Faculty of Sports of the University of Porto

The effect of dual-task on static and dynamic postural control in daily activities and its relationship with sleep quality and physical activity in young adults

The present dissertation was written to achieve the PhD degree included in the doctoral course in Physiotherapy by the Faculty of Sport of the University of Porto, under the Decree-Law nº. 74/2006 from March 24th.

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DEDICATIONS

To all who were there
during this entire stage.

“Great things happen to those who don´t stop believing,

trying, learning, and being grateful.”

(Roy T. Bennett)

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LIST OF PUBLICATIONS

This Doctoral Thesis is based on the following original studies, which are referred to in the text by their Roman numerals, respectively:

I. Saraiva, M., Vilas-Boas, J.P., Marouvo, J., Castro, M.A. (2022). The effect of the motor dual-task on static and dynamic postural control and classification of the motor task difficulty - Systematic Review. *Retos*, Nº 46, 264-274.

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The following abstracts were published:

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3) Saraiva, M., Vilas-Boas, J.P., Castro, M.A. (2021). Analysis of hemodynamics response in prefrontal cortex during motor and cognitive dual-task - fNIR study. *European Journal of Public Health*, Volume 31, Issue Supplement_2, August 2021, ckab120.033. – **Accepted on Annual Meeting Coimbra Health School 2021 to publish in the Journal Work (June 2021).**
4) Saraiva, M., Castro, M.A., Cavaleiro, A., Vilas-Boas, J.P. The effect of smartphone use on gait velocity. In: Advances and Current Trends in Biomechanics – Belinha et al. (Eds), *Taylor & Francis*, 2021, 163-166. **– Accepted on Congresso Nacional de Biomecânica 2021 to publish in the Journal Work (February 2021)**.

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RESUMO

Muitas atividades da vida diária exigem a realização simultânea de duas ou mais tarefas que envolvem a integração de habilidades cognitivas e motoras, das quais depende o desempenho das tarefas. O principal objetivo desta tese foi avaliar o efeito da tarefa cognitiva e motora usando um *smartphone* no desempenho de tarefas de controlo postural estático e dinâmico em adultos jovens saudáveis. De acordo com os critérios de elegibilidade, foram selecionados trinta e seis adultos jovens saudáveis com idades entre os 18 e os 35 anos. Os participantes realizaram tarefas simples e duplas com componentes cognitivas e/ou motoras. Os instrumentos utilizados para avaliar o centro de pressão, parâmetros espaciotemporais da marcha, atividade muscular, resposta hemodinâmica no córtex pré-frontal, níveis de atividade física e qualidade do sono foram um sistema ótico de captura de movimento acoplado a duas plataformas de forças, eletromiografia de superfície, espectroscopia funcional no infravermelho próximo, Questionário Internacional de Atividade Física – versão curta e Índice de Qualidade do Sono de Pittsburgh, respetivamente. No geral, os nossos resultados demonstraram um declínio no controlo postural e alterações do padrão motor em ambas as condições de dupla-tarefa em comparação com a manutenção da postura em pé e a marcha normal (tarefas simples). Adultos jovens saudáveis, ao realizarem uma dupla-tarefa cognitiva, apresentaram uma diminuição no desempenho do controlo postural estático, maior regularidade e menor complexidade no deslocamento do centro de pressão, maior ativação do córtex pré-frontal, diminuição da atividade muscular na postura estática e aumento durante a marcha, menor comprimento do passo e menor velocidade da marcha em comparação com a dupla-tarefa motora e as tarefas simples. Uma qualidade do sono pobre associou-se a um pior desempenho do controlo postural no deslocamento, velocidade média e amplitude do centro de pressão nas direções mediolaterais na dupla-tarefa cognitiva. Além disso, foi encontrada uma correlação moderada e positiva entre a qualidade do sono e a diferença de hemoglobina no córtex pré-frontal durante a realização simultânea da marcha e da tarefa cognitiva. No entanto, a atividade física não se correlacionou com o controlo postural estático nem dinâmico. Em conclusão, a realização de uma dupla-tarefa cognitiva parece ser mais desafiante do que uma dupla-tarefa motora, contribuindo para um declínio maior do desempenho do controlo postural estático e dinâmico em relação à manutenção da postura em pé ou à marcha normal.

Palavras-chave: controlo postural; dupla-tarefa; qualidade do sono; atividade física, fNIR.

ABSTRACT

Many daily activities require the simultaneous performance of two or more tasks that involve the integration of cognitive and motor skills, on which the performance outcome depends. The main aim of this thesis was to assess the effect of cognitive and motor tasks using a smartphone on the performance of static and dynamic postural control tasking in healthy young adults. According to eligibility criteria, thirty-six healthy young adults aged between 18 and 35 were selected. They performed single- and dual-tasks with cognitive and/or motor components. The instruments used to assess center of pressure, spatiotemporal gait parameters, muscle activity, hemodynamic response in the prefrontal cortex, physical activity levels, and sleep quality were an optical motion capture system coupled with two force plates, surface electromyography, functional near-infrared spectroscopy, International Physical Activity Questionnaire-Short Form, and Pittsburgh Sleep Quality Index, respectively. In general, our results showed a decline in postural control and motor pattern changes during both dual-tasks conditions compared to keeping a standing posture and normal walking (single-tasks). Young adults, when performing a cognitive-dual task, showed a decrease in static postural control performance, greater regularity and lower complexity in the center of pressure displacement, more prefrontal cortex activation, decreased muscle activity in a static posture and increased during gait, lower stride length, and lower gait speed compared with the motor dual-task and single-task conditions. Poor sleep quality was associated with a worse postural control performance in displacement, mean velocity, and amplitude of center of pressure in medial-lateral directions under cognitive dual-task. Furthermore, a moderate and positive correlation was found between sleep quality and hemoglobin difference in the prefrontal cortex while walking with simultaneously performing a cognitive task. However, physical activity was not correlated with static and dynamic postural control. In conclusion, performing a cognitive dual-task appears to be more challenging than a motor dual-task, contributing to a greater decline in static and dynamic postural control performance relative to keeping a static standing posture or normal walking.

Key-words: postural control; dual-task; sleep quality; physical activity; fNIR.

LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

A

A-AP – Amplitude of the center of pressure in the anterior-posterior direction

A-ML – Amplitude of the center of pressure in the medial-lateral direction

AP – Anterior-posterior

ApEn – Approximate Entropy

ApEn-AP – Approximate Entropy of the anterior-posterior displacement of the center of pressure

ApEn-ML – Approximate Entropy of the medial-lateral displacement of the center of pressure

B

BESTest – Balance Evaluation – Systems Test

BF – Biceps femoris

BMI – Body Mass Index

C

CCI – Co-Contraction Index

CEA – 95% Confidence ellipse sway area of the center of pressure

COBI – Cognitive Optical Brain Imaging

CoDim – Correlation dimension

cog-DT – Cognitive dual-task

cogDTC – Cognitive task performance (dual-task cost of secondary task)

cog-DTC – Cognitive dual-task cost

cog-DTC$_{\textbf{CoP variable}}$ – Cognitive dual-task cost of the center of pressure (variables)

CoP – Center of pressure

CoP-ML – Displacements of the center of pressure in the medial-lateral direction

CoP-AP – Displacements of the center of pressure in the anterior-posterior direction

CP – Complex pitcher

CT – Complex tray

D

[deoxy-Hb] – Deoxyhemoglobin concentration

DFA – Detrending fluctuation analysis

DPF – Differential pathlength factor

DT – Dual-task

DTC – Dual-Task Cost

DTC$_{\mathbf{ApEn}}$ – Dual-Task Cost of approximate entropy

DTC$_{\mathbf{CoP}}$ / **DTC**$_{\mathbf{CoP\ variable}}$ – Dual-Task Cost of the center of pressure (linear outcomes/ variables)

DTC$_{\mathbf{difficult}}$ – Dual-task cost of the center of pressure (variables) in difficult cognitive dual-task performance

DTC$_{\mathbf{easy}}$ – Dual-task cost of the center of pressure (variables) in easy cognitive dual-task performance

DTI – Dual-task interference

E

EEG – Electroencephalography

EMG / **sEMG**– Surface electromyography

F

fMRI – functional Magnetic Resonance Imaging

fNIR / **fNIRS** – functional Near-Infrared Spectroscopy

4SST – Four Square Step Test

G

GL – Gastrocnemius lateralis

GM – Gastrocnemius medialis

GMax – Gluteus maximus

I

IPAQ-SF – International Physical Activity Questionnaire-Short Form

IQR – Interquartile range

L

LES – Lumbar erector spinae

LPFC –Left prefrontal cortex

LyE – Lyapunov Exponent

M

M1 – Primary motor cortex

MCI – Mild Cognitive Impairment

MeSH – Medical Subject Headings

ML – Medial-Lateral

mm – Millimeter

mm/s – Millimeter per second

mot-DT – Motor dual-task

mot-DT(A) – Easy motor dual-task

mot-DT(T) – Difficult motor dual-task

motDTC – Motor secondary task performance (dual-task cost of secondary task)

mot-DTC – Motor dual-task cost

mot-DTC$_{\textbf{CoP variable}}$ – Motor dual-task cost of the center of pressure (variables)

MS – Multiple Sclerosis

MVC – Maximal voluntary contraction

MVELO CoP – Mean total velocity displacement of the center of pressure

MVELO CoP-AP – Mean velocity displacement anterior-posterior of the center of pressure

MVELO CoP-ML – Mean velocity displacement medial-lateral of the center of pressure

N

ND – no data

O

[oxy-Hb] – Oxyhemoglobin concentration

P

PA – Physical Activity

PC – Postural Control

PET – Positron-Emission Tomography

PFC – Prefrontal cortex

PRISMA – Preferred Reporting Items for Systematic Reviews and Meta-analysis

PSQI – Pittsburgh Sleep Quality Index

R

RF – Rectus femoris

RF–BF – Co-contraction index between the agonist and antagonist muscles: rectus femoris–biceps femoris

RMS – Root-Mean-Square

ROIs – regions of interest

RPFC – Right prefrontal cortex

Rpm – Revolutions per minute

RTs – Reaction Times

S

α – Scaling exponent

SLST – Single Leg Stance Time

SMAR – Sliding-Window Motion Artifact Rejection

SQ – Sleep Quality

SP – Simple pitcher

ST – Single-task

STr – Simple tray

SD – Standard deviation

STV – Stride time variability

T

TA –Tibialis anterior

TA–GL – Co-contraction index between the agonist and antagonist muscles: tibialis anterior–gastrocnemius lateralis

TA–GM – Co-contraction index between the agonist and antagonist muscles: tibialis anterior–gastrocnemius lateralis medialis

360º DRT – 360º Degrees of Rotation Time

TMWT – Ten Meter Walking Test

[total-Hb] – Total hemoglobin concentration

TOTEX CoP – Total excursion of the center of pressure

TST – Tandem Stance Time

TUGT – Timed Up and Go Test

V

VO_{2max} – Maximum oxygen consumption

CHAPTER I – GENERAL INTRODUCTION

Maintaining a standing posture is a complex task that provides essential information concerning balance and the postural control system, being a basic prerequisite for initiating other activities, like gait (Winter et al., 1998).

Many daily activities involve performing two or more tasks and integrating cognitive and motor skills (Plummer et al., 2013). Therefore, having efficient postural control (PC) is fundamental to the success of most daily tasks. Postural control depends on a complex interaction between the neural and musculoskeletal systems (Huang & Mercer, 2001). Furthermore, the brain's capacity to organize the interactions between tasks is essential to balance and motor control (Plummer et al., 2013).

The center of pressure is considered the gold standard measure to evaluate the postural balance during static postural control (Winter, 1995; Chen et al., 2021). The center of pressure can be assessed based on linear and nonlinear analysis. The linear analysis gives information about the magnitude and variance of the CoP displacement; on the other hand, the nonlinear analysis provides information about the postural control system's regularity, stability, flexibility, and capacity to adapt to an unpredictable environment (Kyvelidou et al., 2009; Ladislao & Fioretti, 2007; Kędziorek & Błażkiewicz, 2020).

The dual-task (DT) paradigm is usually used to study the ability to perform simultaneous tasks in different populations. This paradigm can provide useful information, such as preventing falls in older people (Zijlstra et al., 2008), improving children's learning processes (Reilly et al., 2008), allowing assess attentional or cognitive load and concurrent tasks performance (Bijarsari, 2021).

The attentional demands of a task and the interference between concurrent tasks could be influenced by several factors, such as age, the performer´s skills, and the nature of the tasks (Huang & Mercer, 2001). When performing two tasks simultaneously, the performance of one or both tasks can stay compromised due to competition for attentional resources resulting in interference of one or both tasks relative to another (Lacour et al., 2008; Woollacott & Shumway-Cook, 2002). The change in performance or interference between the tasks can be obtained through the dual-task cost (DTC) (Lacour et al., 2008; Plummer et al., 2013; Woollacott & Shumway-Cook, 2002).

Previous studies reported different results in the influence of cognitive tasks on postural control while performing a static standing posture in young adults. For example, some studies revealed that the postural sway was reduced in dual-task conditions compared to the standing postural (single-task) (Hunter & Hoffman, 2001; Maylor & Wing, 1996; Prado et al., 2007). Conversely, others indicated greater postural sway in dual-task conditions than single-task (Lanzarin et al., 2015).

Capacity sharing, bottlenecks or task switching, and cross-talk theories are commonly used to explain the dual-task interference or the limitation of attentional resources while performing a dual-task (Pashler, 1994). However, there is no consensus about the underlying mechanisms of dual-task interference (Leone et al., 2017).

As evidence suggests that postural control depends on attentional resources beyond automatic processes (Woollacott & Shumway-Cook, 2002), it becomes relevant to analyze cortical activation during dual-task conditions. The prefrontal cortex plays an essential role in various brain functions, such as memory, attention, cognitive and executive functions (Fuster, 2001), and cognitive postural dual-task performance (Marusic et al., 2019). Previous studies found an increase in prefrontal cortex activity during dual-task compared to postural single-task (Fujita et al., 2016). However, other studies suggest a cortical activity diminution when the cognitive task load increases (Callicott et al., 1999).

Investigating the gait parameters while performing natural tasks in real-time is not possible using functional magnetic resonance imaging (fMRI). However, it can be conducted using functional near-infrared spectroscopy (fNIRS) (Hoshi, 2019). For that reason, we used the fNIRS device to record the hemodynamic response in the prefrontal cortex. It measures the oxyhemoglobin and deoxyhemoglobin concentration changes in the active brain regions, which present different absorption wavelength properties in the near-infrared spectrum (Herold et al., 2017; Leff et al., 2011). Furthermore, fNIRS is a valid and feasible neuroimaging technique to measure cortical activity and reproduce reliable and consistent findings with functional magnetic resonance imaging results (Bulgarelli, 2018; Ferrari & Quaresima, 2012).

An example of a dual-task often performed is walking or maintaining a standing posture while using smartphone functions, like walking while talking or maintaining a standing posture while texting. In today's society, smartphones and other technologies are used massively. Nonetheless, using a smartphone while walking carries some risks to pedestrians, such as accidents or injuries (Stavrinos et al., 2011). Observational studies showed that smartphone users remember fewer objects while conversing on their smartphone than those holding a smartphone without conversing (Nasar et al., 2008). In addition, they walked more slowly, changed directions more frequently, presented less skill to acknowledge others (Hyman et al., 2010), and had greater distraction levels (Stavrinos et al., 2011).

When the gait is performed simultaneously with cognitive or other motor tasks, the performance of one or both tasks may be negatively affected because walking requires attentional recourses and high levels of cognition to estimate, plan and execute gait patterns correctly (Abbud et al., 2009). Thus, poor attention can result in motor control impairments during dual-task conditions, compromising static or dynamic balance maintenance. Most studies analyzed the effect of smartphone use on postural control while walking. They found that smartphone use negatively compromises gait stability and kinematics, such as gait speed, stride length, stance phase, and cadence, contributing to a decline in gait performance during dual-tasks conditions (Jeon et al., 2016; Strubhar et al., 2015). Furthermore, smartphone use can reduce physical activity (PA) levels, promote sedentary behaviors among high-frequency users (Lepp et al., 2013), and causes deterioration of sleep quality (SQ) (Sahin et al., 2013).

Sleep quality is an essential quality of life measurement because rest and recovery are among the most important functions of sleep. Several measurements of SQ have been designed. An instrument used in several studies is the Pittsburgh Sleep Quality Index (PSQI) (Mollayeva et al., 2016).

Physical activity also plays an essential role in health status. A good example is that regular and moderate intensity PA (e.g., walking, cycling, or regular sports practice) can reduce cardiovascular disease risks, colon and breast cancer, diabetes and mental illnesses (Pasco et al., 2011; Warburton et al., 2010). High PA appears to modify the neurotransmitters' function to increase the expression of factors associated with synaptic plasticity, such as the glutamatergic system (Molteni et al., 2002). PA and fitness in adolescents were related to cognitive function improvements in adults due to an increase in insulin-like growth factor I production (Ferro et al., 2016). Besides that, oxyhemoglobin concentrations in areas related to executive function were found to be significantly higher in the subjects with high PA than in the subjects with low PA, suggesting the importance of PA for enhancing young adulthood cognitive functions (Matsuda et al., 2017). One of the instruments widely used to assess physical activity level is the International Physical Activity Questionnaire-Short Form (IPAQ-SF) (Craig et al., 2003).

The literature suggests that physical activity levels and sleep quality are associated with postural control performance. Sleep disorders can impair postural control in young adults (Furtado et al., 2016) and increase the risk of falls in the elderly (Robillard et al., 2011). Moreover, postural control declines resultant of sleep disorders are related to work accidents, like driving accidents (Gauchard et al., 2003) and falls among frail populations, such as the elderly (Kurz et al., 2013). On the other hand, physical activity can improve postural stability and reduce fall rates in older people by enhancing their balance (Sherrington et al., 2008; Thomas & Magal, 2014).

Identifying the factors influencing postural control while performing a dual-task in young adults is essential to detect motor and cognitive impairments early. Hence, understanding and analyzing underlying motor control processes of walking or maintaining standing posture while performing cognitive and motor tasks can contribute to developing clinical tools and adopting appropriate clinical practices. For that reason, it is necessary to verify the cognitive task influence on motor task performance and vice versa in daily activities (e.g., performing tasks while using a smartphone) using the dual-task paradigm.

Therefore, the **principal aim of this thesis** was to analyze the effect of cognitive and motor tasks on the performance of static and dynamic postural control tasking in healthy young adults. For that, single- and dual-tasks with cognitive and/or motor components using a smartphone were performed, such as normal walking versus walking while simultaneously typing on a smartphone keyboard; keeping standing posture versus keeping standing posture while simultaneously performing a cognitive smartphone task, to collect the following data: center of pressure behavior (linear and nonlinear analysis), muscle activity pattern, spatiotemporal gait parameters, prefrontal cortex activation, physical activity level and sleep quality.

This thesis is divided into eleven chapters and results in nine studies. Each of the studies addresses a particularly relevant issue about the interference of different tasks on motor and muscular behavior and hemodynamic response in the prefrontal cortex during dual-task performance.

The present document was organized according to the following structure:

The **first chapter** concerns the introduction related to the dual-task paradigm, the effects of the dual-task on static postural control and gait, and the prefrontal cortex's role in the performance of tasks. It also addresses the effect and consequences of frequently performed dual-task (i.e., simultaneous tasks using a smartphone). In addition, some of the benefits of sleep and physical activity and their influences on postural control are described.

Chapters II to **X** were dedicated to the presentation of each study performed during the doctoral process in a journal article format, including an introduction, methodology, results, discussion, conclusion, and references. The content and methodology of each study were designed to respond to the hypotheses arising from the study's objectives. The aims of each study are described below:

Chapter II is a systematic review that analyzes the motor tasks used in motor dual-task studies, classifies them as to their level of difficulty, and determines the effects of task difficulty, both secondary motor tasks and static or dynamic postural control, on dual-task performance.

Chapter III assesses differences in standing posture performance during cognitive dual-task between healthy young adults with good and poor sleep quality. A secondary aim is to analyze the differences in center of pressure (CoP) among single and cognitive dual-task within each sleep quality group.

Chapter IV analyzes CoP behavior in standing posture performance while simultaneously performing motor or cognitive tasks on the smartphone in healthy young adults to identify which tasks interfered most with postural control performance, using linear and non-linear analyses.

Chapter V evaluates and compares the center of pressure behavior and the hemodynamic response of the prefrontal cortex in static postural standing while performing cognitive tasks on a smartphone of increasing difficulty levels in young adults.

Chapter VI analyzes the effect of two motor tasks with different difficulty levels in motor performance complexity of static standing posture in healthy young adults.

Chapter VII analyzes the muscular and prefrontal activity under dual-task performance in healthy young adults.

Chapter VIII analyzes the correlation between PA level and SQ with postural control performance and hemodynamic response in the prefrontal cortex during DT performance in young adults.

Chapter IX assesses the effects of motor and cognitive tasks using a smartphone while simultaneously performing gait on muscle activity and gait spatiotemporal parameters in healthy young adults.

Chapter X assesses gait speed and hemodynamic response in the prefrontal cortex under dual-task conditions. Furthermore, we intend to analyze the correlation between physical activity and sleep quality with gait performance and hemodynamic response in the prefrontal cortex during normal walking and cognitive dual-task performance in healthy young adults.

Chapter XI corresponds to the final considerations of this thesis, in which the results of the nine studies were discussed integratively. The main findings, limitations, practical implications, and directions for future research are reported.

Finally, the appendices and annexes presented documents supporting this thesis's realization and participation in scientific events.

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CHAPTER II – Study I: The effect of the motor dual-task on static and dynamic postural control and classification of the motor task difficulty - Systematic Review

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ABSTRACT

Many daily activities require performing multiple tasks and involve the integration of cognitive and motor skills, on which the outcome depends. Many studies approach the influence of cognitive tasks on gait and postural control, but few studies analyze the effect of another motor task during gait or postural control. This review aims to analyze the motor tasks used in motor dual-tasks studies and classify motor tasks as to their difficulty level. The literature review was conducted according to PRISMA guidelines in the databases: Medline, Web on Science, and Scopus during December 2019, using the key-words: motor dual-task, secondary motor task, gait, and postural control. It included observational studies based on the effects of motor dual-tasking in static and dynamic postural control, published in the last ten years. N = 215 studies were found within the databases, and this review included sixteen studies. One study analyzed gait with secondary motor task of different levels of complexity. Three studies analyzed the primary motor task (gait) at different difficulty levels or conditions. They all found that more complex tasks lead to poorer gait performance.

In conclusion, a classification of the motor tasks is suggested according to their complexity level and suggests the need for more studies with motor tasks of different levels of difficulty. The static and dynamic postural control parameters analyzed in this review were negatively affected compared to the simple motor task, regardless of age or clinical condition.

Key-words: motor dual-task, motor task difficulty, gait, postural control.

INTRODUCTION

Postural control (PC) depends on a complex interaction between the neural and musculoskeletal systems (Huang & Mercer, 2001). An efficient PC is fundamental to the success of most daily tasks. Gait involves bilaterally coordinated limb movements and maintenance of dynamic postural control. People with motor impairment, cognitive decline, or both, have more gait changes in dual-task activities (Woollacott & Shumway-Cook, 2002; Yogev et al., 2008).

The relationship between attention and PC is a developing area of study that has revealed important aspects of the cognitive processing role in PC. The most used methodology to ascertain its relationship is the Dual-Task (DT) paradigm, in which the PC, considered a primary task, and a secondary task, are performed simultaneously (Woollacott & Shumway-Cook, 2002).

The ability to perform a second task while a first one is executed is crucial in most daily activities, especially when some motor act is involved, as a poor gait performance in dual-task can result in a fall (Beauchet et al., 2009).

The attentional demands of a task and the interference effects of concurrent tasks could be influenced by several factors, such as age, skill level, and the nature of the tasks involved (Huang & Mercer, 2001).

The brain's ability to organize multi-task interactions is essential to motor control and balance (Plummer et al., 2013). Dual-Task Cost (DTC) occurs when the simultaneous performance of two different tasks results in performance deterioration (Beurskens et al., 2016; Plummer & Eskes, 2015). It is calculated as the percentage of performance decrements in dual-task relative to the single-task.

Some studies assess task performance using the task prioritization concept, in which it is usually assumed that task prioritization can be obtained by means of an external priority instruction on the importance of each task (Plummer & Eskes, 2015). Other authors impose a focus of attention during the task performed and conclude that the focus of attention on the cognitive task while performing the dual-task can favor motor learning (Arce-Cifuente et al., 2020).

Preserving balance during dual-tasks or multi-tasks is a complex outcome of trunk stability and the sensory-motor and automatic central functions. Therefore, executing simultaneously two tasks demands a higher level of attention, balancing ability, and executive function than a single task performance (Plummer et al., 2013).

The postural control and the motor or cognitive tasks occur at the cortical level, enabling one activity interferes with the other or lead to a reduction in automation (Leone et al., 2017).

There are three theories commonly used to explain the dual-task interference. The capacity sharing, when people share processing capacity or mental resources among tasks. This results in lower capacity for each task, and so the performance of at least one task will be impaired. The other theory is the bottlenecks, task switching, it exists a deterioration in the performance of one or both tasks resulting from serial processing when the two tasks need the same neural processor or networks. The last theory is the cross-talk, where the outcome of the processing required for one task conflicts with the processing required for another task (Pashler, 1994).

Several studies, included in a systematic review, showed that different cognitive tasks (e.g., working memory, reaction time, etc.) when performed simultaneously during gait (DT), caused impairments in spatio-temporal gait parameters, such as decreased gait speed, compared to the single-task (only gait) (Al-Yahya et al., 2011). Other studies showed worst results on gait performance under dual-task conditions when the individuals performed a second motor task as transfer coins (O´Shea et al., 2002) or carry a tray (Bond & Morris, 2000). Thus, walking while simultaneously performing a cognitive or motor task negatively affects the individual's gait performance.

Regarding task difficulty, few studies have simultaneously analyzed the population’s complexity of postural or gait and other motor tasks. For that reason, we based the analysis of the task’s difficulty level on the taxonomy model (McIsaac et al., 2015) and in the classification of the studies included in this review.

There is an ambiguity about the terms task complexity and task difficulty. For some authors, task complexity is a component of difficulty, for others, they are separate concepts. Generally, task difficulty refers to performers experiencing difficulty in executing the task. On the other hand, task complexity can be defined as a result of the interaction between task and performer characteristics, such as the number of task components, concentration, cognitive and physical demands, time pressure, or novelty (Liu & Li, 2012).

Although the amount of research on postural control and dual-tasks has increased in recent years, there are still not many studies that clarify the effect of the difficulty of the static or dynamic postural control tasks on dual-task performance. Besides that, several studies have focused on the effect of the cognitive task component on dual-task. It is challenging to establish conclusions about the influence between concurrent motor and cognitive tasks on postural control, because the studies use different types of tasks, and motor or cognitive tasks performing can require different cognitive resources and motor control (Bayot et al., 2018).

For this reason, the main objective of this review is to analyze the motor tasks used in motor dual-task studies, to classify them as to their level of difficulty, and to determine the effects of task difficulty, both secondary motor tasks and static or dynamic postural control, on dual-task performance.

METHODOLOGY

This review was conducted according to the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) statement (Moher et al., 2009) and followed the PICOS criteria described in PRISMA (population: humans; intervention: dual-task to evaluate static and dynamic postural control; comparison: none; outcomes: motor dual-task and motor task difficulty to study static and dynamic postural control; study design: all quantitative and qualitative studies in the last ten years).

