F (1,14) = 4.28; p = .06, η_p^2 = .23). With exception of the *peak latency* increase after the aerobic exercise bout in the single-task performance, there was a decrease in *peak latency* observed after the aerobic bout (dual-task) and resistance bout

(single- and dual-task), indicating an improvement in speed of stimulus classification (P3 *peak latency*).

Exercise comparison in the P3a mean amplitude, time window one – 300 – 400 ms

Analysis of the P3a *mean amplitude* during this first time window (see Figure 5.4) showed a significant main effect of task (F (1,14) = 9.27; p = .01, η_p^2 = .40), but not exercise or time. The task main effect showed larger *mean amplitudes* in the single- compared to the dual-task (0.533 ± 0.29 and 0.211 ± 0.28 µV respectively). There were no significant interactions. However, the interaction between exercise and time (F (1,14) = 3.05; p = .10, η_p^2 = .18) had a large effect size, showing greater *mean amplitudes* after aerobic (0.730 ± 0.51 and 0.200 ± 0.29 µV respectively) and a decrease in *mean amplitude* after the resistance bout (0.195 ± 0.24 and 0.364 ± 0.25 µV respectively) of exercise.

Exercise comparison in the early P3b mean amplitude, time window two – 400 - 500 ms

Analysis of the early P3b *mean amplitude* during this second time window (see Figure 5.4) showed a significant interaction between exercise and time (F (1,14) = 4.46; p = .05, η_p^2 = .24). In addition, the interaction between exercise and task (F (1,14) = 2.74; p = .12, η_p^2 = .16) had a large effect size. Post-hoc comparisons, however, did not reveal any differences.

Exercise comparison in the late P3b mean amplitude, time window three – 500 – 600 ms

Analysis of the late P3b *mean amplitude* during this third time window (see Figure 5.4) showed a significant main effect of exercise (F (1,14) = 5.09; p = .04, η_p^2 = .27) but not time or task. The main effect for exercise showed a significant difference in *mean amplitude* for the aerobic (2.536 ± 0.51 µV) compared to the resistance (-0.126 ± 0.51 µV) bout of exercise. The main effect of time, however did show a large effect size (F (1,14) = 4.17; p =

.06, η_p^2 = .23), showing an enhanced late P3b *mean amplitude* post compared to pre-exercise (1.283 ± 0.66 and 0.078 ± 0.26 µV respectively). Further, the interactions between exercise and time (F (1,14) = 4.12; p = .06, η_p^2 = .23) and exercise and task (F (1,14) = 3.39; p = .09, η_p^2 = .20) also had large effect sizes. This showed greater *mean amplitudes* post compared to pre (2.610 ± 1.24 and 0.074 ± 0.28 µV respectively) the aerobic bout of exercise and a decrease in *mean amplitude* post compared to pre (-0.044 ± 0.29 and 0.082 ± 0.28 µV respectively) the resistance bout of exercise.

In summary, for N2 *peak latency* there was an overall main effect of time that emerged as shorter N2 *peak latencies* after exercise compared to before, and greater N2 *mean amplitudes* before compared to after exercise irrespective of exercise mode or task type. In regard to the P3 *peak latency* there were large effect sizes relating to shorter *peak latencies* in the single- compared to the dual-task and interactions between exercise and time in the P3 *mean amplitudes* in all time windows examined. Greater *mean amplitudes* after aerobic exercise compared to before were observed specifically in the first and third time windows. There was also a main effect of task irrespective of exercise or time, showing larger *mean amplitudes* in the single- compared to the dual-task.

Of interest is the different pattern of activation between the lateral (exercise and time effects) and midline (exercise, time and task effects) electrodes within the same time windows in P3 *mean amplitude.* This unique observation suggests different spatial patterns of activation linked to exercise mode and task type (Machado et al., 2014).

8. Discussion

The purpose of this study was to evaluate differences in neural activity associated with the performance of a single- and dual-task during locomotion before and immediately after aerobic or resistance exercise in young adults. As predicted, participants completed the

single- and dual-task faster following both aerobic and resistance exercise. In addition, mean trial time was faster in the single-task compared to the dual-task indicating a dual-task effect. Results pertaining to the N2 and P3 ERP components varied. Specifically, there was a significant effect on the N2 *peak latency* (*midline* and *lateral* analysis), large effect sizes for both the N2 (*lateral* and *midline*) and P3 (*midline*) *peak latencies* after exercise for both single- and dual-task performance and interactions between exercise and time for *mean amplitude*s. There was greater N2 *mean amplitude* before exercise and greater P3 *mean amplitudes* in the aerobic exercise condition whereas the resistance condition showed no change or a decrease in *mean amplitude* following the acute bout of exercise. Due to the time-consuming nature of the studies conducted it is impossible to obtain sample sizes which might result in significant differences. Therefore those results with non-significant findings, with large effect-size calculations are discussed as they provide a good indication of whether or not there is an effect of task and/or exercise (Cumming, 2012).

When attempting to interpret these results, specifically in the context of the relationships between the behavioural and neurophysiological results of the exercise protocols, we must consider the underlying principles of the different neural components examined (N2 and P3 ERP components). The N2 ERP neural component is thought to be triggered during response monitoring/inhibition (Donkers & Van Boxtel, 2004; Falkenstein et al., 1999; Schmitt et al., 2000) such as that associated with monitoring for the colour of the presented light stimulus, translation of this sensory information into goals, actions and control of the outcome with the aim of preventing the occurrence of an incorrect response (Gajewski & Falkenstein, 2012; Gajewski, Kleinsorge, & Falkenstein, 2010). The exercise-related influence on the N2 ERP response within this study are in line with what has previously been reported, specifically in relation to the differences observed. Whereas the N2 *peak latency* was shorter after both modes of exercise for both single- and dual-task performance, there

was an overall reduction in N2 *mean amplitude* in the *midline* electrodes after compared to before exercise irrespective of exercise mode or task type.

These findings are consistent with previous research demonstrating an improvement in neural efficiency, response monitoring and allocation of attentional resources, resulting in a reduction in *peak latency* (*lateral* and *midline*) and *mean amplitude* (*midline*) following exercise (Donkers & Van Boxtel, 2004; Drollette et al., 2014; O'Leary et al., 2011; Yeung et al., 2004). In other words, following an acute bout of exercise there is an enhanced capacity to integrate sensory information, visuospatial information and orientation and response monitoring to reduce the risk of performing an error, which resulted in an overall quicker trial completion time.

The P3 ERP neural component is primarily related to the speed with which stimulus classification occurs (*latency*) and the allocation of attentional resources and working memory (*amplitude*) (Duncan-Johnson, 1981; Kutas et al., 1977; Polich, 1987) and has three key different attributes (P3a, early and late P3b). The pattern of exercise-induced differences in the P3 component has been equivocal (Kamijo et al., 2004; Kamijo et al., 2012), with no research to date evaluating the different attributes of the P3 component. This study showed that, although there was no significant difference in P3 *peak latency*, there were large effect sizes relating to the *midline* analysis showing shorter *peak latencies* after exercise in the single- (resistance exercise) and dual-task (aerobic and resistance exercise). These shorter P3 *peak latencies* are representative of an improvement in the speed of stimulus classification. In other words, participants were able to recognise and integrate the colour of the light stimulus and perform the corresponding change in direction of travel.

The aerobic exercise resulted in an increase in P3 *mean amplitudes* in *lateral* time windows (400 – 500 ms and 500 – 600 ms) and *midline* time windows (300 – 400 and 500 – 600 ms). Resistance exercise, on the other hand, resulted in a slight decrease or no change in

mean amplitudes across all time windows. In addition, P3 *mean amplitude* following aerobic exercise was significantly higher compared to resistance exercise for most time windows. These findings suggest that, although participants enhance their performance (i.e., faster completion time), the underlying neural mechanisms vary by exercise mode. Figures 5.7, 5.9 and 5.10 also clearly illustrate the differences in spatial patterns of activation between aerobic and resistance exercise.

The increase in P3 *mean amplitude* observed after aerobic exercise was representative of an overall increase in the allocation of attentional resources with which to integrate and respond to the relevant stimulus (O'Leary et al., 2011). This is in specific reference to an enhanced attentional and memory processing and capacity to evaluate the presented stimulus (P3a), and enhanced working memory, specifically through the encoding and retrieval phases of information processing (early and late P3b) (Brookhuis et al., 1981; Jongsma et al., 2007; Morgan et al., 2008; Scisco et al., 2008). The P3 component pattern of activity, specifically in context to the scalp distribution of the P3a, which has previously been reported as being most prominent over frontal locations, was observed over central parietal and parietal regions. Despite this different spatial distribution of enhanced activity it is reported to still reflect the associated functional processes linked to that of the P3a (Walshe, Patterson, Commins, & Roche, 2015). These P3 component differences allowed participants to respond quicker to the dual-task demands (i.e., reduced dual-task cost), and improved mean trial completion time. This finding was consistent with previous research that has shown faster reaction times and improved interference control, or the ability to inhibit erroneous (secondary) stimuli and respond to the primary stimuli in a cognitive task, such as in a dual-task condition (Davranche, Hall, & McMorris, 2009; Sibley et al., 2006), and improved response speed in working memory tasks (McMorris & Hale, 2012; McMorris, Sproule, Turner, & Hale, 2011).

A physiological change that has been reported to occur with the increase in the allocation of attentional resources (P3 *amplitude*) is state arousal. This is related to activity within the noradrenergic system which is detectable within the signal to noise ratio of EEG patterns and ERPs (Moxon, Devilbiss, Chapin, & Waterhouse, 2007; Nieuwenhuis, Aston-Jones, & Cohen, 2005). Specifically, an enhanced evoked response is linked to state arousal, vigilance, and sustained attention (Dietrich & Audiffren, 2011). Further, it is suggested that there is a link between exercise, arousal and improvements in cognitive function (Dietrich & Audiffren, 2011). As such, the increase in the P3 *mean amplitude* following aerobic exercise may be associated with increased arousal which in turn enhances performance.

Another proposed mechanism that has been associated with an exercise-related improvement in behavioural outcomes (e.g., reaction time) is that of the influence of brain-derived neurotrophic factor (BDNF) (Chang et al., 2012). BDNF is an important molecular mediator of structural and functional plasticity of the brain (S. H. Jung, Kim, Davis, Blair, & Cho, 2011), specifically neural efficiency (McAllister, Katz, & Lo, 1999), and is able to travel through the blood-brain barrier in both directions (Pan, Banks, Fasold, Bluth, & Kastin, 1998). Importantly the transmission and expression of BDNF is reported to be influenced by physical activity (Schinder & Poo, 2000) and is reported to be a modulator in cognitive performance (Tsai, Chen, et al., 2014). To date, however the influence of BDNF production on electrophysiological activity is limited. To date there is a paucity of research that has investigated the relationship between exercise-related improvements in cognitive performance and changes in BDNF production and event-related potentials such as the P3 amplitude. The limited information available is that an increase in BDNF production does not influence electrophysiological responses to exercise (Tsai, Chen, et al., 2014). However, this would be an area of research worth exploring further, to fully explore the relationship between these two characteristics of improvements in cognitive function.

There was no significant difference in the P3 *mean amplitude* after the resistance exercise. If anything there was no change or suppression of the *mean amplitude* across all time windows irrespective of task. Despite this, participants showed faster task completion times following an acute bout of resistance exercise. These findings are consistent with previous research employing fMRI, which showed a differential response between cardiovascular and coordination training on cognitive performance and neural processes in older adults after a 12 month exercise intervention (Voelcker-Rehage, Godde, & Staudinger, 2011). Improved cognitive performance was associated with an increase in neural activity after cardiovascular exercise whereas coordination training did not change neural activity. It was suggested that cognitive improvements after the coordinative training may be attributed to the reduction in compensatory activation required to perform the same task after the intervention (Chang et al., 2014). Furthermore, enhanced neural efficiency has also been observed after a 12 week walking and dual-task exercise intervention. Improvement in performance of a short-term memory task (n-back) was associated with a reduction in effort and improved brain activation compared to baseline (Nishiguchi et al., 2015). In line with this finding, the lack of change or reduction in P3 *mean amplitude* and the associated faster task completion times following resistance exercise in the present study could be due to enhanced neural efficiency in all aspects of stimulus evaluation, attention and memory processing (P3a) and modulation of working memory load during the encoding and retrieval phases of information processing (early and late P3b) (Brookhuis et al., 1981; Jongsma et al., 2007; Morgan et al., 2008; Scisco et al., 2008).

Alternatively, it could be speculated that the improvement in performance may be the consequence of resistance training being discrete in nature which would be associated with higher levels of cognitive processing including the integration of sensory information to perform the exercise efficiently and fluidly (Voelcker-Rehage et al., 2011; Voelcker-Rehage

& Niemann, 2013). This on-going cognitive engagement may act as a form of training or priming resulting in enhanced neural efficiency, specifically a more efficient capacity to integrate and respond to presented stimuli.

Interestingly, within the first time window (300 – 400 ms – P3a) in the *lateral* results there was an interaction between exercise and time and in the *midline* result there was a main effect of task. These results may be in-line with research that has evaluated the spatiotemporal dynamics of P3 visually-evoked potential using standardised low-resolution electromagnetic tomography (sLORETA) (Machado et al., 2014). These authors observed a sequence of significantly different activation of intracerebral structures associated with performance in a visual oddball paradigm. It was suggested by the authors that the spatiotemporal pattern of activation of the P3 component is aligned with the sequential and physiological cognitive functions and exact period of task execution, which provides support for the overall observation of a differential pattern of activation between the *lateral* and *midline* electrodes.

There are some limitations that could be addressed in future research. First, the cognitive task used might not have been sufficiently demanding to show differences in the P3 ERP component between single- and dual-task performances across both exercise protocols. This task was designed to minimize sub-vocal rehearsal, which has the potential to influence EEG recordings, specifically the occurrence of facial movement related artefact. As this is the first research to date to evaluate the influence of an acute bout of resistance exercise on goal-directed neural activity, further research would be suggested to ascertain if the results observed within this study are replicable. Moreover, it would be of interest to examine whether similar neural responses occur across the lifespan. Another limitation relates to the exercise manipulation, specifically exercise intensity based on individual participants VO_2max and 1RM, which were measured using standard protocols. Based on individual

exercise history relating to cardiovascular and resistance based exercise, an individual's exercise tolerance and perception of muscular fatigue for example may have influenced the relative intensity of the exercise bout (Chang & Etnier, 2009a).

In summary, this study demonstrated that, in a novel experimental paradigm, which was more akin to activities of daily living, acute exercise resulted in improved locomotor performance irrespective of exercise mode or task (single or dual). In addition, the improved trial completion time was associated with shorter N2 (*lateral* and *midline*) and P3 (*midline*) *peak latencies* after both exercise bouts and an increase in P3 *mean amplitude* following aerobic but not resistance exercise. We propose that the increase in P3 *mean amplitude* following aerobic exercise is associated with higher arousal levels whereas resistance exercise might enhance neural efficiency and prime the CNS for future behavioural challenges. It is postulated that the behavioural improvements observed involve changes in the N2 and P3 ERP component responses after exercise, however key differences between the effects of an acute bout of aerobic compared to resistance exercise were not fully elucidated within the analyses performed within this chapter. It is therefore the intention to examine the aerobic and resistance bouts of exercise independently in the subsequent chapters (chapters 6 and 7) in an attempt to obtain a more in-depth understanding as to the underlying mechanisms associated with the changes in trial completion time observed.

Chapter Six

Study 3 – Part B

Effect of acute aerobic exercise on neural activity associated with single and dual-task performance during locomotion

1. Introduction

As previously established in chapter five, levels of physical fitness and acute bouts of exercise are associated with improvements in cognitive functioning, with acute exercise being linked to an immediate and transient improvement in cognitive function (Griffin et al., 2011; Schneider et al., 2009). These changes in cognitive function include exercise-induced differences in the N2 and P3 ERP components. As stated in the previous chapter, the N2 ERP component is associated with response monitoring, specifically monitoring for conflict between competing responses such as that involved in dual-task performance (Donkers & Van Boxtel, 2004; Falkenstein et al., 1999; Schmitt et al., 2000). The two key characteristics of the N2 ERP component are *latency*, which refers to the timing of information processing during visual perception and the moment when sensory information is available to formulate the stimulus response decision (Schmitt et al., 2000; Thorpe et al., 1996), and *amplitude* which is an index the of neural effort and processing required for response monitoring (Donkers & Van Boxtel, 2004; Yeung et al., 2004). Whereas the P3 ERP component *latency* is related to the speed with which we can classify sensory stimuli and the *amplitude* is related to the allocation of attentional resources and working memory (Duncan-Johnson, 1981; Kutas et al., 1977; Polich, 1987). The P3 component is further divided into three key attributes, that of the P3a and the early and late P3b. Whereas the P3a relates to attention, stimulus evaluation and memory processing, the early and late P3b is associated with the modulation

of working memory load on retrieval and encoding phases and memory updating (Brookhuis et al., 1981; Jongsma et al., 2007; Kok, 2001; Morgan et al., 2008; Scisco et al., 2008).

Results pertaining to the influence of acute aerobic exercise on the N2 and P3 components are mixed. For example, an increase in the N2 *amplitude* is reported to be related to focusing attentional demands on a specific outcome as opposed to dividing attentional resources to multiple potential outcomes (i.e., a reduction in switching costs) (Gajewski & Falkenstein, 2012). Whereas a reduction in the N2 *amplitude* is related to an enhancement in processing resources associated with retrieval and maintenance of multiple task sets in memory (lower global costs). There are also mixed results relating to the P3 component including an increase in P3 *amplitude* and no change in P3 *latency* after an acute bout of aerobic exercise (Kamijo, Nishihira, Hatta, Kaneda, Kida et al., 2004) and no change in the *amplitude* and a decrease in *latency* (Kumar et al., 2012). In light of these equivocal results, the purpose of this chapter is to evaluate neural activity (N2 and P3 ERP components) associated with the performance of both a single- and dual-task during locomotion before and after an acute bout of aerobic exercise. The hypotheses were: 1) quicker trial completion time would be observed after aerobic exercise; 2) the dual- compared to single-task will take longer to perform irrespective of the bout of aerobic exercise; 3) shorter global N2 *peak latencies* and reduction in *mean amplitude* for both single- and dual-tasks, following a bout of aerobic exercise; 3) shorter global P3 *peak latencies* and increase in *mean amplitudes* across all time windows, for both single- and dual-tasks, following a bout of aerobic exercise; 4) longer N2 and P3 *peak latencies* in the dual- compared to the single-task, following a bout of aerobic exercise; and 5) greater N2 and P3 *mean amplitudes* in the single- compared to the dual-task.

2. Methods

In addition to the key time windows of interest (see Figure 6.1), please refer to the previous studies (see Chapters 3, 4 and 5), for an overview of the methods employed.

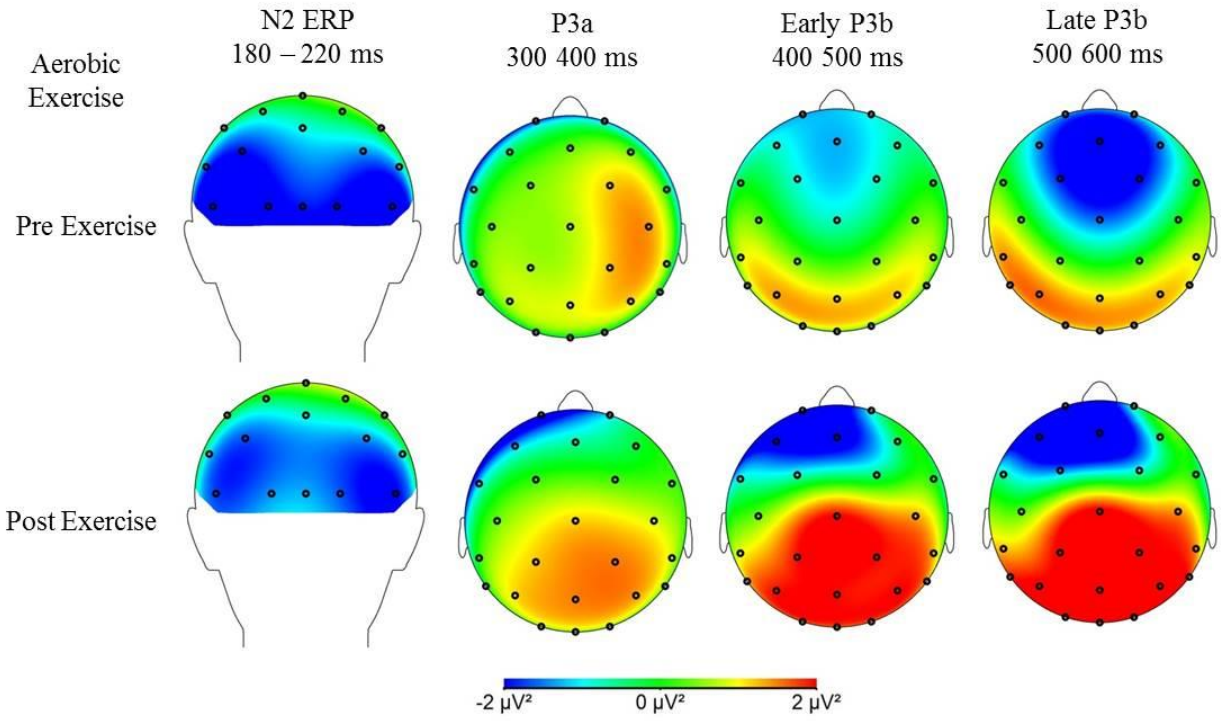

Figure 6. 1: Aerobic Exercise Bout - ERP responses with time windows employed to examine the differences in neural activity (N2 and P3 ERP component *peak latency* and *mean amplitude*).

2.1. Data analyses:

For all analyses procedures for the behavioural (trial completion time) and EEG (neural activity data), please see the process outlined in the previous chapter (Chapter 5 – Part A).

3. Results

For all non-significant data see the attached appendices for a breakdown of means and standard deviations and statistical results summary tables (see Appendices 11 and 12).

3.1 Behavioural data

Single- versus Dual-task time per trial completion in the aerobic exercise:

There was a main effect time (F (1,14) = 8.58; p = .01, η_p^2 = .38), but not task; nor was there a significant interaction between time and task (see Figure 6.2). The pre-exercise mean time per trial was greater than the post-exercise mean time (4.64 ± .15 and 4.49 ± .14 s respectively).

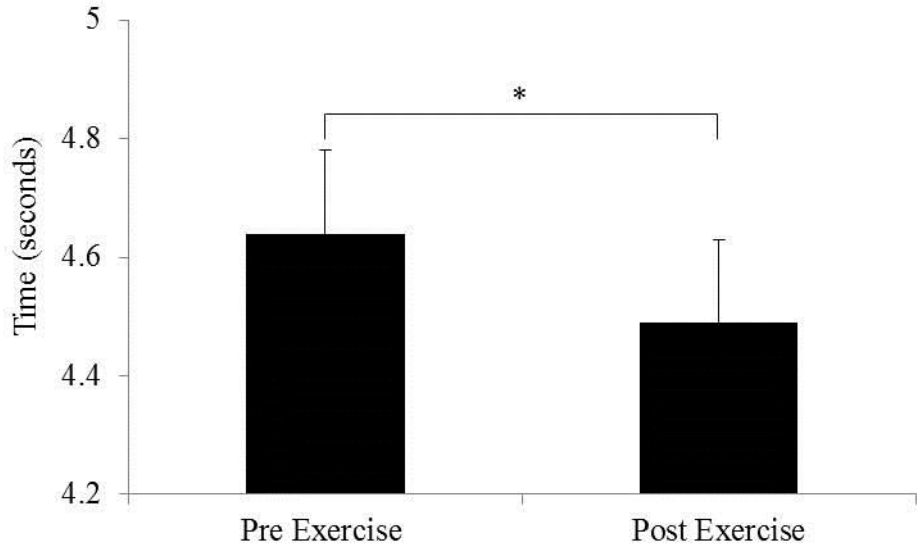

Figure 6. 2: Comparison of trial completion time between pre- and post-exercise (* represents p < .05). Data is presented as mean ± SE.

3.2 Neural activity data

3.2.1 Lateral analyses

N2 peak latency

There was a significant main effect of time (F (1,14) = 8.94; p = .01, η_p^2 = .39) (see Figure 6.3) but not task. In addition, there were no significant interaction effects. However, the interaction between time and task, although not significant, had a large effect size (F (1,14) = 3.83; p = .07, η_p^2 = .22) showing shorter *peak latencies* for both single- and dual-tasks post- compared to pre-exercise. Also, in the pre-exercise condition, shorter *peak*

latencies were observed in the single-compared to the dual-task (207.92 ± 3.33 and 218.20 ± 5.33 ms), whereas in the post-exercise condition shorter *peak latencies* were observed in the dual- compared to the single-task (199.44 ± 2.72 and 202.91 ± 4.77 ms).

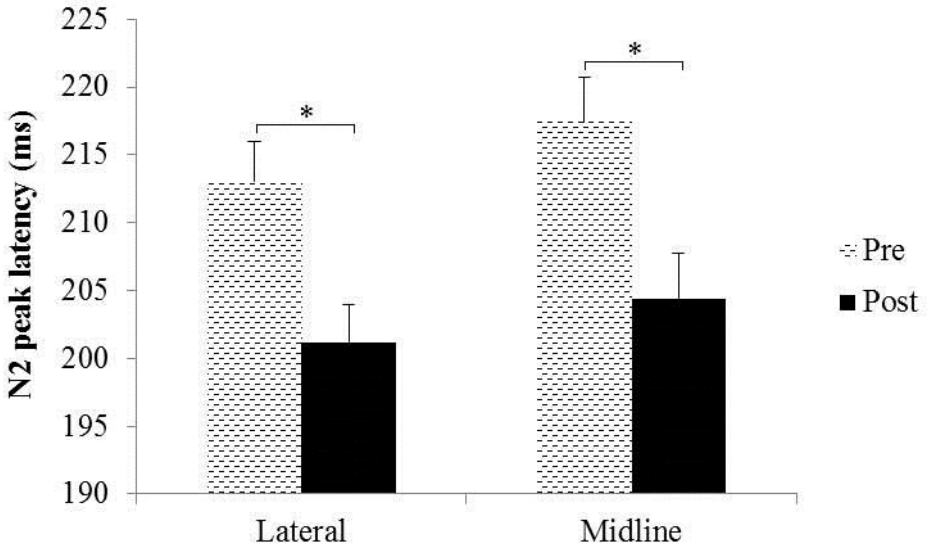

Figure 6. 3: Comparison of the N2 *peak latency* between pre and post exercise (* represents $p < .05$). Data is presented as mean ± SE.