Data sources and search strategy

The study was conducted independently by two reviewers in the databases: Medline, Web on Science, and Scopus, during December 2019. The search terms used were gait, walking, locomotion, dual-task, multi-task, secondary task, motor dual-task, postural control, postural balance, postural sway, and their combination with ‘and’ or ‘or’. The combination of keywords and MeSH (Medical Subject Headings) terms were also adapted to each database. Screening of titles and abstracts to determine if the study meets any of the exclusion criteria was performed. The inclusion criteria for the studies were as follows:

i. English language;
ii. Published in the last ten years;
iii. Observational (cohort study) studies;
iv. Studies that analyze the effects of motor tasks in static and dynamic postural control in healthy and ill subjects.

Other design studies and the following criteria were excluded:

i. Articles based only on the effect of cognitive tasks on postural control and/or on dual-task training;
ii. Studies in which the primary task is not postural control;
iii. Studies with quality lower than four in the Newcastle-Ottawa Scale.

The studies that fulfilled all eligibility criteria were evaluated in full-text and included in the systematic review (Figure 1). The authors independently assessed the eligibility and methodological quality of the included studies. In the event of disagreement, a decision was taken by consensus.

Data extraction

Upon selection for review, the following data were extracted from each article: author, date of publication, sample characteristics, the aim of the study, study methodology (tasks and outcome measures), and results.

Assessment of quality of studies and risk of bias

The methodological quality of observational studies was assessed with the Newcastle-Ottawa Scale. It uses three elements to evaluate the risk of bias in prospective studies: 1) selection of participants (four items: representativeness of the exposed cohort, selection of the non-exposed cohort, ascertainment of the exposure, and demonstration that the outcome of interest was not present at the start of the study); 2) comparability (one item: comparability of cohorts based on the design of the analysis) and 3) outcomes (three items: adequate assessment of outcome, adequate follow-up time, and adequacy of follow-up). A study can be awarded a maximum of 1 point (star) for each numbered item within the selection and outcome categories and a maximum of two points can be given for the comparability category. The maximum score on the Newcastle-Ottawa Scale is 9 (highest quality) (Wells et al., 2019).

The primary reviewer carried out a blinded rating of the methodological quality of the studies, and the second reviewer assessed the methodology quality unblinded. Ambiguous issues were discussed between reviewers, and a consensus was reached.

RESULTS

Figure 1.1 depicts each step's selection, eligibility, inclusion, and the number of studies. Database searches resulted in 215 papers, of which 16 were duplicates. Then, of the 199 papers, 138 articles were excluded based on the title and abstract screening during the selection process. The remaining 61 articles were thoroughly examined, and 45 were discarded as the task type did not include motor tasks. After these steps, 16 studies have been included in this review.

The 16 studies were analytic observational studies (prospective cohort studies). The quality of observational studies (cohort studies) is moderate based on the Newcastle-Ottawa Scale (Table 1.1). Data from the included studies are summarized in Table 1.2.

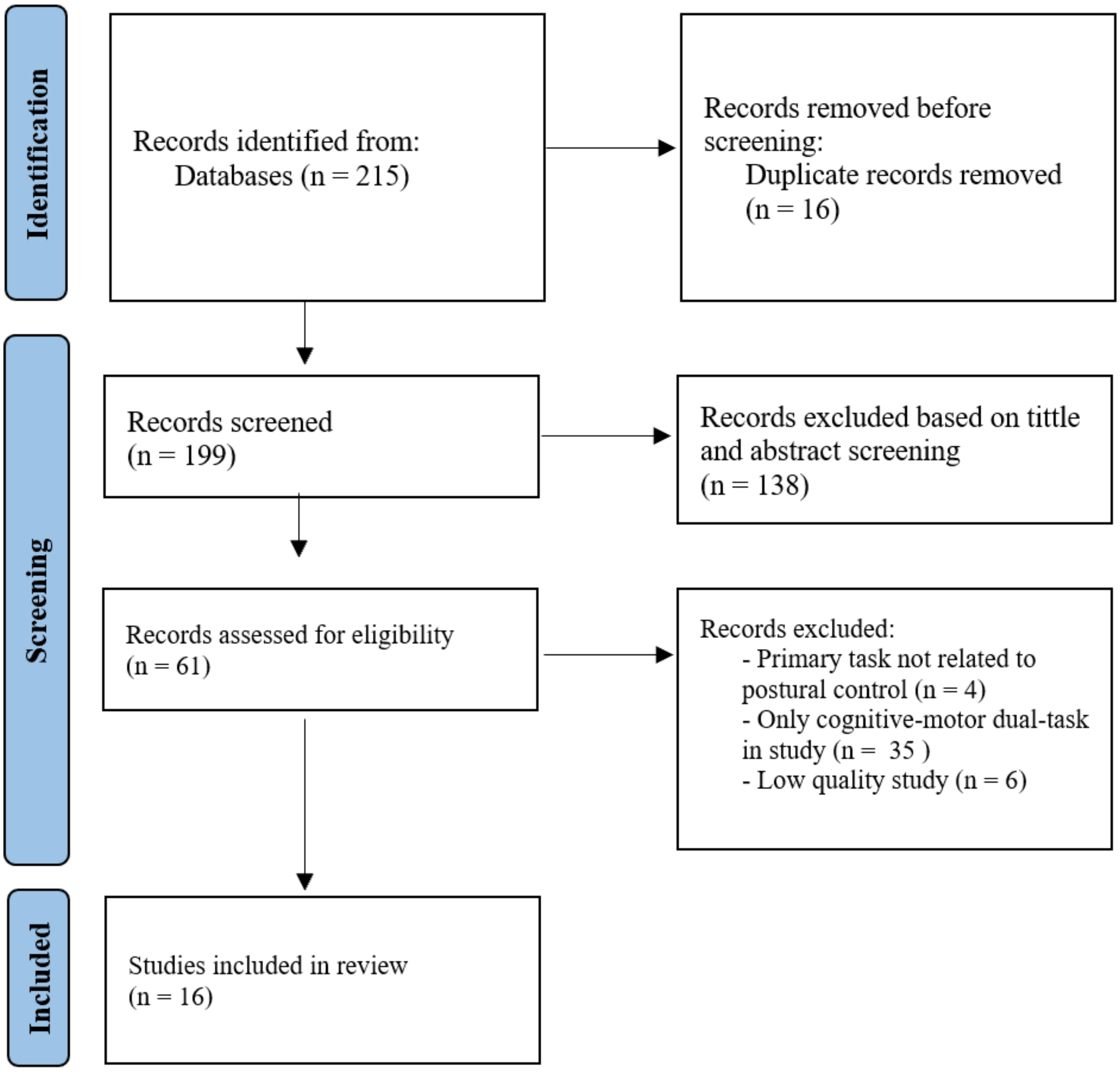

Figure 1.1. Fluxogram of articles included in the review according to PRISMA.

Table 1.1. Quality of observational studies based on Newcastle-Ottawa Scale.

Study	Selection	Comparability	Outcome	Total
Nordin et al. (2010)	**	*	*	4
Beurskens & Bock (2013)	**	*	*	4
Makizako et al. (2013)	***	*	*	5
Oh-Park (2013)	***	**	*	6
Abbruzzese et al. (2014)	**	**	*	5
Asai et al. (2014)	**	*	*	4
Baldan & Elmauer (2015)	**	*	*	4
Tang et al. (2015)	**	*	**	5
Beurskens et al. (2016)	***	*	*	5
Demirci et al. (2016)	**	*	*	4
Freire Junior et al. (2017)	****	*	*	6
Mofateh et al. (2017)	***	*	*	5
Hunter et al. (2018)	***	*	*	5
Liu et al. (2018)	***	*	*	5
Kachouri et al. (2019)	****	*	*	6
Rabaglietti et al. (2019)	****	**	*	7

*=present (1 point); Total Score = 9 points.

Sample Characteristics

Most studies used healthy individuals (Beurskens et al., 2016; Abbruzzese et al., 2014; Asai et al., 2014; Beurskens & Bock, 2013; Makizako et al., 2013; Nordin et al., 2010; Oh-Park et al., 2013; Tang et al., 2015) to analyze postural control in motor dual-tasks. School-age children were compared with young adults (Abbruzzese et al., 2014), young adults with the elderly (Beurskens & Bock, 2013; Makizako et al., 2013; Oh-Park et al., 2013), and older non-fallers with older fallers (Júnior et al., 2017). Only six studies report to clinical conditions, namely Sclerosis Multiple (Mofateh et al., 2017), Stroke (Baldan & Elmauer, 2015; Liu et al., 2018), Ataxia (Demirci et al., 2016), Mild Cognitive Impairment (Hunter et al., 2018), and children with intellectual disability (Kachouri et al., 2019). Five studies use a sample type not making comparisons between groups (Beurskens et al., 2016; Asai et al., 2014; Nordin et al., 2010; Tang et al., 2015; Liu et al., 2018). One study examined the effect of a secondary motor task on walking ability in childhood (Rabaglietti et al., 2019).

Description of motor tasks

In most studies, the principal motor task analyzed was gait (Beurskens et al., 2016; Abbruzzese et al., 2014; Asai et al., 2014; Beurskens & Bock, 2013; Nordin et al., 2010; Oh-Park et al., 2013; Júnior et al., 2017; Mofateh et al., 2017; Baldan & Elmauer, 2015; Liu et al., 2018; Hunter et al., 2018; Kachouri et al., 2019; Rabaglietti et al., 2019).

Only three studies analyzed static and/or dynamic balance as principal motor task (e.g. standing Romberg stance under foam surface; Tandem Stance; Time Up and Go) (Makizako et al., 2013; Tang et al., 2015; Demirci et al., 2016).

The secondary motor tasks used were gross motor tasks, e.g. holding a tray (Abbruzzese et al., 2014; Nordin et al., 2010; Oh-Park et al., 2013) or a cup (Makizako et al., 2013; Tang et al., 2015; Kachouri et al., 2019; Rabaglietti et al., 2019) or fine motor tasks (e.g. buttoning a button (Beurskens & Bock, 2013; Demirci et al., 2016), opening and closing a bag zipper (Demirci et al., 2016), transferring a coin from one pocket to the other (Júnior et al., 2017).

Most studies (Makizako et al., 2013; Nordin et al., 2010; Oh-Park et al., 2013; Tang et al., 2015; Mofateh et al., 2017; Hunter et al., 2018; Kachouri et al., 2019; Rabaglietti et al., 2019) used carrying cups and/or a tray as the secondary motor task. Baldan & Elmauer (2015) and Demirci et al. (2016) used the task of transferring a ball from one hand to another as a secondary motor task.

Only the study by Abbruzzese et al. (2014) analyzed gait with secondary motor tasks of different levels of complexity (simple motor task: ‘Holding an empty tray with both hands’, ‘Holding an empty pitcher with one hand’; complex motor task: ‘Holding a tray with an unsecured empty cup on top with both hands’, ‘Holding a pitcher with a cup of water secured inside with one hand’; simple dual-task: ‘Gait and Empty tray, held with two hands’, ‘Gait and Pitcher with empty cup secured inside, held with one hand by the handle’; complex dual-task: ‘Gait and Tray with unsecured empty cup on top, held with two hands’, ‘Gait and Pitcher with cup of water secured inside, held with one hand by the handle’) and the study by Oh-Park et al. (2013) of task prioritization in motor dual-task (walk and holding a tray with instructions to focus attention on keeping the tray as steady as possible; walk and holding a tray focusing attention on walking at preferred pace).

Three studies analyzed the primary motor task at different levels of difficulty: gait in four different velocities (self-selected comfortable velocity, very slow, slow, and fast) (Asai et al., 2014), walking in four different conditions (wide path and preferred pace, narrow path and preferred pace, wide path and fast pace, obstacles wide path and preferred pace) (Beurskens & Bock, 2013), and three different velocity conditions of gait (slow, normal and fast) (Nordin et al., 2010).

Dual-task outcome measures

The gait variables most analyzed in the motor dual-tasks were gait speed, cadence, stride length, stride width, percent of time in the double support phase, through GAITRitee® System (Abbruzzese et al., 2014; Nordin et al., 2010; Oh-Park et al., 2013; Júnior et al., 2017; Liu et al., 2018; Hunter et al., 2018), MTx® System (Beurskens & Bock, 2013), Qualisys® System (Mofateh et al., 2017) or analytical formulas (Asai et al., 2014; Baldan & Elmauer, 2015).

Balance Evaluation-Systems Test (Júnior et al., 2017), Ten Meter Walking Test (TMWT), and the Timed Up and Go Test (TUGT) (Kachouri et al., 2019) were methodologies also used to analyze gait performance.

Static and dynamic balance in one of the studies was analyzed through clinical trial tests such as Single Leg Stance Time; Tandem Stance Time; Four Square Step Test; 360º Degrees of Rotation Time; TUGT completing time (Demirci et al., 2016). In another study, which evaluated balance in motor dual-tasks, the variable analyzed was anterior-posterior sway through triaxial accelerometry (Makizako et al., 2013). This study also analyzed the electromyography of the tibialis anterior and medial gastrocnemius ankle muscles.

In one of the studies, the TUGT performance was analyzed in a single TUGT task and motor dual-task (TUGT while carrying a cup of water) (Tang et al., 2015).

Table 1.2. Results of motor tasks in static and dynamic postural control.

			Methodology								
							Motor Dual Task				
Authors (year)	**Sample Characteristics (n; mean±SD)**	**Aim of the study**	**Primary Motor Task**	**Outcome Primary Motor Task**	**Secondary Motor Task**	**Outcome Secondary Motor Task**	**Dual Task**	**Outcome**	**Task duration**	**Number of trials**	**Results**
Abbruzzese et al. (2014)	School-aged children: n=10 (8.1±1.2 years). Healthy young adults: n=10 (26.8±4.9 years).	To analyze the effects of complexity, type of task, and age on the ability to walk while performing concurrent manual tasks between school-aged	Gait	GAITRite®: Gait velocity, Cadence, Stride length, Base of support, Percent time in double limb support.	Holding an empty pitcher with one hand (SP); Holding an empty tray with both hands (STr); Holding a pitcher with	ND	Gait+SP Gait+STr Gait+CP Gait+CT	GAITRite®: Gait velocity, Cadence, Stride length, Base of support, Percent time in double limb support.	4.6m	3 trials under each DT	The children had a more variable step length and step time than adults in all walking conditions. Gait variability is greater in the

		children and young adults.			a cup of water secured inside with one hand (CP); Holding a tray with an unsecured empty cup on top with both hands (CT).						most complex motor tasks.
Asai et al. (2014)	Healthy older people: n=117 (73.7±4.0 years)	To assess trunk movements during cognitive-task gait and manual-task gait.	Gait in 4 speeds: Self-selected comfortable, Very slow, Slow, Fast.	Triaxial accelerometers: STV RMS in the ML direction RMS in the AP direction Arithmetic formulas: Gait speed	To carry a ball on a tray.	ND	Gait in self-selected comfortable speed +Carrying a ball on a tray.	Triaxial accelerometers: STV RMS in the ML direction RMS in the AP direction Arithmetic formulas: Gait speed	Gait during 10m	1	The trunk oscillation was lower in the motor DT than in the simple gait task.
Baldan & Elmauer (2015)	Adults with stroke: n=12 (56.5±26.92 years). Healthy adults: n=12 (52.33±7.58 years)	To analyze and compare performing DT effect on gait in subjects with stroke and healthy adults.	Gait	Evaluated through arithmetic formulas: Step length, Cadence, Average speed.	To transfer a ball from one hand to another.	ND	Gait+To transfer a ball from one hand to another	Evaluated through arithmetic formulas: Step length, Cadence, Average speed.	Gait during 10m.	3 trials under each DT	The group of adults with stroke had worse motor DT performance than simple task (gait).
Beurskens et al. (2016)	Young adults: n=12 (23.8±2.8 years)	To examine the role of different secondary task demands on gait in young adults and assess the associated neural activation patterns.	Gait	OptoGait-System (10m): Gait velocity; Stride length; Stride time	Held two sticks with a ring at the end, one in each hand.	Total time of contact between the two interconnected rings.	Gait+Held two sticks with a ring at the end	OptoGait-System: Gait velocity; Stride length; Stride time Mobile EEG system: Neural Correlates	2min	1	The motor task affected walking performance in young adults: reduced gait velocity and stride length, increased stride time.
Beurskens & Bock (2013)	Young people: n=15 (21.7±1.2 years) Older people: n=15 (70.5±6.4 years)	To evaluate whether the difficulty of the walking task matters.	Walking along a straight pathway of 20m length in 4 different conditions: 1:Wide path and preferred pace; 2:Narrow path and preferred pace; 3.Wide path and fast pace; 4.Obstacles wide path and preferred pace.	MTx® Evaluated for each step cycle of the lower right leg: Step duration, Step cycles, Step consistency. Gait Speed	Task check (20s) Task button (20s)	Checking speed: number of checked boxes per second. Buttoning speed: number of fixed buttons per second.	Wide+check Narrow+ check Obstacles+ check Wide Fast+check Wide+button Narrow+ button Obstacles+ button Wide Fast+button	MTx® Evaluated for each step cycle of the lower right leg: step duration, step cycles, step consistency. Gait Speed	Gait during 20m	2 trials under each DT	In older people changes in gait pattern is more pronounced in the task check because it needs to be controlled while walking.
Demirci et al. (2016)	Patients with ataxia: n=25 Healthy subjects: n=25	To analyze the effect of motor and cognitive tasks on clinical	Single-Leg Stance Time Tandem Stance time	Static and Dynamic Balance	Taking 3 objects from the bag respectively (money, the	ND	SLST+ Taking 3 objects from the bag respectively (money,	Static and Dynamic Balance	ND	ND	4SST was completed in a longer time in ataxic group when performed

		balance performance of patients with ataxia, by using practical clinical tests.	360º Degrees of Rotation Time Timed up and go test completing time Four Square Step Test		keys, pencil) and putting them back in turn. Carrying a glass on tray. Opening and closing bag zipper. Transferring the ball from one hand to the other. Buttoning up the shirt button.		the keys, pencil) and putting them back in turn. TST+ Carrying a glass on a tray. 360 DRT+ Transferring the ball from one hand to the other TUG completing time+Opening and closing bag zipper 4SST+ Buttoning up the shirt button				with motor task. Motor task deficits were more obvious than cognitive task deficits in 4SST.
Freire Junior et al. (2017)	Older people: non-fallers: n=35 (67.97±4.82 years) fallers: n=27 (67.96±5.7 years)	To evaluate the biomechanical aspects of DT gait in older fallers and non-fallers.	Gait	GAITRite®: Gait speed, Cadence, Stride time, Step length, Single support, Stride time variability BESTest: Functional balance	Transferring a coin from one pocket to the other	ND	Walking+ Transferring a coin from one pocket to the other	GAITRite®: Gait speed, Cadence, Stride time, Step length, Single support, Stride time variability BESTest: Functional balance Dual-task cost	8 m	3	During DT was found slower speed and cadence, shorter step length, longer stride time and single support time, and increased variability compared to single task (gait).
Hunter et al. (2018)	People with MCI: n=41 (76.20±7.65 years) Control group: n=41 (72.10±3.80 years)	To create a framework for task complexity of concurrent motor and cognitive tasks with gait in people with MCI.	Gait	GAITRite® Gait velocity	Carrying a glass of water on a tray with one hand.	ND	Gait+Carrying a glass of water on a tray with one hand.	GAITRite® Gait velocity	ND	ND	Gait velocity decreased for both groups with the addition of the motor and cognitive tasks singly.
Kachouri et al. (2019)	Children with intellectual disability: n=15 (8.6±1.42 years) Control group: n=15 (8.87±1.72 years)	To assess the effects of dual-task on walking performance.	Gait	Ten Meter Walking Test (TMWT) and the Timed Up and Go Test (TUGT)	Carrying a glass of water	ND	TUGT+ Carrying a glass of water. TMWT+ Carrying a glass of water.	Ten Meter Walking Test (TMWT) and the Timed Up and Go Test (TUGT) Poured water was recorded.	Time complete the trial (TUGT and TUGT)	3	DT walking decrements were significantly higher when performing a concurrent motor task than cognitive only.
Liu et al. (2018)	Individuals with Stroke: n=23 (51.5±10.5 years)	To investigate the effects of cognitive and motor DT on gait performance and brain activities in stroke	Gait	GAITRite®: Speed (cm/s); Cadence (steps/min); Stride time (s); Stride length (cm).	Carrying a tray with a bottle of water.	ND	Walking+ With unaffected hand carrying a tray with a bottle of water.	GAITRite®: Speed (cm/s); Cadence (steps/min); Stride time (s); Stride length (cm).	60 s	2	Gait performance deteriorated during cognitive and motor DT and there was no significant difference between these two DT types in individuals with stroke.
Makizako et al. (2013)	Healthy younger adults: n=30 (22.2±1.5 years)	To study age-related differences in the influence	Standing with feet close together	Anterior-posterior sway (triaxial accelerometer	Holding a glass of water in the left hand.	ND	Standing on a compliant foam surface in the	Anterior-posterior sway (triaxial accelerometer	40 s	10 (5 trials*2 sessions)	Younger and older adults exhibited longer RTs

	Healthy older adults: n=27 (71.3±3.4 years)	of cognitive task performance on postural sway and muscle activity on unstable balance conditions.	(Romberg stance) on a compliant foam surface with a glass full of sand in the left hand.	MA3-04Ac, Micro Stone Inc) EMG activity (SX230, Biometrics Ltd) of the ankle musculature (tibialis anterior and medial gastrocnemius of the right leg)			Romberg stance+ Holding a glass of water in the left hand.	MA3-04Ac, Micro Stone Inc) EMG activity (SX230, Biometrics Ltd) of the ankle Musculature (tibialis anterior and medial gastrocnemius of the right leg)			under dual-cognitive compared to control and motor DT conditions.
Mofateh et al. (2017)	MS patients with fall history: n=25 MS patients without fall history: n=25 Healthy controls: n=25	To compare the effects of cognitive or motor tasks on gait performance between healthy controls and MS patients with and without fall history.	Gait in treadmill	Qualisys Inc., Sweden: Cadence, Stride length, Step width, Swing time. Treadmill (BiometrixTM)	Carrying a tray with glasses.	ND	Walking+ Carrying a tray with glasses.	Qualisys Inc., Sweden: Cadence, Stride length, Step width, Swing time. Treadmill (BiometrixTM)	2 min and 5 min rest	3 trials for each DT	In all participants, performing a concurrent cognitive task markedly altered gait parameters compared to a concurrent motor task.
Nordin et al. (2010)	Older people: n=230	To evaluate whether gait pattern changes between single and DT conditions were associated with risk of falling in older people.	Gait in 3 velocity conditions: Slow, Normal, Fast.	GAITRite®: Step-length, Step-width, Step-time, Double-support-time, Gait speed.	Cup (a saucer with a coffee-cup) Tray (a rectangular wooden tray) Tray-Cup (the tray with the saucer and cup on top)	ND	Walking+ Carry a cup in one hand Walking+ Carry a tray using both hands Walking+ Carry a tray with the filled cup using both hands.	GAITRite®: Step-length, Step-width, Step-time, Double-support-time, Gait speed.	ND	1 trial for each DT	DTC's were related to the risk of falling in two of the five DT, i.e. the cognitive task ‘‘Count’’ and the manual task ‘‘Cup’’.
Oh-Park (2013)	Older people: n=16 (74.5±6.4 years) Young individuals: n=18 (19.2±2.7 years)	To analyze the DT effect on subtasks during motor DT under specific instruction of task prioritization in old compared to young adults	Gait	GAITRite®: Gait Velocity, Stride-to-stride variability	Holding a tray as steady as possible during quiet stance for 10s.	ND	Walk+Holding a tray with instructions to focus attention on keeping the tray as steady as possible Walk+Holding a tray focusing attention on walking at preferred pace	GAITRite®: Gait Velocity, Stride-to-stride variability	ND	2 trials for each DT	Compared to young, older adults tend to compromise the task involving upper limbs during motor DT even when instructed to prioritize this task over gait.
Rabaglietti et al. (2019)	Female children: n=53 (10±2 years) Group1: n=17 (7-9 years) Group2:n=36 (10-13 years)	To examine the effect of a secondary motor task on walking ability and whether performance differed according to age in children with typical development.	Gait	Walking test (stopwatch); Gait Speed	Carrying a glass of water; Carrying a ball on a round tray; Carrying a glass of water+a ball on a round tray.	ND	Walking+ Carrying a glass of water; Walking+ Carrying a ball on a round tray; Walking+ Carrying a glass of water and a ball on a round tray.	Walking test (stopwatch); Gait Speed DTC	14m	1 trial for each DT (3 min rest between each task)	Independent of the age, the DT performance might affect walking performance depending on the required secondary task. Exists an association between working memory skills and DTC in

											walking ability.
Tang et al. (2015)	Community-dwelling middle-aged and older adults: n=65 (71.5±8.1 years)	To investigate whether DT TUG could identify prefrail individuals better than single-task TUG.	TUG	Stopwatch: Time to complete TUG test	Carrying a cup of water	ND	TUG+ Carrying a cup of water	TUG performed	Stopwatch: Time to complete TUG test	3	TUG+carrying a cup of water is more valid and sensitive than single task TUG in identifying prefrail individuals.

AP: anterior-posterior; BESTest: Balance Evaluation – Systems Test; CP: complex pitcher; CT: complex tray; DTC: Dual-Task Cost; ND: no data; MCI: Mild Cognitive Impairment; ML: medial-lateral; MS: Multiple Sclerosis; RMS: root-mean-square; rpm: revolutions per minute; RTs: Reaction Times; SLST: Single Leg Stance Time; SP: simple pitcher; STr: simple tray; STV: stride time variability; TST: Tandem Stance Time; TUGT completing time: Timed Up and Go Test completing time; 4SST: Four Square Step Test; 360º DRT: 360º Degrees of Rotation Time.

DISCUSSION

Dual-task paradigms usually are used for two different purposes: to investigate the attentional demands of a motor task and to examine the effects of concurrent cognitive or motor tasks on motor performance (Huang & Mercer, 2001).

In this review, we found that the principal motor task analyzed was the gait (Beurskens et al., 2016; Abbruzzese et al., 2014; Asai et al., 2014; Beurskens & Bock, 2013; Nordin et al., 2010; Oh-Park et al., 2013; Júnior et al., 2017; Mofateh et al., 2017; Baldan & Elmauer, 2015; Liu et al., 2018; Hunter et al., 2018; Kachouri et al., 2019). Most secondary motor tasks refer to gross or fine motor tasks, such as carrying a tray or holding a cup during gait (Makizako et al., 2013; Nordin et al., 2010; Oh-Park et al., 2013; Tang et al., 2015; Mofateh et al., 2017; Hunter et al., 2018; Kachouri et al., 2019), buttoning a button (Beurskens & Bock, 2013; Demirci et al., 2016), opening and closing a bag zipper (Demirci et al., 2016), and transferring a coin from one pocket to the other (Júnior et al., 2017). These secondary motor tasks are tasks commonly used in the natural context of daily life activities.

Samples that include healthy individuals should be homogeneous since when comparing school-age children with young adults or young people with the elderly, there is already a bias due to the physical, psychological, and physiological changes that come from aging. For example, children apply different anticipatory strategies than adults, making last-minute adjustments, while adults plan well ahead of upcoming obstacles (Schott & Klotzbier, 2018), since the level of development and maturation are different.

The Abbruzzese et al. (2014) study verified that children had a more variable step length and step time than adults in all walking conditions. The same was verified in the study of Vallis & McFadyen (2005). The authors found reductions in gait speed and step length in children (9 to 12 years old), only two steps and one step prior to obstacle circumvention, respectively, while adults maintain a constant speed and step length. Cherng, Liang, Hwang & Chen (2007) showed that young children (4 to 6 years old) decrease their stride length and increase the variability of temporal and spatial gait parameters when walking and carrying a tray with or without marbles on it. Other studies showed children with impaired motor performance when walking in DT situations compared to young adults (Krampe et al., 2011), suggesting that children do not demonstrate adult-like use of sensory information in balance control before 12 years old (Peterson et al., 2005). Makisako et al. (2013) found that the cognitive task had a more significant impact than the motor task in decreasing lower limb muscle activity and increasing anterior-posterior trunk acceleration during a Romberg stance in older people compared to young adults.

Júnior et al. (2017) showed that walking while transferring coins from one pocket to the other causes a decrease in speed and cadence, shorter step length, longer stride time, and single support time, and increased variability compared to the single-task (gait) in older people.

In clinical conditions, the gait velocity and gait performance in DT were significantly worse than in a concurrent motor task only (Hunter et al., 2018; Kachouri et al., 2019). In addition, both studies (Baldan & Elmauer, 2015; Liu et al., 2018) that assessed the effect of motor dual-task in subjects with stroke also found deteriorating gait performance in motor dual-task compared to single-task (gait). Demirci et al. (2016) showed that the 4SST took greater time to be completed when concurrently performed with a secondary motor task, buttoning up the shirt button, in subjects with ataxia.

These results show that static and dynamic postural control was negatively affected while simultaneously performing a secondary motor task in clinical conditions. Other studies corroborate these results; for example, Marchese et al. (2003) showed that during motor dual-task, motor sequence of thumb opposition to the other fingers during quiet stance, the postural sway deterioration was more evident in subjects with Parkinson´s Disease than in healthy subjects. O´Shea et al. (2002) showed a decline in speed gait when performing another motor task, transferring coins from one pocket to another. Besides that, they decreased the coin transference rate between the standing and walking conditions in subjects with Parkinson´s Disease.

A complex motor task can require more attention and reduce residual attention capacity. In this situation, the competition for attention to perform different tasks is expected to happen (Laessoe et al., 2008). Few studies (Abbruzzese et al., 2014; Asai et al., 2014; Beurskens & Bock, 2013; Nordin et al., 2010) have analyzed the motor tasks' difficulty level. When the task becomes more complex, and walking is challenged, the focus of attention shifts toward the motor task to maintain gait stability. The types of motor tasks used as the concurrent motor task vary across studies (carrying a cup or tray, transferring coins or balls). Each motor task imposes distinct biomechanical constraints on the upper limbs and trunk, which can cause a greater and presumably also different constraint in the gait. Beurskens & Bock (2013) investigated the role of differently challenging walking conditions in DT and showed that the age-related increase of DTC is considerably greater with the visual demand than with the motor task demand, being more evident when walking on a narrow or obstacles path. Nordin et al. (2010) assessed gait with three different velocities and demands motor tasks: carrying a cup in one hand, carrying a tray using both hands, and carrying a tray with the filled cup using both hands. In this last dual-task, none of the gait parameters was related to the risk of falling, suggesting the cup task was more challenging because the other motor tasks did not affect gait and fall risk.

Rabaglietti et al. (2019) suggest that walking performance under a dual-task depends on the difficulty level; they found similar differences in the dual-task performance between children with 7-9 years and 10-13 years. Abbruzzese et al. (2014) found a higher variability in gait in the most complex motor tasks (holding a pitcher with a cup of water secured inside with one hand and holding a tray with an unsecured empty cup on top with both hands) compared to a simple task (holding an empty pitcher with one hand and holding an empty tray with both hands). The dual-task costs related to performing complex motor tasks during walking are higher in school-age children than young and healthy adults. Also, the temporal changes in spatial gait, decreasing gait speed, cadence, step duration and increasing time spent in double support, occurred under simultaneous motor task conditions.

Only Oh-Park et al. (2013) studied task prioritization. They stated that motivation could influence the walking performance while holding a tray with instructions to focus on keeping the tray as steady as possible. They showed that while focusing attention on keeping the tray, gait performance and tray stability were compromised during dual-task compared to single tasks and differed between the age groups. Other studies (Kelly et al., 2010; Remaud et al., 2013; Yogev-Seligmann et al., 2010) have also reported that the instructed focus of attention can affect dual-task performance.

Although the secondary motor tasks and methodologies are heterogeneous, only one study analyzed motor tasks with different complexities (Abbruzzese et al., 2014) and three studies analyzed the primary motor task (gait) in different conditions (Asai et al., 2014; Beurskens & Bock, 2013; Nordin et al., 2010). Then, based on the taxonomy model for classifying motor tasks (McIsaac et al., 2015) and in the single and dual-tasks used in studies of this review, we suggest the classification of motor tasks difficulty level presented in table 1.3.

Table 1.3. Classification of motor tasks difficulty level based on the task taxonomy model (McIsaac et al., 2015) and on the motor tasks used in the studies of this review.

Type of task	Task Novelty	Task Complexity	
		Low	High
Single Task	Low	Holding an empty pitcher with one hand. Holding an empty tray with both hands. Carrying a tray with glasses. Taking 3 objects from the bag respectively (money, the keys, pencil) and putting them back in turn. Gait/ walking. Walking wide path and preferred pace.	Holding/Carrying a glass/cup of water. Buttoning a button. Transferring a coin from one pocket to the other. Opening and closing a bag zipper. Carrying a glass of water and a ball on a round tray. Walking wide path and fast pace.
	High	Carrying a ball on a tray. Transferring a ball from one hand to another. Check each box as quickly as possible by an "X", using a pen in their dominant hand (task check). TUGT.	Holding a pitcher with a cup of water secured inside with one hand. Holding a tray with an unsecured empty cup on top with both hands. Held two sticks with a ring at the end, one in each hand and the rings were interlocked (not to let the rings touch each other).

			Standing on a compliant foam surface in the Romberg stance. Execute the SLST. Execute the 360 DRT. Execute the 4SST. Walking with obstacles wide path and preferred pace.
Dual motor-motor	Low	Walking when carrying a cup in one hand. Walking when carrying a glass of water. Walking when holding an empty pitcher with one hand. Walking when holding an empty tray with both hands. Walking when carrying a tray with glasses.	Walking when transferring coins between pockets. Walking when buttoning a button. Walking in a wide path when buttoning a button. Walking and carrying a glass of water and a ball on a round tray.
	High	Walking when carrying a ball on a tray. Walking fast wide path when task check. Walking when transferring a ball from one hand to another. Walking in wide path when task check.	Execute TUG when opening and closing a bag zipper. Execute TUG when carrying a cup of water. Walking when holding a pitcher with cup of water secured inside with one hand. Walking narrow path when check task. Walking obstacles path when check task. Walking narrow path when buttoning a button. Walking obstacles path when buttoning a button. Walking fast wide path when buttoning a button. Walking when holding a tray with an unsecured empty cup on top with both hands. Walking fast when carrying a ball on a tray. Walking when held two sticks with a ring at the end, one in each hand and the rings were interlocked (not to let the rings touch each other).

	Standing on a compliant foam surface in the Romberg stance when holding a glass of water in the left hand. Execute SLST when taking 3 objects from the bag respectively (money, the keys, pencil) and putting them back in turn. Execute TST when carrying a glass on the tray. Execute 360 DRT when transferring the ball from one hand to the other. Execute 4SST when buttoning up the shirt button.

The concepts of difficulty and complexity of the task are frequently confused. For this reason, in the present review, we adapted the classification McIsaac et al. (2015) suggested, according to the primary or secondary motor single tasks and the motor dual-tasks included in the analyzed studies. Thus, the categorization of complexity and novelty is open to the researcher's interpretation. There can be tasks that do not fit well into the categories of the study by McIsaac et al. (2015). For example, “walking when carrying a glass of water” was classified as a low complex dual-task since Rabaglietti et al. (2019) study was considered a dual-task.

The main limitation of this review was the difficulty in classifying the difficulty or complexity of tasks because it is not easy to standardize. Moreover, as already referred to, the concepts of complexity and difficulty are confused, and many studies do not consider the task's perception of difficulty or novelty by the performer of the task. Furthermore, in this review, few studies analyzed the motor tasks with different difficulty levels, making it difficult to compare and classify the tasks' difficulty levels.

In clinical practice, the use of the dual-task paradigm can improve motor and cognitive performance. It can be used to identify individuals’ motor and cognitive abilities by combining motor and cognitive demands while performing two or more tasks simultaneously. For example, studies reported that cognitive and motor dual-task training could improve the single and dual-task walking performance in the elderly (Kuo et al., 2022) and promote the dynamic balance performance of children (Hoshyari et al., 2022).

Criteria such as appropriateness of tasks to age and clinical condition, tasks similar to daily life situations, calculation of dual-task cost, assessing single-task performance in the baseline, randomization of the task order, giving clear instructions, use of homogeneous samples, the same data collection methods and the same study variables of gait and static postural control, are suggested to be included future studies. In addition, we suggest more studies to analyze the effect of a secondary motor task with different difficulty levels on static and dynamic postural control tasks because most studies focus on the cognitive task. Besides, more challenging tasks can help detect early signs of decline in postural control (Laessoe et al., 2008).

CONCLUSIONS

According to the results of the present review, the association of secondary motor tasks with other motor activities, such as static or dynamic postural control tasks while performing other motor tasks, negatively affects the postural control performance during motor dual-tasks, regardless of the age group or the clinical condition.

The motor tasks were classified according to the complexity and novelty of the tasks, based on the tasks found in studies included in this review, and on the existing taxonomy model for classifying tasks. However, we conclude that the classification of task's difficulty or complexity depends on the author's interpretation and performer characteristics, making it challenging to build a standard classification of tasks.

We suggest more studies with motor tasks and different difficulty levels because the effects of motor tasks on gait and static postural control are scarce and use various methodologies. Therefore, further studies are necessary to analyze the effect of a secondary motor task on gait and postural control tasks.

Declaration of interest

No conflicts of interest to declare.

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CHAPTER III – Study II: Postural control and sleep quality in cognitive dual-task in healthy young adults

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ABSTRACT

Although sleep quality disorders can have a negative effect on postural control, studies about this subject are scarce. The aim of this study is to assess the differences in standing posture performance during dual-task between healthy young adults with a good and poor sleep quality. Thirty-five healthy participants (23.09±3.97 years) performed a postural task (standing posture – single task (ST)) and a dual-task (DT): quiet standing while performing a concurrent cognitive task, while the total excursion of the center of pressure (TOTEX CoP), the displacement anterior-posterior (CoP-AP) and medial-lateral (CoP-ML), the mean total velocity displacement of CoP (MVELO CoP) and ellipse sway area (CEA) were measured with a force plate. After assessing the sleep quality with the Pittsburgh Sleep Quality Index, they were divided into two groups (good (n=21) and poor (n=14) sleep quality) to establish comparisons. This study revealed no significant differences in TOTEX CoP, CoP-ML, CoP-AP, MVELO CoP, and CEA among both sleep quality groups. In conclusion, differences in the sleep quality (good or poor sleep quality) on young adults appear not to be a relevant factor in the CoP variation, but the DT versus ST can compromise postural control performing independently of the sleep quality.

Keywords: postural control; dual-task; sleep quality; center of pressure.

INTRODUCTION

Postural control results from the complex integration of the central nervous system with the visual, vestibular, proprioceptive, and musculoskeletal systems. Maintaining adequate postural control during quiet standing or walking is fundamental to perform daily life activities and preventing injuries or falls. During quiet standing, the center of pressure (CoP) is constantly readjusted to achieve human balance and to counteract the sway of the body; for this reason, CoP is the measure more used to assess postural sway during static postural control (Winter, 1995).

Postural control integrates the postural orientation and postural equilibrium, these processes are fundamental requirements to stabilize the body and to maintain balance in an upright stance, and thus it is very important for the successful performance of movements (Horak, 2006). The quiet standing position is a complex task that involves the integration of multiple body segments, musculoskeletal and proprioceptive systems with aim to regulate balance while staying upright in a static position. The standing posture is a requisite basic to perform different tasks, from reaching to locomotion (Ku et al., 2012). The posture provides the mechanical support and anticipatory postural adjustments necessary for performing movements with an adequate support (Massion, 1998; Wallmann, 2009).

In daily life, it is common to perform activities in which a postural task (e.g., quiet standing or walking) is executed concurrently with a secondary task (motor or cognitive task). The relationship between attention and postural control is an increasing area of study that has revealed important aspects of the cognitive processing role in postural control. The most used methodology to ascertain its relationship is the dual-task paradigm, in which the postural control (primary task) and a secondary task are performed simultaneously (Woollacott & Shumway-cook, 2002).

The postural control system declines with age (Borah et al., 2007; Roman-Liu, 2018) and clinical conditions (e.g., Parkinson’s Disease, Multiple Sclerosis) (Cameron & Lord, 2010; Fukunaga et al., 2014). During dual-task performance, it is expected to observe some changes in CoP behavior; these changes are more evident in the elderly, where they are characterized by higher values of sway area and center of pressure velocity during dual tasks, comparatively to young adults (Bergamin et al., 2014). Recently sleep quality has been an object of study in the performance of postural control. Changes in sleep quality seem to have a negative impact on postural control performance (Furtado et al., 2016) and result in higher gait variability during cognitive dual tasking compared to single tasking (only walking) (Agmon et al., 2016). In those with clinical conditions (e.g., fibromyalgia) there is also a decline in postural performance and fall risk compared to healthy people related to sleep quality (Akkaya et al., 2013). Thus, evidence suggests that sleep quality disorders can modify the efficacy of task execution or motor response during dual-task performance.

Good sleep quality can be considered a predictor of physical and mental health, wellness, and vitality (Ohayon et al., 2017). Therefore, sleep is essential for health, and insufficient sleep duration, irregular timing of sleep, poor sleep quality, and circadian/sleep disturbances can cause disorders in people’s health

(Laposky et al., 2016). Essential sleep duration conditions differ across the lifespan and from person to person. For healthy people and people without sleep disorders, the recommendation is 7 to 9 h of sleep per night in adults aged 18 to 64 years (Hirshkowitz et al., 2015).

Sleep quality is an unclear term but, in scientific research, the Pittsburgh Sleep Quality Index (PSQI) provides a measure of global sleep quality, including subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication and daytime dysfunction (Buysse et al., 1989; Krystal & Edinger, 2008).

There is a lack of studies among young adults and healthy people on the postural control and quality of sleep in dual-task performance; therefore, the aim of this study is to assess differences in standing posture performance (CoP) during cognitive dual tasking between healthy young adults with a good and poor sleep quality. A secondary aim is to analyze the differences in CoP among single and cognitive dual tasking within each sleep quality group.

METHODOLOGY

After checking the eligibility criteria, thirty-five young adults were recruited. The inclusion criteria for this study were: healthy young adults (18–35 years). Exclusion criteria included: (1) diseases or injuries that affect the musculoskeletal, nervous, and/or cardiorespiratory system, (2) being on medication, (3) recent surgeries (within less than two months) that interfere with gait, (4) visual impairment or vision not corrected to normal vision, (5) vestibular disorders.

All procedures were conducted in compliance with the Declaration of Helsinki and, after a detailed description of the objectives and research methodology, all subjects that agreed to participate read and signed informed consent. This study was approved by the Ethics Committee of the Polytechnic Institute of Coimbra (approval number: 27_CEPC2/2019, and date of approval 26 November 2019).

Sleep quality was assessed using the PSQI. It is a valid and reliable instrument used to assess the quality and patterns of sleep with the advantage of allowing differentiation between good and poor adult sleepers. It differentiates “poor” from “good” sleep by measuring the seven domains (subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction). To each component is assigned a score between 0 to 3, with 0 being the very good sleep and 3 very bad sleep, where a total equal to or less than 5 points means a good sleep quality and values greater than 5 correspond to poor sleep quality (Buysse et al., 1989).

After assessing sleep quality, the thirty-five healthy young adults (23.09 ± 3.97 years) were divided into two groups: the good sleep quality group (n = 21) and the poor sleep quality group (n = 14).

A Bertec® force plate model FP4060-07-1000 (Bertec Corporation, 6171 Huntley Road, Suite J Columbus, OH 43229 USA) with a maximum capacity of 5000 N was used to measure total excursion of the center of pressure (TOTEX CoP – unit in mm), the displacements of the center of pressure in medial-lateral (CoP-ML – unit in mm) and anterior-posterior (CoP-AP - unit in mm) directions, the mean total velocity displacement of CoP ((MVELO CoP – unit in mm/s) and 95% confidence ellipse sway area (CEA – unit in mm^2). The force plate data were filtered using a 50 Hz low-pass filter, 6th Butterworth and they were processed after the assessment with a Matlab routine (version R2020b, The Mathworks, Inc.).

All participants underwent anthropometric measurements (weight and height) before performing tasks. Then, they were instructed to stand as still as possible in a quiet standing position while focusing on a point at eye-level of the participants (single task – standing posture) for 60 s (Carpenter et al., 2001).

The dual task consisted of keeping a quiet standing position while performing a concurrent cognitive task—arithmetic or memory tasks (cognitive dual task) on their smartphone for 60 s. The arithmetic task consisted of a sum or subtraction calculation with one or two digits (e.g., 6 + 20 = ?; 9 + ? = 58). The memory task consisted of memorizing three elements (number, color of the number and image) and then repeating the memorized elements for a few seconds. For each participant, the cognitive task was chosen randomly. The cognitive task performance on the baseline (sitting in the chair while cognitive task performing) and on the dual task (quiet standing position while performing a concurrent cognitive task) was estimated by the number of correct responses in each task.

Each participant repeated each task once, with a one minute rest period between the tasks. No priority was given to cognitive and standing postural tasks. The participants were instructed to use their personal smartphone and hold it in the usual way while performing the cognitive task.

The statistical analysis was conducted using IBM-SPSS 25.0 software. Quantitative descriptive data related to sample characteristics are reported as mean ± SD (standard deviation). Homogeneity of variances and normality of the distribution of the parameters was tested with the Levene's and Shapiro–Wilk tests, respectively. Some outcomes were not normally distributed; thus, the data were presented as the median and interquartile range (IQR). The differences between groups with different sleep quality scores were assessed through the Mann–Whitney U test. The differences in dual-task performance within each group were analyzed with the related samples Wilcoxon signed-rank test. The statistical significance level was set at $p < 0.05$.

RESULTS

Sample Characteristics

Table 2.1 shows the participants' characteristics. There was no difference between the good and poor sleep quality groups for anthropometric characteristics ($p > 0.05$). There was a significant difference in the total score of the PSQI between the good (3.78 ± 1.40 points) and poor (8.29 ± 2.05 points) sleep quality groups ($p < 0.001$).

Table 2.1. Anthropometrics characteristics and total score PSQI of the total sample and sleep quality groups (mean ± SD).

Variables	**Sample n=35**	**Good Sleep Quality group (n=21)**	**Poor Sleep Quality group (n=14)**
Age (years)	23.09 ± 3.97	22.38 ± 4.20	24.14 ± 3.48
Height (m)	1.71 ± 0.10	1.73 ± 0.08	1.68 ± 0.12
Weight (Kg)	73.53 ± 15.96	74.32 ± 13.35	72.34 ± 19.74
BMI (Kg/m^2)	25.07 ± 4.41	24.86 ± 3.72	25.37 ± 5.40
PSQI total	5.40 ± 2.91	3.78 ± 1.40^1	8.29 ± 2.05^1

BMI, body mass index; PSQI, Pittsburg Sleep Quality Index

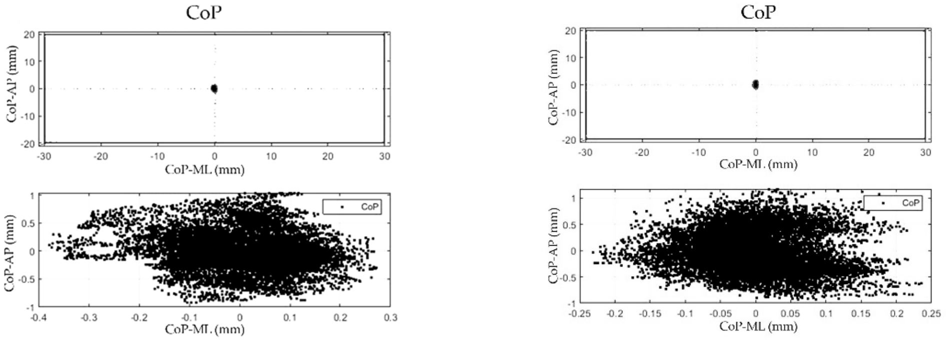
^{1} $p < 0.01$ between two sleep quality groups using Mann-Whitney U test.

The cognitive task performance on the baseline (sitting while performing cognitive task) and on the dual task (maintaining a quiet standing position while performing a concurrent cognitive task) did not differ between good and poor sleep quality groups or within each group ($p > 0.05$).

Postural outcomes

CoP among good sleep and poor sleep quality groups

There were no significant differences in the total excursion of the center of pressure, in the displacements of the center of pressure in anterior–posterior and medial–lateral directions (statokinesigram in figure 2.1), in the mean total velocity displacement of CoP, and in the 95% confidence ellipse sway area during standing posture between the good sleep and poor sleep quality groups ($p > 0.05$). CoP data (median, IQR) and statistical comparisons among groups (Mann–Whitney U test, *p*-value) during standing posture (single task) are summarized in Table 2.2.



(**a**) (**b**)

Figure 2.1. Statokinesigram: displacements of the center of pressure in anterior-posterior and medial-lateral directions during single task: (a) good sleep quality group; (b) poor sleep quality group. ($p > 0.05$).

Table 2.2. Comparisons of CoP behavior among good and poor sleep quality groups during standing posture task (single task), median (IQR).

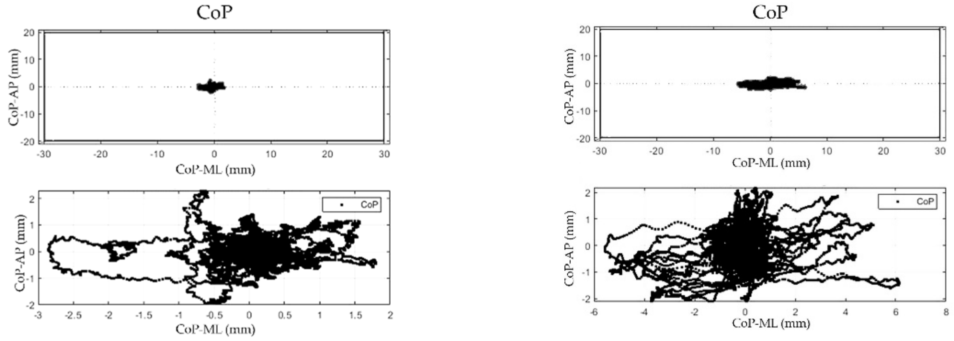
Outcomes	Good Sleep Quality Group (n=21)	Poor Sleep Quality Group (n=14)	*p*-value[1]
TOTEX CoP (mm)	2449.8 (2217.4-2665.8)	2376.9 (2104.1-3032.7)	0.814
CoP-AP (mm)	1848.3 (1684.6-2010.7)	1801.4 (1613.0-2267.9)	0.840
CoP-ML (mm)	1215.7 (1125.3-1347.9)	1224.7 (1034.1-1582.1)	0.762
CEA (mm^2)	215.7 (106.9-386.3)	234.7 (114.2-361.7)	0.762
MVELO CoP (mm/s)	490.0 (443.5-533.2)	475.4 (420.8-606.5)	0.814

TOTEX CoP, total excursion of the center of pressure; CoP-AP, displacement of the center of pressure in anterior-posterior direction; CoP-ML, displacement medial-lateral direction; MVELO CoP, mean total velocity displacement of CoP; CEA, 95% confidence ellipse sway area.

[1] Mann-Whitney U test.

The area of the confidence ellipse during single and cognitive dual tasking was lower in the good sleep quality group (ST—median: 215.7 ((106.9–386.3))mm^2; DT—552.1 ((235.0–1029.6))mm^2) in comparison to the poor sleep quality group (ST—median: 234.7 ((114.2–361.7))mm^2; DT—726.5 ((493.9–1448.2))mm^2), but this difference was not significant ($p > 0.05$).

During dual-task performance (quiet standing position while concurrently performing a cognitive task) there were no significant differences in all CoP variables between the good and poor sleep quality groups ($p > 0.05$). The statokinesigram representative of the displacement of the center of pressure in anterior–posterior and medial–lateral directions between the sleep quality groups during cognitive dual tasking is illustrated in figure 2.2. The CoP data (median, IQR) and statistical comparisons between sleep quality groups (Mann–Whitney U test, *p*-value) during dual tasking are shown in Table 2.3.



(**a**) (**b**)

Figure 2.2. Statokinesigram: displacements of the center of pressure in anterior-posterior and medial-lateral directions during dual-task: (a) good sleep quality group; (b) poor sleep quality group. ($p > 0.05$).

Table 2.3. Comparisons of CoP behavior among good and poor sleep quality groups during quiet standing position while performing a cognitive task (dual-task), median (IQR).

Outcomes	**Good Sleep Quality Group (n=21)**	**Poor Sleep Quality Group (n=21)**	***p*-value**[1]
TOTEX CoP (mm)	2648.5 (2421.0-3058.1)	2497.5 (2364.8-3307.0)	0.946
CoP-AP (mm)	2010.2 (1843.0-2347.0)	1924.4 (1765.0-2457.8)	0.866
CoP-ML (mm)	1292.9 (1189.5-1412.7)	1266.8 (1190.5-1817.5)	0.736
CEA (mm^2)	552.1 (235.0-1029.6)	726.5 (493.9-1448.2)	0.281
MVELO CoP (mm/s)	529.7 (484.2-611.7)	499.5 (473.0-661.5)	0.946

TOTEX CoP, total excursion of the center of pressure; CoP-AP, displacement of the center of pressure in anterior-posterior direction; CoP-ML, displacement medial-lateral direction; MVELO CoP, mean total velocity displacement of CoP; CEA, 95% confidence ellipse sway area.

[1] Mann-Whitney U test.

CoP comparations among ST and DT within each sleep quality group

Within each group, between single and dual-task performance, there was a significant difference ($p < 0.05$) in the total excursion of the center of pressure, in the displacements of the center of pressure in the anterior–posterior and the medial–lateral directions, in the mean total velocity displacement of CoP and the 95% confidence ellipse sway area. These data are summarized in Table 2.4.

Table 2.4. Comparisons of postural outcomes among single and dual-task conditions within good sleep quality group and poor sleep quality group, median and *p*-values.

Outcomes	Good Sleep Quality Group (n=21) ST vs DT	*p*-value[1]	Poor Sleep Quality Group (n=14) ST vs DT	*p*-value[1]
TOTEX CoP (mm)	2449.8 vs 2648.5	0.002	2376.9 vs 2497.5	0.001
CoP-AP (mm)	1848.3 vs 2010.5	0.001	1801.4 vs 1924.4	0.002
CoP-ML (mm)	1215.7 vs 1292.9	0.008	1224.7 vs 1266.8	0.002
CEA (mm^2)	215.7 vs 552.1	0.000	234.7 vs 726.5	0.002
MVELO CoP (mm/s)	490.0 vs 529.7	0.002	475.4 vs 499.5	0.001

TOTEX CoP, total excursion of the center of pressure; CoP-AP, displacement of the center of pressure in anterior-posterior direction; CoP-ML, displacement medial-lateral direction; MVELO CoP, mean total velocity displacement of CoP; CEA, 95% confidence ellipse sway area; ST, single-task; DT, dual-task.

[1] Related samples Wilcoxon signed-rank test.

DISCUSSION

This study investigated the differences in static postural control between good and poor sleep groups during a single task (quiet standing position) and cognitive dual task (quiet standing position while performing a concurrent cognitive task), in healthy young adults. The current study results showed that variability of the center of pressure during single and dual tasks does not differ between good and poor quality sleep groups in healthy young adults. As such, it is suggested that in this study sample sleep quality does not compromise the total excursion of the center of pressure, the displacements of the center of pressure in anterior–posterior and medial–lateral directions, the mean total velocity displacement of CoP, and the 95% confidence ellipse sway area during the static postural control (standing posture) and the dual-task performance.