N2 mean amplitude (time window – 180 – 220 ms)

There was a significant interaction between time and electrode site (F (2,28) = 6.88; p = .01, η_p^2 = .33) (see Figure 6.4) and between time, electrode site and recording hemisphere (F (2,28) = 4.39; p = .02, η_p^2 = .24), but no significant interaction between time and task. Post-hoc comparisons showed significant differences in the pre-exercise mean amplitude between the parietal (P3/P4) and posterior parietal (P7/P8) areas (t (14) = 4.22, $p < .001$, d = 0.75) and the posterior parietal (P7/P8) and occipital (O1/O2) areas (t (14) = -2.93, p = .01, d = 0.62). The greatest *mean amplitude* was within the posterior parietal area compared to both the parietal and occipital areas irrespective of task type (-3.011 ± 0.39, -1.761 ± 0.29 and -2.265 ± 0.35 µV respectively). Post hoc analyses also revealed a significant difference in the post-exercise *mean amplitude* between the parietal (P3/P4) and posterior parietal (P7/P8) areas (t (14) = 5.18, $p < .001$, d = 0.81) and the posterior parietal (P7/P8) and occipital

(O1/O2) areas (t (14) = -3.81, p = .001, d = 0.71). As for the pre-exercise *mean amplitude* the greatest *mean amplitude* was observed within the posterior parietal area compared to both the parietal and occipital areas irrespective of task type (-3.198 ± 0.41, -1.653 ± 0.33 and -2.186 ± 0.38 µV respectively). Regardless of time or task the posterior parietal (P7/P8) area showed the greatest activity during pre- and post-exercise testing compared to the other regions (parietal and occipital) regions examined.

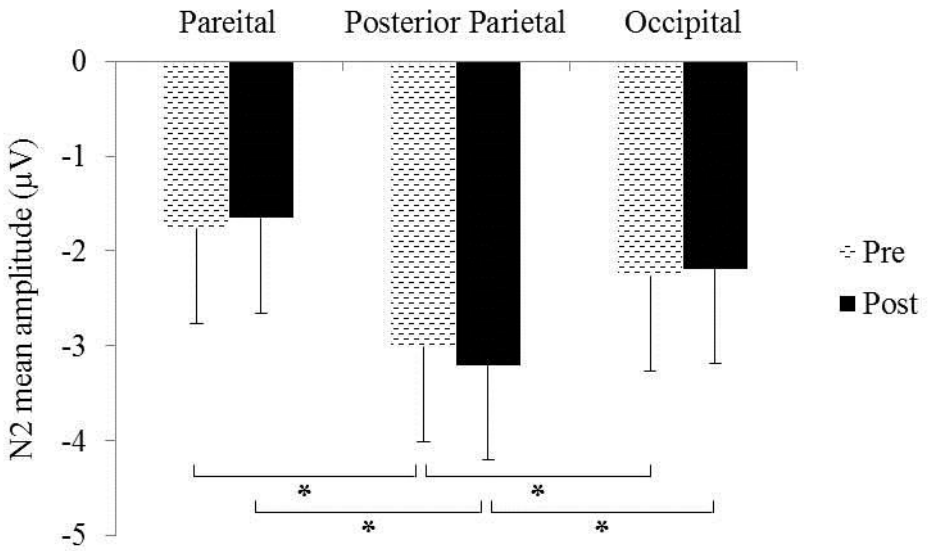

Figure 6. 4: Comparison of the N2 *mean amplitude* between pre and post exercise (* represents $p < .05$). Data is presented as mean ± SE.

P3 peak latency

There was no significant main effect of time or task, nor were any of the interactions significant, although the interaction between electrode site, hemisphere and time had a large effect size (F (4,56) = 2.56; p = .08, η_p^2 = .16) indicating a decrease in *peak latency* post exercise compared to pre in all electrodes (CP2, P3, P4, P7, P8, O1 and O2) with the exception of electrodes C3, C4 and CP1.

P3a mean amplitude (time window one - 300 – 400 ms)

Analysis of the P3a *mean amplitude* during this first time window (see Figure 6.1) showed a significant main effect of time (F (1,14) = 6.81; p =.02, η_p^2 = .33) (see Figure 6.5), but not task. Nor was there a significant interaction between time and task.

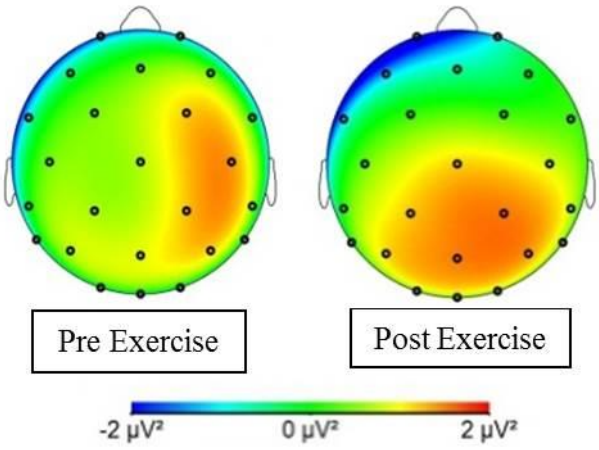

Figure 6. 5: Topographic scalp map comparison of time window one (300 – 400 ms) *lateral* P3a *mean amplitude* following the aerobic bout of exercise.

Early P3b mean amplitude (time window two - 400 – 500 ms).

Analysis of the early P3b *mean amplitude* during this second time window (see Figure 6.1) showed a significant interaction between time, electrode site and recording hemisphere (F (4,56) = 4.75; p = .04, η_p^2 = .25). Follow-up analyses were carried out using five separate contrasts (central – C3 and C4, central parietal – CP1 and CP2, parietal – P3, P4 and P7 and P8 and occipital – O1 and O2) to clarify the interaction between time, electrode site and recording hemisphere, however, these did not reveal any significant differences after p-value correction.

There was also a significant main effect of time (F (1,14) = 7.71; p = .02, η_p^2 = .36), (see Figure 6.6), but not task (F (1,14) = 0.08; p = .78, η^2 = .01) In addition there was no significant interaction between time and task.

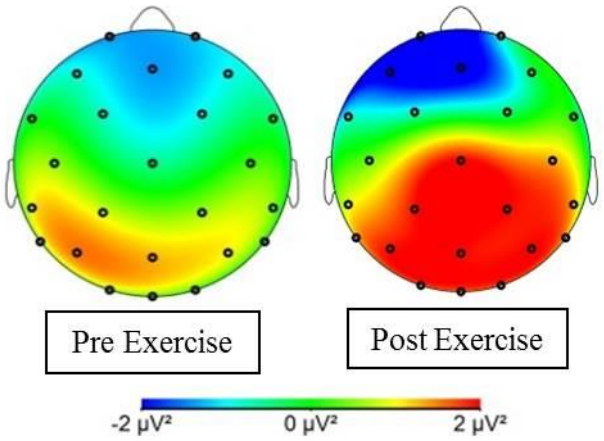

Figure 6. 6: Topographic scalp map comparison of time window one (400 - 500 ms) *lateral* early P3b *mean amplitude* following the aerobic bout of exercise.

Late P3b mean amplitude (time window three - 500 - 600 ms)

Analysis of the late P3b *mean amplitude* during this third time window (see Figure 6.1) showed a significant interaction between time and recording hemisphere (F (1,14) = 7.10; p = .02, η_p^2 = .34) and an interaction between time, electrode site and recording hemisphere (F (4,56) = 4.61; p = .05, η_p^2 = .25). To fully understand the spatial distribution of time effects (pre- versus post-exercise) follow-up analyses were carried out using five separate contrasts (central – C3 and C4, central parietal – CP1 and CP2, parietal – P3, P4 and P7 and P8 and occipital – O1 and O2) to clarify the interaction between time, electrode site and recording hemisphere. This revealed a significant difference in the pre- compared to post-exercise *mean amplitude* within the right and left hemispheres (t (14) = -2.69, p = .02, d = 0.58 and t (14) = -2.13, p = .05, d = 0.49).

There was also a significant main effect of time (F (1, 14) = 6.33; p = .03, η_p^2 = .31) (see Figure 6.7), showing a greater late P3b *mean amplitude* post- compared to pre-exercise.

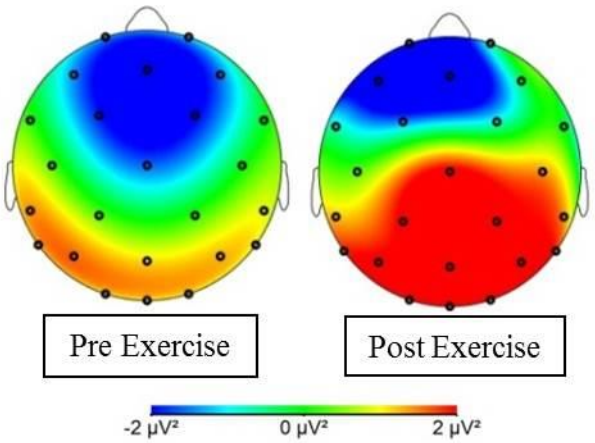

Figure 6. 7: Topographic scalp map comparison of time window one (500 - 600 ms) *lateral* late P3b *mean amplitude* following the aerobic bout of exercise.

In summary, in the N2 *peak latency lateral* analysis, there were shorter overall *peak latencies* after exercise. Before exercise, shorter *peak latencies* were observed in the single- compared to the dual-task condition; however, after exercise the shortest *peak latencies* were observed in the dual- compared to the single-task, indicating a greater improvement in dual- compared to single-task performance. In other words, there is an enhanced attentional capacity to integrate and process information in more complex tasks more efficiently. In regard to the N2 *mean amplitude*, there were interactions between time and electrode site and time, electrode site, and recording hemisphere, showing greater overall *mean amplitudes* pre- and post-exercise within the parietal compared to the posterior parietal and occipital regions. Within the P3 *peak latency lateral* analysis there were overall shorter *peak latencies* after exercise compared to before with a main exception being within the central region. In regard to the P3 (P3a and early and late P3b) *mean amplitudes* there was an overall effect of time within every time window, showing greater P3 *mean amplitudes* after exercise compared to before. There were also interactions between time and recording hemisphere and time, electrode site and recording hemisphere; however, these interactions were not clarified using post-hoc analyses.

3.2.2 Midline analyses

N2 peak latency

There was a significant main effect of time (F (1,14) = 9.13; p = .01, η_p^2 = .40) (see Figure 6.3), but not task. There was no significant interaction between time and task.

N2 mean amplitude (180 – 220 ms)

There was no significant main effect of time or task. Nor was there a significant interaction between time and task.

P3 peak latency

Analysis of the P3 *peak latency* showed a significant interaction between time and electrode site (F (2,28) = 8.53; p < .001, η_p^2 = .38). Follow-up post-hoc comparisons did not reveal any significant difference between time and task.

P3a mean amplitude (time window one - 300 – 400 ms)

Analysis of the P3a *mean amplitude* during this first time window (see Figure 6.1) showed a significant interaction between task and electrode site (F (2,28) = 4.03; p = .05, η_p^2 = .22). Follow-up, post-hoc comparisons did not reveal any significant differences (see Figure 6.8).

Although not significant, there was a large effect size for the time main effect (F (1,14) = 3.66; p = .08, η_p^2 = .21), indicating greater *mean amplitudes* post exercise compared to pre (1.998 ± 1.05 and 0.065 ± 0.30 µV respectively), irrespective of task.

Early P3b mean amplitude (time window two - 400 – 500 ms)

Analysis of the early P3 *mean amplitude* during this second time window (see Figure 6.1) showed a significant interaction between task and electrode site (F (2,28) 4.39; p = .05, η_p^2 = .24). Follow-up post-hoc comparisons did not reveal any significant differences (see Figure 6.8).

Late P3b mean amplitude (time window three - 500 - 600 ms)

Analysis of the late P3b *mean amplitude* during this third time window (see Figure 6.1) showed a significant interaction between task and electrode site (F (2,28) = 5.70; p = .03, η_p^2 = .29). Follow-up post-hoc comparisons did not reveal any significant differences (see Figure 6.8). There was a near significant main effect for time with a large effect size (F (1,14) = 4.18; p = .06, η_p^2 = .23). This showed the greatest *mean amplitudes* post exercise compared to pre (2.610 ± 1.24 and 0.074 ± 0.28 µV respectively), irrespective of task type.

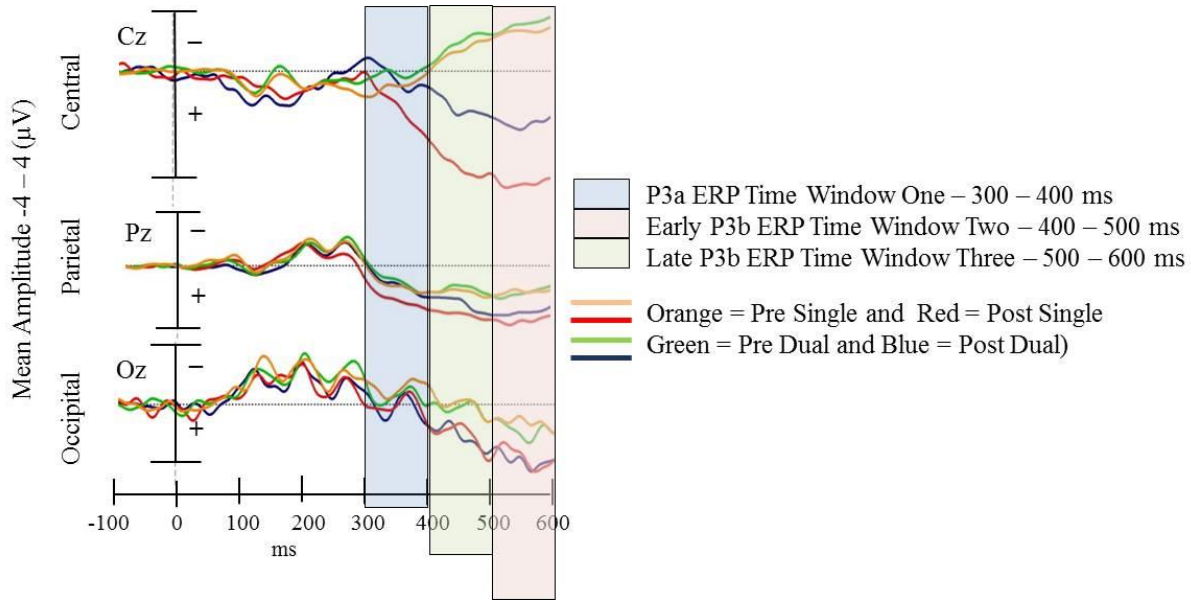

Figure 6. 8: P3 *mean amplitude* responses with the three time windows employed to examine the difference in the midline neural activity over time in response to aerobic exercise.

In summary, in the N2 *peak latency midline* analyses, there was an overall main effect of time that emerged as shorter N2 *peak latencies* after exercise, and no change in N2 *mean amplitude*. In regard to the P3 *peak latency*, there was an interaction between time and electrode site; however, these interactions were not clarified further with post-hoc analyses. Similarly, there were no significant differences for the post-hoc analysis for the interaction between task and electrode site for the P3 *mean amplitude*. A main effect of time was also observed within the first and third (P3a 300 – 400 and late P3b 500 – 600 ms respectively) time windows, showing greater *mean amplitudes* after exercise irrespective of task.

Consistent with observations in the previous chapter relating to the changes in the P3 (P3a and early and late P3b) *mean amplitudes* over time, is the novel finding of overlapping temporal neural generators which have distinct functional properties that showed different spatial patterns of activation. Whereas there was a main effect of time over *lateral* electrodes sites (central, central parietal and parietal sites) with enhanced P3 *mean amplitude* positivity after exercise, irrespective of task, there was a main effect of task over the *midline* electrodes (central and parietal sites) irrespective of exercise or time.

4. Discussion

The purpose of this study was to compare neural activity associated with the performance of both a single- and dual-task during locomotion before and immediately after an acute bout of aerobic exercise in young adults. As predicted, participants completed the single- and dual-task faster following exercise and results pertaining to the N2 and P3 components varied with changes in the N2 *peak latency* (*lateral* and *midline*) and *mean amplitude* (*lateral*) and differences in P3 *peak latency* (*lateral* and *midline*) and *mean amplitude* across all time windows examined.

From a behavioural perspective, quicker trial completion was observed after exercise. This finding is consistent with previous research that has shown quicker reaction times and

improved interference control (i.e., ability to inhibit a habitual response) following acute aerobic exercise (Davranche et al., 2009; Sibley et al., 2006).

The improvement in task performance was associated with neural changes. In particular, a reduction in N2 *peak latency* (*lateral* and *midline*) and an increase in *mean amplitude* (*lateral*), which suggests an improvement in response selection, reduction in error rate and less variability, with lower variability equating to better synchronisation of the target and response in every trial (i.e., quicker trial completion time) (Gajewski & Falkenstein, 2012). Of interest with regard to the N2 *mean amplitude* increase after exercise was the interaction between time and electrode site with the greatest *mean amplitude* being observed within the posterior parietal region (electrodes P7 and P8). In reference to the Brodmann Area Map (Strotzer, 2009), electrodes P7 and P8 are positioned over the posterior inferior and middle temporal and fusiform gyri and are associated with visual analysis and association, specifically visual fixations and monitoring of colour and word retrieval (Friedman et al., 1998; Kellenbach, Hovius, & Patterson, 2005; Richter, Costello, Sponheim, Lee, & Pardo, 2004) . In other words, within the single- and dual-task paradigm, after exercise the participants were more alert and responsive in terms of monitoring and integrating visual feedback as to their location (visual fixations) on the walking grid, whilst simultaneously monitoring for the presentation of the light stimulus (visual analysis and association and reception of information pertaining to light intensity and colour) to enable them to retrieve the correct directional command (word retrieval relating to the left, right or straight command) to perform the alteration to their direction of travel. The observation of a greater N2 *mean amplitude* and shorter *peak latency* after exercise would be representative of enhanced response selection capacity (word retrieval relating to the directional command and shopping list) and synchronisation of the target (colour and word) and response (decision made with regard to change in direction of travel) (Gajewski & Falkenstein, 2012).

The present study showed that there was a change in P3 *peak latency* within the *lateral* electrodes where a large effect size relating to an interaction between time, electrode site and recording hemisphere, was observed showing shorter *peak latencies* post exercise compared to pre and an interaction between time and electrode side within the *midline* analyses. Of interest is the differential P3 *mean amplitude* responses between the *lateral* and *midline* analysis. Specifically, there was an overall increase in P3 *mean amplitude* post-exercise (*lateral* electrodes), showing greater *mean amplitudes* compared to pre-exercise and an interaction between task and electrode sites (*midline* electrodes), showing greater P3 *mean amplitudes* within the single- compared to the dual-task. This differential pattern of activity was observed across all time windows examined.

The increase in the overall P3 *mean amplitudes* observed after aerobic exercise is representative of an increase in the allocation of attentional resources with which to integrate and respond to the relevant stimulus (O'Leary et al., 2011). Similar to that observed in the previous chapter (Chapter 5) the change in the overall P3 component response is in specific reference to an enhanced attentional and memory processing and capacity to evaluate the presented stimulus (P3a), and enhanced working memory, specifically through the encoding and retrieval phases of information processing (early and late P3b) (Brookhuis et al., 1981; Jongsma et al., 2007; Morgan et al., 2008; Scisco et al., 2008).These enhanced P3 *mean amplitude* responses is suggested to be associated with an exercise-induced increase in state arousal levels and is likely to be associated with an improved capacity to process the varying task demands (i.e., reduced dual-task cost), and improve overall trial completion time. Overall, this finding is consistent with previous research that has shown an improvement in cognitive processing (McMorris & Hale, 2012; McMorris et al., 2011). Furthermore, this enhanced neural activity has been associated with state arousal, which is detectable within the ERP signal, specifically an enhanced evoked response which is representative of state

arousal, vigilance and sustained attention (Dietrich & Audiffren, 2011; Moxon et al., 2007; Nieuwenhuis et al., 2005).

Consistent with observations in the previous chapter, there was a differential neural response between the *lateral* and *midline* analysis. Whereas there was an exercise-induced enhancement in P3 *mean amplitudes laterally*, there was a task effect within the *midline* electrodes showing enhanced P3 *mean amplitudes* in the single-compared to the dual-task irrespective of time. This novel observation is suggestive of overlapping temporal neural generators that appear to have distinct functional properties and are associated with different spatial patterns of activation. In other words, there is a spatiotemporal pattern of activation of the P3 component which is aligned with the integration of the sensory stimuli and response generation to perform the correct change in direction of travel (Machado et al., 2014).

Finally, the relationship between the N2 and P3 components must be considered. The decrease in the N2 *mean amplitude* is likely to have an influence on the increase in the P3 *mean amplitude*. The enhanced response selection (shorter N2 *peak latency* and an increase in N2 *mean amplitude*) leads to a greater awareness of the correct response required leading to an increase in available cognitive resources with which to process the presented stimuli. This, in turn, is likely to result in the subsequent decrease in P3 *peak latency* and increase in P3 *mean amplitude* (Gajewski & Falkenstein, 2012). Together, these neural changes following a bout of aerobic exercise might partly explain the quicker trial completion time.

In summary, the individual analysis of the influence of an acute bout of aerobic exercise is consistent with previous findings. Enhanced performance seems to be associated with shorter N2 *peak latency* (*lateral* and *midline*) and the enhanced N2 (*lateral*) and P3 (*lateral* and *midline*) *mean amplitudes* post exercise (Gajewski & Falkenstein, 2012). The novel observation of a differential effect on the P3 *mean amplitude* pertaining to the interaction between exercise and time (*lateral*) and main effect of task (*midline*) in the early

phases (300 – 400 ms), provides evidence to support the proposal that there are different spatiotemporal patterns of activation that are aligned with the effect of exercise and the sequential performance of single- and dual-tasks (Machado et al., 2014).

Chapter Seven

Study 3 –Part C

Effect of acute resistance exercise on neural activity associated with single- and dual-task performance during locomotion

1. Introduction

Most research to-date has examined the role of acute aerobic exercise on cognitive performance with few studies exploring the role of resistance exercise. Resistance exercise, over a long term intervention (12 months – twice weekly), has shown functional hemodynamic changes in two regions of the cortex (Liu-Ambrose et al., 2012). These changes were suggested to be associated with increased engagement of response inhibition processes and a decrease in preparatory response inhibition.

The few studies which have been conducted suggest that acute, high intensity resistance training (100% 10 RM) improves cognitive processing speed whereas moderate intensity resistance training (70% 10 RM) is associated with enhanced executive functioning immediately following exercise (Chang & Etnier, 2009b). In contrast to these findings, Pontifex et al. (2009) observed shorter reaction times in a working memory test after aerobic but not resistance exercise, providing support for an exercise mode-related differential effect on executive control. However, no research has evaluated the influence of resistance exercise on cognitive function, specifically changes in neural activity (e.g., N2 and P3 ERP component responses) in relation to the influence of exercise on dual-task ability.

In light of the lack of research, it is the intention within this level of analysis to evaluate neural activity (N2 and P3 ERP components) associated with the performance of both a single- and dual-task during locomotion after resistance exercise. It was predicted that: 1) quicker trial completion time would be observed after resistance exercise; 2) the dual-

compared to single-task will take longer to perform irrespective of the bout of resistance exercise; 3) shorter global N2 *peak latencies* and reduction in *mean amplitude* for both single- and dual-tasks, following a bout of resistance exercise; 3) shorter global P3 *peak latencies* and decrease in *mean amplitudes* across all time windows, for both single- and dual-tasks, following a bout of resistance exercise; 4) longer N2 and P3 *peak latencies* in the dual- compared to the single-task, irrespective of a bout of resistance exercise; and 5) greater N2 and P3 *mean amplitudes* in the single- compared to the dual-task.

2. Methods and data analysis

In addition to the key time windows of interest (see Figure 7.1), please refer to the previous studies (see Chapters 3, 4 and 5), for an overview of the methods employed.

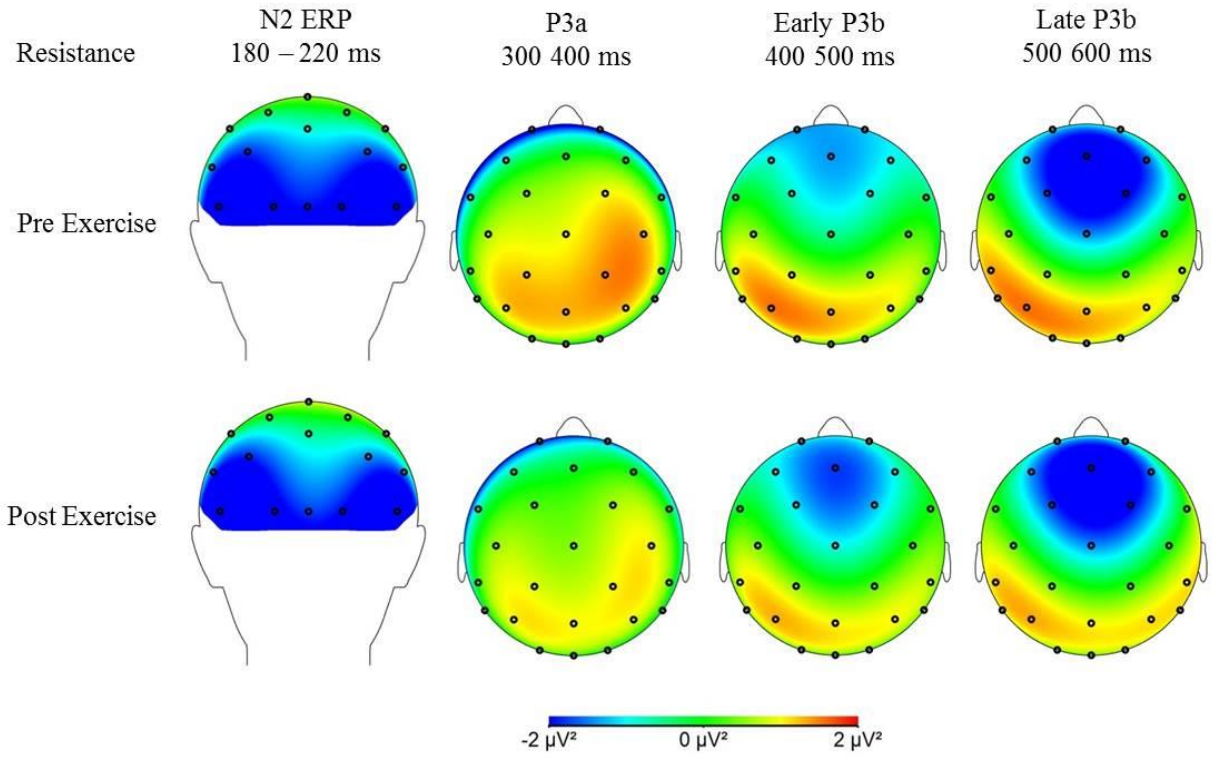

Figure 7. 1: Resistance Exercise Bout - ERP responses with time windows employed to examine the differences in neural activity (N2 and P3 ERP component *peak latency* and *mean amplitudes*).