Although these results were not significant, which challenges comparison, concerning the 95% area of the confidence ellipse during single and cognitive dual tasking we found a lower CEA in subjects that show a good sleep quality compared to the poor sleep quality group. The reduced area postural sway in the good quality group can suggest an effectiveness of postural control and lower risk of fall. Previous studies demonstrate that a greater 95% confidence ellipse area can be associated with an ineffectiveness of postural stability (Wang et al., 2016) and a fall history in older people (Merlo et al., 2012). There are few studies comparing groups with different sleep quality in postural control performance or/and during dual-task performance. A study that assessed the static and dynamic postural control performance under conditions that alter sensory inputs (e.g., eyes open or closed, rigid or soft surface), between higher and lower sleep quality groups using the PSQI and an actigraphy to evaluate the sleep quality in healthy young adults also found no significant differences in static postural control (eyes open—firm surface, eyes closed—firm surface, eyes open—foam surface conditions) between the sleep quality groups. However, in the static postural test with eyes closed on a foam surface, they found a significant difference between groups (lower sleep quality group with worse performance in static postural control). During dynamic postural control, they found that the lower sleep quality group presented a worse performance in postural control than the higher sleep quality group in most dynamics tests (Furtado et al., 2016).

Another study analyzed the relationship between gait performance and sleep behavior during single tasks and dual tasks in older adults. It was found that a lower sleep efficacy was associated with decreased gait speed and increased gait variability during cognitive DT (walking while concurrently performing a cognitive task) but found no correlations between sleep and gait measures during the single task (walking only) (Agmon et al., 2016). Our study found, within each group, the worst results in the total excursion of the center of pressure, in the displacements of the center of pressure in the anterior–posterior and medial–lateral directions, in the mean total velocity displacement of CoP, and the 95% confidence ellipse sway area during the cognitive dual task compared to the single task, regardless of the sleep quality. An explanation for this may be that the performance decrements during the cognitive dual task could be related to the prioritization task and the individual's skills to allocate their cognitive resources (Dault et al., 2001; Woollacott & Shumway-Cook, 2002); in this case, the participants could be more involved in the cognitive task performance than in maintaining balance in the quiet standing posture.

In challenging postural conditions (reduced base support, vision deprivation, cognitive load) the velocity of CoP increases but the CoP displacements decrease during dual tasking, likely due to enhanced lower limb stiffness in healthy adults (Albertsen et al., 2017). Similarly, our results showed an increase in the mean total velocity displacement of CoP of healthy young adults while performing a cognitive task when compared to the single postural task, using a relatively easy postural task (quiet standing position with eyes open) and a cognitive task with some load.

Most studies attempt to establish associations between sleep quality and cognitive or school performance. In our case, there were no differences between good and poor sleep quality groups or within each group regarding cognitive task performance. Similarly, other authors showed that there was no association between sleep quality and cognitive performance (working memory, executive functions and procedural learning) in healthy young adults (Zavecz et al., 2020). Contrarily, other research showed a strong association between worse school performance and sleep disturbances (poor sleep quality, insufficient duration sleep and sleepiness) (Dewald et al., 2010), emphasizing the importance of sleep in cognitive functioning, in the performance of cognitive–motor dual tasks and in daily life conditions. Furthermore, it showed an association between sleep disturbances (e.g., a higher number of awakenings) and a detriment of dual-task performance in children (Möhring et al., 2019).

The current study has some strengths and weaknesses. A major strength was that static postural control was measured objectively in single and dual tasks in the different sleep quality groups. Our study contributed more information about the comparisons between sleep quality and dual-task performance in healthy young adults. Relative to the task choice, we used a smartphone to allow performing dual tasks because we wanted to reproduce the usual situations of daily life; in this case, the dual task was to keep a quiet standing position while the participant played a cognitive game on the smartphone. Our results represented the assessment of sleep quality and postural control in the cognitive dual task in healthy individuals, contrary to other studies that describe postural stability after sleep deprivation and/or with visual manipulation (Gomez et al., 2008; Nakano et al., 2001; Robillard et al., 2011). Thus, our results characterize the real environment and add information about the normal sleep condition (normal sleep night) and its influence on postural control in dual tasking in healthy young adults.

A limitation was the sample size was not large enough to create different sleep quality groups with a greater sample number and to facilitate adequate statistical power. Some studies analyze the sleep quality in sleep privation conditions, and they find that alterations in sleep quality and pattern during consecutive days can affect balance (Bougard et al., 2011; Montesinos et al., 2018). We used the PSQI to assess the subjective sleep quality during the previous month only and the results of total score PSQI in the global sample (*n* = 35) approached a better sleep quality than poor sleep quality, and this can have contributed to no difference in postural control between sleep quality groups.

We suggest a better understanding of the influence on sleep quality in postural control performance during dual tasking because sleep can steady and improve the consolidation of gross motor tasks in healthy adults, despite the fact this association among learning and sleep parameters is still controversial (Christova et al., 2018).

CONCLUSIONS

Good or poor sleep quality in healthy young adults appears not to be a relevant factor influencing CoP variation. However, intra-group changes were observed in all CoP variables in a study during cognitive dual tasking versus single task performance and this suggests that while performing dual tasks the postural control is negatively affected, resulting in a greater oscillation and compromising the postural control independently of the sleep quality.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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Conflicts of Interest: The authors declare no conflict of interest.

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CHAPTER IV – Study III: Standing Posture in motor and cognitive dual-task during smartphone use: linear and nonlinear analysis of postural control

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ABSTRACT

Analysis of the center of pressure (CoP) during cognitive or motor dual-tasking is widely used to characterize postural control. Most studies use traditional measures of CoP to quantify postural control, but given its complexity, nonlinear analysis of CoP is of growing interest in the area. This study aims to analyze CoP behavior in healthy young adults during standing posture performance while simultaneously performing motor or cognitive tasks on a smartphone, using linear and nonlinear analysis of CoP. Thirty-six healthy participants (23.08 ± 3.92 years) were found eligible for this study. They performed a single task (ST), cognitive dual-task (cog-DT), and motor dual-task (mot-DT). The total excursion of CoP, displacement of CoP in the anterior-posterior and medial-lateral directions, mean total velocity of CoP, and mean anterior-posterior and medial-lateral velocities of CoP were measured with a force plate. Approximate entropy (ApEn) of the anterior-posterior (ApEn-AP) and medial-lateral (ApEn-ML) displacement of CoP were also calculated. The results showed that dual-task costs for the total excursion, displacement in the anterior-posterior direction, mean total velocity, and mean anterior-posterior velocity of CoP were greater during the cog-DT than the mot-DT ($p < 0.05$). In the nonlinear analysis of the CoP, there was no difference ($p > 0.05$) between the cog-DT and mot-DT for ApEn values of the anterior-posterior and medial-lateral time series of the CoP. Both linear and nonlinear analyses showed differences between the cog-DT and ST ($p < 0.05$), revealing a decline in postural control during the cog-DT compared with the ST. In conclusion, performing a cog-DT causes sway impairments and lower postural control efficacy compared with motor single and dual-tasks. Furthermore, both linear and nonlinear analyses were able to distinguish between conditions.

Keywords: dual-task; center of pressure; approximate entropy; linear analysis CoP; smartphone use; standing posture.

INTRODUCTION

Postural control refers to the ability to maintain, reach, or restore a state of balance during any posture or activity (Pollock et al., 2000). The ability to stand upright on two feet is a prerequisite for initiating other activities, and provides essential information about balance and the postural control system (Winter et al., 1998).

During human quiet standing, the center of pressure (CoP)—the point of application of the ground reaction force vector—is constantly readjusted to achieve human balance and counteract the body's sway. For this reason, the motion of the CoP is the measure most often used to assess postural sway during static postural control (Winter, 1995); although some authors assess balance performance using the center of gravity, measuring the center of pressure by force plate is considered the gold standard for assessing postural balance (Chen et al., 2021; Huurnink et al., 2013).

There are two main approaches to assessing CoP behavior: linear and nonlinear analysis. Linear analysis describes the quality of movement, the magnitude and/or variance of the CoP displacements (e.g., range of CoP sway, velocity of CoP, ellipse sway area), whereas nonlinear measures provide information about the temporal organization of the variation in CoP displacement regarding motor behavior over time (Kyvelidou et al., 2009). This variability is intrinsic within all biological systems, and an important characteristic of adaptive postural behavior, reflecting variations in time and space (Stergiou et al., 2006). Approximate entropy (ApEn) is one of several measures of nonlinear analysis of the CoP. ApEn is a system complexity and regularity measure that quantifies the randomness in a time series in various situations (Pincus, 1991). It is a useful measure of postural sway complexity in an experimental time series and has been used to describe changes in postural control (Rhea et al., 2011; Turnock & Layne, 2010). ApEn values range between 0 (more regular sway) and 2 (irregular and unpredictable sway) (S. M. Pincus, 1991; Stergiou, 2016). Smaller approximate entropy values are associated with a lower complexity of structure and more regular and predictable CoP signals, whereas higher values indicate larger irregularities in the CoP, being more random and less predictable. The lower complexity of physical movements shows a higher rigidity and lower flexibility of postural control, whereas higher complexity is translated as enhanced self-organization and effective strategy in postural control (Richman & Moorman, 2000).

Maintaining an upright posture while performing one or more concurrent tasks is common in daily activities. For example, using different smartphone functions (e.g., listening to music, sending or reading messages, talking, web surfing, and playing games) while standing, walking, or working (Hyong, 2015). Using the dual-task, it is possible to assess the effects of concurrent motor or cognitive tasks on motor performance and the attentional demands of a motor task (Huang & Mercer, 2001). Simultaneously executing two tasks demands a higher level of attention, balancing ability, and executive function compared with a single-task performance (Plummer et al., 2013). Generally, when performing simultaneous tasks, there is a decline in performance for one or both tasks, which is referred to as dual-task interference (DTI) (Leone et al., 2017).

The performance decline in dual-tasks has been demonstrated in several studies, showing a decrease in postural stability under cognitive or motor dual-task conditions in healthy individuals (young and older people) and neurological patients (e.g., Parkinson's disease, multiple sclerosis, etc.) through sway analysis (traditional CoP analysis) (Ghai et al., 2017). The smartphone is an electronic device massively used worldwide by all ages, and its use is associated with pedestrian accidents (Nasar & Troyer, 2013) and physical and psychological problems (Eitivipart et al., 2018; Elhai et al., 2017). However, studies that have considered smartphone use as a secondary task when assessing postural stability are limited, particularly in studies where the primary task is standing posture (Nurwulan & Jiang, 2016).

Based on entropy analysis, previous studies that have assessed cognitive dual-task performance during standing have suggested that the regularity of CoP trajectories is positively correlated with the amount of cognitive involvement in postural control (Donker et al., 2007; Roerdink et al., 2006). This means less cognitive involvement in postural control yields less regular postural sway (higher entropy) when introducing a cognitive task (Donker et al., 2007; Roerdink et al., 2006).

Most studies analyzed the effect of mobile phone use on postural control while walking. They found that mobile phone use negatively compromises gait kinematics (e.g., gait speed, stride length, stance phase, and cadence) and gait stability (Jeon et al., 2016; Strubhar et al., 2015). For this reason, we analyzed the effect of performing cognitive and motor dual-tasks involving smartphone use on static postural control; once that, many of the functions used on the smartphone involve motor and cognitive tasks.

It is important to characterize and understand postural control stability and motor control mechanisms in healthy young adults when performing different tasks in quiet standing posture to predict falls and postural control impairments. The linear analysis of CoP displacements is the usual assessment of postural control in an upright stance, although data is not interpreted from a physiological point of view (Kędziorek & Błażkiewicz, 2020). The nonlinear analysis adds this perspective, as it assesses the flexibility and capacity of the postural control system to adapt to an unpredictable and constantly changing environment (Lipsitz & Goldberger, 1992). Thus, we added the nonlinear analysis to characterize the dynamic organization of CoP displacements during a dual-task in an upright stance because it is a complex task representing the sum of various neuromusculoskeletal systems (Horak, 2006). Moreover, standing posture is fundamental to adequately performing other tasks and movements (Horak, 2006; Massion, 1994); therefore, it is pertinent to assess the regularity and stability of the CoP in health systems to predict diseases or impairments in postural control. To the best of our knowledge, few studies have used approximate entropy in CoP time series analyses during dual-task performance (Cavanaugh et al., 2007; Kuczyński et al., 2011; Stins et al., 2009), especially when maintaining a quiet standing posture while using a smartphone (Nurwulan et al., 2015). Thus, using linear and nonlinear analysis, we aimed to analyze CoP behavior in standing posture performance while simultaneously performing motor or cognitive tasks on the smartphone in healthy young adults to identify which of the tasks interfered most with postural control performance. We hypothesized that: (1) Young adults would have lower postural control performance when performing a cognitive task on their smartphone while maintaining a standing posture than when performing a secondary motor task (dual-task interference); (2) There would be lower complexity of postural control and greater center of pressure kinematic impairments in cognitive and motor dual-tasks than in a single task.

METHODOLOGY

An a priori power analysis was conducted using G*power software (Franz Faul, Edgar Erdfelder, Axel Buchner, Universität Kiel, Kiel, Germany, version 3.1.9.6) to calculate the necessary sample size (Erdfelder et al., 1996). With $\alpha = 0.05$ and a power of 0.95, a minimum of 24 individuals was needed to achieve a large effect size (d = 0.8).

Thirty-six healthy young adults between 18 and 35 years of age participated in this study (see sample characteristics in Table 3.1). They were medication-free, had no neurological, vestibular, visual, musculoskeletal, or cardiorespiratory dysfunctions, and no active disease at the time of data collection. They gave written informed consent for participation in this study, which was approved by the Ethics Committee of the Polytechnic Institute of Coimbra (approval number: 27_CEPC2/2019) and conformed to the Declaration of Helsinki.

Table 3.1. Anthropometric and demographic characteristics and data about smartphone use of the sample (mean ± SD).

Variables	**Sample n = 36**
Age (years)	23.08 ± 3.92
Height (m)	1.71 ± 0.10
Body mass (Kg)	73.99 ± 15.97
BMI (Kg/m^2)	25.15 ± 4.37
Smartphone use (hours/day)	4.26 ± 3.17

BMI, body mass index.

Postural Control assessment

Subjects were instructed to quietly stand upright on a force plate to perform all tasks. Ground reaction forces and moments were recorded using a model FP4060-07-1000 Bertec® force plate (Bertec Corporation, Columbus, OH 43229, USA) with a sampling frequency of 100 Hz. These measures were later used to compute the coordinates of the center of pressure in the anterior-posterior (CoP-AP) and medial-lateral (CoP-ML) axes. We smoothed the signals using a second order low pass Butterworth filter with a cut-off frequency of 50 Hz. Postural control has been characterized by measures of the magnitude and variation of displacements, such as the total excursion of the CoP (TOTEX CoP), displacements of the CoP in medial-lateral (CoP-ML) and anterior-posterior (CoP-AP) directions, mean total velocity of CoP (MVELO CoP), and mean anterior-posterior (MVELO CoP-AP) and medial-lateral (MVELO CoP-ML) velocities of CoP during task performance.

The algorithm for calculating ApEn begins with the time series data of length N with an embedding dimension, m (pattern length), and a lag. The time series of length N is divided into short vectors of length (Stergiou, 2016). The ApEn algorithm was calculated by applying the following Equation (1):

$$\phi_{\mathrm{m}} = (N - m + 1)^{-1} \sum_{i=1}^{N-m+1} \log\,(N_{\mathrm{i}}) \quad (1)$$

After power spectral analysis, the approximate entropy was calculated using the initial data file. We calculated separate ApEn values for the anterior-posterior (ApEn-AP) and medial-lateral (ApEn-ML) components of the CoP coordinate time series. Values of m of 2 or 3 and r ranging from 0.1 to 0.3 have been recommended to analyze the ApEn of physiological signals. The selection of the parameters $m = 2$ and $r = 0.15$ were commonly used to calculate the Approximate Entropy of CoP data (Lake et al., 2002; Ramdani et al., 2009; Yentes et al., 2013). Given a time series of length N, ApEn (m, r, N) is approximately equal to the negative average natural logarithm of the conditional probability that two subseries of length m are similar (within a tolerance given by ± r times the standard deviation of the time series). We used $m = 2$ and $r = 0.1$.

Tasks

Single motor task

A single task was used as baseline control. All subjects were instructed to naturally stand upright on a force plate and relax without smartphone use for 60 s (standing posture) (Carpenter et al., 2001; Onofrei et al., 2020).

Cognitive Dual-task

The cognitive dual-task consisted of keeping a quiet standing posture while performing a concurrent cognitive task: playing a cognitive game based on arithmetic or memory tasks (cog-DT) on their smartphone for 60 s. The arithmetic task consisted of a sum or subtraction calculation with one or two digits. The participants were instructed to verbalize their responses to neutralize the motor component (typing on the smartphone). The memory task consisted of memorizing three different elements (a number, the color of the number, and an image), and then repeating the memorized elements for a few seconds. The cognitive tasks described involve similar cognitive processes and can be classified in the same category (Bayot et al., 2018). For each participant, the cognitive task was randomly chosen.

Motor Dual-task

The participants were instructed to keep a quiet standing posture while performing a concurrent motor task: typing on the smartphone keyboard (mot-DT). They were informed to type randomly on the smartphone keyboard to neutralize the cognitive component (e.g., not thinking in words or constructing sentences or texts).

Each participant repeated each task once, with a 45 s rest period between tasks. No priority was given to cognitive, motor, and standing postural tasks. The participants were instructed to use their smartphone and hold it as they usually did while playing a game (cognitive task) and typing on the smartphone keyboard, maintaining this position and regular smartphone manipulation for an ecological analysis.

Dual-task Cost (DTC)

The following Equation (2) (Doumas et al., 2008) was used to identify which of the secondary tasks interferes most with postural control performance. The DTC represents the percentage of changes in CoP behavior from the single task (ST, baseline) to cognitive and motor dual-task (DT) conditions:

$$\%\,\mathrm{DTC}\ (\mathrm{outcome}) = \frac{\mathrm{DT} - \mathrm{ST}}{\mathrm{ST}} * 100 \tag{2}$$

The DTC was calculated for CoP linear outcomes ($\mathrm{DTC}_{\mathrm{CoP}}$) and ApEn ($\mathrm{DTC}_{\mathrm{ApEn}}$) in both dual-tasks, cognitive dual-task costs (cog-DTC), and motor dual-task costs (mot-DTC).

Higher positive DTC values represent a greater percentage of change from ST to DT in CoP linear outcomes, signifying worse postural control during dual-task performance than single-task performance. On the other hand, in ApEn analysis, negative DTC values represent lower complexity and more regular postural sway (lower entropy), which was found when performing dual-tasks compared with the ST.

Statistical analysis

The statistical analysis was performed using IBM-SPSS 25.0 software. Quantitative descriptive data related to sample characteristics, CoP linear measures and DTC values were reported as mean ± SD (standard deviation); the ApEn data were presented as median values. Homogeneity of variance and normality of the distribution for the parameters were verified using Levene's and Shapiro–Wilk tests, respectively. Some outcomes did not have a normal distribution; thus, these data were assessed using non-parametric tests. The differences in CoP linear outcomes and ApEn between motor and cognitive DTCs were examined with the related samples Wilcoxon signed-rank test, to determine which of the secondary tasks interfered most with postural control performance.

The stabilometric data analysis among the three conditions (single task, motor, and cognitive dual-tasks) was performed with the Friedman test and post-hoc Bonferroni corrections to analyze CoP behavior in standing posture performance while simultaneously performing motor or cognitive tasks.

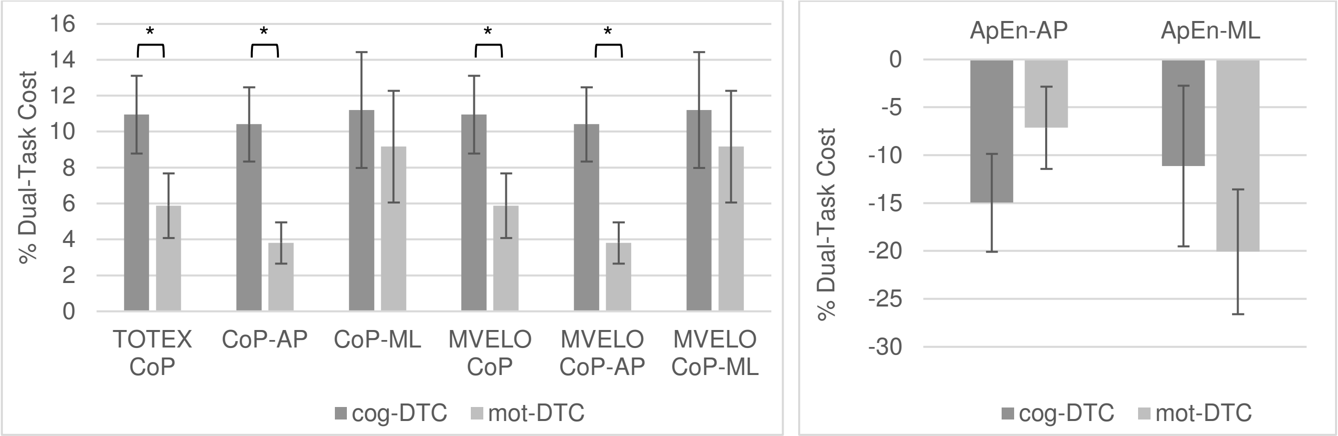
The statistical significance level was set at $p < 0.05$.

RESULTS

During the dual-tasks, most participants held the smartphone with both hands; there were no differences in CoP values between participants who held the smartphone with one versus two hands ($p > 0.05$).

Dual-task interference

Figure 3.1 shows the results obtained for the cognitive and motor dual-task costs and the differences between both dual-task costs in CoP linear outcomes and ApEn. Cognitive and motor dual-task cost results in CoP linear outcomes showed a decrease in postural control performance when simultaneously performing cognitive or motor tasks while maintaining a quiet standing posture compared with performing a single task. The cognitive dual-task cost for CoP linear outcomes was superior to the motor dual-task cost values. Differences between cognitive and motor dual-task costs were observed in the total excursion of the CoP ($p = 0.027$), displacement of the CoP in the anterior-posterior direction ($p = 0.002$), mean total velocity of CoP ($p = 0.027$), and mean anterior-posterior velocity of CoP (p = 0.002). However, there were no differences between cognitive and motor DTC in the displacement of the CoP in the medial-lateral direction and mean medial-lateral velocity of CoP ($p > 0.05$).



(**a**) (**b**)

Figure 3.1. Means and standard errors (error bars) for the cognitive and motor dual-task cost in CoP: (a) linear and (b) nonlinear outcomes.

cog-DTC, cognitive dual-task cost; mot-DTC, motor dual-task cost; TOTEX CoP, total excursion of the center of pressure; CoP-AP, displacement of the center of pressure in anterior-posterior direction; CoP-ML, displacement medial-lateral direction; MVELO CoP, mean total velocity displacement of CoP; MVELO CoP-AP, mean velocity displacement anterior-posterior of CoP; MVELO CoP-ML, mean velocity displacement medial-lateral of CoP; ApEn-Ap, Approximate Entropy for anterior-posterior components of the CoP coordinate time series; ApEn-ML, Approximate Entropy for medial-lateral components of the CoP coordinate time series. * p-value < 0.05: Wilcoxon signed-rank test (using median values): cog-DTC compared to mot-DTC.

Negative DTC values were found in ApEn for the anterior-posterior and medial-lateral components of the COP coordinate time series, showing a decrease in entropy from the single task to the cognitive and motor dual-tasks. However, there were no differences between cog-DTC$_{\text{ApEn}}$ and mot-DTC$_{\text{ApEn}}$ ($p > 0.05$).

CoP - linear and nonlinear analysis

The CoP behavior in standing posture performance with simultaneous performance of motor or cognitive tasks through linear and nonlinear analysis is presented in Figures 3.2 and 3.3, respectively.

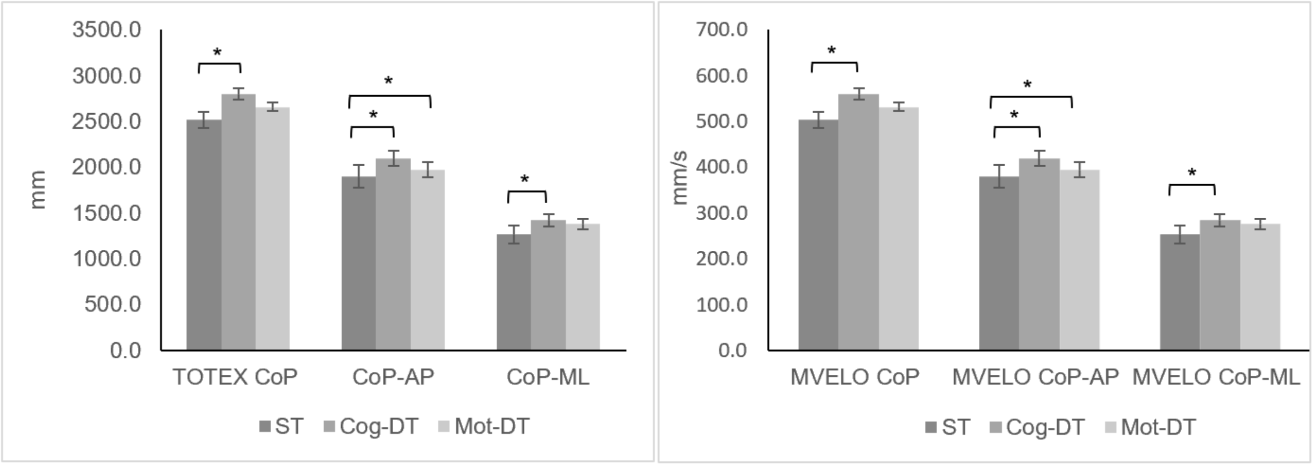


Figure 3.2. Mean and standard errors (error bars) for each CoP linear outcome during the single-task, cognitive and motor dual-task performance.

ST, single-task; cog-DT, cognitive dual-task; mot-DT, motor dual-task; TOTEX CoP, total excursion of the center of pressure; CoP-AP, displacement of the center of pressure in anterior-posterior direction; CoP-ML, displacement medial-lateral direction; MVELO CoP, mean total velocity displacement of CoP; MVELO CoP-AP, mean velocity displacement anterior-posterior of CoP; MVELO CoP-ML, mean velocity displacement medial-lateral of CoP. * *p*-value < 0.05: Friedman test with Bonferroni correction for multiple comparisons.

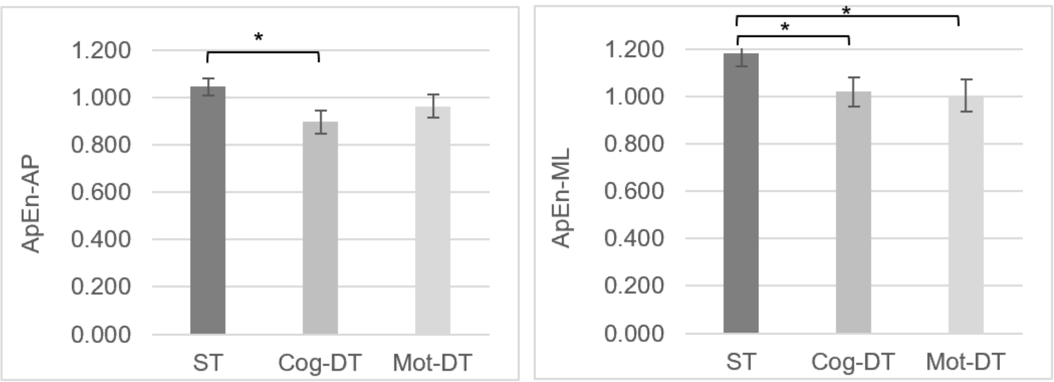


Figure 3.3. Comparisons of CoP behavior among tasks – nonlinear analysis: Approximate Entropy (median values and standard errors (error bars)).

ApEn-AP, Approximate Entropy for anterior-posterior components of the CoP coordinate time series; ApEn-ML, Approximate Entropy for medial-lateral components of the CoP coordinate time series; ST, single-task; Cog-DT, cognitive dual-task; Mot-DT, motor dual-task. * *p*-value < 0.05: Friedman test with Bonferroni correction for multiple comparisons.

Means of the total excursion of the CoP, displacements of the CoP in medial-lateral and anterior-posterior directions, mean total velocity of CoP, and mean anterior-posterior and medial-lateral velocities of CoP increased from single-task to motor and cognitive dual-task conditions (Figure 3.2). Between the single task, motor, and cognitive dual-tasks, there were differences in each CoP linear outcome (TOTEX CoP: $p < 0.001$; CoP-AP: $p < 0.001$; CoP-ML: $p = 0.001$, MVELO CoP: $p < 0.001$; MVELO CoP-AP $p < 0.001$; MVELO CoP-ML; $p = 0.001$). Post-hoc analysis showed differences in all CoP linear outcomes between the single task (i.e., maintaining a quiet standing position without a smartphone) and cognitive dual-task (i.e., maintaining a quiet standing position while concurrently performing a cognitive task on the smartphone). The differences in CoP-AP were also found between the ST and motor dual-task (i.e., maintaining a quiet standing position while random typing on the smartphone keyboard). For each CoP linear outcome, no differences were found between the cognitive and motor dual-tasks ($p > 0.05$).

CoP nonlinear analysis showed a decrease in the ApEn-AP and ApEn-ML time series values from the single task to both dual-tasks (Figure 3.3); the difference between the three tasks was significant (ApEn-AP: $p = 0.009$; ApEn-ML: $p < 0.001$). The cognitive and motor dual-task performance caused lower complexity and greater regularity in the center of pressure sway (smaller ApEn values) than the single task.

Post-hoc analysis (Figure 3.3) showed no difference between cognitive and motor dual-tasks for ApEn-AP and ApEn-ML time series values ($p > 0.05$). However, differences were found between the ST and cog-DT for ApEn-AP ($p = 0.007$) and ApEn-ML ($p = 0.003$) time series values and between ST and mot-DT for ApEn-ML time series values ($p < 0.001$).

DISCUSSION

In the present study, we used linear and nonlinear analysis of the center of pressure to investigate center of pressure behavior (dual-task interference) between a cognitive dual-task (i.e., maintaining a standing posture while performing a cognitive task on the smartphone) and a motor dual-task (i.e., maintaining a standing posture while randomly typing on a smartphone keyboard). In addition, we also analyzed CoP behavior using linear and nonlinear analysis comparing a quiet standing posture without smartphone use and quiet standing posture while concurrently performing cognitive or motor tasks on a smartphone.

The dual-task costs of the total excursion, displacement in the anterior-posterior direction, mean total velocity displacement, and the mean anterior-posterior velocity of the CoP were higher during the cognitive dual-task than during the motor dual-task. This suggests that the cognitive dual-task was more challenging than the motor dual-task and caused greater perturbations on postural control in healthy young adults. In addition, the cognitive and motor DTC values for the ApEn showed lower complexity and greater regularity in the center of pressure sway (smaller ApEn values) than in the single task, suggesting a decrease in postural stability during both dual-task conditions. However, no significant difference was found between the cog-DTC and mot-DTC for ApEn.

When we examined postural control performance between the single task and cognitive and motor dual-tasks, the linear and nonlinear data showed that postural control performance was inferior under dual-task compared with single-task conditions. The total excursion of the CoP, displacements of the CoP in medial-lateral and anterior-posterior directions, mean total velocity of CoP, and mean anterior-posterior and medial-lateral velocities of CoP increased from single-task to motor and cognitive dual-task conditions. ApEn-AP and ApEn-ML time series values decreased from the single task to both dual-tasks. However, the differences were seen to be more consistent between the cognitive dual-task and single task.

Dual-task performance requires integrity of the cognitive process and challenging attentional capacities, such as sharing attention between tasks (Yogev-seligmann et al., 2008). Therefore, participants may have had difficulty maintaining standing sway during the cognitive dual-task, compared with the motor dual-task and single task, because of the inadequate division of attention between two tasks (capacity sharing theory) (Pashler, 1994). Thus, during the cognitive dual-task, brain regions needed to recruit more cognitive resources to perform the task than in the motor dual-task, due to greater cognitive effort and the prefrontal cortex's role in executive function. Some studies using neuroimaging techniques showed higher frontal lobe activity when subjects performed cognitive tasks compared with motor tasks (Ryu et al., 2016); others showed an increase in prefrontal cortex activity when performing a cognitive dual-task compared with a single task (Fujita et al., 2016; Saraiva et al., 2022).

Some tasks (e.g., sitting, standing, or walking) that we judge to be automated require cognitive processing. Thus, postural control is negatively affected during a dual-task, such as maintaining balance while simultaneously performing a second attentionally demanding cognitive or motor task (Pellecchia, 2003; Woollacott & Shumway-Cook, 2002). Our results suggest that young adults prioritized the smartphone tasks, performing secondary tasks rather than maintaining higher postural stability (primary task). Makisako et al. (2013) found that cognitive tasks had a greater impact than motor tasks on increasing anterior-posterior trunk acceleration during a Romberg stance in older people compared with young adults.

Our findings suggest that the cognitive load and verbalization of responses inherent to the cognitive task can explain the increase in postural sway compared with the secondary motor task. Previous studies showed an increase in postural sway in healthy individuals when performing a spoken mental arithmetic task due to the effect of articulation rather than the cognitive activity (Yardley et al., 1999). Another study found an increase in sway area, velocity, and length of sway path of the center of pressure during a verbal task, attributing these findings to the increased respiratory muscle activity during vocalization (Bergamin et al., 2014). Indeed, increasing respiratory frequency increases fluctuations in the displacement of CoP in healthy young adults (Hodges et al., 2002).

Earlier studies reported that texting negatively affected postural stability during walking and quiet standing in healthy young adults (Goddard et al., 2018). Nurwulan et al. (2015) assessed static and dynamic postural control (normal and tandem stance, and star excursion balance tests, respectively) with and without a smartphone (texting messages), using traditional CoP analysis (total excursion, mean displacement velocity, and sway area of CoP) and nonlinear analysis of CoP (multivariate multiscale entropy). They found higher values for stabilometric parameters of traditional CoP and a smaller value for multivariate multiscale entropy when maintaining a normal stance while texting, compared with only maintaining a normal stance, supporting the theory that a secondary task perturbs postural stability.

Another study evaluated the influence of speaking on the phone versus texting on postural balance performance in healthy young adults and concluded that both secondary tasks, when simultaneously performed during a quiet standing posture, caused an increase in the center of pressure path length, 90% confidence area, and maximum CoP speed when compared with the control task (quiet standing posture without smartphone use). This study also reported that talking on the phone affected postural stability more than texting a message (Onofrei et al., 2020).

Our results from the nonlinear analysis of the CoP were consistent with our linear data. They showed that when cognitive or motor dual-tasks were performed, the approximate entropy decreased compared with the single task, suggesting a lower effectiveness of postural control and greater regularity on the center of pressure during dual-task performance. However, no differences were found between the cog-DTC and mot-DTC for ApEn values. On the other hand, when we compared the postural control performance of the single task with the cognitive and motor dual-tasks, there were significant ApEn-Ap and ApEn-ML differences between the cognitive dual-task and single task. Only the ApEn-ML differences were significant between the motor dual-task and single task. These data support previous findings that showed that approximate entropy could detect changes in postural control in young adults (Cavanaugh et al., 2007). Donker et al. (2007) showed that the regularity of CoP was positively correlated with the attentional demand invested in postural control and, in some situations, increasing internal focus could impair postural control. According to our ApEn results, participants were focused on performing the secondary task (motor or cognitive tasks), leading to a loss of motor system complexity during both dual-tasks.

In this study, the ApEn-AP values were higher for the motor dual-task compared with the cognitive dual-task (no significant difference), which demonstrates that motor dual-task performance may lead to greater automatic postural control and complex and irregular sway than cognitive dual-tasks. This suggests a reduced adaptive capacity of postural control during cognitive dual-task performance (Manor et al., 2010). The automatization of postural control during a motor dual-task may be due to how often people communicate via text messaging; thus, spending more time on this task (Deng et al., 2019).

Other studies that evaluated the spatio-temporal structure of CoP oscillation using other methods of entropy analysis found higher entropy values in cognitive dual-tasks compared with single tasks (standing posture). For example, Kuczyński et al. (2011) evaluated balance (CoP) using sample entropy during a quiet stance (single task) and a cognitive dual-task in competitive dancers and non-dancers. They found an increase in sample entropy in dual-tasks compared with single-task performance for both groups, showing no interference of the cognitive task on postural control and higher postural stability in the dual-task. Stins et al. (2009) analyzed CoP fluctuations in health children and children with higher levels of anxiety while maintaining a quiet stance and simultaneously performing a cognitive task; they found a higher sample entropy in healthy children compared with the anxiety group during the cognitive dual-task, demonstrating greater regularity of the CoP time series on children with higher levels of anxiety. However, between the single (standing) and cognitive dual-task, the sample entropy was slightly lower during cognitive dual-task performance in both groups.

Our results showed a more regular pattern for CoP variability and reduced postural control stability during dual-task performance compared with the single task; however, the method for entropy analysis (ApEn) differed between these studies (sample entropy and multivariate multiscale entropy) and the demands of the secondary tasks may have contributed to the different entropy results.

It was difficult to compare our results with other studies because there have been few studies assessing CoP behavior on standing posture while using a smartphone (dual-task) using entropy analysis (Nurwulan et al., 2015). Some studies analyzed postural control during dual-task performance using entropy analysis in individuals with diseases (Cruz-Montecinos et al., 2020; Stins et al., 2009), and there have been different methodological approaches to measure entropy in postural control beyond approximate entropy (e.g., Shannon entropy, Renyi entropy, sample entropy, multiscale entropy). This can influence results and entropy data interpretations (Kędziorek & Błażkiewicz, 2020).

The ApEn is strongly dependent on record length, which can create a bias toward low ApEn values for shorter time series (Pincus, 1995; Richman & Moorman, 2000). Our data collection lasted 60 s for each task. Other studies that assessed ApEn collected data for a shorter duration, such as 30 s (Rigoldi et al., 2013;

Wajda et al., 2016). We suggest that future studies compare different data collection times to provide an adequate record length for entropy analysis. The motor system uses different strategies for postural stability (Shafizadeh et al., 2020). Thus, we also recommend studies that use the same methodology and analyze postural control using other nonlinear measures to better understand the postural control's behavior or adaptive capacity during the dual-task performance. In previous studies that evaluated the influence of smartphone use on static or dynamic postural control, the baseline postural task was performed without smartphone use (Kao et al., 2015; Lee & Lee, 2018; Nurwulan et al., 2015; Oh & LaPointe, 2017). For our baseline task, we also used a single task without smartphone use; however, this task could be considered a limitation of this study because the head positions during the single and dual-tasks were different. The head position was in neck flexion (forward head posture) during smartphone use in the cognitive and motor dual-tasks, and this may have contributed to greater variations in the CoP between the single and the dual-tasks. This may explain the differences in behavior of the CoP between tasks. Furthermore, previous studies have found associations between the stabilometric values of CoP and head position in the frontal plane, reporting an increase in postural instability caused by an increase in the head inclination angle in the frontal plane (Kang et al., 2012; Szczygieł et al., 2016). Thus, analyzing head and neck posture while performing dual-tasks with smartphone usage could be relevant for understanding the effects of head posture on center of pressure behavior. Another limitation could be due to the effect of verbalizing involved in the cognitive dual-task, which could have further influenced CoP behavior. In addition, the respiratory frequency was not controlled, which could have altered CoP displacement.

Future studies are recommended to clarify the influence of verbal tasks on CoP behavior, as the effects of verbalization and the cognitive task are unclear. In other words, it is important to determine which action, talking or the cognitive task, is responsible for the increase in oscillation of the CoP.

The greater regularity of the CoP time series reveals postural control that is more constrained due to mechanical stiffness or neurophysiological impairment (Cavanaugh et al., 2005). Furthermore, during the dual-task, muscle activity decreased, suggesting there was less attentional processing capacity available to maintain postural control during the dual-task performance, in both older and young adults (Rankin et al., 2000). For this reason, we suggest integrating the analysis of muscle activity during tasks using electromyography to better understand the mechanisms involved in postural control.

Smartphone use is associated with physical and mental health problems. Our results showed that when young adults performed a cognitive or motor task on a smartphone while maintaining a standing posture, they compromised their postural control performance. Therefore, clinical recommendations should be made to improve postural control under dual-task conditions, such as dual-task training with associated smartphone tasks.

CONCLUSIONS

Maintaining a quiet standing posture while performing a cognitive task on the smartphone appears to be more challenging than maintaining postural stability while performing a motor task.

The present study also suggests that performing cognitive or motor tasks while using a smartphone impairs similar oscillations of CoP during standing posture compared with single-task performance in young adults. However, the cognitive task increased body sway during a standing posture significantly more than during the single task.

Cognitive dual-task performance caused greater impairment of CoP linear outcomes and greater regularity in the center of pressure; consequently, there was less efficacy in static postural control compared with the motor dual-task and single task conditions in healthy young adults.

Both linear and nonlinear methods were able to highlight the effects of dual-tasks on CoP stability.

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CHAPTER V – Study IV: Influence of Cognitive Task Difficulty in Postural Control and Hemodynamic Response in the Prefrontal Cortex during Static Postural Standing

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ABSTRACT

In daily life, we perform several tasks simultaneously, and it is essential to have adequate postural control to succeed. Furthermore, when performing two or more tasks concurrently, changes in postural oscillation are expected due to the competition for the attentional resources. The aim of this study was to evaluate and compare the center of pressure (CoP) behavior and the hemodynamic response of the prefrontal cortex during static postural standing while performing cognitive tasks of increasing levels of difficulty on a smartphone in young adults. Participants were 35 healthy young adults (mean age ± SD = 22.91 ± 3.84 years). Postural control was assessed by the CoP analysis (total excursion of the CoP (TOTEX CoP), displacements of the CoP in medial–lateral (CoP-ML) and anterior–posterior (CoP-AP) directions, mean total velocity displacement of CoP (MVELO CoP), mean displacement velocity of CoP in medial–lateral (MVELO CoP-ML) and anterior–posterior (MVELO CoP-AP) directions, and 95% confidence ellipse sway area (CEA), the hemodynamic response by the oxyhemoglobin ([oxy-Hb]), deoxyhemoglobin ([deoxy-Hb]), and total hemoglobin ([total-Hb]) concentrations using a force plate and functional near-infrared spectroscopy (fNIR), respectively. The results showed that the difficult cognitive task while performing static postural standing caused an increase in all CoP variables in analysis ($p < 0.05$) and of [oxy-Hb] ($p < 0.05$), [deoxy-Hb] ($p < 0.05$) and [total-Hb] ($p < 0.05$) compared to the postural task. In conclusion, the increase in the cognitive demands negatively affected the performance of the postural task when performing them concurrently, compared to the postural task alone. The difficult cognitive task while performing the postural task presented a greater influence on postural sway and activation of the prefrontal cortex than the postural task and the easy cognitive task.

Keywords: postural standing; dual-task; difficulty; fNIR; center of pressure.

INTRODUCTION

Postural control is considered a complex motor skill that integrates postural equilibrium and postural orientation. It results from the interaction of multiple and dynamic sensorimotor processes, somatosensory, vestibular, visual, and neuro-musculoskeletal systems, necessary to maintain an appropriate balance and perform different tasks (Horak, 2006). Evidence suggests that postural control depends on attentional resources beyond automatic processes; these attentional requirements can depend on age, postural task, nature of the cognitive task, and balance skills (Woollacott & Shumway-Cook, 2002).

In daily life, we are constantly performing several tasks simultaneously. When performing two or more tasks, the attention is divided between both tasks, which results in performance declines in one or both tasks (dual-task interference). The dual-task paradigm is an approach used in various studies to assess the relationship between attention and postural control (Woollacott & Shumway-Cook, 2002).

There are three theories commonly used to explain the dual-task interference or the limitation of attentional resources while performing a dual-task: capacity sharing, bottlenecks or task switching, and cross-talk (Pashler, 1994); however, there is no consensus about the underlying mechanisms of the dual-task interference (Leone et al., 2017).

Postural control has been evaluated under the dual-task paradigm to understand the role of cognitive processes; most studies assessed static or dynamic postural control as a primary task and cognitive task as a secondary task (Cruz-Montecinos et al., 2020; Ghai et al., 2017; Nohelova et al., 2021; Woollacott & Shumway-Cook, 2002).

Keeping balance during a static standing posture while performing other tasks is practiced regularly on a daily basis. Maintaining an upright stance appears to be practically automatic without requiring attention; however, prior studies showed that postural control during standing posture is influenced by cognitive tasks performed simultaneously (Huxhold et al., 2006; Potvin-Desrochers et al., 2017). Previous studies reported divergent results in the influence of cognitive tasks on postural control while performing a static standing posture in young adults. For example, some studies revealed that the postural sway was reduced in dual-task conditions compared to the standing postural (single-task) (Hunter & Hoffman, 2001; Maylor & Wing, 1996; Prado et al., 2007). Conversely, others indicated greater postural sway in dual-task conditions compared to the single-task (Lanzarin et al., 2015).

As available evidence suggests that postural control depends on attentional resources beyond automatic processes to complement and help understand these controversial results about the influence of the dual-task on postural control, it becomes relevant to analyze the cortical activation during the execution of postural motor tasks. Brain activity analysis during static and dynamic postural control tasks has emerged from neuroimaging studies using functional magnetic resonance imaging (fMRI) (Bürki et al., 2017), electroencephalography (EEG) (Little & Woollacott, 2014), positron-emission tomography (PET) (Malouin et al., 2003; Ouchi et al., 1999), and functional near-infrared spectroscopy (fNIRS) (Herold et al., 2017).

The fMIR, fNIR, and PET are neuroimaging techniques that depend on neurovascular coupling, while EEG detects the brain's electrical activity (Pinti et al., 2020). The fMIR and PET record brain activity in all cerebral regions while performing motor imagery or virtual reality tasks (Herold et al., 2017; Shine et al., 2013), so they cannot be used during natural tasks, such as walking or standing while performing other tasks in real-time.

The fNIRS has some advantages compared to other neuroimaging techniques, such as portability, motion tolerance, and low cost (Pinti et al., 2020). It is an optical neuroimaging technique that is based on hemodynamic responses of neuronal cortical tissues, measuring changes in oxygenated and deoxygenated hemoglobin concentrations in the active brain regions (Leff et al., 2011; Villringer & Chance, 1997).

The prefrontal cortex has an essential role in various brain functions, such as memory, attention, executive function, other cognitive functions (Fuster, 2001), and cognitive postural dual-task performance (Marusic et al., 2019).

Previous studies that assessed prefrontal cortex activation during dual-task conditions found an increase in brain activity in the prefrontal cortex during dual-task compared to postural single-task (Fujita et al., 2016). However, others suggest a diminution in cortical activity when the cognitive task load increases (Callicott et al., 1999).

Many studies use the fNIR to analyze the prefrontal cortex (Herold et al., 2017). Given the applicability of fNIR in recording the brain activity in real-time task performance and the importance of the prefrontal cortex in motor control and cognitive functions, we have chosen the fNIR to measure the changes in hemoglobin concentrations in the prefrontal cortex in this study.

It is important to combine the analysis of cortical activity derived from fNIR signals with postural control analysis to study neuromotor control processes, so as to predict risk factors for falls and the developing cognitive diseases (Herold et al., 2017). With this in mind, and considering the ambiguous results of dual-task studies, this study aimed to better understand the influence of attentionally demanding cognitive tasks with different difficulty levels during a simple postural task (static postural standing) using a force plate for the center of pressure analysis. Most of these studies assessed stability postural using center of pressure measures, fNIR for prefrontal cortex activation analysis, and dual-task cost (DTC) to analyze the dual-task interference (determine the cognitive task interference on stability postural).

Using smartphones during postural and walking tasks while performing secondary tasks is common in daily life. However, few studies evaluated the effect of smartphone use on postural stability while performing upright standing (Nurwulan et al., 2015). For this reason, and to contribute to an ecological approach to studying dual-task performance, we examined dual-task performance on postural control by maintaining a quiet standing posture while performing a smartphone cognitive task with different difficulty levels. Furthermore, smartphone use is more frequent among young adults (Deloitte, 2017), and many studies carried out in this group have shown that excessive smartphone use has negative health effects (Lopez-Fernandez et al., 2017; Wacks & Weinstein, 2021). Therefore, it is essential to study the cognitive functions and postural control in young adults to implement early strategies to help reduce accidents or injuries using smartphones and cognitive disturbances at more advanced ages.

We hypothesized that: (i) the young adults would demonstrate a decline in postural control performance and an increase in prefrontal cortex activity when performing the difficult dual-task compared to the easy dual-task and postural single-task; (ii) the dual-task cost in postural stability would be higher when young adults were performing a difficult cognitive task than an easy cognitive task.

METHODOLOGY

Participants

The sample size was calculated using G*power software (Franz Faul, Edgar Erdfelder, Axel Buchner, Universität Kiel, Kiel, Germany, version 3.1.9.6) based on the study design, in an $\alpha = 0.05$ and statistical power of 0.95. Therefore, a minimum of 18 individuals were needed to achieve a large effect size (Cohen's $f = 0.40$).

Thirty-five young adults (mean age ± SD = 22.91 ± 3.84 years; 23 males and 12 females) were recruited to participate in this study. We recruited young, healthy adults between 18 and 35 years and free of musculoskeletal problems, injuries, or disorders affecting balance, neurological diseases, or sensory/visual/hearing impairments. The study was publicized in reseachers' networks, and the volunteers contacted the researchers.

Anthropometric data were collected for all the participants (age, height, body mass; for participants' characteristics, see Table 4.1). The study was conducted according to the Declaration of Helsinki. All participants provided written informed consent forms. The study was approved by the Ethics Committee of the Polytechnic Institute of Coimbra (approval number: 27_CEPC2/2019).

Table 4.1. Anthropometric and demographic characteristics of the sample (mean ± SD; %).

Variables		**Sample n = 35**
Age (years)		22.91 ± 3.84
Height (m)		1.72 ± 0.09
Body mass (Kg)		73.89 ± 16.19
BMI (Kg/m^2)		24.85 ± 4.03
Gender (%)	Male	n = 23; 65.7%
	Female	n = 12; 34.3%

BMI, body mass index.

Task Protocol

Postural task (single-task): Participants stood comfortably on the force plate with their feet shoulder-width apart, eyes open, and arms along the trunk during 60 s (Carpenter et al., 2001; Onofrei et al., 2020).

Cognitive single-task: The cognitive task consisted of an arithmetic and visual–spatial memory task (Bayot et al., 2018) with two different challenging levels (easy and difficult) (Campbell, 1988; Liu & Li, 2012) presented on the participant's smartphone screen in which the participant verbalized the answer during 60 s.

The easy cognitive single-task consisted of adding and subtracting calculations with one digit (e.g., 3 + 2 = ?; 7 + ? = 9) and memorizing the color of each figure displayed on the smartphone screen.

The difficult cognitive single-task consisted of adding and subtracting calculations with one or two digits (e.g., 56 + 23 = ?; 7 + ? = 85) and memorizing each figure's color, number, and the image displayed on the smartphone screen.

The number of correct and incorrect answers was recorded. Then, we measured accuracy as a percentage of correct responses from the given answers to determine cognitive performance.

In dual-task conditions, participants were to maintain the postural task while performing an easy cognitive task on the smartphone (easy dual-task) and the other dual-task consisted of maintaining the postural task while performing a difficult cognitive task on the smartphone (difficult dual-task, Figure 4.1).

Figure 4.1. Prefrontal cortex activation (oxyhemoglobin) during difficult dual-task performance.

The cognitive single-task (easy and difficult) was performed while sitting on a chair as a reference measure for cognitive performance. It was also performed while the participants maintained postural tasks (dual-task).

Participants performed all tasks with the fNIRS equipment attached to the forehead. The changes in oxy and deoxyhemoglobin concentrations relative to a 10 s baseline were recorded immediately before performing each task. Then, the following conditions were performed during which prefrontal cortex oxygenation was recorded for 60 s: cognitive single-task (easy and difficult: sitting on the chair), postural task (standing on force plate), and the cognitive and postural tasks concurrently (dual-task: easy and difficult). All tasks were performed twice during 60 s; between each task, there was a rest period of 45 s (Herold et al., 2017). The participants were not advised which task to prioritize during the dual-task, and the order in which the tasks were performed was random.

The participants used their personal smartphones and held them as usual to maintain ecological validity. However, through qualitative visual analysis, the smartphones' dimensions were similar.

CoP Analysis

The Bertec® force plate model FP4060-07-1000 (Bertec Corporation, 6171 Huntley Road, Suite J, Columbus, OH, USA) was used to collect COP behavior. More specifically, the total excursion of the center of pressure (TOTEX CoP–unit in mm), the displacements of the center of pressure in medial–lateral (CoP-ML–unit in mm) and anterior–posterior (CoP-AP–unit in mm) directions, the mean total displacement velocity of CoP ((MVELO CoP–unit in mm/s), the mean displacement velocity of CoP in medial–lateral (MVELO CoP-ML–unit in mm/s) and anterior–posterior (MVELO CoP-AP–unit in mm/s) directions, and 95% confidence ellipse sway area (CEA–unit in mm^2), were assessed in the present study. These data were filtered using a 50 Hz low-pass filter, a 7th order Butterworth, and they were processed after the assessment with a Matlab routine (version R2020b, The Mathworks, Inc., USA).

fNIR Data Acquisition and Analysis

A fNIR100A-2 (Biopac System Inc., Goleta, CA, USA) device was used to assess the brain activation in the prefrontal area. This particular device records at a frequency of 2 Hz with 16 recording channels with a source–detector separation of 2.5 cm. It measures oxy-Hb and deoxy-Hb (unit in μ mol/L) changes with two peak wavelengths at 730 nm and 850 nm.

For data acquisition and analysis the COBI Studio (v1.2.0.111) and fNIRSoft professional (v3.3), respectively, were used (Biopac software).

Before performing each task, participants were asked to relax and not think about anything for 10 s to collect the baseline changes in oxy-Hb and deoxy-Hb.

First, a visual inspection to eliminate low-quality channels was performed. The raw files were filtered with a low-pass finite impulse response (FIR) filter, with an order of 20 Hamming, and a cutoff frequency set at 0.1 Hz to remove long-term drift, high-frequency noise, and cardiac and respiratory cycle effects (Ayaz et al., 2010; Izzetoglu et al., 2010). Afterward, to remove motion artifacts, the sliding-window motion artifact rejection (SMAR) algorithm was used (window size= 10 s, upper threshold = 0.025 nm, lower threshold = 0.003 nm) (Ayaz et al., 2010). The changes in light absorption were converted to changes in concentration of oxy-Hb and deoxy-Hb using the modified Beer–Lambert Law concerning a 10 s local baseline recorded at the beginning of data collection and a differential pathlength factor (DPF) = 6 (Herold et al., 2017). The total hemoglobin (total-Hb) also was assessed by [total-Hb] = [oxy-Hb] + [deoxy-Hb].