3. Results

For all other data not reported within this chapter, see the attached appendices for a breakdown of results means and standard deviations and statistical summary tables (see Appendices 11 and 12).

3.1 Behavioural data

Single versus Dual task time per trial completion in the resistance exercise:

There was a main effect for time (F (1,14) = 8.87; p = .01, η_p^2 = .39) and task (F (1,14) = 7.00; p = .02, η_p^2 = .33) (see Figure 7.2) This showed that the pre-exercise mean time per trial was greater than the post-exercise mean time (4.73 ± .16 and 4.42 ± .15 s respectively) and that it took longer to perform the dual- compared to the single-task (4.64 ± .14 and 4.51 ± .15 s respectively).

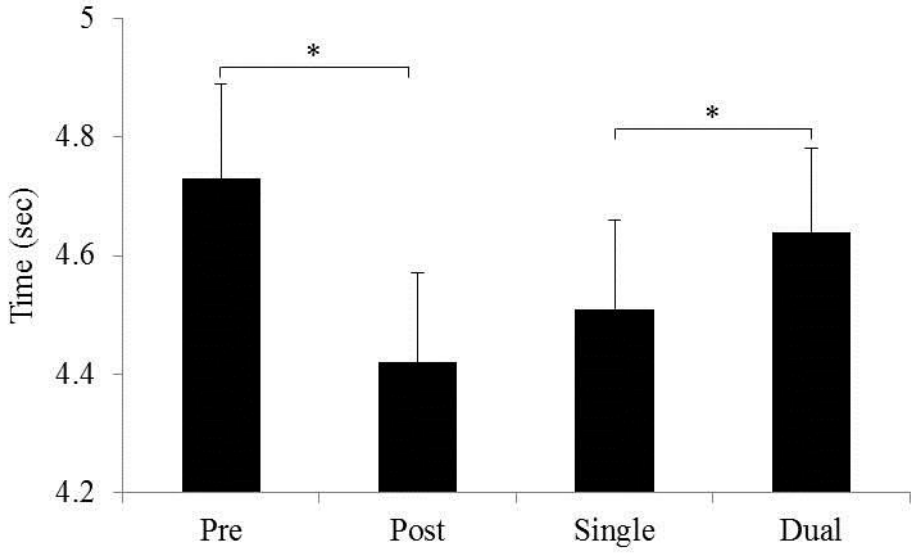

Figure 7. 2: Comparison of trial completion time between pre and post exercise and condition (* represents p < .05). Data is presented as mean ± SE.

3.2 Neural activity data

3.2.1 Lateral analyses

N2 peak latency

There was no significant main effect of time or task, however, the main effect for time (F (1,14) = 3.64; p = .07, η_p^2 = .21) showed a large effect size with shorter *peak latencies* post exercise compared to pre (204.51 ± 3.64 and 210.42 ± 0.5.05 ms respectively), irrespective of task type. Furthermore, there were no significant interaction effects.

N2 mean amplitude (180 – 220 ms)

There was a significant interaction between time and electrode site (F (2,28) = 7.48; p = .01, η_p^2 = .35) and task and electrode site (F (2,28) = 4.26; p = .03, η_p^2 = .23) (see Figure 7.3). Post-hoc comparisons did not show any significant differences.

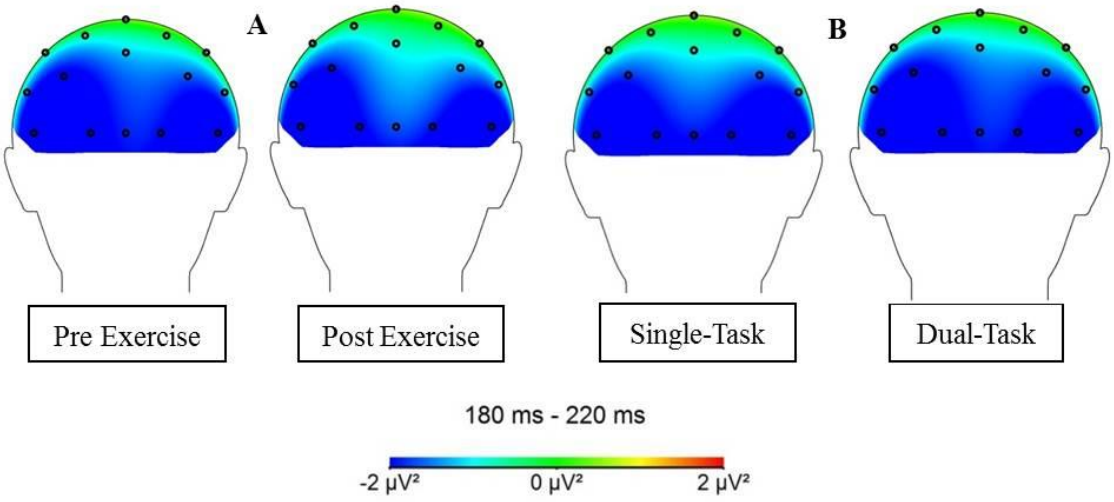

Figure 7. 3: Topographic scalp map comparison of the N2 *mean amplitude* 180 – 220 ms post stimulus time window: A) Significant lateral interaction between time and electrode site; B) Significant lateral interaction between task and electrode site.

P3 peak latency

There was no significant main effect of time or task type. Nor were any of the interactions significant.

P3a mean amplitude (time window one - 300 – 400ms)

Analysis of the P3a *mean amplitude* during this first time window (see Figure 7.1) showed a significant interaction between task and electrode site (F (4,56) = 4.18; p = .04, η_p^2 = .23). To fully understand the spatial distribution of task effects, follow-up analyses were carried out using five separate contrasts (central – C3/C4, central parietal – CP1/CP2, parietal – P3/P4/P7/P8 and occipital – O1/O2) to clarify the interaction between task and electrode site. This revealed a significant difference in the single- compared to the dual-task *mean amplitude* in the central (electrodes C3/C4) and central parietal (CP1/CP2) regions (t (14) = 3.27, p = .01, d = 0.66 and t (14) = 3.07 p = .01, d = 0.63 respectively). These results show more positive going *mean amplitude* in the single- compared to the dual-task condition (see Figures 7.4 and 7.5).

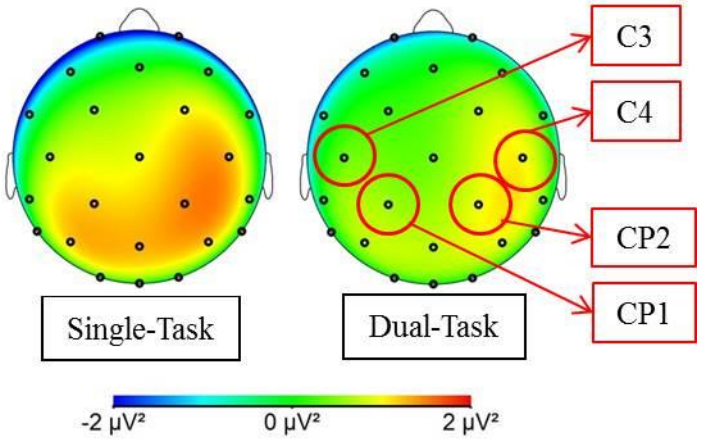

Figure 7. 4: Topographic scalp map of the P3a *mean amplitude*. Scalp maps reflect the average of time window one 300 – 400 ms post stimulus and the activation during the single- compared to the dual-task condition.

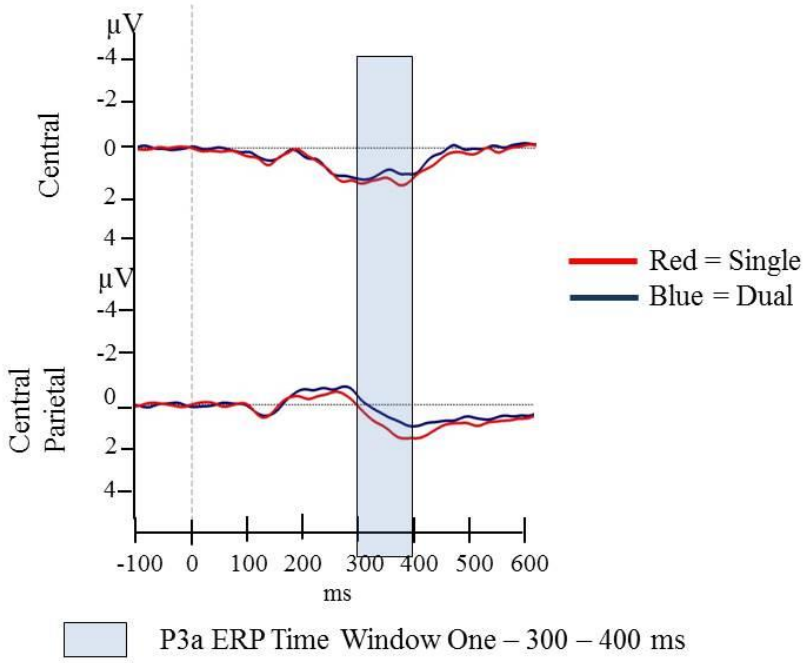

Figure 7. 5: P3a *mean amplitude* responses with time window one (300 – 400 ms) employed to examine the difference in the lateral neural activity related to task difficulty.

There was also a significant main effect of task (F (1,14) = 5.39; p = .04, η_p^2 = .28), (see Figure 7.6), but not time (F (1,14) = 0.38; p = .55, η_p^2 = .03). This showed greater *mean amplitudes* in the single- compared to dual-task (0.427 ± 0.19 and 0.276 ± 0.18 µV respectively) irrespective of time.

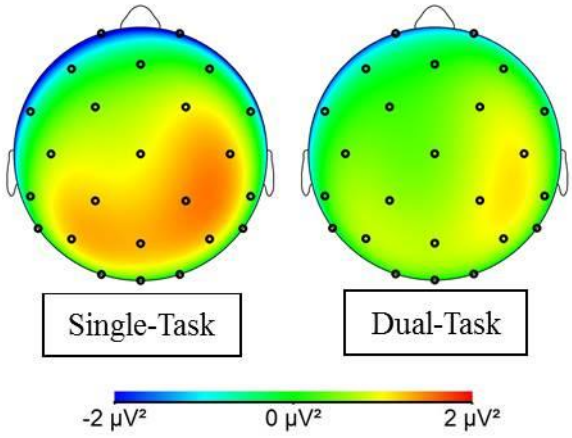

Figure 7. 6: Topographic scalp map comparison of time window one (300 - 400 ms) *lateral* early P3b *mean amplitude* single- compared to dual-task.

Early P3b mean amplitude (time window two - 400 – 500 ms)

Analysis of the early P3b *mean amplitude* during the second time window (see Figure 7.1) showed a significant interaction between task and electrode site (F (4,56) = 4.99; p = .02, η_p^2 = .26). Five separate contrasts (central – C3/C4, central parietal – CP1/CP2, parietal – P3/P4, posterior parietal - P7/P8 and occipital – O1/O2) were conducted to clarify the interaction between task type and electrode site. This revealed a significant difference in the single- compared to the dual-task *mean amplitude* in the central region (C3/C4) (t (14) = 3.12, p = .01, d = 0.64). These results show more positive going *mean amplitude* in the single- compared to the dual-task condition in the central region (.937 ± .18 and .681 ± .19 µV respectively) (see Figure 7.7).

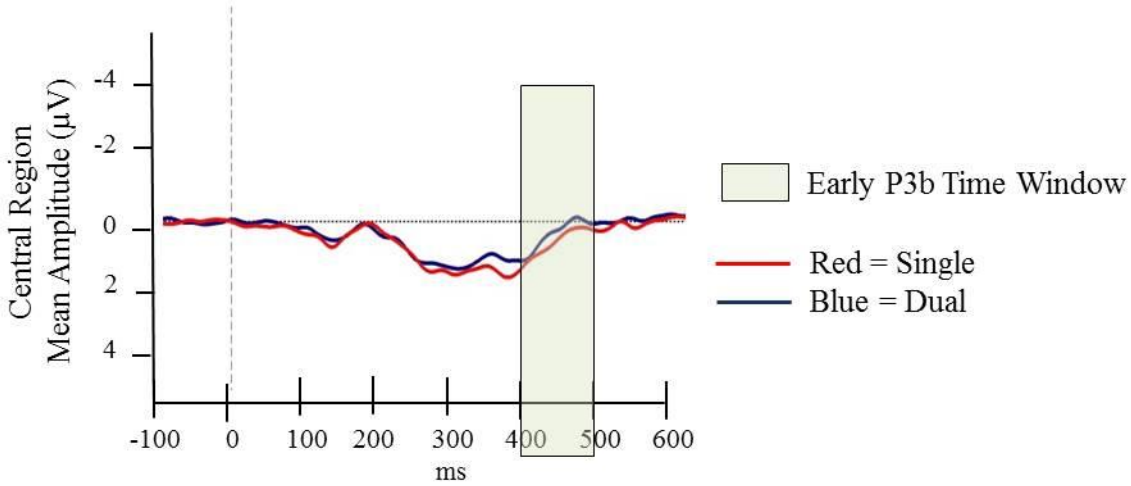

Figure 7. 7: Early P3b *mean amplitude* responses with time window one (400 - 500 ms) employed to examine the difference in the lateral neural activity related to task.

Late P3b mean amplitude (time window three - 500 - 600 ms)

Analysis of the late P3b *mean amplitude* during the third time window (see Figure 7.1) showed a significant interaction between task and electrode site (F (4,56) = 6.76; p = .01, η_p^2 = .33) and a significant interaction between time, electrode site and recording hemisphere (F (4,56) = 3.43; p = .03, η_p^2 = .20). Five separate contrasts (central – C3/C4, central parietal – CP1/CP2, parietal – P3/P4/P7/P8 and occipital – O1/O2) were conducted to clarify the

interaction between task and electrode site and the interaction between time, electrode site and recording hemisphere. This revealed a significant difference in the single- compared to the dual-task *mean amplitude* in the parietal region (P7/P8) (t (14) = -3.26, p = .01, d = 0.66). These results show more positive going *mean amplitude* in the dual- compared to the single-task condition (1.176 ± .31 and .834 ± .28 respectively) (see Figure 7.8). Follow-up contrasts were performed to clarify the interaction between time, electrode site and recording hemisphere, however further differences were not identified.

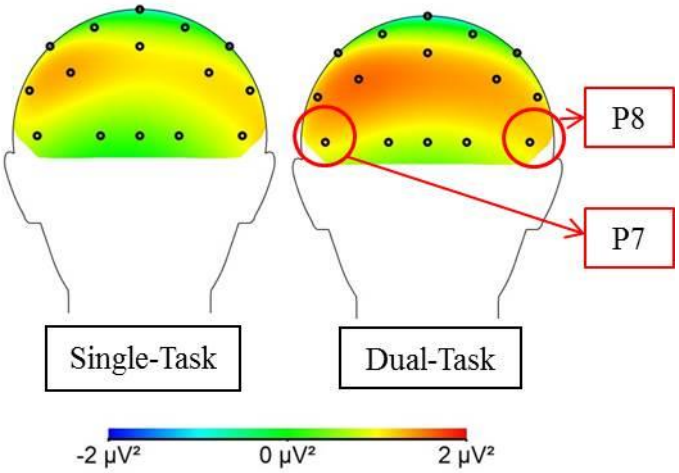

Figure 7. 8: Topographic scalp map comparison of time window one (500 - 600 ms) *lateral* late P3b *mean amplitude* single- compared to dual-task.

There was also a significant main effect of task (F (1,14) = 5.08; p = .04, η_p^2 = .27) (see Figure 7.9), but not time, showing greater *mean amplitude* in the dual- compared to the single-task (0.838 ± 0.17 and 0.660 ± 0.17 µV respectively) irrespective of time.

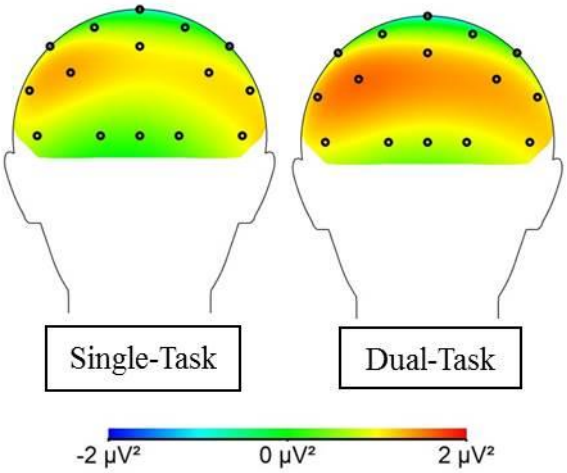

Figure 7. 9: Topographic scalp map comparison of time window three (500 – 600 ms) *lateral* late P3b *mean amplitude* single- compared to dual-task.

In summary, N2 *peak latency* had a large effect within the *lateral* analysis showing shorter *peak latencies* after resistance exercise. There were also interactions between time and electrode and task and electrode site, however these interactions were not unpacked further with post-hoc analysis. Within the P3 *peak latency* and *mean amplitude* lateral analysis there was no change in P3 *peak latencies* and an overall effect of task within each time window, showing greater P3 *mean amplitudes* in the single- compared to the dual-task. This effect of task appeared to alter over time with this effect beginning within the central and central parietal regions within time window one (300 – 400 ms – P3a), then to only the central region within the second time window (400 – 500 ms – early P3b) and finally being prominent within the parietal region in the third and final time window (500 – 600 ms – late P3b), irrespective of a time effect.

3.2.2 Midline analyses

N2 peak latency

There was no significant main effect of time or task type. Nor were any of the interactions significant.

N2 mean amplitude (180 – 220 ms)

Analyses revealed a significant interaction between task and electrode site (F (1,14) = 4.75; p = .05, η_p^2 = .25). Post-hoc comparisons showed a significant difference in N2 *mean amplitude* in electrode Pz in the single- compared to the dual-task (t (14) = 2.82, p = .01, d = 0.60) showing a greater *mean amplitude* in the dual- compared to the single-task (-.945 ± .30 and -.696 ± .26 µV respectively) (see Figure 7.10).

There was also a significant main effect of time (F (1,14) = 7.84; p = .01, η_p^2 = .36) but not task, showing a greater *mean amplitude* pre- compared to post-exercise (-1.357 ± 0.27 and -1.094 ± 0.27 µV respectively).

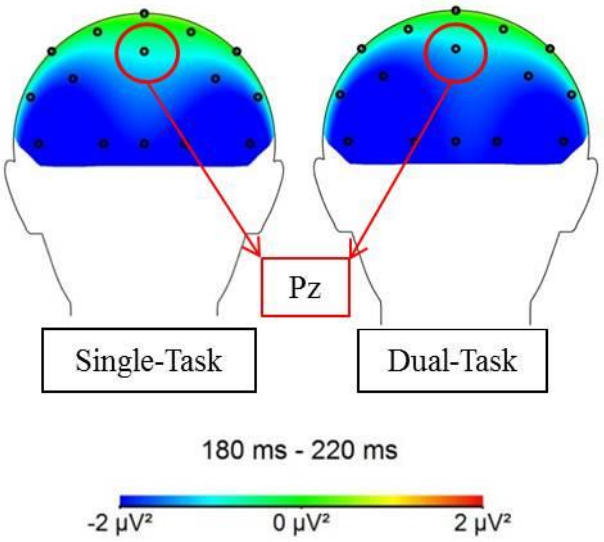

Figure 7. 10: Topographic scalp map of the N2 *mean amplitude*. Scalp maps reflect the average of 180 – 220 ms post stimulus epoch of an interaction between task and electrode site in the *midline* electrode Pz (parietal region).

P3 peak latency

There was no significant main effect of time or task type. Nor were any of the interactions significant.

P3a mean amplitude (time window one - 300 – 400 ms)

Analysis of the P3a *mean amplitude* during this first time window (see Figure 7.1) showed a significant main effect for task (F (1,14) = 8.34; p = .01, η_p^2 = .37) but not time. A greater *mean amplitude* was observed in the single- compared to the dual-task (0.431 ± 0.24 and 0.127 ± 0.25 µV respectively), irrespective of time (see Figure 7.11).

Early P3b mean amplitude (time window two - 400 – 500 ms)

Analysis of the early P3b *mean amplitude* during this second time window (see Figure 7.1) showed a significant interaction between task and electrode site (F (2,28) = 67.2; p = .01, η_p^2 = .32). To fully understand the spatial distribution of task effects follow up analyses were carried out on electrodes (central – Cz, parietal – Pz and occipital – Oz) to clarify the interaction between task type and electrode site. These did not reveal any significant differences after p-value correction.

There was also a significant main effect of time (F (1,14) = 4.81; p = .05, η_p^2 = .26) that showed a greater *mean amplitude* pre- compared to post-exercise (0.180 ± 0.27 and -0.120 ± 0.26 µV respectively), irrespective of task (see Figure 7.11).

Late P3b mean amplitude (time window three - 500 - 600 ms)

Analysis of the late P3b *mean amplitude* during this third time window (see Figure 7.1) showed a significant interaction between task and electrode site (F (2,28) = 5.86; p = .02, η_p^2 = .30) (see Figure 7.11). To fully understand the spatial distribution of task effects follow up analyses were carried out for the different midline electrodes (central – Cz, parietal – Pz and occipital – Oz) to clarify the interaction between task and electrode site. These did not reveal any significant differences after p-value correction.

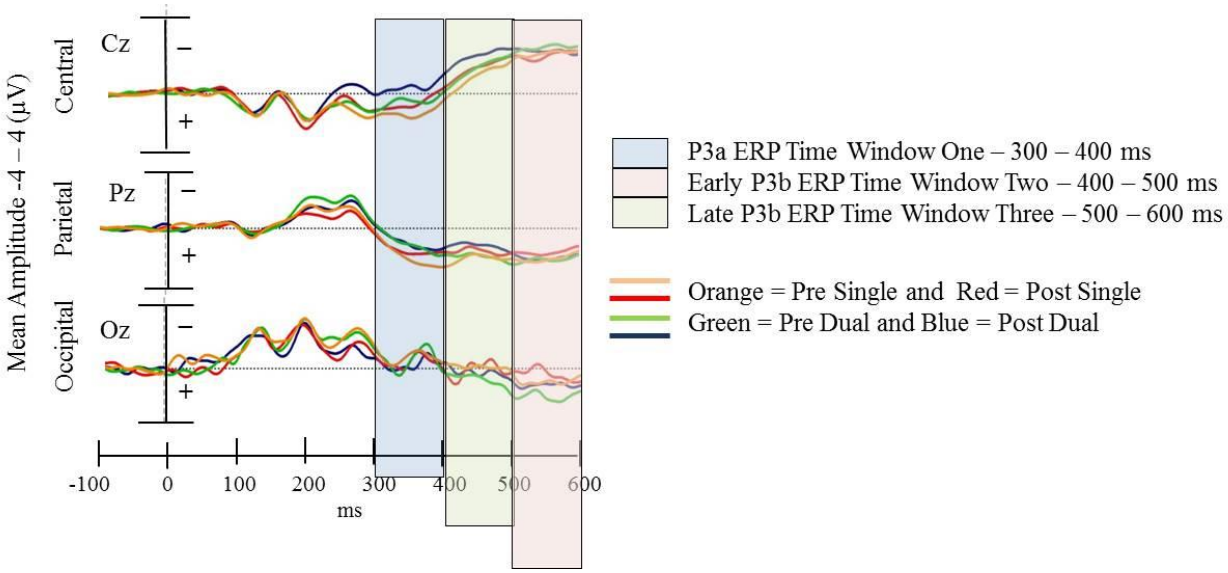

Figure 7. 11: P3 *mean amplitude* responses with the three time windows employed to examine the difference in the lateral neural activity over time in response to resistance exercise.

In summary, in the *midline* analyses, there was an overall main effect of time that emerged as a reduction in the N2 *mean amplitude* after exercise, specifically within the parietal region (Pz) regardless of task. The P3 *mean amplitude midline* analyses results varied with an overall effect of task being observed across all time windows. Within the first time window (300 – 400 ms – P3a) an enhanced P3a *mean amplitude* was observed within the single- compared to the dual-task, however in the subsequent time windows (400 – 500 and 500 – 600 ms – early and late P3b) overall enhanced P3b *mean amplitudes* were observed within the dual- compared to the single-task condition, irrespective of time. Finally, a main effect of time was observed in the second time window (400 – 500 ms – early P3b), showing a reduction in early P3b *mean amplitude* after exercise, irrespective of task.

4. Discussion

The purpose of this study was to compare neural activity associated with the performance of both a single- and dual-task during locomotion before and after resistance

exercise in young adults. As predicted, quicker trial completion was observed after the resistance exercise. Further, there was a significant effect of task, with the dual-task taking longer to perform compared to the single task. Improved performance after the resistance exercise is consistent with previous research that has shown quicker reaction times, which have been attributed to an improvement in lower and higher level cognitive processes (i.e., speed of information processing and interference control respectively) (Chang & Etnier, 2009a; Chang et al., 2014). To understand the potential underlying mechanisms associated with this behavioural improvement however, the assessment of neural activity, specifically the N2 and P3 ERP components, were evaluated.

Results pertaining to the *lateral* analysis of the N2 showed shorter *peak latencies* post-exercise compared to pre-exercise and greater *mean amplitudes* in the dual- compared to the single-task, specifically within the parietal region (Pz) regardless of time. In reference to the Brodmann Area Map (Strotzer, 2009), electrode Pz is positioned over the superior parietal lobule (SPL), which is associated with visuospatial attention and processing, specifically the integration of visual and motor information, with information within this region being sent to the premotor areas (Poulin-Lord et al., 2014). The implication of this finding is that during the dual- compared to the single-task condition there is enhanced activation within the SPL to focus visuospatial attention and integrate the information to perform the task efficiently and accurately regardless of the bout of resistance exercise. As such, the longer trial completion time observed in the dual-task condition is suggested to be linked to other factors. For example, the neural processing subsequent to the onset of the N2 ERP component. There was a decrease in N2 *mean amplitude* post-exercise within the *midline* analysis. This decrease might be due to an exercise-induced improvement in neural processes associated with response monitoring and allocation of attentional resources (Drollette et al., 2014; O'Leary et al., 2011). It represents lower global costs, and an enhancement in processing resources

associated with retrieval and maintenance of multiple task sets in memory (Gajewski & Falkenstein, 2012). In other words, a reduction in cognitive effort required to process the visual stimuli, which is associated with an overall improvement in trial completion time.