Dual-Task Interference

The dual-task cost (DTC) evaluated cognitive and motor interference (dual-task interference) expressed as a percentage change in performance during dual-task (DT) relative to single-task (ST) conditions using the following equation (1) (Doumas et al., 2008):

$$\mathrm{DTC} = \frac{\mathrm{DT} - \mathrm{ST}}{\mathrm{ST}} * 100\% \tag{1}$$

The DTC was calculated for postural control stability (CoP analysis) and cognitive performance (accuracy of percent correct answers) at different cognitive difficulty levels ($\mathrm{DTC}_{\mathrm{easy}}$ and $\mathrm{DTC}_{\mathrm{difficult}}$). Positive DTC values for CoP reflected a decrement in the performance of a DT (increased postural instability) relative to the performance of a postural task (single-task), while negative values indicate benefices (decreased postural instability) in DT performance compared to the postural task. Conversely, a positive percentage in DTC for cognitive performance demonstrated an increase in accuracy (increased percentage of correct answers) during DT relative to the performance of a cognitive single-task, while negative DTC values indicate cognitive performance deterioration in DT compared to ST.

Statistical Analysis

Data were analyzed with IBM SPSS Statistics 25.0 software for Windows (SPSS, Inc., Chicago, IL, USA). Homogeneity of variances and normality of the distribution of the parameters was tested with Levene's and Shapiro–Wilk's test, respectively. Each of the variables, the hemodynamic responses ([oxy-Hb], [deoxy-Hb], [total-Hb], and the CoP variables, were compared in the different tasks (postural task versus DT (easy and difficult)) with a Friedman test with Bonferroni-corrected post hoc tests for pairwise comparations.

DTC was calculated for each CoP parameter (TOTEX CoP, CoP-ML, CoP-AP, MVELO CoP, MVELO CoP-ML, MVELO CoP-AP, CEA) using the equation described above. DTC cognitive task performance using the percentage of correct answers was also calculated for the DT (easy and difficult) using the same equation. The differences between DTC easy and difficult for each cognitive and motor performance analysis were determined with the Wilcoxon signed-rank test. Statistical significance was set at the level of $p < 0.05$.

RESULTS

Cognitive Task Performance

Young adults increased the percentage of correct answers from the cognitive single-task (easy and difficult) to both dual-task conditions (Figure 4.2). The differences were of statistical significance between the difficult cognitive single-task and difficult dual-task ($p = 0.004$).

The percentage of correct answers in the difficult cognitive single-task and difficult dual-task was smaller than in the easy cognitive single-task and easy dual-task. These differences between easy and difficult cognitive single-task performance ($p < 0.001$), and easy and difficult dual-task ($p < 0.001$) performance, were significant.

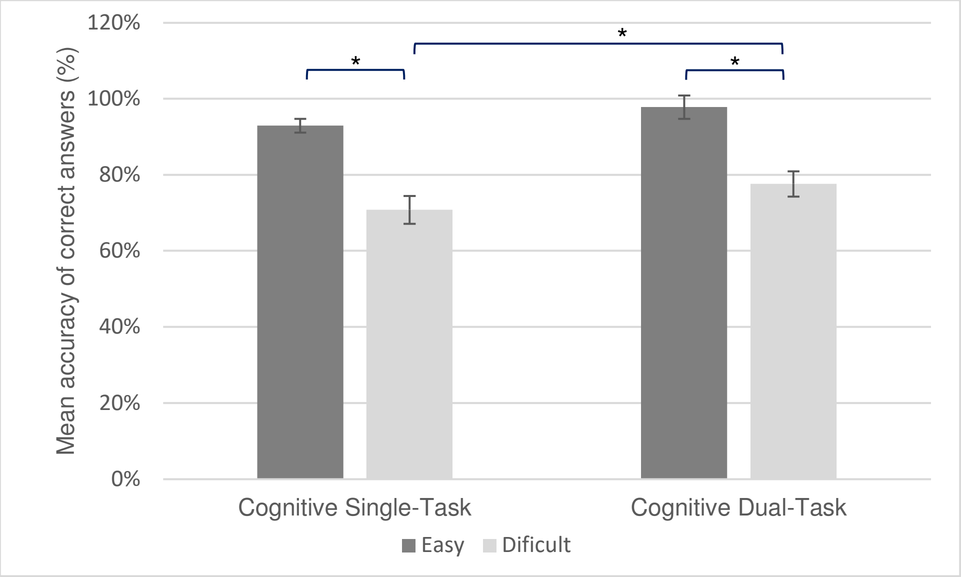

Figure 4.2. Mean accuracy and standard errors (error bars) of the percentage of the correct answers during cognitive single-task and dual-task.

$p < 0.05$: significant difference between difficult cognitive single-task and difficult dual-task, easy and difficult cognitive single-task, easy and difficult dual-task; not statistically significant between easy cognitive single-task and easy dual-task (Wilcoxon signed-rank test).

Postural Control

Analysis showed significant differences for all parameters of CoP (total excursion, displacements of the CoP in medial–lateral and anterior–posterior, mean total velocity displacement, mean velocity displacement of CoP in medial–lateral and anterior–posterior, and 95% confidence ellipse sway area) between the postural task and dual-task with two different challenging levels ($p < 0.001$, see Table 4.2).

Table 4.2. Comparisons of CoP behavior among the postural task (ST), easy and difficult dual-task, median (IQR).

Outcomes	**Single-task**	**Easy DT**	**Difficult DT**	***p*-Value** [1]
TOTEX CoP	2428.4 (2194.1–2873.0)	2635.6 (2311.7–3033.2)	2610.2 (2411.9–3123.8)	<0.001 *
CoP-AP	1837.5 (1648.6–2186.1)	1960.6 (1779.8–2309.5)	2028.2 (1817.7–2338.2)	<0.001 *
CoP-ML	1221.0 (1075.9–1427.9)	1319.9 (1170.1–1529.2)	1282.2 (1204.1–1497.6)	<0.001 *
CEA	224.6 (150.7–425.6)	724.1 (236.2–1303.7)	674.5 (326.2–1786.8)	<0.001 *
MVELO CoP	485.7 (438.9–574.7)	527.2 (462.4–606.7)	522.1 (482.4–624.8)	<0.001 *
MVELO CoP-AP	367.5 (329.7–437.2)	392.1 (356.0–461.9)	405.7 (363.6–467.7)	<0.001 *
MVELO CoP-ML	244.2 (215.2–285.6)	264.0 (234.0–305.9)	256.5 (240.8–299.5)	<0.001 *

TOTEX CoP, total excursion of the center of pressure (mm); CoP-AP, displacement of the center of pressure in anterior–posterior direction (mm); CoP-ML, displacement medial–lateral direction (mm); CEA, 95% confidence ellipse sway area (mm2); MVELO CoP, mean total velocity displacement of CoP (mm/s); MVELO CoP-AP, mean velocity displacement anterior–posterior of CoP (mm/s); MVELO CoP-ML, mean velocity displacement medial–lateral of CoP (mm/s); ST, single-task; DT, dual-task. [1] Friedman test; * $p < 0.05$.

Post hoc analyses showed a significant increase for all CoP variables during dual-task performing compared to the postural task (TOTEX CoP: ST versus easy DT: $p < 0.001$; ST versus difficult DT: $p < 0.001$; CoP-AP: ST versus easy DT and ST versus difficult DT: both $p < 0.001$; CoP-ML: ST versus easy DT: $p = 0.001$; ST versus difficult DT: $p < 0.001$; CEA: ST versus easy DT and ST versus difficult DT: $p < 0.001$; MVELO CoP: ST versus easy DT and ST versus difficult DT: $p < 0.001$; MVELO CoP-AP: ST versus easy DT and ST versus difficult DT: $p < 0.001$; MVELO CoP-ML: ST versus easy DT: $p = 0.004$; ST versus difficult DT: $p < 0.001$). However, no significant differences among easy dual-task and difficult dual-task were found (all CoP variables: $p > 0.05$).

Hemodynamic Changes in the Prefrontal Cortex

The changes in hemoglobin concentrations (oxy-Hb, deoxy-Hb and total-Hb) in the prefrontal cortex during the postural task and dual-task (easy and difficult) performance are presented in Figure 4.3.

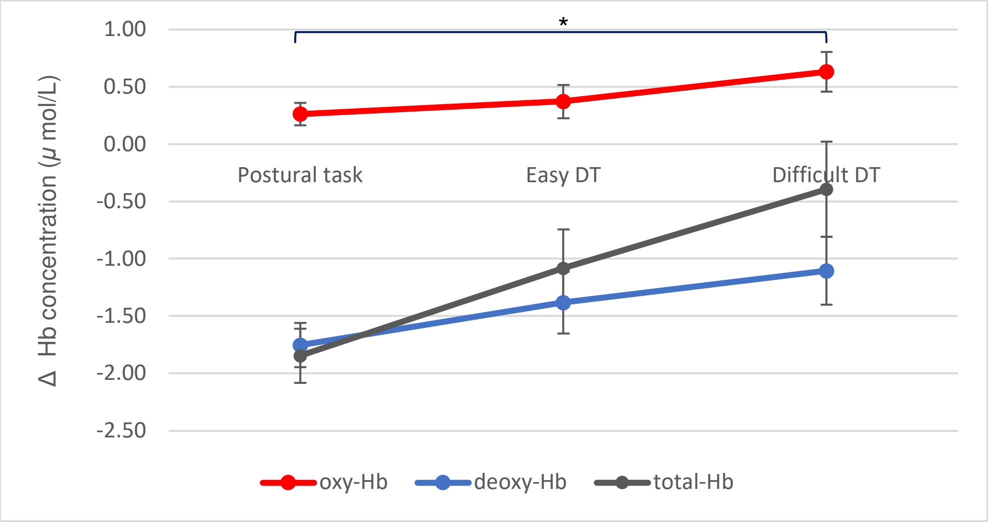

Figure 4.3. Changes in hemoglobin concentrations in the prefrontal cortex during the postural task and dual-task (easy and difficult) performance.

The y–axis displays relative concentration (median values and standard error (error bars)) changes of hemoglobin (Hb in µ mol/L). The x–axis displays tasks performance: postural task (single-task), easy DT (easy dual-task), difficult DT (difficult dual-task). The oxyhemoglobin concentration, [oxy-Hb], is indicated by the red line, the deoxyhemoglobin concentration, [deoxy-Hb], by the blue line, and total hemoglobin concentration, [total-Hb], by the grey line. * $p < 0.05$ in changes [Oxy-Hb], [deoxy-Hb] and [total-Hb] between the difficult dual-task and postural task (Friedman test with Bonferroni correction).

The oxy-Hb concentration increased from the postural task to both dual-task conditions and from easy dual-task to the difficult dual-task ($p = 0.032$), although hemodynamic changes for oxy-Hb values were only observed between the postural task and difficult dual-task ($p = 0.026$).

For deoxy-Hb values, there were significant differences between the postural task and dual-task with two different challenge levels ($p = 0.001$). However, the post hoc analyses showed a significant difference only between the postural task and difficult dual-task ($p = 0.001$).

There were significant differences in the total-Hb between the postural task and both dual-tasks ($p < 0.001$). The post hoc analyses showed a significant difference between the postural task and easy dual-task ($p = 0.026$), and the postural task and difficult dual-task ($p < 0.001$). However, no significant differences were found between the easy and difficult dual-task ($p = 0.167$) in total-Hb.

Dual-Task Interference

There was an improvement in the cognitive performance during dual-task (postural task while performing a cognitive task) than cognitive single-task (seated) conditions ($DTC_{easy} = 6.7\%$ and $DTC_{difficult} = 13.9\%$). In addition, relative to cognitive performance, the difference between DTC_{easy} and $DTC_{difficult}$ was significant ($p = 0.047$).

Positive DTC values were found in all CoP variables under analysis, reflecting a postural stability deterioration from the postural task to the easy and difficult dual-task due to cognitive task interference. For CoP variables, the $DTC_{difficult}$ values were slightly higher than DTC_{easy} values; however, the difference was not significant (DTC_{easy} vs $DTC_{difficult}$: $p > 0.05$ for all CoP variables).

DISCUSSION

The aim of this study was to evaluate and compare the CoP behavior and the hemodynamics response of the prefrontal cortex during dual-task performances of increasing levels of cognitive difficulty using the smartphone in young adults.

The CoP impairments (postural instability) and the activation of the PFC were increased with the more demanding cognitive task during the dual-tasks performances compared to the postural task.

In the cognitive–motor dual-task interference analysis by DTC, young adults showed a pattern of cognitive priority trade-off (Plummer et al., 2013) with improvements in cognitive task performance and deterioration in all COP parameters during both dual-task conditions (easy and difficult) compared to postural and cognitive single-tasks.

Greater center of pressure sway was observed in more challenging conditions (dual-task) than the postural task, showing that the young adults prioritized the concurrent task (cognitive task) under dual-task conditions. Furthermore, performing a concurrent cognitive task (easy and difficult) in static standing posture negatively affected postural control, and the differences in the CoP variables were significant between the postural task and the easy dual-task and the postural task and the difficult dual-task. However, the increase in cognitive load was not reflected in a significant difference in postural control between the dual-tasks with different demanding levels (easy DT versus difficult DT). Furthermore, the DTC for each CoP variable showed that the difficult cognitive task had slightly more interference in postural stability deterioration than the easy cognitive task; however, this difference was not significant.

Another indicator that young adults prioritized the cognitive task over postural control was the percentage of change in cognitive task performance from cognitive single-task to dual-task. The accuracy of correct answers was higher during dual-task than cognitive single-task. However, the increase in the accuracy of correct answers was only significant between the difficult cognitive single-task and difficult dual-task.

The present study demonstrated that the oxy-Hb, deoxy-Hb, and total-Hb concentrations during the difficult dual-task performance were higher than in the easy dual-task and postural task (single-task). However, only the oxy-Hb and deoxy-Hb concentrations differed significantly across the postural task and difficult dual-task. On the other hand, significant differences were found in total-Hb concentrations between the easy dual-task and postural task, and the difficult dual-task and postural task.

The hemodynamic response usually reflects an increase in [Oxy-Hb] and a decrease in [deoxy-Hb]. The increase in the oxyhemoglobin concentration is related to increased cerebral blood volume in response to cortical activation; but is more confounded with physiological factors (e.g., heart rate, respiration); and the deoxyhemoglobin is more robust to systemic changes (Tachtsidis & Scholkmann, 2016). Our results showed changes in [Oxy-Hb], [deoxy-Hb] and [total-Hb] during the difficult dual-task compared to the postural task, demonstrating an increase in neural activity, possibly due to the higher load of the cognitive task. To our knowledge, we did not find other studies that report this difference in all these parameters using the fNIR device, especially during the simple postural task (static standing postural).

A study demonstrated an increase in the brain activity in the high working memory span group during dual-task compared to the low working memory span group. The authors suggested that in the low working memory span group, the changes in the brain activity may have been difficult to detect due to low working memory capacity and the postural task to be more challenging (one leg standing) (Fujita et al., 2016). Another study showed that the frontal brain activation during the dual-task (walking while performing a cognitive task) was associated with the cognitive load during gait and not a response to verbalizing words (Mirelman et al., 2014). Our results also showed a significant increase in prefrontal activity during difficult dual-task. However, this change was found during a simple postural task (static standing posture), suggesting that the brain activity increase can be independent of the levels of difficulty of the postural task and be more related to cognitive demands.

The total excursion, displacements of the CoP in medial–lateral and anterior–posterior, mean total displacement velocity, mean displacement velocity of CoP in medial–lateral and anterior–posterior directions, and 95% confidence ellipse sway area were negatively affected during easy and difficult dual-task performance compared to the postural task. Our study is in line with previous research. For example, a study showed that the center of pressure path length, 90% confidence area, and maximum CoP speed were significantly affected by the use of different smartphone functions (talking, texting, and sending a text message on the smartphone) in young adults (Onofrei et al., 2020).

A recent systematic review and meta-analysis about the effect of cognitive task complexity on dual-task postural stability suggest that the cognitive task complexity cannot determine a positive or negative change in postural stability during quiet standing in healthy young adults (Salihu et al., 2022). The outcomes analyzed in this review included the center of pressure sway area, sway velocity, sway variability, total sway path length, and sway frequency, but not including hemodynamic response in the prefrontal cortex analysis. We also used similar CoP variables to analyze postural stability during dual-task. In the difficult dual-task compared to the postural task, our results showed an increase in brain activity in the prefrontal cortex and postural instability, and an increase in cognitive performance, demonstrating an increase in attentional resource competition among cognitive and postural tasks; and that postural control is not an automatic process. Contrarily, most studies included in recent systematic review and meta-analysis referred to non-significant changes in cognitive performance during dual-task in static standing postural and reported that postural instability occurs when postural tasks are more challenging (Salihu et al., 2022).

Another previous study has also shown that young adults under dual-task conditions increased their cognitive performance. However, in oxyhemoglobin concentration and CoP sway path (total, AP, and ML) did not find changes from the single-task (standing) to dual-task in young adults (Marusic et al., 2019). The differences in cognitive demands during the postural task may explain the inconsistency between these and our results.

The bottleneck theory can explain the postural stability deterioration during difficult dual-task performance due to the need to share the same neural or cognitive resources. On the other hand, the capacity sharing theory can explain the interference between cognitive and postural tasks because there was an increase in cognitive performance and a decline in postural performance, possibly because both require common limited resources (Bayot et al., 2018; Pashler, 1994).

This study's essential strong point was to evaluate the differential effects of cognitive tasks with different difficulty levels while performing postural standing simultaneously by analyzing the center of pressure, hemodynamic response in the prefrontal cortex, and cognitive–motor dual-task interference. Regarding the level of cognitive task difficulty, the choice of tasks proved to be adequate since the young adults had a significantly better cognitive performance in the easy cognitive task than in the difficult cognitive task in both single and dual-task conditions.

In our study, the postural task was performed without a smartphone, based on previous studies (Jeon et al., 2016; Lee et al., 2019; Onofrei et al., 2020). However, some studies reported an increase in postural instability due to head position in the frontal plane (Kang et al., 2012; Szczygieł et al., 2016); for that reason, we recommend postural analysis in following studies and the addition of a single-task in which the participants hold the smartphone when standing.

Although we processed the fNIR data, we could have added complementary measures (e.g., blood pressure, heart rate, respiratory cycle, etc.) to monitor systematic changes since oxyhemoglobin is sensitive to physiological changes.

A study that used the EEG showed that the cognitive emotion regulation strategies are associated with working memory, cognitive function, and visual/sensory perception (Aydın, 2021). Thus, it would be interesting to integrate the fNIR and the EEG (hemodynamic changes and electrical activity of the brain) to investigate the interaction between emotions and cognitive and motor performance during the dual-task, especially in depression and anxiety conditions, negative and positive emotions in athletes.

It would also be interesting, in future studies, to incorporate the muscular activity in the lower limbs for muscular synergy analysis, the non-linear analysis of the center of pressure to complement the CoP linear analysis, and to include a multichannel fNIR device to cover other brain regions beyond the prefrontal cortex.

Concerning the reduced postural stability found under dual-task conditions in our results, we recommend dual-task training (Ghai et al., 2017) in clinical practice to help reduce accidents or injuries caused by the negative effects of smartphone use on postural control. Furthermore, the cognitive–motor dual-task training, including different tasks, can improve motor and cognitive performance (Wollesen et al., 2022).

CONCLUSIONS

This study showed that dual-tasking performance with different levels of challenge influences CoP behavior and hemodynamic response in the prefrontal cortex in healthy young adults. The increase in the cognitive demands negatively affected the performance of the postural task when performed concurrently, compared to the postural task alone. Maintaining the postural task while performing a difficult cognitive task on the smartphone proved to be more challenging due to increased postural instability and the hemodynamic response in the prefrontal cortex.

Under both dual-task conditions, young adults improved their cognitive task performance and increased their postural instability, suggesting the prioritization of the cognitive task over the postural task.

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CHAPTER VI – Study V: Effects of motor task difficulty on postural control complexity during dual-task in young adults: a nonlinear approach

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ABSTRACT

Few studies have evaluated the effect of a secondary motor task on the standing posture based on nonlinear analysis. However, it is helpful to extract information related to the complexity, stability, and adaptability to the environment of the human postural system. This study aimed to analyze the effect of two motor tasks with different difficulty levels in motor performance complexity on the static standing posture in healthy young adults. Thirty-five healthy participants (23.08 ± 3.92 years) performed a postural single task (ST: keep a quiet standing posture) and two motor dual tasks (DT). i.e., mot-DT(A)—perform the ST while performing simultaneously an easy motor task (taking a smartphone out of a bag, bringing it to the ear, and putting it back in the bag)—and mot-DT(T)—perform the ST while performing a concurrent difficult motor task (typing on the smartphone keyboard). The approximate entropy (ApEn), Lyapunov exponent (LyE), correlation dimension (CoDim), and fractal dimension (detrending fluctuation analysis, DFA) for the mediolateral (ML) and anterior-posterior (AP) center-of-pressure (CoP) displacement were measured with a force plate while performing the tasks. A significant difference was found between the two motor dual tasks in ApEn, DFA, and CoDim-AP ($p < 0.05$). For the ML CoP direction, all nonlinear variables in the study were significantly different ($p < 0.05$) between ST and mot-DT(T), showing impairment in postural control during mot-DT(T) compared to ST. Differences were found across ST and mot-DT(A) in ApEn-AP and DFA ($p < 0.05$). The mot-DT(T) was associated with less ef-fectiveness in postural control, a lower number of degrees of freedom, less complexity and adaptability of the dynamic system than the postural single task and the mot-DT(A).

Key-words: motor dual-task, center of pressure, Approximate Entropy, DFA, correlation dimension, Lyapunov exponent.

INTRODUCTION

Many studies use linear measures to assess the center of pressure (CoP) behavior and to characterize postural sway during quiet standing with the aim to analyze changes in postural control during aging or in dual-task conditions (Cavalheiro et al., 2009; Petrigna et al., 2021), to evaluate the risk of fall (Quijoux et al., 2020), or to study postural control impairments in pathological conditions

(Bekkers et al., 2018; Walker & Rene, 2011), for example. However, the traditional linear characteristics of the center of pressure trajectories can not be sensitive to changes in postural control associated with age or diseases (Liau et al., 2019). Thus, a need has emerged for consistent approaches to obtain physiological information from stabilograms using nonlinear approaches to assess CoP temporal time series (Kędziorek & Błażkiewicz, 2020). Furthermore, non-linear measures can be more sensitive in detecting postural control impairments than linear measures (Purkayastha et al., 2019).

Nonlinear measures quantify the regularity, stability, adaptability to the environment, dimensionality, and complexity of the human postural system (Ladislao & Fioretti, 2007; Pascolo et al., 2006; Yamada, 1995). We chose to analyze four nonlinear measures: the approximate entropy (ApEn), the Lyapunov exponent (LyE), the correlation dimension (CoDim), and the detrended fluctuation (DFA, detrended fluctuation analysis) by the scaling exponent (α), because these measures reflect the deterministic and stochastic components of motor control (regularity, local stability, number of degrees of freedom, and the presence or absence of correlations in the CoP trajectories).

Approximate entropy is a measure to assess a system's complexity and the regularity in time-series data. The algorithm of ApEn was introduced by Pincus (S. Pincus, 1995; Steven M. Pincus, 1991; Steven M Pincus et al., 1991) to quantify the regularity of biological signals and clinical time series data. Furthermore, some studies used the approximate entropy method for the center of pressure time-series analysis (Cavanaugh et al., 2007; Montesinos et al., 2018). The ApEn values range from 0 to 2; a high ApEn value corresponds to random time series and an increased system complexity with less regular patterns in the time series of the CoP (S. Pincus, 1995; Steven M. Pincus, 1991).

The Lyapunov exponent measures the rate at which nearby orbits converge or diverge in the state space. It has been used to assess the presence of chaos in dynamic systems and analyze various biological systems (e.g., gait, postural sway) (K. Liu et al., 2015; Mehdizadeh, 2018; Stergiou, 2016; Yamada, 1995). A high LyE value can indicate a faster response capacity of postural control in the face of different perturbations to body movement (Kędziorek & Błażkiewicz, 2020).

The correlation dimension was introduced by Grassberger and Procaccia (Grassberger & Procaccia, 1983) for calculating the dimensionality of an attractor. It allows evaluating how the data point in a time series of a dynamic system is organized within a state space, in which a small correlation dimension value (between 1.5 and 2.5) can be associated with a small number of degrees of freedom involved and, generally, characterize data of a deterministic nature (Stergiou, 2016).

Detrended fluctuation analysis is a fractal dimension analysis method for biological time series indicating the presence or absence of correlations in the CoP trajectories by the scaling exponent (α). A scaling exponent equal to 0.5 corresponds to white noise (uncorrelated data), α equal to 1.0 indicates pink noise, and α equal to 1.5 indicates Brown noise (Peng et al., 1995). The pink noise may be representative of a complex movement (more flexible), the brown noise of a constrained movement, and the white noise of an incoherent movement (Stergiou, 2016). Although the DFA can be used to analyze the time series of the CoP trajectories (Blázquez et al., 2010), it also has other practical applications, such as in the prediction of type 2 diabetes mellitus (Colás et al., 2019) and in the analysis of heart rate times series (Peng et al., 1995).

Although these measures represent different aspects of system dynamics, they are related concepts. Combining them can give researchers different insights into system dynamics and postural stability patterns (see (Kędziorek & Błażkiewicz, 2020) for a recent review).

Maintaining a controlled upright posture is essential to performing various activities of daily living; beyond that, most people stand or walk while performing another task (cognitive or motor secondary task); this is called dual task. When people perform a dual task, there is usually a deterioration in one or both tasks' performance (Woollacott & Shumway-Cook, 2002). For example, some studies showed that walking while simultaneously carrying a cup (Kachouri, Laatar, Borji, Rebai, 2019) or transferring coins from one pocket to the other (Freire Júnior et al., 2017) reduces the gait performance compared to only walking. Others studies reported that maintaining an upright position while performing a cognitive task decreases the postural stability compared to performing a single task (Lanzarin et al., 2015; Pellecchia, 2003).

Currently, a prevalent dual task is the use of smartphone functions while walking or standing. However, smartphone use is associated with sedentary behaviors (Lepp et al., 2013), injuries (Stavrinos et al., 2011) and sleep disorders (Akçay, D, Akçay, 2018) and affects the balance ability negatively (Azab et al., 2017; Sung-Hak et al., 2014; Villafaina et al., 2019). In addition, studies showed that smartphone use while maintaining a standing posture increased postural sway (Nurul Retno Nurwulan et al., 2015; Onofrei et al., 2020) and might cause changes in the complexity of the center of pressure during some dual-task conditions (Nurul Retno Nurwulan et al., 2015).

To our knowledge, there are few studies evaluating the effect of secondary motor tasks on standing posture (primary motor task) (Makizako et al., 2013; Onofrei et al., 2020; Tang et al., 2015). Besides, few studies used nonlinear measures to assess postural control during dual-task conditions (Kuczyński et al., 2011; Madeleine et al., 2011; Potvin-Desrochers et al., 2017). Concerning the effect of smartphone use on postural stability, the dual-task studies' results are contradictory, and few were based on a nonlinear analysis (N. R. Nurwulan et al., 2015). Thus, this study aimed to evaluate the effects of two motor secondary tasks with different levels of difficulty on static standing posture, based on CoP nonlinear analysis. We hypothesized that young adults present less effectiveness, complexity, and adaptability of the postural control when performing a difficult motor dual task than a postural single task and easy motor dual task. We conjecture that these nonlinear time series analyses will provide helpful information about secondary motor tasks' effects on the motor complexity of standing posture performance.

METHODOLOGY

The number of participants in the study was determined using G*power software (Franz Faul, Edgar Erdfelder, Axel Buchner, Universität Kiel, Germany, version 3.1.9.6) based on the study design, with a significance level of $\alpha = 0.05$, a power of 0.95, and a large effect size (Cohen's $f = 0.40$). A sample minimum number of 18 individuals was found to be necessary.

The study was publicized on social networks and in groups of friends to recruit young adults between 18 and 35 years interested in participating and fulfilling the eligibility criteria. Thirty-five healthy young adults (22 males and 13 females) were recruited, without cognitive, vestibular, neurological, or musculoskeletal disorders (the sample characteristics are reported in Table 5.1).

All participants gave prior consent to the experimental procedures in agreement with the Declaration of Helsinki. The data were collected in the RoboCorp Laboratory, Polytechnic Institute of Coimbra, and the study was approved by the Ethics Committee of the Polytechnic Institute of Coimbra (approval number: 27_CEPC2/2019).

Table 5.1. Anthropometric characteristics of the sample (mean ± SD).

Variables	**Sample n = 35**
Age (years)	22.94 ± 3.88
Height (m)	1.71 ± 0.10
Body mass (Kg)	73.63 ± 16.06
BMI (Kg/m^2)	24.98 ± 4.32

BMI, body mass index.

Task protocol

Each participant performed each task twice for 60 seconds, with 45 s of rest between each task, i.e., the static standing posture (postural single task) and two motor dual tasks with different challenges while using their smartphone (easy and difficult motor dual tasks) (figure 5.1). No priority was given to the secondary motor and standing postural tasks. Instead, the participants were instructed to use their smartphone and hold it as usual while performing the easy and difficult dual tasks.

Postural Single-Task (ST)

The participants were instructed to stand comfortably on a force plate with feet shoulder-width apart, eyes open, looking in the forward direction, and with their arms naturally at their sides during 60 s (Carpenter et al., 2001; Onofrei et al., 2020). This task is usually used as the baseline in dual-task studies on static postural standing (Nurul Retno Nurwulan et al., 2015; Onofrei et al., 2020).

Dual-task conditions

Easy motor dual-task (mot-DT(A)). The participants were instructed to perform the postural single task while simultaneously taking their smartphone out of a bag, bringing it to the ear, and putting it back in the bag. All participants had a bag with the same dimensions placed in the middle of the pelvis.

Difficult motor dual task (mot-DT(T)). The participants were instructed to perform the postural single task while simultaneously typing on a smartphone. The participants were informed to type randomly on the smartphone keyboard at a self-selected pace to neutralize or minimize the cognitive component.

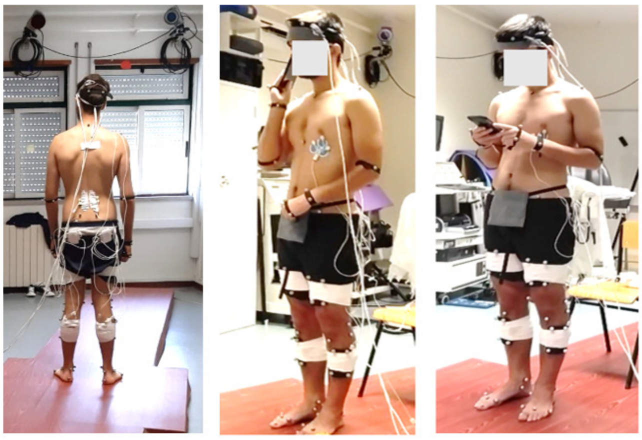


Figure 5.1. Center of pressure time series in the anterior-posterior and mediolateral displacement collected from a force plate during the postural single task and the easy and difficult motor dual tasks, respectively, from left to right.

Standing postural sway dynamics analysis

The center of pressure time series in the anterior-posterior and mediolateral displacement were collected from a Bertec® force plate computation (model FP4060-07-1000; Bertec Corporation, 6171 Huntley Road, Suite J Columbus, OH 43229 USA).

Four nonlinear measures were considered to evaluate the behavioral features of the postural motor task: approximate entropy, largest Lyapunov exponent, detrending fluctuation analysis, and correlation dimension. The nonlinear measures were calculated for each task using a code through Matlab (version R2020b, The Mathworks, Inc.). The data time series were calculated as follows. To analyze the ApEn of physiological signals, values of m of 2 or 3 and of r ranging from 0.1 to 0.3 have been recommended. For the calculation of the approximate entropy of the CoP data, the parameters m = 2 and r = 0.15 were commonly selected. Given time series data of length (N), the approximate entropy was calculated using a lag value of 20, a pattern length (m) of 2, and an error tolerance (r) of 0.2 times the standard deviation of the data file (Grassberger and Procaccia, 1983; Pincus, 1995; Pincus and Goldberger, 1994).

The phase space was reconstructed to determine time lag and embedding dimension according to the method of Broomhead (Broomhead and King, 1986; Matilla-García et al., 2021; de Pedro-Carracedo et al., 2020). The state space reconstruction was made for calculating the nonlinear parameters by embedding time lag (τ) copies of the time series. The average mutual information (AMI) was used to calculate τ, and we selected the first minimum of the AMI (Fraser and Swinney, 1986; Stergiou, 2016). The embedding dimension or the minimum number of variables required to form a valid state space from a given time series was calculated using the false nearest neighbor (FNN) method, with code from the UNO Biomechanics Laboratory. After finding these two parameters, we used the Wolf algorithm created by the University of Nebraska Omaha (UNO) based on the Wolf's method (Wolf et al., 1985), to calculate the large Lyapunov exponent. We used the Lyapunov exponent to quantify the chaotic behavior of postural sway, i.e., how the movement trajectories under study were related to each other in time. Positive values greater than zero indicate that the postural control system derives from a process exhibiting chaotic dynamics. The largest Lyapunov exponent and the correlation dimension were calculated using a time lag value of 20 and an embedding dimension of 5. The correlation dimension quantifies the dimensionality of the attractor using the Grassberger and Procaccia method (Grassberger and Procaccia, 1983), well explained in the Appendix by Gurses and Celik (Gurses and Celik, 2013).

The detrended fluctuation analysis analyzes the self-similarities between fluctuation patterns across progressively long time series. The DFA assesses the growth rate of detrended root-mean-square (RMS) values over many different measurement time scales. To determine the alfa value (scaling exponent, $\alpha 1$), the code from UNO was used to first integrate the time series and then create a new time series. Second, we calculated the root mean of the new time series. This time series was divided into boxes of equal length, and the best-fitting line segment determined the trend within each box. Finally, the average distance fluctuation F(s) of each point in a time series from a local trend line was estimated at a given scale. This method was introduced by Peng et al. (Peng et al., 1995) and permits the detection of long-range correlations embedded in a nonstationary time series. The scaling exponent α1, obtained from the slope of the linear regression of F(s) over on a log–log scale, quantifies the long-range correlations in the time series. We used the code from UNO to calculate the values of a scaling component based on some studies (see references (Damouras et al., 2010; Mirzayof and Ashkenazy, 2010; Peng et al., 1995; Stergiou, 2016) for more details).

Statistical analysis

The analyses were performed using IBM-SPSS 25.0 software. The statistical significance level was set at $p < 0.05$. Descriptive statistics were used to summarize the sample characteristics using mean ± SD (standard deviation).

Homogeneity of variances and normality of the distribution of the parameters was tested with Levene's and Shapiro–Wilk tests, respectively. Some outcomes were not normally distributed; thus, the median and interquartile range (IQR) represented the data. The Friedman test was used to compare the differences between the postural single task, mot-DT (A), and motor-DT (T) for each nonlinear parameter with post hoc Bonferroni correction to evaluate pairwise comparisons.

RESULTS

Most of the examined young adults (97.1%) performed mot-DT (T) (keep a quiet standing position while typing on a smartphone keyboard) with both hands. During mot-DT (A), 85.7 % of the participants held their smartphone with the right hand. There were no differences in the nonlinear measures between the participants who held the smartphone with one or both hands ($p > 0.05$).

The results of approximate entropy, Lyapunov exponent, detrending fluctuation analysis (short-term: α1), and correlation dimension for the postural single task and the dual tasks with different difficulty levels in anterior-posterior and mediolateral directions are presented in table 5.2, and the post hoc analyses in figure 5.2.

Table 5.2. Comparisons of CoP time series displacements among postural single task and easy and difficult motor dual tasks, median (IQR).

Non-linear measures	**Single-task**	**Mot-DT (A)**	**Mot-DT (T)**	***p*-Value [1]**
ApEn-AP	0.73 (0.62–0.91)	0.91 (0.77–1.03)	0.69 (0.57–0.91)	< 0.001 *
ApEn-ML	0.95 (0.72–1.20)	0.94 (0.88–1.06)	0.72 (0.49–0.96)	< 0.001 *
LyE-AP	1.60 (0.42–6.47)	2.64 (1.00–4.82)	0.97 (0.17–5.61)	0.091
LyE-ML	3.89 (0.93–17.81)	3.10 (1.23–5.77)	0.93 (0.18–8.27)	0.016 *
α1-AP	1.42 (1.30–1.51)	1.24 (1.16–1.34)	1.41 (1.30–1.47)	< 0.001 *
α1-ML	1.22 (1.09–1.32)	1.12 (1.03–1.27)	1.32 (1.24–1.51)	< 0.001 *
CoDim-AP	4.54 (4.49–4.59)	4.60 (4.51–4.65)	4.50 (4.38–4.60)	0.022 *
CoDim-ML	4.56 (4.49–4.67)	4.56 (4.39–4.66)	4.49 (4.38–4.55)	0.019 *

ST, single task; Mot-DT (A), easy motor dual task—performing the postural single task while simultaneously taking the smartphone out of a bag, bringing it to the ear, and putting it back in the bag; Mot-DT (T), difficult motor dual-task—performing the postural single task while simultaneously typing on the smartphone; ApEn, approximate entropy; LyE, Lyapunov exponent; α1, detrending fluctuation analysis (short-term); CoDim, correlation dimension, AP, anterior-posterior; ML, mediolateral.

[1] Friedman test (differences between the three tasks); * $p < 0.05$.

Approximate Entropy

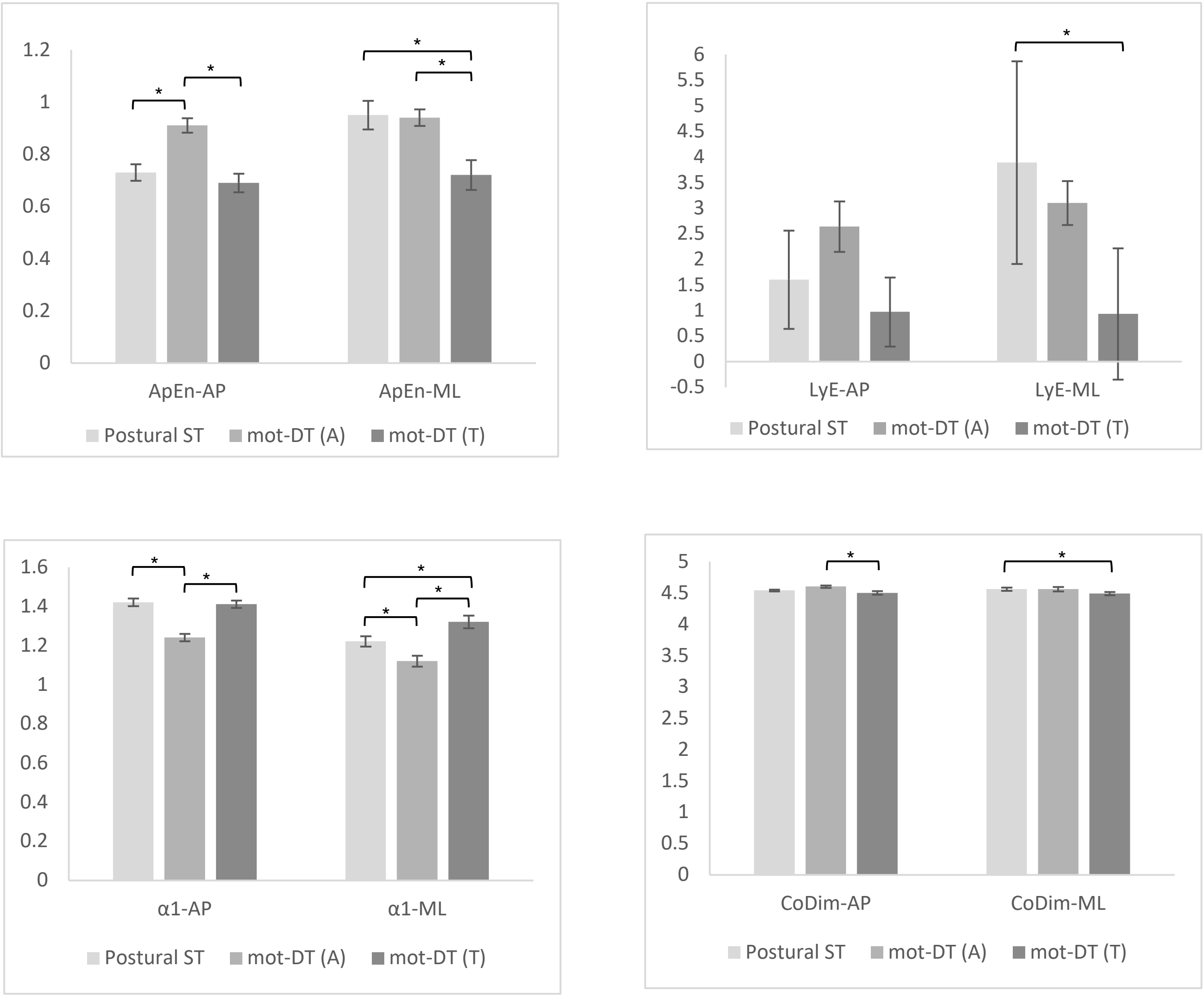
The results showed a significant difference for ApEn-AP and ApEn-ML between the postural single task and the dual tasks with two different challenging levels ($p < 0.001$ for anterior-posterior and mediolateral directions). The post hoc analyses showed a significant increase in ApEn-AP during the performance of the easy motor dual task compared to the postural single task ($p < 0.001$) and the difficult motor dual task ($p < 0.001$). However, no differences between postural single task and the difficult motor dual task were found. The ApEn-ML decreased from the postural single-task to both dual-task conditions; there was a significant difference between the performance of the postural single task and that of the difficult motor dual task ($p = 0.002$) and the performances of the easy and difficult motor dual tasks ($p = 0.001$). However, no performance differences between the postural single task and the easy motor dual task were found.

Lyapunov Exponent

The analysis showed a significant difference in the Lyapunov exponent in the mediolateral direction between the postural single task and the dual tasks with two different challenging levels (*p* = 0.016). However, no differences were found between the three tasks for the anterior-posterior direction.

In LyE-ML, post hoc analyses showed a significant decrease between the postural single task and the difficult motor dual task (*p* = 0.012). However, no differences were found between the easy and the difficult motor dual tasks and between the postural single the task and easy motor dual task.

Figure 5.2. Comparisons between postural single-task (ST), easy and difficult motor dual-task: CoP nonlinear analysis.



ST, single task; Mot-DT (A), easy motor dual task; Mot-DT (T), difficult motor dual task; ApEn, approximate entropy; LyE, Lyapunov exponent; α1, detrending fluctuation analysis (short-term); CoDim, correlation dimension, AP, anterior-posterior; ML, mediolateral. The y−axis displays the median values of the nonlinear measures, and the error bars, the standard error.

* $p < 0.05$: Friedman test with Bonferroni correction for multiple comparisons.

Detrending fluctuation analysis (short-term: α1)

The results showed a significant difference for α1-AP ($p < 0.001$) and α1-ML ($p < 0.001$) between postural single task and dual tasks with two different challenging levels.

The post hoc analyses showed a significant increase in α1-AP during the difficult motor dual task compared to the easy motor dual task ($p < 0.001$). There was a significant decrease in α1-AP from the postural single task to the easy motor dual task ($p < 0.001$). However, no differences between postural single task and difficult motor dual task were found. The α1-ML was higher during the difficult motor dual task than the easy motor dual task and the postural single task; these differences were significant ($p < 0.001$ and $p = 0.004$, respectively). There was a significant decrease in α1-ML from the postural single task to the easy motor dual task ($p = 0.036$).

Correlation Dimension

The analysis showed a statistical significance for CoDim-AP ($p = 0.022$) and CoDim-ML ($p = 0.019$) between the postural single task and the dual tasks with two different challenging levels. The post hoc analyses showed a significant decrease in CoDim-AP from the easy motor dual task to the difficult motor dual task ($p = 0.018$) and in CoDim-ML from the postural single task to the difficult motor dual task ($p = 0.018$). However, no differences were found between the postural single task and the easy motor dual task in CoDim anterior-posterior and mediolateral directions. No significant differences were found between the postural single task and the difficult motor dual task in CoDim anterior-posterior direction. Furthermore, no differences were found between the easy and the difficult motor dual tasks in CoDim-ML.

DISCUSSION

In this study, we used de nonlinear analysis to infer about the complexity of the postural task (standing posture performance) during dual-task with different difficulty levels. Based on CoP nonlinear analysis, our results showed changes in postural control complexity from single-task to dual-task conditions with different challenge levels. The results suggested that performing a difficult motor dual-task represents less effectiveness in postural control, less complexity and adaptability of the dynamic system than postural single-task and the easy motor dual-task.

Across the postural single-task to the difficult motor dual-task, the young adult showed a significant decrease in the LyE-ML and ApEn-ML values and an increase in the α1-ML (close to brown noise), suggesting lower postural control adaptability to external and internal perturbations. The ApEn-ML and α1-ML values followed the same trend across the easy to difficult dual-task. These results represent less postural control in mediolateral center of pressure direction during difficult dual-task than postural single-task and easy motor dual-task.

Previous studies reported that performing dual-task (standing while performing a cognitive task) is associated with diminished complexity of postural control compared to single-task (quietly standing) in older adults using multiscale entropy analysis (Kang et al., 2009; D. Zhou et al., 2015). A study found higher sample entropy values in the mediolateral direction for each dual-task condition (with different challenging cognitive task levels) than single task (quietly standing) in young adults, showing an increase in the efficiency of postural control during the dual-task (St-Amant et al., 2020). Another study found no differences between standing upright with eyes open while performing a cognitive task (DT) and single task (stand upright with eyes open) using sample entropy analysis in young adults. However, the authors found an increase in LyE and CoDim during dual-task compared to the single task (Donker et al., 2007), contradicting our LyE and CoDim results. Furthermore, the use of secondary cognitive tasks while performing a postural task appears to improve postural control (increased stability) due to automatized postural control (Potvin-Desrochers et al., 2017; Richer & Lajoie, 2020). The results of these studies may not be the most adequate to explain our results since they use cognitive tasks instead of secondary motor tasks. However, our study also showed that the nonlinear analysis performed allowed us to detect a short-term change in postural control complexity in response to adding a secondary motor task while simultaneously keeping a standing posture.

Contrary to our difficult motor dual-task results, a study that assessed the effect of texting using a mobile phone on the postural stability of young adults using multivariate multiscale entropy analysis found no difference between the normal stance (single task) and normal stance with texting (dual-task). However, it found differences between conditions with and without texting in tandem stance, showing more complexity during dual-task in tandem stance (Nurul Retno Nurwulan et al., 2015). An explanation for this could be that the task of texting has a cognitive component (involves reading and typing), and in our study, the young adults only randomly type on the smartphone's keyboard during a normal stance; besides, the entropy analysis method used is different.

During the difficult motor dual-task, young adults keep their gaze directed towards the smartphone screen, reducing their field of vision (reduced visual input) compared to postural single-task and easy motor dual-task, and maybe for that reason, an increase in α1. Since a higher α short-term value is associated with decreased center of pressure complexity during quiet standing with eyes closed in young adults (J. Zhou et al., 2013).

Both tasks' correlation dimension values were high, characterizing completely random data (Stergiou, 2016). However, the young adults demonstrated a significant reduction in correlation dimension in their center of pressure data in the mediolateral direction across the postural single-task to the difficult motor dual-task. Furthermore, this reduction was also verified from the easy to the difficult motor dual-task, but in the anterior-posterior direction. These results can indicate that in the difficult motor dual-task, there was an increased postural control in the mediolateral and anterior-posterior center of pressure components compared to the postural single-task and the easy motor dual-task, respectively, due to the reduced degrees of freedom involved.

In anterior-posterior displacement of the center of pressure, a significant decrease in the ApEn and an increase in the α1 (close to brown noise) were found in young adults while performing difficult dual-task compared to the easy motor dual-task. These data demonstrated that the young adults during difficult motor dual-task presented less complexity and adaptability of the postural control in anterior-posterior CoP direction than during easy motor dual-task.

Across the postural single-task to the easy motor dual-task, the results showed a significant decrease in α1 (anterior-posterior and mediolateral directions, close to pink noise) and an increase in the ApEn-AP, showing less regularity and more complexity and adaptability of the postural control during the easy motor dual-task than the postural single-task. During arm raising, the anticipatory postural adjustments occur in the direction opposite to the reaction forces caused by arm movement (Bouisset & Zattara, 1987), thus preserving postural control during the perturbation caused by upper limb elevation. Furthermore, the automatic postural responses can be modified by maturation and motor experience (Sveistrup & Woollacott, 1997), and how young adults spend more time using their phones in their daily lives (Auter, 2007; Berolo et al., 2011), the anticipatory postural adjustments under easy motor dual-task condition are possibly more efficient than the postural single-task, which may be an explanation for these results. Based on ApEn analysis, a study also found a higher ApEn value (more random) in CoP-AP time series during dual-task (performing the Sensory Organization Test while performing a cognitive task) than single-task (Cavanaugh et al., 2007). A strength of this study is the nonlinear analysis of motor dual-task conditions with different challenge levels, reflecting the characteristics and changes of the complexity and variability of the center of pressure displacement during natural daily life tasks. Furthermore, using a dual-task paradigm to evaluate if the nonlinear analysis can detect a short-term change in postural control in response to the addition of a secondary motor task while keeping a standing posture was an innovation.

Our results show that typing on the smartphone keyboard could be more difficult due to less complexity and adaptability of the postural system during difficult motor dual-task. Furthermore, the difficult motor dual-task implies a closed posture, fine motor movements to manipulate the smartphone and involves more visual monitoring and reduced field of view than the easy motor dual-task. Based on some definitions and research about task difficulty (for more details, see (Bootsma et al., 2020; Guadagnoll & Lee, 2004; Robinson, 2001)), we defined that typing on the smartphone keyboard would be a difficult motor task, and taking the smartphone out of the bag, bringing it to the ear, and putting it back in the bag, an easy task. Although there is not a clear and explicit definition of task difficulty, it also involves the interaction between task, task performer, and task context, referring to the perception of task performers' difficulty in performing a task (P. Liu & Li, 2012). However, we did not ask the participants about their difficulty perception regarding the tasks used. Thus, we considered this a limitation of this study and recommended that future studies assess the perception of the difficulty by the task performer pre and post-task to help define motor task difficulty level.

Future research should include electromyographic and nonlinear analysis to understand better the maintenance of balance by muscle activation around the ankle joint and the complexity of the center of pressure while performing dual-task. Besides, it would be interesting to analyze other methods of nonlinear analysis in dual-task conditions. For example, the extended detrended fluctuation analysis can be helpful in posturography to identify differences in postural control strategies between healthy and pathological groups while performing everyday tasks (Tigrini et al., 2022). The ApEn algorithm inherently includes a bias towards regularity when counting self-matches from each subseries (Montesinos et al., 2018); therefore, comparing the results obtained through ApEn with other entropy analysis methods would be relevant.

In addition, we recommended applying this study's methodology to other age groups, pathological conditions, and postural tasks with different levels of demand to assess the dual-task effect on the dynamic postural system. Finally, future research should also include the study of other behaviors, as well as multitasking.

The present study's nonlinear results can provide helpful information about secondary motor tasks' effects on the motor complexity and adaptability of the dynamic system of CoP during dual-task conditions. Furthermore, differences in postural control complexity from single-task to the easy and difficult motor dual-task suggest that motor demands vary in their impact on the postural sway complexity.

The increased motor task demand during dual-task causes a loss of motor system complexity, showing an increasingly ineffective and inadequate postural control strategy. Therefore, it is essential in clinical practice to implement strategies to improve postural control performance, like dual-task training using different tasks to enhance the dynamic organization of the center of pressure displacements.

CONCLUSIONS

We found changes in postural control complexity from postural single task to motor dual-task conditions with different difficulty levels using a nonlinear analysis of the center of pressure. Furthermore, our results suggested that performing a difficult motor dual task is associated with less effectiveness in postural control and less complexity and adaptability of the dynamic system of the center-of-pressure displacement than performing a postural single task and an easy motor dual task. For this reason, it is important to implement appropriate clinical practices, such as dual-task training, to improve the postural control complexity under dual-task conditions. We suggest that the nonlinear analysis of the center of pressure be performed in other age groups, pathological conditions, and with postural tasks with different levels of demand to evaluate the effect of dual tasks on the postural system complexity.

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Conflicts of Interest

The authors declare no conflict of interest.

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CHAPTER VII – Study VI: Muscular and prefrontal cortex activity during dual-task performing in young adults

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ABSTRACT

Postural control depends on attentional resources besides automatic processes. Dual-task paradigm is a possible approach to analyzing the interference and performance between motor and/or cognitive tasks. Various studies showed that, when individuals perform two tasks simultaneously, the postural stability can decline during dual-task compared to single-task due to the attentional resources required to perform the tasks. However, little is known about the cortical and muscular activity pattern during dual-task performance. Therefore, this study aims to analyze the muscular and prefrontal activity under dual-task performance in healthy young adults. Thirty-four healthy young adults (mean age ± SD = 22.74 ± 3.74 years) were recruited to perform a postural task (standing posture) and a dual-task (maintain standing posture while performing a cognitive task). Lower limb muscle activity was collected from five muscles bilaterally, using surface electromyography (sEMG), and co-contraction index (CCI) was also calculated for selected muscle pairings. The oxy and deoxyhemoglobin concentrations (prefrontal cortex activity) were recorded using functional near-infrared spectroscopy (fNIR). Data were compared between single and dual-task performance. Prefrontal activity increased ($p < 0.05$), and muscle activity decreased in most analyzed muscles ($p < 0.05$), from the single task to cognitive dual-task performing. The co-contraction index patterns changed from single to dual-task conditions in most selected muscle pairs ($p < 0.05$). We conclude that the cognitive task negatively interfered with motor performance once the muscle activity decreased and prefrontal cortex activity increased under dual-task, suggesting that young adults prioritized cognitive task performance, and they allocated more attentional resources to the cognitive task over the motor performance. However, future studies are recommended to assess and monitor muscular and cortical activity during the dual-task performance to provide additional information about the cortical and muscular activity patterns in postural control while performing dual-task.

Key-words: dual-task, EMG, fNIR, muscle activity, prefrontal cortex, co-contraction index.

INTRODUCTION

The literature report an interaction between some cognitive functions and motor performance/function in healthy and diseased individuals (Behrangrad et al., 2021; Plummer et al., 2013; Reilly et al., 2008). An approach to assess that influence is the dual-task paradigm. In real-life situations, when individuals perform their daily tasks or respond to unexpected situations, they adopt strategies to maintain or recover adequate postural control. However, when they perform various tasks simultaneously, the performance of one or both tasks can decrease due to the attentional resources required to perform the tasks (Woollacott & Shumway-Cook, 2002). Thus, the loss of balance can happen due to the brain center's inability to adequately allocate the attentional resources necessary for postural stability (Rankin et al., 2000).

Most studies included in a systematic review (Ghai et al., 2017) assessed the effect of dual-task on postural control through the postural sway analysis. They reported impairments in postural stability during dual-task performing in neurological conditions and healthy individuals. Furthermore, the results obtained in young adults showed ambiguous; some studies showed enhancements in postural stability, others a decrease.

Postural control is a complex motor skill resulting from the interaction of multiple sensorimotor processes and neuro-musculoskeletal systems (Horak, 2006). Therefore, the human standing posture also depends on the balance between the load stiffness at the ankle resulting from gravity and the ankle stiffness created by ankle muscle and tendon structures (Baudry et al., 2012). In addition, muscle co-contraction is important for joint stabilization during motor performance, and it defines the simultaneous contraction of agonist and antagonist muscles around a joint (Iwamoto et al., 2017). Furthermore, maintaining the standing postural control requires attentional resources and the involvement of cortical networks (Ozdemir et al., 2016; Woollacott & Shumway-Cook, 2002).