The present study showed that, whereas there was no change in P3 *peak latency* within the *lateral* or *midline* electrodes, there were differences in P3 *mean amplitudes* across all time windows. There was also an overall effect of task observed across all time windows for the *lateral* analysis and within the first time window (300 – 400 ms – P3a) for the *midline* analysis. This showed greater P3a *mean amplitudes* for the single- compared to the dual-task. This pattern of activation varied over time. Whereas in the first time window (300 – 400 ms – P3a) the greatest *mean amplitude* was observed within the central (C3 and C4) and central parietal (CP1 and CP2) regions, in the second time window (400 – 500 ms – early P3b) the greatest *mean amplitude* was only within the central (C3 and C4) region and finally within the third time window (500 – 600 ms – late P3b) *mean amplitude* was greatest within only the parietal (P7 and P8) region only. These changes were independent of a bout of resistance exercise.

Electrodes C3 and C4 are positioned over the primary somatosensory and primary motor cortices and are associated with processing of somatic sensory sensations, including sense of our body (Mima et al., 1996) and verbal encoding (Baker, Sanders, Maccotta, & Buckner, 2001). CP1 and CP2 are positioned over the secondary sensorimotor cortex and are associated with spatial orientation, specifically somatosensory processing and association, including working memory (Catalan, Honda, Weeks, Cohen, & Hallett, 1998). Finally, P7 and P8 are positioned over the posterior inferior and middle temporal gyrus and fusiform gyrus and are associated with visual analysis and association, including visual fixations and monitoring of colour and word retrieval (Friedman et al., 1998; Kellenbach et al., 2005; Richter et al., 2004). The functional relevance of the placement of these electrodes within the

single- and dual-task paradigm employed, relates to the participants being required to process somatic sensory sensations and visuospatial feedback as to their location (i.e., sense of body and visual fixations) on the walking grid, whilst simultaneously monitoring for the presentation of the light stimulus (i.e., visual analysis and association and reception of information pertaining to light intensity and colour) to enable them to retrieve the correct directional command to perform the alteration to their direction of travel (i.e., verbal encoding and working memory). Finally, in both the single- and dual-task conditions there were components of active word retrieval. In the context of the light stimulus and directional word association, and in addition, specific to the dual-task condition, active processes of word retrieval were required to remember the three key words (verbal encoding) during each of the three blocks of testing. Within each task (i.e., single and dual), however, the degree of cognitive load differs. The dual-task would represent a higher cognitive load compared to that required to perform the single-task, which is shown in the dual-task reduction in *mean amplitude*. This reduction is suggested to result from the increased demand on the allocation of attentional resources with which to perform the task accurately and efficiently. The task-related reduction in the P3 *mean amplitude* is suggested to be due to the need to spread what attentional resources are available over a broader context to simultaneously manage both locomotive and additional cognitive component of this task.

A novel observation within these data is the significant main effect of time observed in the *midline* analysis within the same time window (400 – 500 ms – early P3b) as the effect of task observed in the *lateral* analysis. These results show both enhanced early P3b *mean amplitude* in the single- compared to the dual-task *laterally*, irrespective of time and significantly greater *mean amplitude* pre- compared to post-exercise in the *midline* analysis irrespective of task. This differential response may be suggestive of overlapping temporal neural generators, specifically, a spatiotemporal pattern of activation of the early P3b

attribute of the P3 component, which is aligned with the sequential and physiological cognitive functions and exact period of task execution (Machado et al., 2014). In other words, during the same time window, there is activation of different neural generators to manage both the exercise-related differences in neural activity (*midline* enhanced early P3b *mean amplitude*) and in the allocation of attentional resources, specifically the encoding and retrieval of memory updating to manage the respective tasks (*lateral* single-task enhanced early P3b *mean amplitude*) (Brookhuis et al., 1981; Kok, 2001; Morgan et al., 2008; Scisco et al., 2008).

As the only result pertaining to an actual exercise-induced effect was in relation to the significant decrease in P3 *mean amplitudes* in the *midline* analysis, it is difficult to provide a definitive explanation for why the behavioural improvement occurred. It could be postulated that the observation of no change or suppression of the *mean amplitude* across all time windows irrespective of task is related to a reduction in compensatory activation required to perform the same task after the intervention (Chang et al., 2014) and that this enhanced neural efficiency is associated with a reduction in effort and improved brain activation after exercise (Nishiguchi et al., 2015), therefore resulting in a reduction in trial completion time. In support of this, resistance exercise-induced improvements after a six month intervention have been observed in higher-level cognitive processing, such as that associated with the performance of complex tasks involving spatial working memory (Nagamatsu et al., 2013) and an improvement in selective attention, conflict resolution and associative memory (Nagamatsu, Handy, Hsu, Voss, & Liu-Ambrose, 2012). It could therefore be proposed that there is a relationship between resistance exercise and enhanced neural efficiency, specifically the reduction in effort required to perform tasks of increasingly difficulty (single- and dual-tasks), not just long-term, but also after acute bouts of exercise.

In summary, the individual analysis of the influence of acute resistance exercise provides new evidence relating to a differential pattern of neural activation compared to that observed after aerobic exercise, both of which were associated with behavioural improvements (trial completion time). The results within this level of analysis are in-line with previous research that has suggested that resistance exercise promotes neural efficiency (no change or reduction in *mean amplitude*), in context of reduced effort (cognitive demand) associated with performing tasks of increasing difficulty (Nagamatsu, 2013; Nagamatsu, et al., 2012; Nishiguchi et al., 2015). Finally, the results within this chapter provide further evidence to support the proposal of different spatiotemporal patterns of activation, both within the same time windows between *lateral* and *midline* electrodes and exercise-induced differences in this pattern. The differential results observed between the individual analysis of the aerobic and resistance exercise will be discussed within the next chapter.

Chapter Eight

Overall discussion

1. Summary of findings

There is a wealth of research that has examined task- and exercise-related differences in cognitive processes and function (Chang et al., 2013; Chu et al., 2015; Hall et al., 2011). In this thesis differences associated with gaze behaviour and neural activity whilst performing tasks of increasing complexity (e.g., single- and dual-tasking) and the influence of acute bouts of exercise of different modalities were examined.

The overarching goal of this research was to examine whether an acute bout of exercise (aerobic versus resistance) could influence the ability to perform tasks of increasing difficulty in a more real world application. Therefore, the purpose of each of the studies was to: 1) design a dual-task locomotive paradigm that would enable the evaluation of gaze behaviour (Chapter 3) and neural activity (Chapter 4) during the performance of tasks requiring whole body movement, and 2) evaluate the effects of an acute bout of aerobic compared to resistance exercise on neural activity during single- and dual-task performance (Chapters 5 – 7) utilising the paradigm designed in study one.

In *study one* (Chapter 3), a new dual-task locomotive paradigm was designed and validated, specifically in the context of measuring task-related differences in trial completion time and gaze behaviour. These results specifically showed task-related differences in fixation count and location, and QE offset. These findings represented less efficient visual search patterns, anticipatory eye movement in relation to looking in the direction the participant predicted they would travel prior to the onset of the auditory stimulus, and a later time point in which there was sufficient information with which to perform the change in direction of travel in dual-task performance. In *study two*, despite the lack of significant task-

related differences in neural activity, strategies were identified to ensure the valid and reliable collection of EEG data. The methodological design developed and refined in studies *one* and *two* provided two important advancements over existing dual-task paradigms in context of the analysis of neural activity. First, this method maintained functionality by engaging the participant in dual-task performance requiring whole body movement. It also provided practical strategies for minimising environmental and equipment movement-related artefact during data collection and the attenuation of other non-cerebral artefact. In *study three,* as predicted, there were behavioural improvements after both exercise bouts. This was indexed by improvements in trial completion time of the single- and dual-task performance. Consistent with studies *one* and *two* the dual-, compared to the single-task, took longer to perform. Interestingly, there was a differential exercise-induced neural response associated with the behavioural improvements. Novel findings within this research included: 1) a uniform increase in the P3 *mean amplitude* after the aerobic exercise bout and either no change or a reduction in P3 *mean amplitude* after the resistance bout of exercise, and 2) the differential pattern of neural activity between the *lateral* and *midline* electrodes, highlighting a differential spatiotemporal pattern of activation.

2. Limitations - Issues with EEG data collection

The results of the studies provide evidence to support the new dual-task locomotive paradigm to evaluate both gaze behaviour and neural activity; however there are some important limitations. Issues associated with paradigm design included:

1) Participant variability in maintaining a relaxed shoulder, arm and neck position to minimise the occurrence of EMG artefact. This is significant due to the fact that, within this walking paradigm there is a risk of tension through the shoulders, neck movement and arm swinging whilst walking which would exacerbate the occurrence of muscle tension. This could result in the presence of movement-related artefact within electrodes positioned on the

mastoid (TP9 and TP10). This artefact was identified in study *one*. To minimise the magnitude of movement-related artefact it was vital to instruct participants at the beginning of the data collection and between phases to remind them to keep a relaxed and comfortable posture and gait; b) Being able to control participants gait to minimise the risk of heal strike artefact (not observed within studies *two* or *three*). Within the current research participants were instructed to maintain an easy and relaxed gait whilst walking around the grid, to minimise the risk of this occurring; c) An alternative online reference electrode was required due to the degree of movement-related artefact observed within the mastoid region (TP9 and TP10). For the purpose of this dynamic paradigm, the most stable reference site that would be least affected by EMG-related artefact was identified as Cz (midline central placement). This online reference was employed for studies *two* and *three*. However, using Cz as an online reference is also problematic within the context of examining task-related differences as this is a key position whereby task-related differences have previously been reported (Hahn et al., 2011; Kamijo et al., 2009).

2) EEG system limitations: To ensure continuous signal transmission and prevent the occurrence of signal loss, the transmitter and receiver must be in direct line of sight and no more than 6 m (transmission radius) apart. Further to these EEG system limitations, within the dual-task paradigm designed in study *one*, it was found that no more than a 2 – 3 m distance between the transmitter and receiving antennas was required, at all times, to prevent loss of signal. To address these issues, it was initially thought that the entire hardwired EEG system could be placed within a backpack for the participant to wear whilst walking around the grid. However, due to concern of how the additional weight (5 kg) might alter participants gait as a consequence of the difference in centre of mass, an alternative strategy was developed. To optimise transmission and ensure continuous signal transmission the transmitter (approximately 200 grams) was secured to the mid-section of the participants

back on a GPS harness and set up of the EEG receiver and hardwired components were secured to a moveable trolley which was pushed behind the participant throughout the duration of data collection. As there has been significant development over the past couple of years in wireless EEG systems, a more portable and light weight EEG system would be recommended to enable continuous and reliable neural data collection in a more natural and unrestricted context.

3) Sensory stimulus: a) In the development of the initial auditory stimulus some technical restrictions and requirements were encountered, including the need to account for the parameters of sound propagation (approximately 343 m/sec), which, due to the dimensions of the walking grid, would result in the auditory tone being received at different time points depending on distance from the speakers. The key problem being that any transmission time beyond 10 ms can result in a smearing effect of the neural data due to the different time points in which the participant would receive and integrate the auditory stimuli. Because of this fundamental parameter a tone generation system was constructed that had that capacity to send the tone wirelessly to the participant within a 10 ms time frame; b) Due to ongoing issues relating to equipment configuration relating to placement of the hardwired components of the EEG and the auditory delivery/trigger system, for the purpose of study *three,* a visual stimulus system that was able to be triggered via wireless control (time delay between button press, light display and EEG time stamp = 1ms) was developed, resolving the contamination and signal transmission issues.

4) Due to the fact that the neurophysiological origins of most middle and late ERP components have yet to be elucidated, a critical approach must be employed when attempting to determine the relationships between neural activity recorded at the scalp and the potential subsequent cognitive interpretation. For example an increase in the amplitude of the P300

could imply that as more attentional resources are being allocated the system as a whole is less neurally efficient.

3. Future research directions

This is the first research to evaluate: 1) the influence of a locomotive single- and dual-task on neural activity, specifically the N2 and P3 ERPs, and 2) the influence of an acute bout of resistance exercise on single- and dual-task related neural activity. The dual-task paradigm designed is a platform with which to begin to start bridging the gap between current neuroscience research and application, specifically with the goal of evaluating differences in neural activity in a more real world context. This paradigm could be used to evaluate: 1) the validity and reliability of using a mobile EEG system to compare task performance in a dynamic (walking) and passive (seated) scenario; 2) the influence of an acute bout of aerobic compared to resistance exercise upon different neural activity, such as other ERPs and oscillatory patterns of activity. For example, the relationship between low frequency oscillations (delta and theta) and the subsequent P3 ERP component response (Anokhin et al., 2001); 3) examine what effect different intensities or modes of exercise may have on cognitive function, such as high intensity compared to resistance exercise or exercise of different durations; 4) measures of cognitive function after exercise over different durations, for example, after moderate intensity aerobic and resistance exercise, cognitive behavioural and physiological measures, including both saliva and blood samples taken to measure cortisol (arousal levels) and BDNF (which is linked to improvements in cognitive function) (Hung et al., 2013), over a 2 hour period to evaluate the time course of the acute exercise effect; 5) the measure of different aspects of cognitive function, specifically in the context of executive function (e.g., planning and execution, problem solving, working memory, inhibition and cognitive flexibility), which have only previously been evaluated in a stationary (seated or supine) context (Chen, Yan, Yin, Pan, & Chang, 2014; Miyake,

Friedman, Rettinger, Shah, & Hegarty, 2001); 6) the influence of short and long term exercise interventions, including aerobic exercise compared to brain training with non-action video games, which has previously shown improvements in processing speed, attention and spatial memory (Ballesteros et al., 2015); 7) changes in neural activity in a fatigued state; 8) future studies could adopt a lifespan approach to examine the acute and long-term effects of exercise or brain training interventions on cognitive functioning in a broader context, incorporating the various aspects of executive function. This would allow for the development of recommendations for healthy and diseased populations to improve cognitive function, the ability to perform activities of daily living, and overall quality of life.

4. Practical implications

There is a positive relationship between acute bouts of moderate intensity aerobic and resistance exercise, specifically for improving goal-directed behaviour in a dynamic setting. These changes were observed in young healthy adults, which is promising in the context of the potential benefits that may be had across the lifespan. This is of specific relevance in an older adult population which experience greater dual-task deficits, which has been associated with an increase in fall rates (Ayers et al., 2014). The findings provide evidence to suggest that exercise improves cognitive functioning in different ways. Aerobic exercise resulted in improvements in task completion time, which was associated with overall increases in P3 *mean amplitude*. This implies that this mode and intensity of exercise is specifically beneficial in situations that involve performing tasks of increasing difficulty, requiring recruitment of additional attentional resources (representative of an increase in level of arousal) to perform the goal-directed behaviour, such as those associated with activities of daily living. While resistance exercise also resulted in improvements in task completion time, there was either no change or a diminished P3 *mean amplitude* response, which is suggested to be associated with an increase in neural efficiency. In other words, after resistance exercise

less effort is required to perform tasks of increasing difficulty, which might be more beneficial for tasks requiring complex reasoning.

5. Conclusion

The dual-task locomotive paradigm designed and validated within this research provides a mechanism by which to begin to bridge the gap between existing static paradigms and the evaluation of differences in neural activity in a more dynamic paradigm that enables whole body movement and behaviour. This body of work has demonstrated that the novel paradigm, which is more akin to activities of daily living, is a valid and reliable tool with which to measure both task-related differences in trial completion time, gaze behaviour, and neural activity. Further, an acute bout of aerobic and resistance exercise resulted in improved single- and dual-task performance. However, the underlying changes in neural activity associated with these improvements differed, specifically in context of changes in the P3 *mean amplitude* and spatiotemporal patterns of activity. The latter is an important novel finding and has potentially theoretical and practical implications, but further research is required.

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Appendices

Appendix 1

INFORMATION TO PARTICIPANTS INVOLVED IN RESEARCH

You are invited to participate

You are invited to participate in a research project entitled: The role of visual attention and neural activity in goal-directed behaviour: Age-related decrements and the moderating effect of exercise.

This project is being conducted by a student researcher Shelley Duncan as part of a PhD study at Victoria University under the supervision of Prof Remco Polman and Dr Derek Panchuk from the Institute of Sport, Exercise and Active Living (ISEAL) at Victoria University.

Project explanation

Older adults generally use less areas of the brain to initiate and control movements than younger adults and this leads to a normal decline in our ability to perform effective movements as we age. This decrease in brain function can however lead to movements becoming slower and problems with balance that increase the risk of falls and trips. One of the biggest risk factors associated with tripping and falling is our ability to perform multiple tasks at one time (what we call dual-task performance). For example, stepping down from a curb to cross the road while looking out for oncoming cars and pedestrians requires that we pay attention to what is going on around us while performing the movement. Understanding how the brain deals with these situations and how we control attention while performing multiple tasks could potentially lead to the development of treatment programs to help minimize the risk of falling but, at the moment, this is quite limited. For this reason it is important to study what normal behaviour looks like in young, healthy adults so we can recognise changes that occur as we age.

The aim of the present study is to measure visual attention (where you look) and brain activity while performing multiple tasks with increasing difficulty.

What will I be asked to do?

If you choose to participate you will be asked to take part in one session that lasts no more than 2 hours. This session will involve answering a few questions about yourself so we can determine whether you can participate, and, performing a walking task with varying degrees of difficulty while wearing eye tracking glasses (so we can see where you're looking) and an electroencephalography (EEG) cap (so we can measure your brain activity). The tasks you will be asked to do are outlined below:

1. Walking around a track.
2. Walking around a track and responding to an auditory command.
3. Walking around a track, responding to an auditory command and performing a memory task.

What will I gain from participating?

You will receive no direct benefit from participating in the study, however, your involvement will contribute to our understanding of mental and physical function while individuals perform multiple tasks and provide a comparison for future research aimed at older adults.

How will the information I give be used?

The information will be presented in academic journals and conferences as well as a PhD Thesis. All results will be presented as group data and any identifying information will be removed. Any personal information you provide will be kept in a secure location and will remain completely confidential.

What are the potential risks of participating in this project?

The risks are minimal (no different than walking down a hallway), and these will be reduced by the provision of clear instructions and an uncluttered environment free from any potential hazards.

Please note that your participation is entirely voluntary; you are entitled to withdraw from this study at any time and this will not jeopardise you in any way.

How will this project be conducted?

Participation in this study will require you to attend one session which is expected to take less than 2 hours.

The session will include:
1. Completing an initial risk factor questionnaire.
2. Explanation of the tasks and fitting the EEG and eye tracking equipment.
3. Completion of each task while we measure your eye movements and brain activity.

This study will be conducted between January 2013 – July 2013 at the Victoria University premises, Footscray Park campus.

Who is conducting the study?

Shelley Duncan
ISEAL and School of Sport and Exercise Science
Victoria University
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Chief Investigator
Prof Remco Polman
ISEAL and School of Sport and Exercise Science
Victoria University

Dr Derek Panchuk
ISEAL and School of Sport and Exercise Science
Victoria University

Any queries about your participation in this project may be directed to the Chief Investigator listed above.
If you have any queries or complaints about the way you have been treated, you may contact the Research Ethics and Biosafety Manager, Victoria University Human Research Ethics Committee, Victoria University, PO Box 14428, Melbourne, VIC, 8001 or phone (03) 9919 4148.

Appendix 2

CONSENT FORM FOR PARTICIPANTS INVOLVED IN RESEARCH

INFORMATION TO PARTICIPANTS:
We would like to invite you to be a part of a study into "The role of visual attention and neural activity in goal-directed behaviour: Age-related decrements and the moderating effect of exercise".

The aim of the present study is to measure visual attention and brain activity while performing multiple tasks (memory and walking) with increasing difficulty in healthy young (18 – 35 years) individuals.

CERTIFICATION BY SUBJECT

I, _____ of
_____(Suburb)

certify that I am at least 18 years old* and that I am voluntarily giving my consent to participate in the study:
The role of visual attention and neural activity in goal-directed behaviour: Age-related decrements and the moderating effect of exercise being conducted at Victoria University by: Prof Remco Polman, Dr Derek Panchuk, and Shelley Duncan PhD Student.

I certify that the objectives of the study, together with any risks and safeguards associated with the procedures listed hereunder to be carried out in the research, have been fully explained to me by:

Shelley Duncan PhD Student

and that I freely consent to participation involving the below mentioned procedures:

- Collection of electroencephalography (EEG; brain activity) and eye tracking data.

I certify that I have had the opportunity to have any questions answered and that I understand that I can withdraw from this study at any time and that this withdrawal will not jeopardise me in any way.

I have been informed that the information I provide will be kept confidential.

Signed:

Date:

Any queries about your participation in this project may be directed to the researcher
Shelley Duncan
0451 508 324
Shelley.Duncan@live.vu.edu.au

If you have any queries or complaints about the way you have been treated, you may contact the Research Ethics and Biosafety Manager, Victoria University Human Research Ethics Committee, Victoria University, PO Box 14428, Melbourne, VIC, 8001 or phone (03) 9919 4148.

Appendix 3

VICTORIA UNIVERSITY EXERCISE REHABILITATION

RISK FACTOR ASSESSMENT QUESTIONNAIRE

Please return this form to:

Shelley Duncan
Victoria University
Email: shelley.duncan@vu.edu.au

NAME: _____ **DATE** _____

ADDRESS: _____ **SEX** **M / F**

_____ **Postcode:** _____ ***AGE*** _____ **YRS**

TELEPHONE: Work: _____ ***WEIGHT*** _____ **KG**

TELEPHONE: Mobile: _____ ***HEIGHT*** _____ **CM**

TELEPHONE: Home: _____ **EMAIL:** _____

MEDICAL HISTORY:

In the past have you ever had (tick No or Yes. Also tick Current if you still have the illness or injury).

Medical Condition	**NO**	**YES**	**CURRENT**	***Medical Condition***	**NO**	**YES**	**CURRENT**
Heart Attack	❑	❑	n/a	Congenital Heart Disease	❑	❑	n/a
Chest Pain (angina)	❑	❑	❑	Disease of Arteries/Veins	❑	❑	❑
Heart Murmur	❑	❑	❑	Asthma	❑	❑	❑
Heart Rhythm Disturbance	❑	❑	❑	Lung Disease (eg. emphysema)	❑	❑	❑
Heart Valve Disease	❑	❑	❑	Epilepsy	❑	❑	❑
Heart Failure	❑	❑	❑	Stroke	❑	❑	n/a

***Back or neck injury**	❑	❑	❑	***Shoulder, elbow or wrist injury**	❑	❑	❑
***Hip injury**	❑	❑	❑	***Knee or ankle injury**	❑	❑	❑

***Give details of injuries to your back, neck, shoulders, elbows, wrists, hips, knees, or ankles in your medical history**

_____

_____

List any prescribed medications being taken

_____

_____

List any surgical procedures that you have had (write the year in brackets):
Example: appendix (1979)

_____

_____

ALLERGIES: Do you have any allergies **NO** ❑ **YES** ❑ If yes, give details:

_____

SYMPTOMS DURING OR AFTER EXERCISE
As a result of exercise, have you ever experienced any of the following:

Symptom during exercise	NO	YES	Symptom during exercise	NO	YES
Pain or discomfort in the chest, back, arm, or jaw	❑	❑	Palpitations (heart rhythm disturbance)	❑	❑
Severe shortness of breath or problems with breathing during mild exertion	❑	❑	Pain in the legs during mild exertion	❑	❑
Dizziness, nausea or fainting	❑	❑	Severe heat exhaustion	❑	❑

CARDIOVASCULAR RISK FACTORS:
Do you have (tick NO, YES or circle ? for DON'T KNOW)

Cardiovascular Risk Factors	*NO*	*YES*	**DON'T KNOW**
High Blood Pressure	❑	❑	**?**
High Blood Cholesterol/Triglycerides	❑	❑	**?**
Diabetes	❑	❑	**?**
Current Smoker	❑	❑	Average/day =
Ex-smoker	❑	❑	Average/day =

Do you drink alcohol regularly? ❑ ❑ Average/day = drinks

FAMILY MEDICAL HISTORY:

Have members of your immediate family ever had any of the following conditions: (tick NO, YES or circle ? for DON'T KNOW). If you answer Yes or ?, write beside this the member of the family affected (F=father, M=mother, B=brother, S=sister, GM=grandmother, GF=grandfather).

Family medical history	**NO**	**YES**	**?**	**FAMILY MEMBER**	**AGE (Years)**	**ALIVE NOW?**
Heart Attack	❑	❑	**?**	_____	_____	_____
Chest Pain (Angina)	❑	❑	**?**	_____	_____	_____
Stroke	❑	❑	**?**	_____	_____	_____
High Blood Pressure	❑	❑	**?**	_____	_____	_____
High Blood Cholesterol/Triglycerides	❑	❑	**?**	_____	_____	_____
Diabetes	❑	❑	**?**	_____	_____	_____

PERSONAL LIFESTYLE:

A. Exercise

List the sports, exercise or physically active hobbies (eg. gardening or playing with the kids) that you are **currently** engaged in:

Sport/Activity	**Day(s) of week Sa-Su-Mo-Tu-We-Th-Fr**	**Time of the day eg. 6 p.m.**	**Approximate duration eg. 30 minutes**
		TOTAL	

B. Nutrition

List a typical day's eating pattern.

Breakfast	**Lunch**	**Dinner**	**Snacks**	**Drinks**

C. Rest/Recreation

How many hours sleep do you usually have? _____ hours/night

On average how much time do you spend each day on passive hobbies (i.e. watching TV) or just relaxing?

_____ minutes/hours per day.

Do you feel that you usually get enough restful sleep and time to relax? **Yes/No**

Client Declaration
I declare that the above information is to my knowle
true and correct, and that I have not omitted any
information that is requested on this form.

SIGNED: _____

DATE: _____

OFFICE USE ONLY
CLEARANCE TO UNDERGO AN EXERCISE TEST
This person has been cleared to undergo a Fitness test:

- ❑ Without medical supervision
- ❑ With medical supervision
- ❑ A fitness test is not advisable at this time

Signed: Dr/Mr/Mrs/Ms _____

(Circle appropriate title: Physician/exercise physiologist)

Please turn over and provide the information requested overleaf.

PHYSICAL EXAMINATION
This section should be completed by the medical practitioner.

(a) General appearance including glands, and lymph nodes

_____

(b) Cardiovascular system

(i) Peripheral vessel and pulses

(ii) Neck veins

(iii) Apex beat position

(iv) Heart sounds

(v) Resting heart rate

(vi) Blood Pressure: Lying: _____ mmHg, Standing: _____mmHg

(vii) 12 leads ECG (a copy of resting ECG should be on file).

(c) Respiratory system

_____

(d) Abdomen

_____

(e) Nervous system

(f) Fundi

(g) Locomotor system

(h) Varicose veins

(j) Blood profile: Date of last blood test:

TC: LDL: HDL: Triglyceride:

Glucose: HbA1c : Other:

(k) Other examinations:

_____

(11) MEDICAL PRACTITIONER'S SUMMARY:

(a) Comments (detail any significant abnormalities or reservations):

_____
_____
_____

(b) Recommendations:

The medical practitioner should underline and initial the appropriate clause:

(i) Fit to undergo maximal exercise test

(ii)Not fit to undergo maximal exercise test, but may undergo submaximal test without special precautions

(iii) Not fit to undergo maximal exercise test but may undergo submaximal test with the following precautions:

Precaution:

_____
__
_____
_____
____

(iv) Not fit to undergo any exercise test

Signed: _____

Name: _____

Date: _____

Contact Telephone Number: (Wk) _____ (Mobile)
_____

Appendix 4

INFORMATION TO PARTICIPANTS INVOLVED IN RESEARCH

You are invited to participate

You are invited to participate in a research project entitled: The role of visual attention and neural activity in goal-directed behaviour: Age-related decrements and the moderating effect of exercise.

This project is being conducted by a student researcher Shelley Duncan as part of a PhD study at Victoria University under the supervision of Prof Remco Polman and Dr Derek Panchuk from the Institute of Sport, Exercise and Active Living (ISEAL) at Victoria University.

Project explanation

Older adults generally use less areas of the brain to initiate and control movements than younger adults and this leads to a normal decline in our ability to perform effective movements as we age. This decrease in brain function can however lead to movements becoming slower and problems with balance that increase the risk of falls and trips. One of the biggest risk factors associated with tripping and falling is our ability to perform multiple tasks at one time (what we call dual-task performance). For example, stepping down from a curb to cross the road while looking out for oncoming cars and pedestrians requires that we pay attention to what is going on around us while performing the movement. Understanding how the brain deals with these situations and how we control attention while performing multiple tasks could potentially lead to the development of treatment programs to help minimize the risk of falling but, at the moment, this is quite limited. For this reason it is important to study what normal behaviour looks like in young, healthy adults so we can recognise changes that occur as we age.

The aim of the present study is to measure visual attention (where you look) and brain activity while performing multiple tasks with increasing difficulty.

What will I be asked to do?

If you choose to participate you will be asked to take part in one session that lasts no more than 2 hours. This session will involve answering a few questions about yourself so we can determine whether you can participate, and, performing a walking task with varying degrees of difficulty while wearing eye tracking glasses (so we can see where you're looking) and an electroencephalography (EEG) cap (so we can measure your brain activity). The tasks you will be asked to do are outlined below:

1. Walking around a track.
2. Walking around a track and responding to an auditory command.
3. Walking around a track, responding to an auditory command and performing a memory task.

What will I gain from participating?

You will receive no direct benefit from participating in the study, however, your involvement will contribute to our understanding of mental and physical function while individuals perform multiple tasks and provide a comparison for future research aimed at older adults.

How will the information I give be used?

The information will be presented in academic journals and conferences as well as a PhD Thesis. All results will be presented as group data and any identifying information will be removed. Any personal information you provide will be kept in a secure location and will remain completely confidential.

What are the potential risks of participating in this project?

The risks are minimal (no different than walking down a hallway), and these will be reduced by the provision of clear instructions and an uncluttered environment free from any potential hazards.

Please note that your participation is entirely voluntary; you are entitled to withdraw from this study at any time and this will not jeopardise you in any way.

How will this project be conducted?

Participation in this study will require you to attend one session which is expected to take less than 2 hours.

The session will include:
1. Completing an initial risk factor questionnaire.
2. Explanation of the tasks and fitting the EEG and eye tracking equipment.
3. Completion of each task while we measure your eye movements and brain activity.

This study will be conducted between January 2013 – July 2013 at the Victoria University premises, Footscray Park campus.

Who is conducting the study?

Shelley Duncan
ISEAL and School of Sport and Exercise Science
Victoria University
0451 508 324
Shelley.duncan@live.vu.edu.au

Chief Investigator
Prof Remco Polman
ISEAL and School of Sport and Exercise Science
Victoria University

Dr Derek Panchuk
ISEAL and School of Sport and Exercise Science
Victoria University

Any queries about your participation in this project may be directed to the Chief Investigator listed above.
If you have any queries or complaints about the way you have been treated, you may contact the Research Ethics and Biosafety Manager, Victoria University Human Research Ethics Committee, Victoria University, PO Box 14428, Melbourne, VIC, 8001 or phone (03) 9919 4148.

Appendix 5

CONSENT FORM FOR PARTICIPANTS INVOLVED IN RESEARCH

INFORMATION TO PARTICIPANTS:
We would like to invite you to be a part of a study into "The role of visual attention and neural activity in goal-directed behaviour: Age-related decrements and the moderating effect of exercise".

The aim of the present study is to measure visual attention and brain activity while performing multiple tasks (memory and walking) with increasing difficulty in healthy young (18 – 35 years) individuals.

CERTIFICATION BY SUBJECT

I, _____ of
_____(Suburb)

certify that I am at least 18 years old* and that I am voluntarily giving my consent to participate in the study:
The role of visual attention and neural activity in goal-directed behaviour: Age-related decrements and the moderating effect of exercise being conducted at Victoria University by: Prof Remco Polman, Dr Derek Panchuk, and Shelley Duncan PhD Student.

I certify that the objectives of the study, together with any risks and safeguards associated with the procedures listed hereunder to be carried out in the research, have been fully explained to me by:

Shelley Duncan PhD Student

and that I freely consent to participation involving the below mentioned procedures:

- Collection of electroencephalography (EEG; brain activity) and eye tracking data.

I certify that I have had the opportunity to have any questions answered and that I understand that I can withdraw from this study at any time and that this withdrawal will not jeopardise me in any way.

I have been informed that the information I provide will be kept confidential.

Signed:

Date:

Any queries about your participation in this project may be directed to the researcher
Shelley Duncan
0451 508 324
Shelley.Duncan@live.vu.edu.au

If you have any queries or complaints about the way you have been treated, you may contact the Research Ethics and Biosafety Manager, Victoria University Human Research Ethics Committee, Victoria University, PO Box 14428, Melbourne, VIC, 8001 or phone (03) 9919 4148.

Appendix 6

INFORMATION TO PARTICIPANTS INVOLVED IN RESEARCH

You are invited to participate

You are invited to participate in a research project entitled: The influence of an acute bout of exercise on neural activity during goal-directed behaviour.

This project is being conducted by a student researcher Shelley Duncan as part of a PhD study at Victoria University under the supervision of Prof Remco Polman and Dr Liam Johnson from the Institute of Sport, Exercise and Active Living (ISEAL) at Victoria University, and Dr Derek Panchuk from the Australian Institute of Sport (AIS), Canberra.

Project explanation

One of the key decrements observed in the older adult population is the reduced capacity to perform efficient and effective whole-body movement. This decrement has been associated with a decline in mental function, namely: fine motor control, balance, coordination, and movement slowing. These declines can lead to an increased risk of falls and trips and can also be seen in dual-task performance, which involves the performance of both mental and physical tasks at the same time. For example, stepping down from a curb to cross the road (motor task) while paying attention to other factors such as oncoming cars and pedestrians (cognitive task). At the moment we know very little about the role that changing mental processes, such as brain activity and attention, play in declining dual-task performance.

The aim of the present study is to investigate brain activity whilst performing single and dual-tasks in healthy young (18 – 35 years) and older (60 – 80 years) individuals. You will be asked to complete four sessions including pre-screening, an incremental fitness test and muscle strength testing familiarisation in the first session. In the second session you will perform the muscle strength testing on three different exercises. Sessions three and four will involve performing single and dual-task activities of increasing difficulty before and after either moderate aerobic bout of cycling or strength training.

What will I be asked to do?

If you choose to participate you will be required to be available for four sessions (one per week over a four week period). Prior to enrolment in the study you will be asked to complete a risk factor questionnaire and if you are over 60 years of age, undergo a medical examination by your GP to ensure that you are medically safe to participate in this study. If there is any evidence that participation in this study might be dangerous to your health, the study may not be suitable for you. After screening, you will be asked to perform the following assessments;

To participate in this study you will be asked to come to the Institute of Sport, Exercise and Active Living (ISEAL) located at Victoria University, Footscray Park Campus.

Session one
Fitness assessment – estimated time 2 hours
In your first session you will be asked to;

- Wear a heart rate monitor so that your heart rate can be monitored during exercise.
- Complete an incremental exercise test. This test involves continuous exercise on a cycle machine with the exercise intensity (effort) being progressively increased until you are tired. We will closely monitor

you and your heart rate during exercise to ensure your safety. The test is completed when you become tired but not exhausted (or wish to stop before you become tired), or unless we stop the test earlier for safety due to you displaying an abnormal response to exercise, such as inappropriate heart rate or sweating response, chest pain, or severe shortness of breath.

- Participants over the age of 60 will be connected to a 12 lead ECG to monitor your heart rate and rhythm throughout fitness testing. The use of a 12-lead ECG is a precautionary measure only and is not present as a diagnostic tool. We are not qualified to interpret ECG, however, if we recognise an abnormal pattern we will follow that up with your GP or specialist.
- Participants (under 40 years of age) will wear a polar watch to monitor so that we can monitor your heart rate throughout the fitness testing.

Muscle strength testing familiarisation

- A week prior to your muscle strength testing you will perform a familiarisation session. This will include being taught about correct lifting and breathing technique and you will be provided with an opportunity to practice the three different exercises including the two upper body and one lower body exercise.

Session two – estimated time 1 ½ hours

Muscle strength testing (one repetition maximum, 1RM)

We will measure your muscle strength which involves;

- 1RM that is defined as the heaviest weight you are able to lift once, using a proper lifting technique. 1RM strength will be assessed for three different exercises including two upper body and one lower body exercises.
- The tests will commence after a light warm-up on a stationary cycle, a warm up circuit on each of the three exercise machines (one set of 10 repetitions at a relatively light load), followed by a gradual increase in load until 1RM is achieved.
- A two - three minute rest period will be provided between each attempt.

Sessions three and four – estimated time less than 4 hours

During these sessions you will be required to wear a cap on your head that has small electrodes that monitor your brain activity. This will enable us to collect information on your brain activity while performing the single and dual-tasks. The brain activity equipment is non-invasive, non-painful and there is no known risk to brain function. These sessions will be identical with the exception of the mode of the exercise performed, which will be:

- 1) moderate continuous aerobic for 45 min. This involves cycling on a stationary cycle performing exercise at 60 – 70% of your HR_{peak} that was determined in the fitness testing and
- 2) a 45 min bout of strength based exercise, which will include a five minute warm up on a stationary cycle, a warm up circuit of the two upper and one lower body exercises
- You will then perform three sets of 8 – 12 reps of each exercise at 80% of the 1RM.
- Sessions three and four will also include pre and post exercise measures of single and dual-task performance (described below).

Single and Dual-Task Paradigm:

Baseline and post exercise testing, this will include repeat performance of the four phases as outlined below. In between the baseline and post testing you will perform a 45 minute exercise session. The order of exercise (moderate continuous aerobic and strength based exercise) will be randomised between the third and fourth sessions, this means that there will be a 50% chance that you will be required to perform the aerobic exercise in the third session and the strength based exercise in the fourth session. Before beginning these sessions you will be fitted with a cap with small electrodes so that we can measure your brain activity throughout testing, this will take approximately 45 minutes.

Phase 1 - 10 minutes. Baseline performance that requires you to walk around a track. You will be presented with two different visual lights (green and red) throughout this phase.

Phase 2 – 5 minutes. You will receive instructions as to the directional commands associated with the presentation of the lights (red = right and green = left), to enable you to perform the correct turn at each T-junction around the walking track. Once you are confident with being able to identify each respective light command you will progress to either the single or dual-task phases of testing.

Phase 3 – 15 minutes. The single task condition requires you to walk around a track performing left and right hand turns at the T-Junction in response to the command lights presented. You will complete 4 blocks that includes 45 turns per block and a 1 minute break between each block.
Phase 4 – 15 minutes. The dual-task condition is the same as in the single task condition with the inclusion of a memory task. You will be presented with a 15 word shopping list at the beginning of each block and asked to remember three of the words. At the end of each block you will be asked to recall these three specific words (out of the 15 you are presented at the beginning of the block).

What will I gain from participating?

You will receive no direct benefit from participating in the study. It is possible, however, that the findings from this study will contribute to knowledge regarding age-related decline in memory and physical function and the benefits of exercise.

How will the information I give be used?

The information will be shared by publishing the findings in academic journals and presenting the findings at conferences. In addition, findings will be reported within a PhD Thesis. All data will be coded and presented without any information that can be used for identification. All personal information will be kept confidential.

What are the potential risks of participating in this project?

Before you volunteer to be part of this study, there are some important things to understand:

1. It is important that you do not have one or more of the following conditions;
    i. Heart attack or cardiac arrest during the most recent 6 months.
    ii. Heart failure with symptoms at rest.
    iii. Exercise Test that resulted in chest pain, or chest pain at any other time in the past 6 months related to exertion.
    iv. Current muscle and joint pain (e.g. arthritis) and/or nerve pain that will prevent comfortable participation in exercise;
2. All exercise activity, carries a risk of injury and, in extreme cases, risks of suffering a heart attack or stroke. We will take all reasonable precautions, performing an exercise screening test. All exercise will be supervised by an exercise physiologist.

There may be additional unforeseen or unknown risks.

We will use every possible safety measure to protect you while performing the activities in this research:

1. In the case of medical emergencies, a call to 000 will be made. The researchers will commence appropriate resuscitation methods while waiting for an emergency team to arrive. In the event of emergencies, you will need to undergo an additional medical review and consent process before you will be permitted to return to the study.

2. During the exercise sessions, you may experience some muscle or other soft tissue soreness / injury. In this case, you will be treated immediately using appropriate sports first aid (e.g. ice treatment). If an injury persists, or the injury needs medical evaluation and/or treatment, you will be referred to appropriate medical or allied health practitioners at no cost to you, and will not return to the study until cleared to do so by the treating practitioner.

3. For all other adverse events of a physical nature, exercise will be terminated immediately, you will be consulted and reassured and then we will make and arrangements for you for appropriate follow-up (e.g. immediate review by a medical practitioner or early referral to an appropriate health professional) at no cost to you.

4. The psychological risks incidences are expected to be very infrequent, but some participants may feel overwhelmed and stressed about the thought of completing exercise testing.

Counselling and independent follow-up:

Participation in this study is voluntary. You may change your mind or withdraw from the study at any time or withdrawn if develop any of the above conditions that would indicate that you need to withdraw from the program. In the event that you experience psychological distress and wish to talk to someone about your experience, we invite you to contact Prof Tony Morris (99195353), a registered psychologist who is not in any way connected to the research, and who will provide counselling free of charge to you.

How will this project be conducted?

Participation in this study will require you to attend four sessions, with session one expected to take less than 2 hours, session two will take 1 ½ hours and sessions three and 4 are expected to take less than four hours.

Session one will include:

1. Pre-screening
2. Familiarisation of the single and dual-task activities
3. Fitness testing
4. Familiarisation of the muscle strength testing

Session two will include:

1. Muscle strength testing on three different fixed weight exercises

Sessions three and four will include:

1. Completion of the single and dual-task activities
2. An acute bout of exercise
3. Repeat single and dual-task activity

Who is conducting the study?

Shelley Duncan
ISEAL and College of Sport and Exercise Science
Victoria University
0451 508 324
Shelley.duncan@vu.edu.au

Chief Investigator
Prof Remco Polman
ISEAL and College of Sport and Exercise Science
Victoria University

Dr Derek Panchuk
Australian Institute of Sport
Canberra

Dr Liam Johnson
ISEAL and College of Sport and Exercise Science
Victoria University

Any queries about your participation in this project may be directed to the Chief Investigator listed above.
If you have any queries or complaints about the way you have been treated, you may contact the Research Ethics and Biosafety Manager, Victoria University Human Research Ethics Committee, Victoria University, PO Box 14428, Melbourne, VIC, 8001 or phone (03) 9919 4148.

Appendix 7

CONSENT FORM FOR PARTICIPANTS INVOLVED IN RESEARCH

INFORMATION TO PARTICIPANTS:
We would like to invite you to be a part of a study into "The influence of an acute bout of exercise on neural activity during goal-directed behaviour".

The aim of the present study is to investigate brain activity whilst performing dual-tasks with increasing difficulty in healthy young (18 – 35 years) and older (60 – 80 years) individuals.

CERTIFICATION BY SUBJECT

I, _____ of
_____(Suburb)

certify that I am at least 18 years old* and that I am voluntarily giving my consent to participate in the study: The influence of an acute bout of exercise on neural activity during goal-directed behaviour being conducted at Victoria University by: Prof Remco Polman, Dr Derek Panchuk, Dr Liam Johnson and Shelley Duncan PhD Student.

I certify that the objectives of the study, together with any risks and safeguards associated with the procedures listed hereunder to be carried out in the research, have been fully explained to me by:

Shelley Duncan PhD Student

and that I freely consent to participation involving the below mentioned procedures:

Session one
Pre-screening
Fitness assessment

- If under 40 years of age wear a heart rate monitor so that my heart rate can be monitored during exercise.
- If over 60 years of age wear a 12 lead ECG so that my heart rate and rhythm can be monitored during exercise.
- Complete an incremental exercise test on a cycle machine with the exercise intensity (effort) being progressively increased until I am tired.

Muscle strength testing familiarisation

- Familiarisation session to learn the correct lifting and breathing technique and practice for three different exercises including two upper body and one lower body exercises.

Session two
Muscle strength testing (one repetition maximum, 1RM)

- Complete muscle strength testing to define my 1RM for three different exercises two upper body and one lower body exercises.

Sessions three and four

Experiment

- During these sessions I agree to wear a cap with electrodes on my head that will enable the collection of my brain activity data.

- Complete 1) a moderate continuous aerobic (45 min at 60 – 70% HR_{peak}) during one session and 2) a 45 min bout of strength based exercise where I will be required to perform three sets of 8 – 12 reps of each exercise at 80% of the 1RM, including two upper body and one lower body exercises in the other session.

- Before and after the bout of exercise I will perform the progressive single and dual-tasks as follows:

    - Phase one (baseline condition) walking around the track performing left and right-hand turns at each of the T-Junctions.
    - The single-task condition walking around the track performing the correct turn in response to the presentation of a green or red light.
    - The dual-task condition repeating that as outlined in the single task phase in addition to performing a memory task (15 word shopping list).

I certify that I have had the opportunity to have any questions answered and that I understand that I can withdraw from this study at any time and that this withdrawal will not jeopardise me in any way.

I have been informed that the information I provide will be kept confidential.

Signed:

Date:

Any queries about your participation in this project may be directed to the researcher
Shelley Duncan
0451 508 324
Shelley.Duncan@live.vu.edu.au

If you have any queries or complaints about the way you have been treated, you may contact the Research Ethics and Biosafety Manager, Victoria University Human Research Ethics Committee, Victoria University, PO Box 14428, Melbourne, VIC, 8001 or phone (03) 9919 4148.

Appendix 8

VICTORIA UNIVERSITY
MELBOURNE AUSTRALIA

EXERCISE PHYSIOLOGY UNIT

SCHOOL OF SPORT AND EXERCISE SCIENCE
PO BOX 14428
MELBOURNE MC, VIC 8001
TELEPHONE: (03) 9919 4129

INFORMED CONSENT FOR UNDERTAKING AN EXERCISE TEST FOR VOLUNTEERS UNDER THE AGE OF 40 YEARS WITH NO CARDIOVASCULAR RISK FACTORS

1. EXPLANATION OF THE GRADED EXERCISE TEST

A VO_2max measures the maximal ability of the body to utilise oxygen during exercise. The test begins at a low intensity and progressively increases in intensity until the point at which the participant can no longer continue (typically 8 to 12 min).

You will perform a graded exercise test on the bicycle ergometer or a motor-driven treadmill. The exercise intensities will begin at a level you can easily accomplish and will be advanced in stages, depending on your functional capacity. We may stop the test at any time if signs or symptoms occur or you may stop whenever you wish to because of personal feelings of fatigue or discomfort. We do not wish you to exercise at a level which is abnormally uncomfortable for you; for maximum benefit from the test, exercise as long as is comfortable.

2. RISK AND DISCOMFORTS

There exists the possibility of certain changes occurring during the test. They include abnormal blood pressure, fainting, disorders of heart beat, and in very rare instances, heart attack, stroke or death. Every effort will be made to prevent these by preliminary screening and careful monitoring during the test. Should you feel any symptoms if discomfort of any kind, indicate this to us and we will terminate the test immediately. Please note that body hair covering the sites needed to record an electrocardiograph (ECG) may need to be shaved. This will involve shaving up to 10 areas on the chest, each the size of a 50 cent piece.

3. RESPONSIBILITIES OF THE PARTICIPANT

Information you possess about your health status or previous experiences of unusual feelings with physical effort may affect the safety and value of your exercise test. You are responsible to fully disclose such information on the accompanying sheets or when requested by the testing staff. Furthermore you are expected to disclose any feelings of discomfort during the exercise test. The staff will take all reasonable precautions to ensure the safety and value of your exercise test but we

can not be held responsible in the event that you fail to disclose important information to us.

4. BENEFITS TO BE EXPECTED

The results obtained from the exercise test assist in the evaluation of the types of physical activities you might engage in with no or low hazards.

5. INQUIRIES

Any questions about the procedures used in the graded exercise test or in the estimation of functional capacity are encouraged. If you have any doubts or questions, please ask us for further explanations.

6. MEDICAL SUPERVISION

Normally it is not necessary for someone under the age of 35 to need a doctor to be present for an exercise test, but we will arrange for a medically supervised test if you prefer. Note: if your cardiovascular risk factor and medical history indicate the need for medical coverage, we MUST arrange for a doctor to be present.

7. FREEDOM OF CONSENT

Your permission to perform this graded exercise test is voluntary. You are free to *deny consent now or withdraw consent at any time* (including during the exercise test) if you so desire.

I have read this form and I understand the test procedures and the conditions under which this test will be conducted. I consent to participate in this fitness test without medical supervision.

VOLUNTEER'S CONSENT

I have read this form and I understand the procedures involved and the conditions under which the tests will be conducted. I am under the age of 18 and consent to participate in this test **WITHOUT** medical supervision.

_____	_____	___/_____/_____
Name of Volunteer	**Signature of Volunteer**	**Date**
_____	_____	___/_____/_____
Name of Witness	**Signature of Witness**	**Date**

Appendix 9: Study Two Mean ± SD Tables

Behavioural Measures

Table 1: Trial completion time

Per trial completion time (seconds)	
Single	*Dual*
3.20 ± .35	3.30 ± .37

Neural Activity Measures

Table 2: N2 ERP *Peak Latency* and *Mean Amplitude* (180 – 220 ms)

Electrodes		**N2 *peak latency* ± SD**		**N2 *mean amplitude* ± SD 180 – 220 ms**	
		Single	*Dual*	*Single*	*Dual*
Left	P3	197.75 ± 27.72	204.00 ± 29.22	-1.6478 ± 1.1860	-1.6695 ± .8809
	P7	196.92 ± 31.40	206.08 ± 31.49	-.2058 ± 1.9421	-.5024 ± 1.5884
	O1	203.92 ± 22.65	206.17 ± 25.81	-1.2192 ± 1.5334	-1.4295 ±1.4914
Right	P4	208.75 ± 25.36	209.58 ± 31.70	-.7530 ± .9468	-.7179 ± .8653
	P8	205.92 ± 32.71	193.58 ± 28.37	.4095 ± 1.0495	.5677 ± 1.0663
	O2	205.00 ± 20.77	205.92 ± 24.65	-.9800 ± 1.3461	-1.2009 ± 1.4337
Midline	Cz	201.75 ± 21.95	204.83 ± 16.16	-2.1039 ± 1.6911	-1.9217 ± 1.9893
	Pz	206.17 ± 19.21	209.33 ± 18.53	-2.2814 ± 1.4462	-2.1022 ± .9221
	Oz	203.92 ± 21.51	208.25 ± 23.69	-1.0598 ± 1.5080	-1.3289 ± 1.4869

Table 3: P3 ERP *Peak Latency* and *Mean Amplitude* (300 – 400 ms)

Electrodes		**P3 *peak latency* ± SD**		**P3 *mean amplitude* ± SD 300 – 400 ms**	
		Single	*Dual*	*Single*	*Dual*
Left	P3	312.83 ± 20.54	313.25 ± 23.07	.0093 ± 1.4206	-.2050 ± 1.3849
	P7	306.92 ± 13.17	321.25 ± 27.00	.7953 ± 1.6068	.6455 ± 1.7047
	O1	305.33 ± 18.31	303.67 ± 28.10	.1771 ± 1.8520	-.0984 ± 1.7217
Right	P4	304.42 ± 20.30	311.17 ± 34.44	.4211 ± .9284	.3955 ± 1.0361
	P8	303.83 ± 18.76	307.17 ± 34.74	.6920 ± .6169	.9876 ± .8580
	O2	304.17 ± 24.08	302.50 ± 34.69	.4608 ± 1.5231	.3839 ± 1.6635
Midline	Pz	306.33 ± 27.39	308.67 ± 27.30	.0254 ± 1.2809	-.4545 ± 1.4004
	Oz	306.92 ± 24.88	308.58 ± 29.88	.5892 ± 1.6367	.3655 ± 1.5616

Table 4: P3 ERP *Mean Amplitudes* (400 – 500 and 500 – 600 ms)

Electrodes		**P3 *mean amplitude* ± SD 400 – 500 ms**		**P3 *mean amplitude* ± SD 500 – 600 ms**	
		Single	*Dual*	*Single*	*Dual*
Left	P3	.6201 ± 1.0884	.4898 ± 1.3376	.4104 ± 1.1866	.2761 ± 1.1403
	P7	1.4486 ± 1.6602	1.1779 ± 1.4644	1.0186 ± 1.7318	.7870 ± 1.6748
	O1	.8494 ± 1.9746	.6848 ± 2.0025	.5296 ± 2.0120	.5879 ± 1.7822
Right	P4	.6644 ± .8554	.7194 ± .8654	.6072 ± .9336	.7898 ± .6467
	P8	.8014 ± .8606	.9890 ± .7670	.8034 ± 1.2658	.9897 ± 1.0893
	O2	1.1078 ± 1.3317	.9834 ± 1.5261	.8225 ± 1.7314	1.116 ± 1.3720
Midline	Pz	.4582 ± 1.1198	.3117 ± 1.4125	.1798 ± 1.2136	.2492 ± 1.2942
	Oz	1.3178 ± 1.5272	1.1282 ± 1.6060	1.0913 ± 1.6918	1.2318 ± 1.3984

Appendix 10: Study Two One Way ANOVA Results

Behavioural Measures

Table 1: Trial completion time

Per trial completion time (seconds)		
Single	*Dual*	*Main effect of task*
3.20 ± .35	3.30 ± .37	t (11) = -2.82, p = .02

Neural Activity Measures

Table 2: N2 ERP *Peak Latency*

Location	**Electrode**	***df***	**N2 *peak latency* (ms)**
Left Hemisphere	P3	(1,23)	F = 0.29; p = .60
	P7		F = 0.51; p = .48
	O1		F = 0.05; p = .82
Right Hemisphere	P4		F = 0.01; p = .94
	P8		F = 0.97; p = .34
	O2		F = 0.01; p = .92
Midline	Cz		F = 0.15; p = .70
	Pz		F = 0.17; p = .69
	Oz		F = 0.22; p = .64

Table 3: N2 ERP *Mean Amplitude* (180 – 220 ms)

Location	**Electrode**	***df***	**N2 *mean amplitude* (μV)**
Left Hemisphere	P3	(1,23)	F = 0.00; p = .96
	P7		F = 0.17; p = .69
	O1		F = 0.12; p = .74
Right Hemisphere	P4		F = 0.01; p = .93
	P8		F = 0.13; p = .72
	O2		F = 0.15; p = .70
Midline	Cz		F = 0.06; p = .81
	Pz		F = 0.13; p = .72
	Oz		F = 0.19; p = .66

Table 4: P3 ERP *Peak Latency*

Location	**Electrode**	***df***	**P3 *peak latency* (ms)**
Left Hemisphere	P3	(1,23)	$F = 0.00$; $p = .96$
	P7		$F = 2.73$; $p = .11$
	O1		$F = 0.03$; $p = .87$
Right Hemisphere	P4		$F = 0.34$; $p = .57$
	P8		$F = 0.09$; $p = .77$
	O2		$F = 0.02$; $p = .89$
Midline	Pz		$F = 0.04$; $p = .84$
	Oz		$F = 0.02$; $p = .88$

Table 5: P3 ERP *Mean Amplitude* (300 – 400 ms)

Location	**Electrode**	***df***	**P3 mean amplitude (µV) 300 – 400 ms**
Left Hemisphere	P3	(1,23)	$F = 0.14$; $p = .71$
	P7		$F = 0.05$; $p = .83$
	O1		$F = 0.14$; $p = .71$
Right Hemisphere	P4		$F = 0.00$; $p = .95$
	P8		$F = 0.94$; $p = .34$
	O2		$F = 0.01$; $p = .91$
Midline	Pz		$F = 0.77$; $p = .39$
	Oz		$F = 0.12$; $p = .74$

Table 6: P3 ERP M*ean Amplitude* (400 – 500 ms)

Location	**Electrode**	***df***	**P3 *mean amplitude* (µV) 400 – 500 ms**
Left Hemisphere	P3	(1,23)	$F = 0.07$; $p = .80$
	P7		$F = 0.18$; $p = .68$
	O1		$F = 0.04$; $p = .84$
Right Hemisphere	P4		$F = 0.02$; $p = .88$
	P8		$F = 0.32$; $p = .58$
	O2		$F = 0.05$; $p = .83$
Midline	Pz		$F = 0.08$; $p = .78$
	Oz		$F = 0.09$; $p = .77$

Table 5: P3 ERP *Mean Amplitude* (500 – 600 ms)

Location	**Electrode**	***df***	**P3 *mean amplitude* (µV) 500 – 600 ms**
Left Hemisphere	P3	(1,23)	$F = 0.08$; $p = .78$
	P7		$F = 0.11$; $p = .74$
	O1		$F = 0.01$; $p = .94$
Right Hemisphere	P4		$F = 0.31$; $p = .58$
	P8		$F = 0.15$; $p = .70$
	O2		$F = 0.21$; $p = .65$
Midline	Pz		$F = 0.02$; $p = .89$
	Oz		$F = 0.05$; $p = .83$

Appendix 11: Study Three (Aerobic and Resistance Exercise) means and SD's.

Behavioural Measures

Table 1: Trial completion time

Per trial completion time (seconds)				
	Single		*Dual*	
	Pre	*Post*	*Pre*	*Post*
Aerobic	4.61 ± .58	4.43 ± .50	4.67 ± .63	4.56 ± .62
Resistance	4.68 ± .60	4.34 ± .63	4.77 ± .61	4.51 ± .56

Neural Activity Measures

Table 2: N2 ERP *Peak Latency* – Aerobic Exercise

Aerobic					
N2 peak latency ± SD		*Single*		*Dual*	
		Pre	*Post*	*Pre*	*Post*
Left	P3	201.8 ± 18.78	200.93 ± 29.22	223 ± 33.14	200.27 ± 20.52
	P7	203.93 ± 16.19	203.93 ± 23.56	215.67 ± 24.27	198 ± 12.18
	O1	219.2 ± 25.13	209.93 ± 19.57	221.87 ± 29.82	202.73 ± 17.95
Right	P4	201.4 ± 22.27	196.67 ± 21.71	219.53 ± 38.03	197.27 ± 25.59
	P8	200.87 ± 12.78	196.73 ± 22.06	209.8 ± 33.07	194.67 ± 16.5
	O2	220.33 ± 26.57	209.27 ± 23.12	219.33 ± 28.75	203.73 ± 18.76
Midline	Pz	204.4 ± 23.27	202 ± 33.36	220.2 ± 38.06	202.6 ± 24.93
	Oz	221.53 ± 24.91	209.27 ± 21.15	223.6 ± 30.69	203.87 ± 19.68

Table 3: N2 ERP *Mean Amplitude* (180 – 220 ms) – Aerobic Exercise

Aerobic					
N2 180 220 mean amplitude ± SD		*Single*		*Dual*	
		Pre	*Post*	*Pre*	*Post*
Left	P3	-2.0215 ± 1.294	-1.8375 ± 1	-2.1256 ± 1.0729	-2.04 ± 1.258
	P7	-3.1603 ± 2.0274	-3.0032 ± 1.9593	-3.1648 ± 1.7123	-3.3905 ± 1.7964
	O1	-2.4591 ± 1.5854	-1.9919 ± 1.5444	-2.3714 ± 1.6611	-2.3379 ± 1.5864
Right	P4	-1.4597 ± 1.5131	-1.3649 ± 1.5499	-1.4371 ± 1.2778	-1.3711 ± 1.966
	P8	-2.9094 ± 1.8108	-3.2012 ± 1.9035	-2.8113 ± 1.4153	-3.1976 ± 2.0178
	O2	-2.1193 ± 1.4613	-2.1389 ± 1.7819	-2.1105 ± 1.4209	-2.2772 ± 1.6691
Midline	Pz	-0.9225 ± 0.9513	-0.6057 ± 1.0164	-0.727 ± 1.1674	-0.6184 ± 1.0893
	Oz	-1.7292 ± 1.3941	-1.5305 ± 1.6116	-1.7349 ± 1.3492	-1.7614 ± 1.5838

Table 4: N2 ERP *Mean Amplitude* (180 – 220 ms) – Aerobic Exercise

Resistance					
N2 180 220 mean amplitude ± SD		*Single*		*Dual*	
		Pre	*Post*	*Pre*	*Post*
Left	P3	-1.9032 ± 1.6033	-1.9747 ± 1.444	-2.313 ± 1.7168	-2.0798 ± 1.5224
	P7	-2.8123 ± 1.8582	-3.3552 ± 2.0965	-2.8535 ± 2.0634	-2.9845 ± 2.015
	O1	-2.2732 ± 1.5614	-2.3748 ± 1.9606	-2.4012 ± 1.5808	-2.174 ± 1.8284
Right	P4	-1.672 ± 1.5383	-1.4761 ± 1.6337	-1.7157 ± 1.8341	-1.4023 ± 1.5011
	P8	-3.0479 ± 1.3279	-3.2387 ± 1.939	-2.8056 ± 1.8603	-3.0343 ± 1.6217
	O2	-2.3468 ± 1.3811	-2.044 ± 1.7525	-1.9724 ± 1.2671	1.9748 ± 1.6
Midline	Pz	-0.8125 ± 1.1102	-0.5805 ± 1.037	-1.1386 ± 1.3809	-0.751 ± 1.0131
	Oz	-1.74 ± 1.2902	-1.5681 ± 1.6711	-1.7375 ± 1.2564	-1.4762 ± 1.5562

Table 5: P3 ERP *Peak Latency* – Aerobic Exercise

Aerobic					
P3 peak latency ± SD		*Single*		*Dual*	
		Pre	*Post*	*Pre*	*Post*
Left	C3	298.73 ± 28.33	303.13 ± 36.98	309.33 ± 51.34	308.33 ± 31.67
	CP1	310.13 ± 28.06	320.8 ± 31.15	317.53 ± 48.23	326.2 ± 24.29
	CP5	311.87 ± 26.58	330.47 ± 44.52	314.8 ± 44.52	319.33 ± 33.92
	P3	346.4 ± 31.81	331.93 ± 34.82	350.07 ± 35.19	342.6 ± 43.6
	P7	343.93 ± 28.76	336.33 ± 55.32	351.33 ± 35.75	346.27 ± 50.1
	O1	330.93 ± 36.58	331 ± 53.29	341.87 ± 41.37	321.13 ± 48.37
Right	C4	303.2 ± 36.6	312.73 ± 44.13	302.87 ± 40.56	313.67 ± 37
	CP2	315.47 ± 31.75	322.87 ± 34.42	322.07 ± 41.7	309.93 ± 25.97
	CP6	317.93 ± 38.12	317.2 ± 40.29	302.53 ± 37.61	317.53 ± 29.14
	P4	337.87 ± 35.54	334.13 ± 38.59	344.87 ± 40.95	342.33 ± 52.55
	P8	343.13 ± 33.72	330.27 ± 48.14	352.6 ± 49.41	345.07 ± 52.95
	O2	330.87 ± 37.6	330.67 ± 54.56	340.13 ± 40.54	326.27 ± 50.05

Table 6: P3 ERP *Peak Latency* – Resistance Exercise

Resistance					
P3 peak latency ± SD		*Single*		*Dual*	
		Pre	*Post*	*Pre*	*Post*
Left	C3	312.27 ± 35.02	309.47 ± 29.21	302.13 ± 37.03	323.4 ± 43.2
	CP1	316.33 ± 29.83	310.87 ± 30.78	303.8 ± 40.27	325.2 ± 35.38
	CP5	317.2 ± 34.32	310.8 ± 34.47	304.6 ± 33.59	321.4 ± 33.85
	P3	334.8 ± 36.57	338.47 ± 36.18	340.2 ± 29.73	337.73 ± 31.93
	P7	338.73 ± 47.01	341.6 ± 40.46	339.87 ± 41.59	343.33 ± 35.02
	O1	332 ± 55.91	328.47 ± 55.33	336.73 ± 51.23	319.53 ± 58.09
Right	C4	303.53 ± 35.7	309.33 ± 30.99	297.8 ± 27.38	310.87 ± 32.77
	CP2	314.2 ± 28.09	309.2 ± 30.02	295.6 ± 27.17	321.2 ± 30.67
	CP6	309.73 ± 34.37	303.53 ± 26.62	301.4 ± 25.22	316.47 ± 32.86
	P4	331.4 ± 44.35	340.33 ± 39.29	341.4 ± 29.16	343.6 ± 42.34
	P8	329 ± 50.12	338 ± 51.38	347.4 ± 45.58	343.33 ± 50.86
	O2	334 ± 58.39	328 ± 54.53	338.8 ± 53.17	319 ± 57.52
Midline	Cz	305.4 ± 33.75	303.27 ± 31.33	292.6 ± 26.84	310 ± 34.83
	Pz	337.33 ± 37.09	334.8 ± 38.98	340.07 ± 31.43	333.4 ± 34.27
	Oz	332.53 ± 58.12	328.67 ± 56.23	336.33 ± 53.23	318.87 ± 58.5

Table 7: P3 ERP *Mean Amplitude* (300 - 400 ms) – Aerobic Exercise

Aerobic					
P3 300 400 ± SD		*Single*		*Dual*	
		Pre	*Post*	*Pre*	*Post*
Left	C3	0.5312 ± 0.7486	0.4207 ± 0.6456	0.21478 ± 0.6608	0.3229 ± 0.7942
	CP1	0.5696 ± 1.2442	1.0263 ± 1.4519	0.3195 ± 1.1571	0.629 ± 1.6364
	CP5	-0.1764 ± 1.4283	0.0572 ± 1.3915	-0.2314 ± 1.1817	0.4138 ± 0.827
	P3	0.8635 ± 1.3749	1.2844 ± 1.447	0.6157 ± 1.0342	0.8471 ± 1.7723
	P7	-1.3744 ± 2.2472	-0.4614 ± 2.3148	-1.0991 ± 1.8349	-0.0355 ± 1.9249
	O1	-0.6651 ± 1.8754	0.2809 ± 2.0208	-0.3466 ± 1.5393	0.3532 ± 1.9993
Right	C4	1.4418 ± 0.9787	0.9682 ± 2.532	1.1103 ± 1.0114	1.8664 ± 2.0797
	CP2	1.234 ± 1.3463	1.4006 ± 1.0766	0.9089 ± 1.4754	1.1562 ± 1.5967
	CP6	0.558 ± 1.1485	0.7882 ± 1.4348	0.5972 ± 1.1355	0.9799 ± 1.346
	P4	1.2421 ± 1.2841	1.4933 ± 1.7676	1.1189 ± 1.2256	1.1468 ± 1.747
	P8	-0.7296 ± 1.9963	0.088 ± 2.1234	-0.2269 ± 1.79	0.3116 ± 2.1209
	O2	-0.7962 ± 1.9232	0.3931 ± 2.0828	-0.3768 ± 1.4302	0.5247 ± 2.1639

Table 8: P3 ERP *Mean Amplitude* (300 - 400 ms) – Resistance Exercise

Resistance					
P3 300 400 ± SD		*Single*		*Dual*	
		Pre	*Post*	*Pre*	*Post*
Left	C3	0.7003 ± 0.7088	0.6782 ± 0.7291	0.442 ± 0.5293	0.298 ± 0.826
	CP1	1.1995 ± 0.9977	0.8712 ± 0.9176	0.6348 ± 0.8675	0.4008 ± 1.3423
	CP5	0.1401 ± 0.9003	0.0487 ± 0.8803	0.0168 ± 0.9068	-0.0009 ± 0.7127
	P3	1.2677 ± 1.0971	1.108 ± 0.9499	0.7878 ± 0.7805	0.8866 ± 1.2098
	P7	-0.8343 ± 1.7779	-0.9194 ± 1.7169	-0.8443 ± 1.5025	-0.6635 ± 1.4254
	O1	-0.253 ± 1.78	-0.0766 ± 1.8721	-0.3012 ± 1.433	-0.0018 ± 1.9101
Right	C4	1.3292 ± 1.0212	1.0399 ± 1.1936	1.0341 ± 1.1909	0.949 ± 1.1456
	CP2	1.5196 ± 1.2067	1.0408 ± 1.164	1.0017 ± 1.3481	0.692 ± 1.568
	CP6	0.4748 ± 1.1848	0.3359 ± 1.336	0.4267 ± 1.1203	0.4347 ± 1.2846
	P4	1.2347 ± 1.4521	0.9831 ± 1.1816	0.954 ± 1.2897	0.9273 ± 1.4567
	P8	-0.7019 ± 1.4672	-0.6147 ± 1.7077	-0.4425 ± 1.385	-0.4415 ± 1.5745
	O2	-0.5911 ± 1.6503	-0.4358 ± 1.6548	-0.423 ± 1.2711	-0.3697 ± 1.8191
Midline	Cz	0.7888 ± 1.3738	0.3689 ± 1.4962	0.3066 ± 1.148	-0.2884 ± 1.7352
	Pz	1.2002 ± 1.3735	0.9142 ± 1.042	0.6588 ± 1.1883	0.6085 ± 1.6541
	Oz	-0.4438 ± 1.7261	-0.2408 ± 1.8393	-0.3295 ± 1.3697	-0.1913 ± 1.9364

Table 9: P3 ERP *Mean Amplitude* (400 – 500 ms) – Aerobic Exercise

Aerobic					
P3 400 500 ± SD		*Single*		*Dual*	
		Pre	*Post*	*Pre*	*Post*
Left	C3	0.4433 ± 0.7057	0.3678 ± 0.8369	0.3291 ± 0.6508	0.4109 ± 0.926
	CP1	0.4014 ± 1.352	1.3081 ± 1.8359	0.3009 ± 1.1617	1.0673 ± 1.7195
	CP5	0.8114 ± 0.7563	0.7554 ± 1.1884	0.8065 ± 0.8434	1.2084 ± 0.7408
	P3	1.4661 ± 1.0713	2.3327 ± 2.1025	1.2945 ± 1.0482	1.8996 ± 1.8485
	P7	0.0041 ± 1.8194	0.9613 ± 2.949	0.26 ± 1.7421	1.4325 ± 2.2768
	O1	0.1497 ± 1.745	1.3197 ± 3.0217	0.2613 ± 1.6712	1.4237 ± 2.2146
Right	C4	0.4441 ± 0.9026	2.4898 ± 3.4012	0.3021 ± 1.1781	2.7056 ± 4.9627
	CP2	0.5139 ± 1.5341	0.7605 ± 1.5563	0.4134 ± 1.326	0.6574 ± 1.5658
	CP6	0.6307 ± 1.0949	0.9968 ± 1.4448	0.8096 ± 1.0584	1.204 ± 1.3793
	P4	1.227 ± 1.279	2.395 ± 2.2658	1.1948 ± 1.0236	1.8497 ± 2.0023
	P8	-0.1094 ± 1.808	1.1264 ± 2.1585	0.5562 ± 1.7772	1.3609 ± 2.3084
	O2	0.0224 ± 1.5232	1.3321 ± 2.3994	0.2893 ± 1.3865	1.4528 ± 2.1747
Midline	Cz	-0.885 ± 1.8752	3.9764 ± 9.0273	-1.1809 ± 1.921	1.5289 ± 9.0529
	Pz	1.1193 ± 1.617	2.0533 ± 1.8661	0.9883 ± 1.4801	1.6126 ± 1.8767
	Oz	0.1199 ± 1.5954	1.3978 ± 3.1076	0.2276 ± 1.4652	1.4219 ± 2.3808

Table 10: P3 ERP *Mean Amplitude* (400 – 500 ms) – Resistance Exercise

Resistance					
P3 400 500 ± SD		*Single*		*Dual*	
		Pre	*Post*	*Pre*	*Post*
Left	C3	0.6159 ± 0.8917	0.51148 ± 0.8223	0.446 ± 0.7937	0.2874 ± 0.8787
	CP1	0.8991 ± 1.1109	0.5639 ± 1.2927	0.6449 ± 1.1189	0.2847 ± 1.4455
	CP5	0.9615 ± 0.8992	0.891 ± 0.8229	0.9641 ± 0.7635	0.9961 ± 0.9129
	P3	1.596 ± 1.1054	1.3684 ± 1.1232	1.5659 ± 1.0289	1.3348 ± 1.1364
	P7	0.274 ± 1.491	0.1855 ± 1.2411	0.5151 ± 1.3649	0.6109 ± 1.5101
	O1	0.1661 ± 1.6473	0.1312 ± 1.4992	0.6154 ± 1.6242	0.3154 ± 1.5982
Right	C4	0.2939 ± 1.0985	0.227 ± 1.1583	0.0739 ± 1.1024	0.0816 ± 1.3056
	CP2	0.7242 ± 1.3572	0.3651 ± 1.5845	0.5211 ± 1.3569	0.1366 ± 1.58
	CP6	0.5121 ± 0.8556	0.7119 ± 1.08	0.4955 ± 0.9267	0.7851 ± 1.0623
	P4	0.9827 ± 1.3533	1.0142 ± 1.4374	1.0372 ± 1.2926	0.9669 ± 1.3253
	P8	-0.1728 ± 1.0033	0.2641 ± 1.5391	0.111 ± 1.3491	0.4573 ± 1.4547
	O2	-0.1463 ± 1.1859	0.137 ± 1.4075	0.4432 ± 1.3322	0.2318 ± 1.5493
Midline	Cz	-0.7918 ± 1.6366	-1.1174 ± 1.691	-1.1099 ± 1.3085	-1.6066 ± 2.0318
	Pz	1.2567 ± 1.4061	0.9668 ± 1.586	1.2098 ± 1.3886	0.7508 ± 1.566
	Oz	-0.0235 ± 1.3852	0.0607 ± 1.3982	0.5401 ± 1.4375	0.226 ± 1.5864

Table 11: P3 ERP *Mean Amplitude* (500 – 600 ms) – Aerobic Exercise

Aerobic					
P3 500 600 ± SD		*Single*		*Dual*	
		Pre	*Post*	*Pre*	*Post*
Left	C3	0.4088 ± 0.5557	0.2963 ± 0.859	0.1972 ± 0.6184	0.2482 ± 0.9553
	CP1	0.3428 ± 0.9595	1.3378 ± 1.6466	0.2499 ± 0.8607	1.197 ± 1.6537
	CP5	1.3526 ± 0.9819	0.9729 ± 0.8391	1.2025 ± 0.8705	1.2044 ± 1.0323
	P3	1.6835 ± 1.0054	2.5859 ± 2.1976	1.4927 ± 0.8796	2.2675 ± 1.6372
	P7	1.0374 ± 1.4767	1.8297 ± 2.724	1.0405 ± 1.4863	2.0582 ± 2.332
	O1	0.8264 ± 1.5993	2.0434 ± 2.9076	1.0219 ± 1.8619	2.0883 ± 2.5389
Right	C4	0.0643 ± 0.746	2.9993 ± 5.0621	-0.1545 ± 1.2076	3.7189 ± 7.3297
	CP2	0.1877 ± 1.4584	0.4884 ± 1.4843	0.069 ± 1.3267	0.6132 ± 1.4265
	CP6	0.8352 ± 0.9714	0.9979 ± 1.2033	0.8427 ± 0.923	1.2848 ± 1.5199
	P4	1.3289 ± 1.1433	2.7371 ± 2.3742	1.3747 ± 0.9982	2.5773 ± 2.3033
	P8	0.7394 ± 1.4702	1.8423 ± 2.0887	1.2378 ± 1.5566	2.0867 ± 2.2991
	O2	0.8615 ± 1.6584	2.027 ± 2.3276	1.2944 ± 1.9192	2.1368 ± 2.2214
Midline	Cz	-1.6917 ± 1.5204	4.677 ± 10.8333	-1.9921 ± 1.8413	2.1453 ± 10.4029
	Pz	1.0785 ± 1.4556	2.2777 ± 1.8505	1.1008 ± 1.2781	1.9265 ± 1.6459
	Oz	0.8229 ± 1.8114	2.249 ± 3.3426	1.1234 ± 2.0767	2.382 ± 3.0071

Table 12: P3 ERP *Mean Amplitude* (500 – 600 ms) – Resistance Exercise

Resistance					
P3 500 600 ± SD		*Single*		*Dual*	
		Pre	*Post*	*Pre*	*Post*
Left	C3	0.4995 ± 0.9175	0.4113 ± 0.8622	0.30589 ± 0.5765	0.3545 ± 0.6381
	CP1	0.6069 ± 0.8943	0.5382 ± 0.8695	0.4701 ± 0.9387	0.5399 ± 0.8562
	CP5	1.2555 ± 0.8718	1.0938 ± 1.0024	1.3473 ± 0.8094	1.2456 ± 0.8909
	P3	1.6065 ± 0.9839	1.3849 ± 0.8758	1.7076 ± 1.0497	1.6372 ± 0.885
	P7	0.9944 ± 1.3434	0.8228 ± 1.2855	1.404 ± 1.5055	1.1174 ± 1.3692
	O1	0.6687 ± 1.4429	0.3113 ± 1.3629	1.1055 ± 1.4839	0.8153 ± 1.4268
Right	C4	-0.0388 ± 0.8963	0.0822 ± 0.8914	-0.1392 ± 0.9076	0.0497 ± 0.9655
	CP2	0.3972 ± 1.2951	0.2154 ± 1.1876	0.2958 ± 1.1113	0.2555 ± 1.1461
	CP6	0.7284 ± 0.6427	0.9836 ± 0.8585	0.8906 ± 0.9613	1.056 ± 0.9648
	P4	1.029 ± 1.1313	1.1282 ± 0.9797	1.2103 ± 1.1861	1.3526 ± 0.8332
	P8	0.5128 ± 1.0448	1.0055 ± 1.1532	1.0712 ± 1.4794	1.1105 ± 1.3032
	O2	0.452 ± 1.4739	0.5712 ± 1.3187	1.2116 ± 1.6799	0.8837 ± 1.5237
Midline	Cz	-1.6946 ± 1.6645	-1.63 ± 1.6519	-1.9467 ± 1.3477	-1.772 ± 1.8886
	Pz	1.2278 ± 1.1628	0.9673 ± 1.2965	1.2751 ± 1.2577	1.2105 ± 1.1399
	Oz	0.5216 ± 1.5555	0.2648 ± 1.5006	1.1096 ± 1.622	0.6951 ± 1.6625

Appendix 12: Study Three (Aerobic and Resistance Exercise), Repeated Measures ANOVA statistical results

Behavioural Data

Table 1: Trial completion time

Per trial completion time (seconds)		
Aerobic	***df***	
Time	(1,14)	$F = 8.58$; $p = .01$, $\eta_p^2 = .38$
Task		$F = 1.71$; $p = .21$, $\eta_p^2 = .11$
Resistance		
Time		$F = 8.87$; $p = .01$, $\eta_p^2 = .39$
Task		$F = 7.00$; $p = .02$, $\eta_p^2 = .33$

Neurophysiological Data

Table 2: N2 ERP *Peak Latency* – Aerobic compared to Resistance Exercise

N2 *Peak Latency*	***df***	**Left and Right Hemisphere**	***df***	**Midline**
Exercise	(1,14)	$F = 0.01$; $p = .91$, $\eta_p^2 = .00$	(1,14)	$F = 0.00$; $p = .97$, $\eta_p^2 = .00$
Time		$F = 11.69$; $p = .00$, $\eta_p^2 = .46$		$F = 7.66$; $p = .02$, $\eta_p^2 = .35$
Task		$F = 0.70$; $p = .42$, $\eta_p^2 = .05$		$F = 0.05$; $p = .83$, $\eta_p^2 = .00$
Electrode	(2,28)	$F = 2.43$; $p = .13$, $\eta_p^2 = .15$		$F = 0.42$; $p = .53$, $\eta_p^2 = .03$
Hemisphere	(1,14)	$F = 2.42$; $p = .14$, $\eta_p^2 = .15$		
Exercise*Time		$F = 1.50$; $p = .24$, $\eta_p^2 = .10$	(1,14)	$F = 3.35$; $p = .09$, $\eta_p^2 = .19$
Exercise*Task		$F = 0.14$; $p = .71$, $\eta_p^2 = .01$		$F = 0.34$; $p = .57$, $\eta_p^2 = .02$
Time*Task		$F = 1.85$; $p = .20$, $\eta_p^2 = .12$		$F = 0.43$; $p = .53$, $\eta_p^2 = .03$
Exercise*Time*Task		$F = 3.20$; $p = .10$, $\eta_p^2 = .19$		$F = 2.47$; $p = .14$, $\eta_p^2 = .15$
Exercise*Electrode	(2,28)	$F = 0.94$; $p = .37$, $\eta_p^2 = .06$		$F = 1.25$; $p = .28$, $\eta_p^2 = .08$
Time*Electrode		$F = 0.18$; $p = .75$, $\eta_p^2 = .01$		$F = 1.04$; $p = .33$, $\eta_p^2 = .07$

Exercise*Time*Electrode	(2,28)	$F = 0.16$; $p = .74$, $\eta_p^2 = .01$	(1,14)	$F = 0.02$; $p = .89$, $\eta_p^2 = .00$
Task*Electrode		$F = 3.74$; $p = .05$, $\eta_p^2 = .21$		$F = 3.35$; $p = .09$, $\eta_p^2 = .19$
Exercise*Task*Electrode		$F = 0.52$; $p = .57$, $\eta_p^2 = .04$		$F = 0.03$; $p = .87$, $\eta_p^2 = .00$
Time*Task*Electrode		$F = 0.80$; $p = .42$, $\eta_p^2 = .05$		$F = 0.43$; $p = .52$, $\eta_p^2 = .03$
Exercise*Time*Task* Electrode		$F = 0.05$; $p = .85$, $\eta_p^2 = .00$		$F = 0.01$; $p = .92$, $\eta_p^2 = .00$
Exercise*Hemisphere	(1,14)	$F = 0.32$; $p = .58$, $\eta_p^2 = .02$		
Time*Hemisphere		$F = 0.15$; $p = .71$, $\eta_p^2 = .01$		
Exercise*Time* Hemisphere		$F = 0.04$; $p = .85$, $\eta_p^2 = .00$		
Task*Hemisphere		$F = 0.05$; $p = .83$, $\eta_p^2 = .00$		
Exercise*Task* Hemisphere		$F = 0.00$; $p = .95$, $\eta_p^2 = .00$		
Time*Task*Hemisphere		$F = 0.04$; $p = .85$, $\eta_p^2 = .00$		
Exercise*Time*Task* Hemisphere		$F = 4.74$; $p = .05$, $\eta_p^2 = .25$		
Electrode*Hemisphere	(2,28)	$F = 2.81$; $p = .09$, $\eta_p^2 = .02$		
Exercise*Electrode* Hemisphere		$F = 1.72$; $p = .20$, $\eta_p^2 = .11$		
Time*Electrode* Hemisphere		$F = 0.25$; $p = .77$, $\eta_p^2 = .02$		
Exercise*Time* Electrode*Hemisphere		$F = 0.85$; $p = .41$, $\eta_p^2 = .06$		
Task*Electrode* Hemisphere		$F = 0.42$; $p = .57$, $\eta_p^2 = .03$		
Exercise*Task* Electrode*Hemisphere		$F = 0.33$; $p = .68$, $\eta_p^2 = .02$		
Time*Task*Electrode* Hemisphere		$F = 0.26$; $p = .73$, $\eta_p^2 = .02$		
Exercise*Time*Task* Electrode*Hemisphere		$F = 0.57$; $p = .73$, $\eta_p^2 = .02$		

Table 3: N2 ERP *Mean Amplitude* (180 – 220 ms) – Aerobic compared to Resistance Exercise

N2 (180 – 220 ms)	*df*	Left and Right Hemisphere	*df*	Midline
Exercise	(1,14)	$F = 0.00$; $p = .98$, $\eta_p^2 = .00$	(1,14)	$F = 0.02$; $p = .90$, $\eta_p^2 = .00$
Time		$F = 0.00$; $p = .999$, $\eta_p^2 = .00$		$F = 13.89$; $p = .00$, $\eta_p^2 = .50$
Task		$F = 0.01$; $p = .93$, $\eta_p^2 = .00$		$F = 0.57$; $p = .46$, $\eta_p^2 = .04$
Electrode	(2,28)	$F = 10.63$; $p = .00$, $\eta_p^2 = .43$		$F = 6.93$; $p = .02$, $\eta_p^2 = .33$
Hemisphere	(1,14)	$F = 0.94$; $p = .35$, $\eta_p^2 = .06$		
Exercise*Time		$F = 0.00$; $p = .998$, $\eta_p^2 = .00$	(1,14)	$F = 0.38$; $p = .55$, $\eta_p^2 = .03$
Exercise*Task		$F = 1.03$; $p = .33$, $\eta_p^2 = .07$		$F = 0.21$; $p = .66$, $\eta_p^2 = .01$
Time*Task		$F = 0.02$; $p = .90$, $\eta_p^2 = .00$		$F = 0.05$; $p = .84$, $\eta_p^2 = .00$
Exercise*Time*Task		$F = 1.22$; $p = .29$, $\eta_p^2 = .08$		$F = 1.29$; $p = .28$, $\eta_p^2 = .08$
Exercise*Electrode	(2,28)	$F = 1.18$; $p = .32$, $\eta_p^2 = .08$	(1,14)	$F = 1.12$; $p = .31$, $\eta_p^2 = .07$
Time*Electrode		$F = 14.41$; $p = .00$, $\eta_p^2 = .51$		$F = 0.82$; $p = .38$, $\eta_p^2 = .06$
Exercise*Time*Electrode		$F = 0.51$; $p = .57$, $\eta_p^2 = .04$		$F = 0.03$; $p = .87$, $\eta_p^2 = .00$
Task*Electrode		$F = 1.57$; $p = .23$, $\eta_p^2 = .10$		$F = 0.11$; $p = .75$, $\eta_p^2 = .01$
Exercise*Task*Electrode		$F = 1.30$; $p = .29$, $\eta_p^2 = .09$		$F = 5.48$; $p = .04$, $\eta_p^2 = .28$
Time*Task*Electrode		$F = 0.61$; $p = .53$, $\eta_p^2 = .04$		$F = 0.03$; $p = .88$, $\eta_p^2 = .00$
Exercise*Time*Task* Electrode		$F = 0.12$; $p = .85$, $\eta_p^2 = .01$		$F = 0.02$; $p = .90$, $\eta_p^2 = .00$
Exercise*Hemisphere	(1,14)	$F = 0.33$; $p = .57$, $\eta_p^2 = .02$		
Time*Hemisphere		$F = 0.17$; $p = .68$, $\eta_p^2 = .01$		
Exercise*Time* Hemisphere		$F = 4.78$; $p = .05$, $\eta_p^2 = .25$		
Task*Hemisphere		$F = 5.35$; $p = .04$, $\eta_p^2 = .28$		
Exercise*Task* Hemisphere		$F = 0.01$; $p = .93$, $\eta_p^2 = .00$		
Time*Task*Hemisphere		$F = 0.30$; $p = .59$, $\eta_p^2 = .02$		

Exercise*Time*Task* Hemisphere	(1,14)	F = 4.63; p = .05, η_p^2 = .25	
Electrode*Hemisphere	(2,28)	F = 1.65; p = .22, η_p^2 = .11	
Exercise*Electrode* Hemisphere		F = 1.36; p = .27, η_p^2 = .09	
Time*Electrode* Hemisphere		F = 1.87; p = .18, η_p^2 = .12	
Exercise*Time* Electrode*Hemisphere		F = 1.41; p = .26, η_p^2 = .09	
Task*Electrode* Hemisphere		F = 0.58; p = .11, η_p^2 = .15	
Exercise*Task* Electrode*Hemisphere		F = 2.37; p = .53, η_p^2 = .04	
Time*Task*Electrode* Hemisphere		F = 0.36; p = .70, η_p^2 = .03	
Exercise*Time*Task* Electrode*Hemisphere		F = 1.76; p = .20, η_p^2 = .11	

Table 4: P3 ERP *Peak Latency* – Aerobic compared to Resistance Exercise

P3 *Peak Latency*	*df*	Left and Right Hemisphere	*df*	Midline
Exercise	(1,14)	$F = 0.27$; $p = .61$, $\eta_p^2 = .02$	(1,14)	$F = 1.30$; $p = .27$, $\eta_p^2 = .09$
Time		$F = 0.00$; $p = .96$, $\eta_p^2 = .00$		$F = 0.14$; $p = .71$, $\eta_p^2 = .01$
Task		$F = 1.03$; $p = .33$, $\eta_p^2 = .07$		$F = 0.03$; $p = .87$, $\eta_p^2 = .00$
Electrode	(4,56)	$F = 11.24$; $p = .00$, $\eta_p^2 = .45$		$F = 10.26$; $p = .00$, $\eta_p^2 = .42$
Hemisphere	(1,14)	$F = 0.33$; $p = .58$, $\eta_p^2 = .02$		
Exercise*Time		$F = 0.62$; $p = .44$, $\eta_p^2 = .04$	(1,14)	$F = 0.09$; $p = .76$, $\eta_p^2 = .01$
Exercise*Task		$F = 0.31$ $p = .59$, $\eta_p^2 = .02$		$F = 0.12$; $p = .74$, $\eta_p^2 = .01$
Time*Task		$F = 0.00$; $p = .97$, $\eta_p^2 = .00$		$F = 0.64$; $p = .44$, $\eta_p^2 = .04$
Exercise*Time*Task		$F = 0.74$; $p = .41$, $\eta_p^2 = .05$		$F = 4.28$; $p = .06$, $\eta_p^2 = .23$
Exercise*Electrode	(4,56)	$F = 0.29$; $p = .77$, $\eta_p^2 = .02$		$F = 0.14$; $p = .87$, $\eta_p^2 = .01$
Time*Electrode		$F = 2.51$; $p = .10$, $\eta_p^2 = .15$		$F = 7.00$; $p = .00$, $\eta_p^2 = .33$
Exercise*Time*Electrode		$F = 0.37$; $p = .69$, $\eta_p^2 = .03$		$F = 0.44$; $p = .62$, $\eta_p^2 = .03$
Task*Electrode		$F = 0.66$; $p = .51$, $\eta_p^2 = .05$		$F = 0.45$; $p = .60$, $\eta_p^2 = .03$
Exercise*Task*Electrode		$F = 0.00$; $p = .99$, $\eta_p^2 = .00$		$F = 0.08$; $p = .83$, $\eta_p^2 = .01$
Time*Task*Electrode		$F = 1.85$; $p = .18$, $\eta_p^2 = .12$		$F = 1.43$; $p = .26$, $\eta_p^2 = .09$
Exercise*Time*Task* Electrode		$F = 1.49$; $p = .24$, $\eta_p^2 = .10$		$F = 3.07$; $p = .08$, $\eta_p^2 = .18$
Exercise*Hemisphere	(1,14)	$F = 0.50$; $p = .49$, $\eta_p^2 = .03$		
Time*Hemisphere		$F = 0.12$; $p = .73$, $\eta_p^2 = .01$		
Exercise*Time* Hemisphere		$F = 0.00$; $p = .98$, $\eta_p^2 = .00$		
Task*Hemisphere		$F = 0.08$; $p = .79$, $\eta_p^2 = .01$		
Exercise*Task* Hemisphere		$F = 1.15$; $p = .30$, $\eta_p^2 = .08$		
Time*Task*Hemisphere		$F = 0.76$; $p = .40$, $\eta_p^2 = .05$		

Exercise*Time*Task* Hemisphere	(1,14)	$F = 0.31$; $p = .59$, $\eta_p^2 = .02$	
Electrode*Hemisphere	(4,56)	$F = 0.25$; $p = .83$, $\eta_p^2 = .02$	
Exercise*Electrode* Hemisphere		$F = 1.95$; $p = .14$, $\eta_p^2 = .12$	
Time*Electrode* Hemisphere		$F = 2.29$; $p = .09$, $\eta_p^2 = .14$	
Exercise*Time* Electrode*Hemisphere		$F = 1.34$; $p = .28$, $\eta_p^2 = .09$	
Task*Electrode* Hemisphere		$F = 1.88$; $p = .18$, $\eta_p^2 = .12$	
Exercise*Task* Electrode*Hemisphere		$F = 0.23$; $p = .84$, $\eta_p^2 = .02$	
Time*Task*Electrode* Hemisphere		$F = 0.22$; $p = .81$, $\eta_p^2 = .02$	
Exercise*Time*Task* Electrode*Hemisphere		$F = 2.07$; $p = .14$, $\eta_p^2 = .13$	

Table 4: P3 ERP *Mean Amplitude* (300 – 400 ms) – Aerobic compared to Resistance Exercise

P3 (300 – 400 ms)	*df*	Left and Right Hemisphere	*df*	Midline
Exercise	(1,14)	$F = 0.74$; $p = .40$, $\eta_p^2 = .05$	(1,14)	$F = 0.56$; $p = .47$, $\eta_p^2 = .04$
Time		$F = 5.56$; $p = .03$, $\eta_p^2 = .28$		$F = 0.65$; $p = .43$, $\eta_p^2 = .04$
Task		$F = 1.64$; $p = .22$, $\eta_p^2 = .11$		$F = 9.27$; $p = .01$, $\eta_p^2 = .40$
Electrode	(4,56)	$F = 8.50$; $p = .00$, $\eta_p^2 = .38$		$F = 2.51$; $p = .12$, $\eta_p^2 = .15$
Hemisphere	(1,14)	$F = 3.55$; $p = .08$, $\eta_p^2 = .20$		
Exercise*Time		$F = 4.80$; $p = .05$, $\eta_p^2 = .26$	(1,14)	$F = 3.05$; $p = .10$, $\eta_p^2 = .18$
Exercise*Task		$F = 2.97$; $p = .11$, $\eta_p^2 = .18$		$F = 0.03$; $p = .87$, $\eta_p^2 = .00$
Time*Task		$F = 0.32$; $p = .58$, $\eta_p^2 = .02$		$F = 0.75$; $p = .40$, $\eta_p^2 = .05$
Exercise*Time*Task		$F = 0.07$; $p = .80$, $\eta_p^2 = .01$		$F = 0.67$; $p = .43$, $\eta_p^2 = .05$
Exercise*Electrode	(4,56)	$F = 0.42$; $p = .62$, $\eta_p^2 = .03$		$F = 0.25$; $p = .69$, $\eta_p^2 = .02$
Time*Electrode		$F = 4.50$; $p = .03$, $\eta_p^2 = .24$		$F = 0.65$; $p = .46$, $\eta_p^2 = .04$
Exercise*Time*Electrode		$F = 0.93$; $p = .38$, $\eta_p^2 = .06$		$F = 0.71$; $p = .47$, $\eta_p^2 = .05$
Task*Electrode		$F = 5.13$; $p = .02$, $\eta_p^2 = .27$		$F = 5.06$; $p = .03$, $\eta_p^2 = .27$
Exercise*Task*Electrode		$F = 0.33$; $p = .74$, $\eta_p^2 = .02$		$F = 0.92$; $p = .38$, $\eta_p^2 = .06$
Time*Task*Electrode		$F = 0.74$; $p = .48$, $\eta_p^2 = .05$		$F = 0.35$; $p = .61$, $\eta_p^2 = .02$
Exercise*Time*Task* Electrode		$F = 1.01$; $p = .38$, $\eta_p^2 = .07$		$F = 0.13$; $p = .81$, $\eta_p^2 = .01$
Exercise*Hemisphere	(1,14)	$F = 4.26$; $p = .06$, $\eta_p^2 = .23$		
Time*Hemisphere		$F = 0.52$; $p = .49$, $\eta_p^2 = .04$		
Exercise*Time* Hemisphere		$F = 0.04$; $p = .85$, $\eta_p^2 = .00$		
Task*Hemisphere		$F = 2.42$; $p = .14$, $\eta_p^2 = .15$		
Exercise*Task* Hemisphere		$F = 0.02$; $p = .89$, $\eta_p^2 = .00$		
Time*Task*Hemisphere		$F = 0.14$; $p = .71$, $\eta_p^2 = .01$		

Exercise*Time*Task* Hemisphere	(1,14)	F = 0.14; p = .71, η_p^2 = .01	
Electrode*Hemisphere	(4,56)	F = 7.54; p = .00, η_p^2 = .35	
Exercise*Electrode* Hemisphere		F = 0.16; p = .92, η_p^2 = .01	
Time*Electrode* Hemisphere		F = 0.77; p = .52, η_p^2 = .05	
Exercise*Time* Electrode*Hemisphere		F = 1.50; p = .23, η_p^2 = .10	
Task*Electrode* Hemisphere		F = 0.53; p = .52, η_p^2 = .04	
Exercise*Task* Electrode*Hemisphere		F = 0.53; p = .54, η_p^2 = .04	
Time*Task*Electrode* Hemisphere		F = 1.83; p = .19, η_p^2 = .12	
Exercise*Time*Task* Electrode*Hemisphere		F = 0.29; p = .64, η_p^2 = .02	

Table 5: P3 ERP *Mean Amplitude* (400 – 500 ms) – Aerobic compared to Resistance Exercise

P3 (400 – 500 ms)	*df*	Left and Right Hemisphere	*df*	Midline
Exercise	(1,14)	$F = 5.06$; $p = .04$, $\eta_p^2 = .27$	(1,14)	$F = 3.84$; $p = .07$, $\eta_p^2 = .22$
Time		$F = 9.78$; $p = .01$, $\eta_p^2 = .41$		$F = 2.78$; $p = .12$, $\eta_p^2 = .17$
Task		$F = 0.19$; $p = .67$, $\eta_p^2 = .01$		$F = 3.52$; $p = .08$, $\eta_p^2 = .20$
Electrode	(4,56)	$F = 3.22$; $p = .07$, $\eta_p^2 = .19$		$F = 3.80$; $p = .05$, $\eta_p^2 = .21$
Hemisphere	(1,14)	$F = 0.04$; $p = .84$, $\eta_p^2 = .00$		
Exercise*Time		$F = 5.60$; $p = .03$, $\eta_p^2 = .29$	(1,14)	$F = 4.46$; $p = .05$, $\eta_p^2 = .24$
Exercise*Task		$F = 0.01$; $p = .92$, $\eta_p^2 = .00$		$F = 2.74$; $p = .12$, $\eta_p^2 = .16$
Time*Task		$F = 0.39$; $p = .54$, $\eta_p^2 = .03$		$F = 2.64$; $p = .13$, $\eta_p^2 = .16$
Exercise*Time*Task		$F = 0.00$; $p = .99$, $\eta_p^2 = .00$		$F = 0.78$; $p = .39$, $\eta_p^2 = .05$
Exercise*Electrode	(4,56)	$F = 0.98$; $p = .38$, $\eta_p^2 = .07$		$F = 2.31$; $p = .15$, $\eta_p^2 = .14$
Time*Electrode		$F = 3.27$; $p = .04$, $\eta_p^2 = .19$		$F = 1.56$; $p = .23$, $\eta_p^2 = .10$
Exercise*Time*Electrode		$F = 0.53$; $p = .65$, $\eta_p^2 = .04$		$F = 2.55$; $p = .13$, $\eta_p^2 = .15$
Task*Electrode		$F = 3.39$; $p = .04$, $\eta_p^2 = .20$		$F = 7.00$; $p = .01$, $\eta_p^2 = .33$
Exercise*Task*Electrode		$F = 1.06$; $p = .36$, $\eta_p^2 = .07$		$F = 1.52$; $p = .24$, $\eta_p^2 = .10$
Time*Task*Electrode		$F = 0.41$; $p = .67$, $\eta_p^2 = .03$		$F = 1.37$; $p = .26$, $\eta_p^2 = .09$
Exercise*Time*Task* Electrode		$F = 0.40$; $p = .67$, $\eta_p^2 = .03$		$F = 2.43$; $p = .14$, $\eta_p^2 = .15$
Exercise*Hemisphere	(1,14)	$F = 6.57$; $p = .02$, $\eta_p^2 = .32$		
Time*Hemisphere		$F = 3.52$; $p = .08$, $\eta_p^2 = .20$		
Exercise*Time* Hemisphere		$F = 0.64$; $p = .44$, $\eta_p^2 = .04$		
Task*Hemisphere		$F = 0.15$; $p = .70$, $\eta_p^2 = .01$		
Exercise*Task* Hemisphere		$F = 0.07$; $p = .79$, $\eta_p^2 = .01$		
Time*Task*Hemisphere		$F = 0.53$; $p = .48$, $\eta_p^2 = .04$		

Exercise*Time*Task* Hemisphere	(1,14)	F = 0.01; p = .93, η_p^2 = .00	
Electrode*Hemisphere	(4,56)	F = 1.99; p = .15, η_p^2 = .12	
Exercise*Electrode* Hemisphere		F = 4.21; p = .05, η_p^2 = .23	
Time*Electrode* Hemisphere		F = 4.18; p = .05, η_p^2 = .23	
Exercise*Time* Electrode*Hemisphere		F = 5.00; p = .03, η_p^2 = .26	
Task*Electrode* Hemisphere		F = 0.03; p = .91, η_p^2 = .00	
Exercise*Task* Electrode*Hemisphere		F = 0.06; p = .85, η_p^2 = .01	
Time*Task*Electrode* Hemisphere		F = 0.61; p = .48, η_p^2 = .04	
Exercise*Time*Task* Electrode*Hemisphere		F = 0.13; p = .78, η_p^2 = .01	

Table 6: P3 ERP *Mean Amplitude* (500 – 600 ms) – Aerobic compared to Resistance Exercise

P3 (500 – 600 ms)	*df*	Left and Right Hemisphere	*df*	Midline
Exercise	(1,14)	$F = 6.35$; $p = .02$, $\eta_p^2 = .31$	(1,14)	$F = 5.09$; $p = .04$, $\eta_p^2 = .27$
Time		$F = 8.40$; $p = .01$, $\eta_p^2 = .38$		$F = 4.17$; $p = .06$, $\eta_p^2 = .23$
Task		$F = 4.04$; $p = .06$, $\eta_p^2 = .22$		$F = 1.18$; $p = .30$, $\eta_p^2 = .08$
Electrode	(4,56)	$F = 6.05$; $p = .01$, $\eta_p^2 = .30$		$F = 8.00$; $p = .01$, $\eta_p^2 = .36$
Hemisphere	(1,14)	$F = 0.01$; $p = .92$, $\eta_p^2 = .00$		
Exercise*Time		$F = 4.70$; $p = .05$, $\eta_p^2 = .25$	(1,14)	$F = 4.12$; $p = .06$, $\eta_p^2 = .23$
Exercise*Task		$F = 0.94$; $p = .35$, $\eta_p^2 = .06$		$F = 3.39$; $p = .09$, $\eta_p^2 = .20$
Time*Task		$F = 0.01$; $p = .93$, $\eta_p^2 = .00$		$F = 1.58$; $p = .23$, $\eta_p^2 = .10$
Exercise*Time*Task		$F = 0.09$; $p = .77$, $\eta_p^2 = .01$		$F = 2.11$; $p = .17$, $\eta_p^2 = .13$
Exercise*Electrode	(4,56)	$F = 2.59$; $p = .08$, $\eta_p^2 = .16$		$F = 2.99$; $p = .10$, $\eta_p^2 = .18$
Time*Electrode		$F = 1.64$; $p = .22$, $\eta_p^2 = .11$		$F = 2.98$; $p = .10$, $\eta_p^2 = .18$
Exercise*Time*Electrode		$F = 1.35$; $p = .28$, $\eta_p^2 = .09$		$F = 2.40$; $p = .14$, $\eta_p^2 = .15$
Task*Electrode		$F = 2.30$; $p = .13$, $\eta_p^2 = .14$		$F = 9.74$; $p = .01$, $\eta_p^2 = .41$
Exercise*Task*Electrode		$F = 0.73$; $p = .44$, $\eta_p^2 = .05$		$F = 1.85$; $p = .19$, $\eta_p^2 = .12$
Time*Task*Electrode		$F = 0.86$; $p = .45$, $\eta_p^2 = .06$		$F = 1.55$; $p = .23$, $\eta_p^2 = .10$
Exercise*Time*Task* Electrode		$F = 0.47$; $p = .62$, $\eta_p^2 = .03$		$F = 2.39$; $p = .14$, $\eta_p^2 = .15$
Exercise*Hemisphere	(1,14)	$F = 4.93$; $p = .04$, $\eta_p^2 = .26$		
Time*Hemisphere		$F = 9.69$; $p = .01$, $\eta_p^2 = .41$		
Exercise*Time* Hemisphere		$F = 3.09$; $p = .10$, $\eta_p^2 = .18$		
Task*Hemisphere		$F = 0.95$; $p = .35$, $\eta_p^2 = .06$		
Exercise*Task* Hemisphere		$F = 0.51$; $p = .49$, $\eta_p^2 = .04$		
Time*Task*Hemisphere		$F = 0.10$; $p = .76$, $\eta_p^2 = .01$		

Exercise*Time*Task* Hemisphere	(1,14)	$F = 0.23$; $p = .64$, $\eta_p^2 = .02$	
Electrode*Hemisphere	(4,56)	$F = 1.94$; $p = .17$, $\eta_p^2 = .12$	
Exercise*Electrode* Hemisphere		$F = 3.94$; $p = .06$, $\eta_p^2 = .22$	
Time*Electrode* Hemisphere		$F = 4.39$; $p = .05$, $\eta_p^2 = .24$	
Exercise*Time* Electrode*Hemisphere		$F = 4.79$; $p = .04$, $\eta_p^2 = .26$	
Task*Electrode* Hemisphere		$F = 0.08$; $p = .82$, $\eta_p^2 = .01$	
Exercise*Task* Electrode*Hemisphere		$F = 0.08$; $p = .82$, $\eta_p^2 = .01$	
Time*Task*Electrode* Hemisphere		$F = 0.62$; $p = .50$, $\eta_p^2 = .04$	
Exercise*Time*Task* Electrode*Hemisphere		$F = 0.22$; $p = .70$, $\eta_p^2 = .02$	

Table 7: N2 ERP *Peak Latency*– Aerobic Exercise

N2 *Peak Latency*	*df*	Left and Right Hemisphere	*df*	Midline
Time	(1,14)	$F = 8.94$; $p = .01$ $\eta_p^2 = .39$	(1,14)	$F = 9.13$; $p = .01$, $\eta_p^2 = .40$
Task		$F = 0.47$; $p = .50$, $\eta_p^2 = .03$		$F = 0.30$; $p = .60$, $\eta_p^2 = .02$
Recording Hemisphere		$F = 1.90$; $p = .19$, $\eta_p^2 = .12$		
Electrode Site	(2,28)	$F = 2.89$; $p = .09$, $\eta_p^2 = .17$		$F = 1.03$; $p = .33$, $\eta_p^2 = .07$
Time*Task	(1,14)	$F = 3.83$; $p = .07$, $\eta_p^2 = .22$		$F = 2.22$; $p = .16$, $\eta_p^2 = .14$
Time*Recording Hemisphere		$F = 0.04$; $p = .84$, $\eta_p^2 = .00$		
Task*Recording Hemisphere		$F = 0.07$; $p = .80$, $\eta_p^2 = .01$		
Time*Task*Recording Hemisphere		$F = 1.04$; $p = .33$, $\eta_p^2 = .07$		
Time*Electrode Site	(2,28)	$F = 0.27$; $p = .67$, $\eta_p^2 = .02$		$F = 0.46$; $p = .51$, $\eta_p^2 = .03$
Task*Electrode Site		$F = 1.77$; $p = .19$, $\eta_p^2 = .11$		$F = 1.22$; $p = .29$, $\eta_p^2 = .08$
Time*Task*Electrode Site		$F = 0.45$; $p = .57$, $\eta_p^2 = .03$		$F = 0.20$; $p = .66$, $\eta_p^2 = .01$
Recording Hemisphere *Electrode Site		$F = 1.21$; $p = .31$, $\eta_p^2 = .08$		
Time* Recording Hemisphere*Electrode Site		$F = 0.20$; $p = .77$, $\eta_p^2 = .01$		
Task*Recording Hemisphere*Electrode Site		$F = 0.09$; $p = .86$, $\eta_p^2 = .01$		
Time*Task*Recording Hemisphere*Electrode Site		$F = 0.05$; $p = .93$, $\eta_p^2 = .04$		

Table 8: N2 ERP *Peak Latency* – Resistance Exercise

N2 *Peak Latency*	*df*	Left and Right Hemisphere	*df*	Midline
Time	(1,14)	$F = 3.64$; $p = .08$, $\eta_p^2 = .21$	(1,14)	$F = 1.46$; $p = .25$, $\eta_p^2 = .10$
Task		$F = 0.02$; $p = .88$, $\eta_p^2 = .00$		$F = 0.21$; $p = .65$, $\eta_p^2 = .02$
Recording Hemisphere		$F = 1.92$; $p = .19$, $\eta_p^2 = .12$		
Electrode Site	(2,28)	$F = 0.59$; $p = .50$, $\eta_p^2 = .04$		$F = 0.01$; $p = .94$, $\eta_p^2 = .00$
Time*Task	(1,14)	$F = 0.56$: $p = .47$, $\eta_p^2 = .04$		$F = 1.04$; $p = .33$, $\eta_p^2 = .07$
Time*Recording Hemisphere		$F = 0.18$; $p = .68$, $\eta_p^2 = .01$		
Task*Recording Hemisphere		$F = 0.10$; $p = .92$, $\eta_p^2 = .00$		
Time*Task*Recording Hemisphere		$F = 1.31$; $p = .27$, $\eta_p^2 = .09$		
Time*Electrode Site	(2,28)	$F = 0.00$; $p = .98$, $\eta_p^2 = .00$		$F = 0.26$; $p = .62$, $\eta_p^2 = .02$
Task*Electrode Site		$F = 2.91$; $p = .11$, $\eta_p^2 = .17$		$F = 2.55$; $p = .13$, $\eta_p^2 = .15$
Time*Task*Electrode Site		$F = 0.13$; $p = .74$, $\eta_p^2 = .01$		$F = .011$; $p = .75$, $\eta_p^2 = .01$
Recording Hemisphere*Electrode Site		$F = 3.88$; $p = .04$, $\eta_p^2 = .22$		
Time*Recording Hemisphere*Electrode Site		$F = 0.75$; $p = .48$, $\eta_p^2 = .05$		
Task*Recording Hemisphere*Electrode Site		$F = 0.63$; $p = .48$, $\eta_p^2 = .04$		
Time*Task*Recording Hemisphere*Electrode Site		$F = 0.74$; $p = .50$, $\eta_p^2 = .05$		

Table 9: N2 ERP *Mean Amplitude* (180 – 220 ms) – Aerobic Exercise

N2 180 to 220 ms	*df*	Left and Right Hemisphere	*df*	Midline
Time	(1,14)	$F = 0.00$; $p = 0.999$, $\eta_p^2 = .00$	(1,14)	$F = 1.53$; $p = .24$, $\eta_p^2 = .10$
Task		$F = 0.37$; $p = .55$, $\eta_p^2 = .03$		$F = 0.01$; $p = .93$, $\eta_p^2 = .00$
Recording Hemisphere		$F = 1.19$; $p = .29$, $\eta_p^2 = .08$		
Electrode Site	(2,28)	$F = 12.31$; $p < .00$, $\eta_p^2 = .47$		$F = 7.97$; $p = .01$, $\eta_p^2 = .36$
Time*Task	(1,14)	$F = 0.48$; $p = .50$, $\eta_p^2 = .03$		$F = 0.80$; $p = .39$, $\eta_p^2 = .05$
Time*Recording Hemisphere		$F = 1.77$: $p = .20$, $\eta_p^2 = .11$		
Task*Recording Hemisphere		$F = 2.44$; $p = .14$, $\eta_p^2 = .15$		
Time*Task*Recording Hemisphere		$F = 0.79$; $p = .39$, $\eta_p^2 = .05$		
Time*Electrode Site	(2,28)	$F = 6.88$; $p = .01$, $\eta_p^2 = .33$		$F = 0.86$; $p = .37$, $\eta_p^2 = .06$
Task*Electrode Site		$F = 0.02$; $p = .98$, $\eta_p^2 = .00$		$F = 01.13$; $p = .31$, $\eta_p^2 = .07$
Time*Task*Electrode Site		$F = 0.39$; $p = .62$, $\eta_p^2 = .03$		$F = 0.00$; $p = .97$, $\eta_p^2 = .00$
Recording Hemisphere*Region		$F = 1.38$; $p = .27$, $\eta_p^2 = .09$		
Time*Recording Hemisphere*Electrode Site		$F = 4.39$; $p = 02$, $\eta_p^2 = .24$		
Task*Recording Hemisphere*Electrode Site		$F = 1.31$; $p = .29$, $\eta_p^2 = .09$		
Time*Task* Recording Hemisphere*Electrode Site		$F = 0.60$; $p = .51$, $\eta_p^2 = .04$		

Table 10: N2 ERP *Mean Amplitude* (180 – 220 ms) – Resistance Exercise

N2 180 to 220 ms	*df*	Left and Right Hemisphere	*df*	Midline
Time	(1,14)	$F = 0.00$; $p = .997$, $\eta_p^2 = .00$	(1,14)	$F = 7.84$; $p = .01$, $\eta_p^2 = .36$
Task		$F = 0.78$; $p = .39$, $\eta_p^2 = .05$		$F = 1.07$; $p = .32$, $\eta_p^2 = .07$
Recording Hemisphere		$F = 0.67$; $p = .43$, $\eta_p^2 = .05$		
Electrode Site	(2,28)	$F = 8.23$; $p = .00$, $\eta_p^2 = .37$		$F = 5.37$; $p = .04$, $\eta_p^2 = .28$
Time*Task	(1,14)	$F = 0.26$; $p = .62$, $\eta_p^2 = .02$		$F = 0.18$; $p = .68$, $\eta_p^2 = .01$
Time*Recording Hemisphere		$F = 1.15$; $p = .30$, $\eta_p^2 = .08$		
Task*Recording Hemisphere		$F = 2.61$; $p = .13$, $\eta_p^2 = .16$		
Time*Task*Recording Hemisphere		$F = 3.13$; $p = .10$, $\eta_p^2 = .18$		
Time*Electrode Site	(2,28)	$F = 7.48$; $p = .01$, $\eta_p^2 = .35$		$F = 0.28$; $p = .61$, $\eta_p^2 = .02$
Task*Electrode Site		$F = 4.26$; $p = .03$, $\eta_p^2 = .23$		$F = 4.75$; $p = .05$, $\eta_p^2 = .25$
Time*Task*Electrode Site		$F = 0.42$; $p = .64$, $\eta_p^2 = .03$		$F = 0.07$; $p = .80$, $\eta_p^2 = .01$
Recording Hemisphere*Electrode Site		$F = 1.98$; $p = .17$, $\eta_p^2 = .12$		
Time*Recording Hemisphere*Electrode Site		$F = 0.19$; $p = .82$, $\eta_p^2 = .01$		
Task*Recording Hemisphere*Electrode Site		$F = 1.49$; $p = .25$, $\eta_p^2 = .10$		
Time*Task*Recording Hemisphere*Region		$F = 1.81$; $p = .18$, $\eta_p^2 = .12$		

Table 11: P3 ERP *Peak Latency* – Aerobic Exercise

P3 *Peak Latency*	*df*	Left and Right Hemisphere	*df*	Midline
Time	(1,14)	$F = 0.54$; $p = .47$, $\eta_p^2 = .04$	(1,14)	$F = 0.00$; $p = .99$, $\eta_p^2 = .00$
Task		$F = 0.82$; $p = .38$, $\eta_p^2 = .06$		$F = 0.02$; $p = .90$, $\eta_p^2 = .00$
Recording Hemisphere		$F = 0.02$; $p = .90$, $\eta_p^2 = .00$		
Electrode Site	(4,56)	$F = 12.33$; $p = .00$, $\eta_p^2 = .47$	(2,28)	$F = 9.21$; $p = .00$, $\eta_p^2 = .40$
Time*Task	(1,14)	$F = 0.16$; $p = .70$, $\eta_p^2 = .01$	(1,14)	$F = 2.37$; $p = .15$, $\eta_p^2 = .15$
Time*Recording Hemisphere		$F = 0.05$; $p = .84$, $\eta_p^2 = .00$		
Task*Recording Hemisphere		$F = 0.73$; $p = .41$, $\eta_p^2 = .05$		
Time*Task*Recording Hemisphere		$F = 0.04$; $p = .84$, $\eta_p^2 = .00$		
Time*Electrode Site	(4,56)	$F = 1.22$; $p = .31$, $\eta_p^2 = .08$	(2,28)	$F = 8.53$; $p = .00$, $\eta_p^2 = .40$
Task*Electrode Site		$F = 0.25$; $p = .73$, $\eta_p^2 = .02$		$F = 0.28$; $p = .65$, $\eta_p^2 = .02$
Time*Task*Electrode Site		$F = 0.74$; $p = .46$, $\eta_p^2 = .05$		$F = 3.16$; $p = .06$, $\eta_p^2 = .18$
Electrode Site*Recording Hemisphere		$F = 0.50$; $p = .62$, $\eta_p^2 = .03$		
Time*Electrode Site*Recording Hemisphere		$F = 2.58$; $p = .08$, $\eta_p^2 = .16$		
Task*Electrode Site*Recording Hemisphere		$F = 1.07$; $p = .36$, $\eta_p^2 = .07$		
Time*Task*Electrode Site*Recording Hemisphere		$F = 0.74$; $p = .52$, $\eta_p^2 = .05$		

Table 12: P3 ERP *Peak Latency* – Resistance Exercise

P3 *Peak Latency*	*df*	Left and Right Hemisphere	*df*	Midline
Time	(1,14)	$F = 0.24$; $p = .63$, $\eta_p^2 = .02$	(1,14)	$F = 0.16$; $p = .69$, $\eta_p^2 = .01$
Task		$F = 0.25$; $p = .63$, $\eta_p^2 = .02$		$F = 0.22$; $p = .65$, $\eta_p^2 = .02$
Recording Hemisphere		$F = 0.98$; $p = .34$, $\eta_p^2 = .07$		
Electrode Site	(4,56)	$F = 6.00$; $p = .01$, $\eta_p^2 = .30$	(2,28)	$F = 6.87$; $p = .01$, $\eta_p^2 = .33$
Time*Task	(1,14)	$F = 0.15$; $p = .70$, $\eta_p^2 = .01$	(1,14)	$F = 0.00$; $p = .95$, $\eta_p^2 = .00$
Time*Recording Hemisphere		$F = 0.11$; $p = .75$, $\eta_p^2 = .01$		
Task*Recording Hemisphere		$F = 0.36$; $p = .56$, $\eta_p^2 = .03$		
Time*Task*Recording Hemisphere		$F = 2.02$; $p = .18$, $\eta_p^2 = .13$		
Time*Electrode Site	(4,56)	$F = 1.63$; $p = .21$, $\eta_p^2 = .10$	(2,28)	$F = 1.79$; $p = .19$, $\eta_p^2 = .11$
Task*Electrode Site		$F = 0.56$; $p = .59$, $\eta_p^2 = .04$		$F = 0.16$; $p = .76$, $\eta_p^2 = .01$
Time*Task*Electrode Site		$F = 2.47$; $p = .10$, $\eta_p^2 = .15$		$F = 1.82$; $p = .18$, $\eta_p^2 = .12$
Electrode Site*Recording Hemisphere		$F = 1.47$; $p = .24$, $\eta_p^2 = .10$		
Time*Electrode Site*Recording Hemisphere		$F = 0.42$; $p = .73$, $\eta_p^2 = .03$		
Task*Electrode Site*Recording Hemisphere		$F = 1.39$; $p = .27$, $\eta_p^2 = .09$		
Time*Task*Electrode Site*Recording Hemisphere		$F = 1.02$; $p = .38$, $\eta_p^2 = .07$		

Table 13: P3 ERP *Mean Amplitude* (300 – 400 ms) – Aerobic Exercise

P3 300 to 400 ms	*df*	Left and Right Hemisphere	*df*	Midline
Time	(1,14)	$F = 6.81$; $p = .02$, $\eta_p^2 = .33$	(1,14)	$F = 1.67$; $p = .22$, $\eta_p^2 = .11$
Task		$F = 0.01$; $p = .93$, $\eta_p^2 = .00$		$F = 3.50$; $p = .08$, $\eta_p^2 = .20$
Recording Hemisphere		$F = 8.53$; $p = .01$, $\eta_p^2 = .38$		
Electrode Site	(4,56)	$F = 6.06$; $p = .01$, $\eta_p^2 = .30$	(2,28)	$F = 1.74$; $p = .21$, $\eta_p^2 = .11$
Time*Task	(1,14)	$F = 0.05$; $p = .84$, $\eta_p^2 = .00$	(1,14)	$F = 0.86$; $p = .37$, $\eta_p^2 = .06$
Time*Recording Hemisphere		$F = 0.15$; $p = .70$, $\eta_p^2 = .01$		
Task*Recording Hemisphere		$F = 0.87$; $p = .37$, $\eta_p^2 = .06$		
Time*Task*Recording Hemisphere		$F = 0.18$; $p = .68$, $\eta_p^2 = .01$		
Time*Electrode Site	(4,56)	$F = 2.74$; $p = .10$, $\eta_p^2 = .16$	(2,28)	$F = 0.15$; $p = .74$, $\eta_p^2 = .01$
Task*Electrode Site		$F = 2.66$; $p = .07$, $\eta_p^2 = .16$		$F = 4.03$; $p = .05$, $\eta_p^2 = .22$
Time*Task*Electrode Site		$F = 1.12$; $p = .34$, $\eta_p^2 = .07$		$F = 0.16$; $p = .74$, $\eta_p^2 = .01$
Electrode Site*Recording Hemisphere		$F = 5.31$; $p = .00$, $\eta_p^2 = .28$		
Time*Electrode Site*Recording Hemisphere		$F = 1.34$; $p = .27$, $\eta_p^2 = .09$		
Task*Electrode Site*Recording Hemisphere		$F = 0.55$; $p = .51$, $\eta_p^2 = .04$		
Time*Task*Electrode Site*Recording Hemisphere		$F = 0.97$; $p = .35$, $\eta_p^2 = .06$		

Table 14: P3 ERP *Mean Amplitude* (300 – 400 ms) – Resistance Exercise

P3 300 to 400 ms	*df*	Left and Right Hemisphere	*df*	Midline
Time	(1,14)	$F = 0.38$; $p = .55$, $\eta_p^2 = .03$	(1,14)	$F = 2.30$; $p = .15$, $\eta_p^2 = .14$
Task		$F = 5.39$; $p = .04$, $\eta_p^2 = .28$		$F = 8.34$; $p = .01$, $\eta_p^2 = .37$
Recording Hemisphere		$F = 0.59$; $p = .45$, $\eta_p^2 = .04$		
Electrode Site	(4,56)	$F = 9.38$; $p = .00$, $\eta_p^2 = .40$	(2,28)	$F = 3.27$; $p = .08$, $\eta_p^2 = .19$
Time*Task	(1,14)	$F = 0.23$; $p = .64$, $\eta_p^2 = .02$	(1,14)	$F = 0.00$; $p = .996$, $\eta_p^2 = .00$
Time*Recording Hemisphere		$F = 0.82$; $p = .38$, $\eta_p^2 = .06$		
Task*Recording Hemisphere		$F = 1.28$; $p = .28$, $\eta_p^2 = .08$		
Time*Task*Recording Hemisphere		$F = 0.04$; $p = .84$, $\eta_p^2 = .00$		
Time*Electrode Site	(4,56)	$F = 2.15$; $p = .15$, $\eta_p^2 = .13$	(2,28)	$F = 2.17$; $p = .15$, $\eta_p^2 = .13$
Task*Electrode Site		$F = 4.18$; $p = .04$, $\eta_p^2 = .23$		$F = 3.28$; $p = .08$, $\eta_p^2 = .19$
Time*Task*Electrode Site		$F = 0.17$; $p = .86$, $\eta_p^2 = .01$		$F = 0.51$; $p = .57$, $\eta_p^2 = .04$
Electrode Site*Recording Hemisphere		$F = 6.05$; $p = .00$, $\eta_p^2 = .30$		
Time*Electrode Site*Recording Hemisphere		$F = 0.25$; $p = .85$, $\eta_p^2 = .02$		
Task*Electrode Site*Recording Hemisphere		$F = 0.27$; $p = .84$, $\eta_p^2 = .02$		
Time*Task*Electrode Site*Recording Hemisphere		$F = 2.68$; $p = .07$, $\eta_p^2 = .16$		

Table 15: P3 ERP *Mean Amplitude* (400 – 500 ms) – Aerobic Exercise

P3 400 to 500 ms	*df*	Left and Right Hemisphere	*df*	Midline
Time	(1,14)	$F = 7.71$; $p = .02$, $\eta_p^2 = .36$	(1,14)	$F = 3.66$; $p = .08$, $\eta_p^2 = .21$
Task		$F = 0.08$; $p = .78$, $\eta_p^2 = .01$		$F = 3.82$; $p = .07$, $\eta_p^2 = .21$
Recording Hemisphere		$F = 0.69$; $p = .42$, $\eta_p^2 = .05$		
Electrode Site	(4,56)	$F = 2.73$; $p = .09$, $\eta_p^2 = .16$	(2,28)	$F = 0.38$; $p = .59$, $\eta_p^2 = .03$
Time*Task	(1,14)	$F = 0.17$; $p = .69$, $\eta_p^2 = .01$	(1,14)	$F = 1.65$; $p = .22$, $\eta_p^2 = .11$
Time*Recording Hemisphere		$F = 2.24$; $p = .16$, $\eta_p^2 = .14$		
Task*Recording Hemisphere		$F = 0.13$; $p = .73$, $\eta_p^2 = .01$		
Time*Task*Recording Hemisphere		$F = 0.16$; $p = .70$, $\eta_p^2 = .01$		
Time*Electrode Site	(4,56)	$F = 1.66$; $p = .19$, $\eta_p^2 = .11$	(2,28)	$F = 2.06$; $p = .17$, $\eta_p^2 = .13$
Task*Electrode Site		$F = 1.73$; $p = .20$, $\eta_p^2 = .11$		$F = 4.39$; $p = .05$, $\eta_p^2 = .24$
Time*Task*Electrode Site		$F = 0.30$; $p = .72$, $\eta_p^2 = .02$		$F = 1.97$; $p = .18$, $\eta_p^2 = .12$
Electrode Site*Recording Hemisphere		$F = 3.41$; $p = .07$, $\eta_p^2 = .20$		
Time*Electrode Site*Recording Hemisphere		$F = 4.75$; $p = .04$, $\eta_p^2 = .25$		
Task*Electrode Site*Recording Hemisphere		$F = 0.01$; $p = .3695$ $\eta_p^2 = .00$		
Time*Task*Electrode Site*Recording Hemisphere		$F = 0.33$; $p = .60$, $\eta_p^2 = .02$		

Table 16: P3 ERP *Mean Amplitude* (400 – 500 ms) – Resistance Exercise

P3 400 to 500 ms	*df*	Left and Right Hemisphere	*df*	Midline
Time	(1,14)	$F = 0.43$; $p = .52$, $\eta_p^2 = .03$	(1,14)	$F = 4.81$; $p = .05$, $\eta_p^2 = .26$
Task		$F = 0.25$; $p = .63$, $\eta_p^2 = .02$		$F = 0.20$; p = .66, $\eta_p^2 = .01$
Recording Hemisphere		$F = 1.34$; $p = .27$, $\eta_p^2 = .09$		
Electrode Site	(4,56)	$F = 3.19$; $p = .07$, $\eta_p^2 = .19$	(2,28)	$F = 14.26$; $p = .00$, $\eta_p^2 = .51$
Time*Task	(1,14)	$F = 0.22$; $p = .64$, $\eta_p^2 = .02$	(1,14)	$F = 2.61$; p = .13, $\eta_p^2 = .16$
Time*Recording Hemisphere		$F = 3.02$; $p = .10$, $\eta_p^2 = .18$		
Task*Recording Hemisphere		$F = 0.01$; $p = .95$, $\eta_p^2 = .00$		
Time*Task*Recording Hemisphere		$F = 0.16$; $p = .70$, $\eta_p^2 = .01$		
Time*Electrode Site	(4,56)	$F = 2.05$; $p = .15$, $\eta_p^2 = .13$	(2,28)	$F = 0.42$; $p = .57$, $\eta_p^2 = .03$
Task*Electrode Site		$F = 4.99$; $p = .02$, $\eta_p^2 = .26$		$F = 6.72$; $p = .01$, $\eta_p^2 = .32$
Time*Task*Electrode Site		$F = 1.00$; $p = .39$, $\eta_p^2 = .07$		$F = 0.27$; $p = .70$, $\eta_p^2 = .02$
Electrode Site*Recording Hemisphere		$F = 0.69$; $p = .56$, $\eta_p^2 = .05$		
Time*Electrode Site*Recording Hemisphere		$F = 1.55$; $p = .22$, $\eta_p^2 = .10$		
Task*Electrode Site*Recording Hemisphere		$F = 0.86$; $p = .46$, $\eta_p^2 = .06$		
Time*Task*Electrode Site*Recording Hemisphere		$F = 0.92$; $p = .42$, $\eta_p^2 = .06$		

Table 17: P3 ERP *Mean Amplitude* (500- 600 ms) – Aerobic Exercise

P3 500 to 600 ms	*df*	Left and Right Hemisphere	*df*	Midline
Time	(1,14)	$F = 6.33$; $p = .03$, $\eta_p^2 = .31$	(1,14)	$F = 4.18$; $p = .06$, $\eta_p^2 = .23$
Task		$F = 0.40$; $p = .54$, $\eta_p^2 = .03$		$F = 2.52$; $p = .14$, $\eta_p^2 = .15$
Recording Hemisphere		$F = 0.83$; $p = .38$, $\eta_p^2 = .06$		
Electrode Site	(4,56)	$F = 5.98$; $p = .01$, $\eta_p^2 = .30$	(2,28)	$F = 0.60$; $p = .48$, $\eta_p^2 = .04$
Time*Task	(1,14)	$F = 0.06$; $p = .81$, $\eta_p^2 = .00$	(1,14)	$F = 1.91$; $p = .19$, $\eta_p^2 = .12$
Time*Recording Hemisphere		$F = 7.10$; $p = .02$, $\eta_p^2 = .34$		
Task*Recording Hemisphere		$F = 0.83$; $p = .38$ $\eta_p^2 = .06$		
Time*Task*Recording Hemisphere		$F = 0.02$; $p = .89$, $\eta_p^2 = .00$		
Time*Electrode Site	(4,56)	$F = 1.65$; $p = .22$, $\eta_p^2 = .11$	(2,28)	$F = 2.76$; $p = .12$, $\eta_p^2 = .17$
Task*Electrode Site		$F = 0.55$; $p = .52$, $\eta_p^2 = .04$		$F = 5.70$; $p = .03$, $\eta_p^2 = .29$
Time*Task*Electrode Site		$F = 0.62$; $p = .54$, $\eta_p^2 = .04$		$F = 2.18$; $p = .16$, $\eta_p^2 = .14$
Electrode Site*Recording Hemisphere		$F = 2.99$; $p = .10$, $\eta_p^2 = .18$		
Time*Electrode Site*Recording Hemisphere		$F = 4.61$; $p = .05$, $\eta_p^2 = .25$		
Task*Electrode Site*Recording Hemisphere		$F = 0.07$; $p = .81$, $\eta_p^2 = .01$		
Time*Task*Electrode Site*Recording Hemisphere		$F = 0.37$; $p = .57$, $\eta_p^2 = .03$		

Table 18: P3 ERP *Mean Amplitude* (500 – 600 ms) – Resistance Exercise

P3 500 to 600 ms	*df*	Left and Right Hemisphere	*df*	Midline
Time	(1,14)	$F = 0.11$; $p = .75$, $\eta_p^2 = .01$	(1,14)	$F = 1.03$; $p = .33$, $\eta_p^2 = .07$
Task		$F = 5.08$; $p = .04$, $\eta_p^2 = .27$		$F = 2.14$; $p = .17$, $\eta_p^2 = .13$
Recording Hemisphere		$F = 2.10$; $p = .17$, $\eta_p^2 = .13$		
Electrode Site	(4,56)	$F = 5.06$; $p = .01$, $\eta_p^2 = .27$	(2,28)	$F = 33.81$; $p < .00$, $\eta_p^2 = .71$
Time*Task	(1,14)	$F = 0.04$; $p = .85$, $\eta_p^2 = .00$	(1,14)	$F = 0.12$; $p = .73$, $\eta_p^2 = .01$
Time*Recording Hemisphere		$F = 4.19$; $p = .06$, $\eta_p^2 = .23$		
Task*Recording Hemisphere		$F = 0.11$; $p = .74$, $\eta_p^2 = .01$		
Time*Task*Recording Hemisphere		$F = 1.20$; $p = .29$, $\eta_p^2 = .08$		
Time*Electrode Site	(4,56)	$F = 0.77$; $p = .48$, $\eta_p^2 = .05$	(2,28)	$F = 0.94$; $p = .37$, $\eta_p^2 = .06$
Task*Electrode Site		$F = 6.76$; $p = .01$, $\eta_p^2 = .33$		$F = 5.86$; $p = .02$, $\eta_p^2 = .30$
Time*Task*Electrode Site		$F = 0.98$; $p = .38$, $\eta_p^2 = .07$		$F = 0.36$; $p = .64$, $\eta_p^2 = .03$
Electrode Site*Recording Hemisphere		$F = 1.48$; $p = .23$, $\eta_p^2 = .10$		
Time*Electrode Site*Recording Hemisphere		$F = 3.43$; $p = .03$, $\eta_p^2 = .20$		
Task*Electrode Site*Recording Hemisphere		$F = 0.17$; $p = .89$, $\eta_p^2 = .01$		
Time*Task*Electrode Site*Recording Hemisphere		$F = 1.37$; $p = .27$, $\eta_p^2 = .09$		