Studies assessing muscle activity and co-contraction during the dual-task performance are scarce. However, they showed that lower extremity muscle activity could be altered under dual-task conditions and affect postural control performance (Lo et al., 2017; Makizako et al., 2013; Rankin et al., 2000). A study showed that during the cognitive dual-task performance, the elderly reduced their lower limb muscle activity and increased their postural sway; however, this behavior did not happen in young adults (Makizako et al., 2013). One of the tools to measure muscle activity is surface electromyography (sEMG). It is a non-invasive technique that measures electrical muscle activity through surface electrodes placed on the skin overlying muscle fibers (Drost et al., 2006; Hermens, 2000).

On the other hand, the studies that assess cortical activity during dual-task have been growing in recent years. Prefrontal cortex can play a role in selecting the appropriate motor responses according to various conditions in maintaining balance (Fujita et al., 2020). Functional near-infrared spectroscopy (fNIR) is one of the neuroimage techniques used to analyze the prefrontal cortex activity by measuring the hemodynamic responses of neuronal cortical tissues (Leff et al., 2011). Some studies reported increased prefrontal cortex activity during the dual-task performance (Herold, et al., 2017a); others found a decrease due to the load of the cognitive tasks (Callicott et al., 1999).

So, understanding the functional connectivity of the brain and the muscle activity during dual-task performance can be a valuable tool for assessing the neuromotor performance of healthy and diseased individuals. Furthermore, limited studies have compared EMG of lower limb musculature during single and dual-tasks, and fewer combined EMG analyses and prefrontal cortex activity.

Therefore, we want to contribute to clarifying the interference of the cognitive task over motor control, specifically over muscular activity, combining the assessment of the hemodynamic response in the prefrontal cortex in young adults while simultaneously performing a cognitive and motor task (static standing posture). Thus, this study aims to analyze the muscular and prefrontal activity under dual-task performance in healthy young adults. We hypothesized that: (1) the addition of a cognitive task while performing a static standing posture (cognitive dual-task) decreases their lower limb muscle activity and increases the hemodynamic response in the prefrontal cortex than performing a single-task in young adults; (2) the co-contraction index decreases from the single to the dual-task performing.

METHODOLOGY

The sample size was calculated using G*power software (Franz Faul, Edgar Erdfelder, Axel Buchner, Universität Kiel, Germany, version 3.1.9.6). Based on the study design, to achieve a large effect size (d = 0.80), in an α = 0.05 and statistical power of 0.95, a minimum of 24 individuals would be needed.

A total of 34 healthy young adults (23 males and 11 females; mean age ± SD = 22.74 ± 3.74 years; mean ± SD: body mass of 74.30 ± 16.26 Kg and height of 1.72 ± 0.09 m) without a history of cognitive, physical, vestibular, or mental disorders participated in this study. This study was approved by the Ethics Committee of the Polytechnic Institute of Coimbra (approval number: 27_CEPC2/2019), and all participants gave informed consent to participate in it.

Tasks Protocol

The muscle activity by sEMG and hemodynamic response in the prefrontal cortex by fNIR were collected in single and dual-tasks. Each participant performed each task for 60 s, with a rest period between each task of the 45 s, twice.

In the single-task (motor task), the young adults were instructed to stand upright naturally on the force plate with their feet shoulder-width apart, eyes open, and arms comfortably at their side along the trunk, without the smartphone (Onofrei et al., 2020).

The cognitive dual-task consisted of performing the single-task simultaneously with a cognitive task. With the purpose of maintaining an ecologically valid study, young adults performed the cognitive dual-task using their smartphone and holding it with their preferred hand or both hands. The cognitive task consisted of arithmetic or visual-spatial memory tasks displayed on the smartphone screen. The participants verbalized the answers, and these were recorded during dual-task performing and while sitting on a chair as a baseline task to assess cognitive task performance by the percentage of correct answers.

Prefrontal cortex acquisition and analysis

The fNIR100A-2 device (Biopac System Inc., USA) was used to measure the prefrontal cortex activity based on the cortical response hemodynamic. This device measures oxy and deoxyhemoglobin concentration changes, recording fluctuations in levels of infrared light at 850 and 730 nm wavelengths. It has 16 recording channels with a source-detector separation of 2.5 cm (figure 6.1) and records at a frequency of 2 Hz.

Cognitive Optical Brain Imaging Studio and fNIRSoft professional (v3.3) (Biopac software) were used for data acquisition and analysis, respectively. Prior, raw data were visually inspected to remove low-quality signals from the channels. Then, the raw light intensity was filtered with a low-pass finite impulse response (FIR) filter, with an order of 20 Hamming, and a cutoff frequency set at 0.1 Hz to remove high-frequency noise, cardiac and respiratory cycle effects (Ayaz et al., 2010; Izzetoglu et al., 2010). The Sliding-window Motion Artifact Rejection algorithm was used (window size= 10 s, upper threshold= 0.025 nm, lower threshold= 0.003 nm) to remove motion artifacts (Ayaz et al., 2010).

The modified Beer-Lambert Law was used to calculate the changes in the oxygenated and deoxygenated hemoglobin concentrations concerning the 10 s local baseline recorded at the beginning of data collection (Herold et al., 2017b). Considering some regions of interest (ROIs) used for the prefrontal cortex analysis: left dorsolateral prefrontal cortex (channels 1 to 4), left medial prefrontal cortex (channels 5 to 8), right medial prefrontal cortex (channels 9 to 12), and right dorsolateral prefrontal cortex (channels 13 to 16) (Liang et al., 2016); we consider for this study that the left hemisphere of prefrontal cortex includes the mean of the channels 1 to 8 (left dorsolateral prefrontal cortex and left medial prefrontal cortex), and the right hemisphere of prefrontal cortex includes the mean of the channels 9 to 12 (right medial prefrontal cortex and right dorsolateral prefrontal cortex).

Figure 6.1. fNIR100A-2 device attachment in the participant head – prefrontal cortex region.

Muscular activity assessment

Before electrode placement, the skin was carefully prepared, involving hair removal and cleaning the skin with alcohol to decrease the interface's impedance between the skin and the electrode. Telemetric equipment manufactured by bioPLUX research 2010 (PLUX, Lisbon, Portugal) with Bluetooth connectivity was used to record and amplify the EMG signals. Active surface electrodes (Al/AgCl, rectangular shape 30mm x 22 mm) using the AMBU BlueSensor N (AMBU, Ballerup, Denmark) were placed on the left and right sides (figure 6.2) of the following muscles: biceps femoris (BF), rectus femoris (RF), tibialis anterior (TA), gastrocnemius medialis (GM), and gastrocnemius lateralis (GL). In addition, two ground electrodes were attached to the clavicle bone. EMG signals were amplified with a bandpass (10–500 Hz), with a common-mode rejection ratio of 110 dB and an input impedance greater than 100 mV. The EMG data were sampled at 1000 Hz, digitally filtered (20–490 Hz), full-wave rectified, and smoothed through a low-pass filter (12 Hz, fourth-order Butterworth digital filter). For amplitude normalization, the peak 200-ms EMG signal (EMG_{MAX}) of the MVC was used as a reference. The EMG average value was calculated during each task performance and participant. A routine in the Matlab software (version R2020b, The Mathworks, Inc.) was used for processing. Experienced researchers visually inspected the EMG patterns before processing them to ensure EMG signal quality. The electrodes were aligned with the muscle fiber orientation (center-to-center distance of 20 mm) at the most prominent part of the muscle bellies and were placed following the descriptions in Hermens et al. (1999).

The procedures described by Konrad (2005) and Hermens et al. (1999) to evaluate maximal voluntary contraction (MVC) were used (Hermens et al., 1999; Konrad, 2006). All participants were verbally encouraged during the maximal isometric efforts, and to avoid fatigue, a 2 min rest period was allowed between repetitions. Three isometric repetitions of 3 to 4 s were performed for each muscle to determine the EMG_{MAX}.

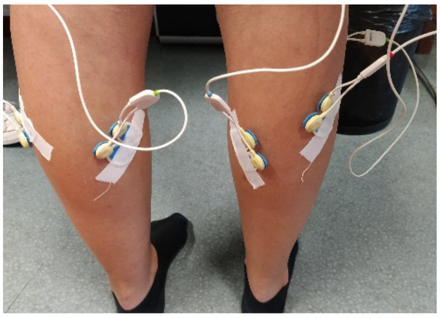

Figure 6.2. Surface electrode placement in gastrocnemius medialis and gastrocnemius lateralis muscles bilaterally.

Co-contraction index (CCI) between the agonist and antagonist muscles: rectus femoris–biceps femoris (RF–BF), tibialis anterior–gastrocnemius lateralis (TA–GL) and tibialis anterior–gastrocnemius medialis (TA–GM) for left and right sides was calculated using the following equation (1) (Rudolph et al., 2000):

$$\text{Co} - \text{contraction Index} = (\text{lower EMG} + \text{higher EMG}) * (\text{lower EMG}/\text{higher EMG}) \qquad (1)$$

The lower EMG and higher EMG represent the normalized EMG data value (% MVC) of the less active and the more active muscle, at each time point, during single and dual-task performance.

Statistical Analysis

Statistical normality analysis was assessed for all variables using the Shapiro–Wilk's test, showing that data did not present a normal distribution. Hence, the Wilcoxon test was chosen to compare the muscular and prefrontal cortex activity between single-task and dual-task; and between left and right sides of muscle and prefrontal activity in the single and dual-tasks conditions. Kruskal-Wallis test was used to evaluate the differences in the variables under analysis between hands position (both hands, right or left hand) to hold the smartphone. Descriptive data were expressed as mean ± standard deviation (SD) or median (interquartile range (IQR): 25th, 75th percentile).

Data were analyzed using the IBM SPSS Statistics 25.0 software for Windows (SPSS, Inc., Chicago, IL, USA). The significance level was set at $p < 0.05$ for the present study.

RESULTS

Young adults performed the cognitive dual-task holding their smartphone with their preferred hand or both hands. However, there were no differences in muscular and prefrontal cortex activity between the young adults holding smartphones with both hands (79.4%) and their preferred hand (left hand: 2.9%; right hand: 17.6%) when performing cognitive dual-task ($p > 0.05$).

During the single-task, there were no differences in muscle activity between each muscle's left and right sides (TA, GM, GL, RF and BF: $p > 0.05$). However, during the dual-task, differences in muscle activity (% MVC) were found between the left and right sides of each muscle (TA, GM, GL, RF and BF: $p < 0.05$), showing less muscle activity on the right side muscles compared to the left side muscles.

The comparison between single-task and dual-task muscle activity (% MVC) is presented in Figure 6.3. Muscle activity decreased significantly from the single task to the dual-task in the tibialis anterior and gastrocnemius medialis of both sides (left TA: $p = 0.001$ and right TA: $p < 0.001$; left GM: $p = 0.001$ and right GM: $p < 0.001$), gastrocnemius lateralis ($p < 0.001$), rectus femoris ($p < 0.001$) and biceps femoris ($p < 0.001$) of the right side. The left rectus femoris activity was significantly higher during dual-task performance compared to the single-task ($p = 0.012$).

There were no differences ($p > 0.05$) between single and dual-task in left gastrocnemius lateralis and left biceps femoris activity.

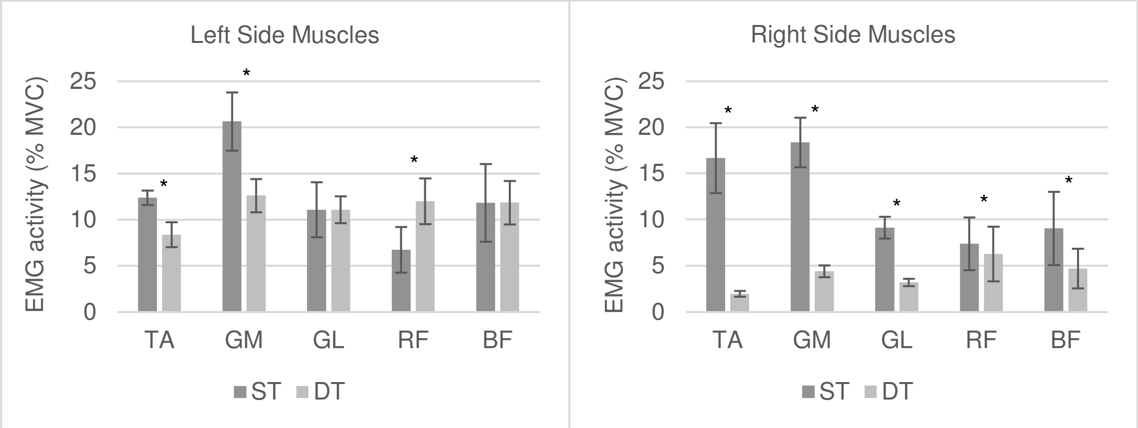

Figure 6.3. Mean and standard error (error bars) of the EMG activity during single and dual-task.

ST, single-task; DT, dual-task; EMG, electromyographic activity (% MVC, maximum voluntary contraction) measured in the TA, tibialis anterior; GM, gastrocnemius medialis; GL, gastrocnemius lateralis; RF, rectus femoris; BF, biceps femoris.

* p-value < 0.05; Wilcoxon signed test using median values (comparison between ST and DT).

There were no differences in the co-contraction index between left and right sides during single-task ($p > 0.05$). However, the right side's TA–GM, TA–GL, and RF–BF co-contraction index was lower than the left side's TA–GM, TA–GL, and RF–BF co-contraction index during the dual-task performance ($p < 0.05$).

The differences in co-contraction index between single and dual-task are presented in Figure 6.4. The right side's TA–GM, TA–GL, and RF–BF co-contraction index were lower during the dual-task performance than single-task ($p < 0.001$; $p < 0.001$; $p = 0.002$, respectively). Left RF–BF co-contraction index was higher during the dual-task compared to the single-task ($p < 0.001$). There was no difference between single-task and dual-task for the left side's TA–GL and TA–GM co-contraction index ($p > 0.05$).

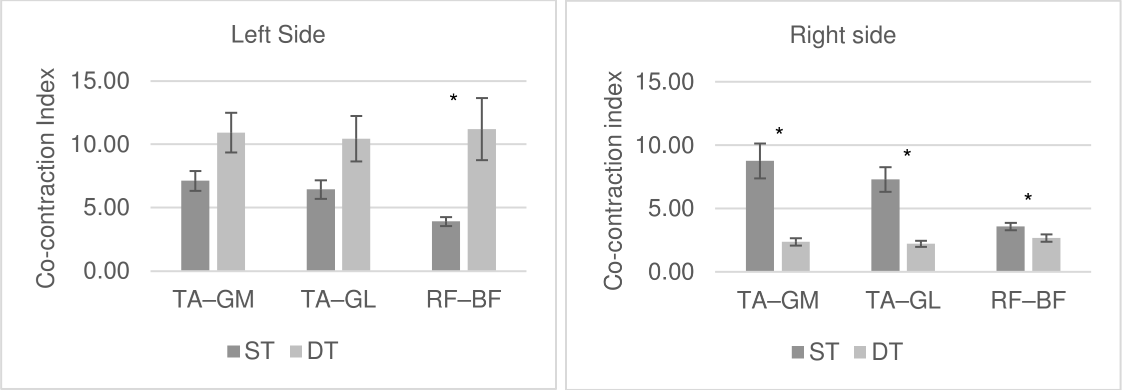

Figure 6.4. Mean standard error (error bars) of the co-contraction index during single and dual-task.

ST, single-task; DT, dual-task; TA–GM, tibialis anterior–gastrocnemius medialis; TA–GL, tibialis anterior–gastrocnemius lateralis; RF–BF, rectus femoris–biceps femoris.

* p-value < 0.05; Wilcoxon signed test using median values (comparison between ST and DT).

There was an increase in cognitive task performance, measured by the percentage of correct answers, from the cognitive single-task (sitting position) to the dual-task ($p = 0.007$).

In the single-task and dual-task performance, no differences were found in the prefrontal cortex's oxyhemoglobin concentration between the left and right hemispheres ($p > 0.05$). However, the deoxy-Hb concentration was higher in the left prefrontal cortex than the right prefrontal cortex during single-task ($p = 0.017$);

while performing dual-task, the deoxy-Hb concentration was higher in the right prefrontal cortex than the left prefrontal cortex ($p = 0.011$).

The changes in hemoglobin concentrations (oxy-Hb and deoxy-Hb) in the prefrontal cortex between single-task and dual-task performance were significant ($p < 0.05$) and are presented in Table 6.1. The oxy-Hb and deoxy-Hb concentrations increased from the single-task to the dual-task conditions in the prefrontal cortex region, left hemisphere of the prefrontal cortex and right hemisphere of the prefrontal cortex.

Table 6.1. Comparisons of the hemodynamic response among single-task and cognitive dual-task, median (IQR).

		Single-task	**Dual-task**	***p*-value**[1]
[oxy-Hb]	PFC	0.419 (-0.099-0.660)	0.812 (0.025-1.297)	0.029
	LPFC	0.393 (-0.132-0.755)	0.689 (-0.193-1.489)	0.033
	RPFC	0.302 (-0.107-0.677)	0.525 (0.154-1.437)	0.035
[deoxy-Hb]	PFC	-1.864 (-2.916-(-1.239))	-0.897 (-2.347-0.530)	0.001
	LPFC	-1.614 (-2.903-(-0.984))	-0.909 (-2.601-(-0.289))	0.008
	RPFC	-1.974 (-2.891-(-1.166))	-0.883 (-2.634-0.938)	0.001

[oxy-Hb], oxyhemoglobin concentration (μ mol/L); [deoxy-Hb], deoxyhemoglobin concentration (μ mol/L); PFC, prefrontal cortex; LPFC, left prefrontal cortex; RPFC, right prefrontal cortex.

[1] Wilcoxon signed test and *p*-value < 0.05.

DISCUSSION

This study aimed to determine and compare the muscle activity of the lower limbs and hemodynamic response of the prefrontal cortex when simultaneously performing static standing posture and cognitive tasks in young adults. We hypothesized that muscle activity decreases under dual-task conditions and hemodynamic response increases in the prefrontal cortex. Our findings supported this hypothesis by demonstrating that muscle activity decreased from single task to cognitive dual-task performing in most analyzed muscles, such as tibialis anterior and gastrocnemius medialis of both sides, gastrocnemius lateralis, rectus femoris and biceps femoris of the right side. On the other hand, brain activity increased from single-task to cognitive dual-task in the prefrontal cortex, increasing oxyhemoglobin concentration. This data suggests that cognitive task negatively interferes with motor performance once the muscle activity decreases during the cognitive dual-task performance in young adults compared to single-task. Furthermore, young adults prioritized cognitive performance over motor performance because there was an improvement in cognitive task performance and a decline in motor task performance during dual-task relative to single-task, suggesting a cognitive-priority trade-off (Plummer & Eskes, 2015). The apparent focus on the cognitive task can have been reflected in the increase of the prefrontal cortex activity from single to dual-task, indicating a higher allocation of attentional resources to the cognitive task performance. Beyond that, the decrease in muscle activity in most muscles analyzed from the single to the dual-task can demonstrate muscle relaxation, possibly, due to the decentralization of attention.

Young adults performed a cognitive task based on the mental tracking/working memory task category (Bayot et al., 2018). The prefrontal cortex has a role in cognitive control, attention, executive function, and working memory (Fuster, 2001). Furthermore, studies showed a functional connectivity between the dorsolateral prefrontal cortex and primary motor cortex (M1) (Rowe et al., 2002; Rowe et al., 2005). Concerning our results, we assume that the increase in prefrontal cortex activity during dual-task performance can have contributed to the reduction of efferent motor information and decreased muscle unit recruitment, decreasing the muscular activity of most muscles from single to dual-task. Thus, postural control can be compromised, leading to a decline in postural stability. Some studies suggested that a higher muscle co-contraction can be considered a strategy to stiffen the joint and improve postural stability (Hortobágyi & Devita, 2000; Melzer et al., 2001).

Some similar studies to ours corroborate our results (Fujita et al., 2020; Rankin et al., 2000), but others do not (Makizako et al., 2013). For example, a study that assessed the influence of ankle muscle activities, coactivation and dorsolateral prefrontal cortex activity on postural stability during dual-task showed a higher tibialis anterior muscle activity and tibialis anterior–gastrocnemius lateralis coactivation in the shorter sway path length group than the longer group. Furthermore, the left dorsolateral prefrontal cortex activity was superior during the performance of dual-task (performing calculations while standing still) than the single-task (Fujita et al., 2020). Another study showed a decline in gastrocnemius and tibialis anterior muscle activity during cognitive dual-task in young and older adults, suggesting a less attentional processing capacity available to the balance control under dual-task conditions (Rankin et al., 2000). On the other hand, a study showed that the right leg's medial gastrocnemius and tibialis anterior activity decreased during cognitive dual-task performing compared to the single-task (standing in the Romberg stance on a compliant foam surface and holding a glass in the left hand) in older adults; however, no difference in muscle activity was found in young adults (Makizako et al., 2013).

The muscle activity on each right side muscle and TA–GM, TA–GL, and RF–BF co-contraction index were inferior compared to the left side muscles under dual-task conditions. The left prefrontal cortex is associated with working memory, logical process and speech (Gabrieli et al., 1998; Nielsen et al., 2013; Siddiqui et al., 2008). So, the higher left prefrontal cortex activity than the right prefrontal cortex can happen because the participants verbalized the answers when performing the cognitive task, contributing to increased load in the left prefrontal cortex. Therefore, the increased hemodynamic response in the left prefrontal cortex during dual-task can explain the decrease in the right side muscle activity and co-contraction index. Another reason to explain the difference between the left and right co-contraction index may be due to the postural control strategies adopted during the dual task to maintain balance, such as the ankle, hip, or mixed strategies (Nashner, 1985).

Performing cognitive tasks can reduce central nervous system resources that are utilized during physical tasks requiring maximal voluntary muscular force production (Bray et al., 2012). That can explain the decrease in the right lower limb co-contraction index when young adults performed the cognitive dual-task. Although we investigated a simple motor task (static standing posture), the increased left prefrontal cortex activity from the single to cognitive dual-task suggests that young adults allocate fewer cognitive resources to motor tasks due to cognitive task effort.

Our results identified differences between muscular and cortical activity in dual-task conditions compared to the single task in healthy young adults. A study that analyzed cortico-muscular coherence after balance perturbations found a higher coherence between cortical activity from the motor cortex (C1 – central area) with electromyographic recordings of rectus femoris muscle in elderly and tibialis anterior in young adults (Ozdemir et al., 2018). Given these and our results, it would be necessary to combine fNIR, EEG and EMG in future research to assess the interactions between motor and cognitive cortical activity with muscular activity during the dual-task performance to add tools to the analysis of the mechanisms involved in motor control. Furthermore, fNIR can also be used to investigate muscle physiology, evaluating oxidative skeletal muscle performance (Perrey & Ferrari, 2018). Thus, we recommend a future study that evaluates the oxidative skeletal muscle performance and hemodynamic response in the prefrontal cortex using the fNIRS device during dual-task conditions to improve sports performance and the type of training.

We report the following limitations in our study: the fNIR device that we used only allowed us to measure the prefrontal cortex activity; we did not measure the motor cortex activity. Therefore, in our study was not possible to assess the interaction between the prefrontal cortex and the brain motor-network areas, such as the motor cortex, limiting understanding of the motor response resulting from the cognitive task interference during dual-task performance. In addition, we assume that the reduction in muscle activity and the increase in prefrontal cortex activity can compromise postural control by reducing postural stability.

Our research showed that adding a cognitive task while performing a motor task interferes with muscle and prefrontal cortex activity, which can compromise the maintenance of postural control, and might contribute to the risk of falls or musculoskeletal injuries (e.g., the loss of static postural control can occur when being shoved while waiting for the bus in the upright posture). Motor performance is further compromised by the addition of cognitive tasks in Individuals with musculoskeletal injuries (Burcal et al., 2019). So understanding the neurophysiological changes can help adopt the better clinical practice in rehabilitation and prevention of injuries.

CONCLUSION

The muscle activity decreased, and the prefrontal cortex activity increased during the cognitive dual-task compared to the single-task, suggesting that young adults allocated more attentional resources to the cognitive task over the motor task under dual-task conditions. Furthermore, performing a dual-task can alter co-contraction index patterns in the lower limb muscles, showing the interference of cognitive tasks over muscle activity. However, future studies are recommended to assess and monitor muscular and cortical activity during the dual-task performance to provide additional information about the cortical and muscular activity patterns in postural control while performing dual-task.

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Conflicts of Interest

The authors declare no conflict of interest.

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CHAPTER VIII – Study VII: Relationship between physical activity level and sleep quality with postural control and hemodynamic response in the prefrontal cortex during dual-task performance

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ABSTRACT

Understanding the cortical activation and postural control behavior during dual-task (DT) has been an object of study. However, despite the multiple benefits of exercise and good sleep quality, less is known about the correlation between physical activity (PA) and sleep quality (SQ) on postural control and brain activation under dual-task performance. This study aimed to analyze the correlation between PA level and SQ with postural control performance and hemodynamic response in the prefrontal cortex during the DT performance in young adults. Thirty-four healthy young adults (mean age ± SD = 22.91 ± 3.90 years) participated in this study, and they performed a single-task and cognitive and motor DT using their smartphones. Postural control was assessed using a force plate to record the center of pressure (CoP) data (total excursion of CoP (TOTEX CoP), displacements of the CoP in anterior-posterior (CoP-AP) and medial-lateral (CoP-ML) directions, mean total velocity displacement of CoP (MVELO CoP), mean displacement velocity of CoP in anterior-posterior (MVELO CoP-AP) and medial-lateral (MVELO CoP-ML) directions, amplitude of CoP in anterior-posterior (A-AP) and medial-lateral (A-ML) directions, and 95% confidence ellipse sway area (CEA)). The hemodynamic response was measured by the oxyhemoglobin and deoxyhemoglobin concentrations using the functional near-infrared spectroscopy. The Pittsburg Sleep Quality Index and International Physical Activity Questionnaire-Short Form questionnaires assessed SQ and level of PA, respectively. Results indicated a positive correlation between SQ and cognitive DT cost for CoP-ML ($r_s = 0.422$, $p = 0.013$), MVELO CoP-ML ($r_s = 0.422$, $p = 0.013$) and A-ML ($r_s = 0.579$, $p < 0.001$). There were no significant relations between the other outcomes ($p > 0.05$). In conclusion, poor sleep quality was associated with a worse postural control performance in CoP-ML, MVELO CoP-ML and A-ML parameters under cognitive dual-task conditions. The differences found in the postural control and hemodynamic response during dual-task performance do not correlate with physical activity level.

Keywords: simultaneous tasks, physical exercise, cognitive, motor control, sleep, fNIR, young adults.

INTRODUCTION

People frequently perform multi-tasks simultaneously in daily life, and adequate postural control is essential for the success of tasks performed. When two tasks are performed simultaneously (dual-task, DT), the performance of one or both tasks decreases (dual-task interference); this interference can be due to sharing attentional resources (Pashler, 1994; Woollacott & Shumway-Cook, 2002;), having demonstrated the efficacy of practicing dual-task to improve the cognitive status of people (Nobari et al., 2021). Thus, understanding cortical activation and postural control behavior during dual-task has been an object of research; showing the results of a study conducted with women with fibromyalgia showed the same electrical brain activity pattern during the single-task and dual-task conditions, whereas healthy controls seem to adapt their brain activity to task commitment (Villafaina et al., 2020). It is necessary to carry out studies that allow to standardize the approaches for the measurement of cortical activity during the tasks of walking and balance with functional near-infrared spectroscopy (fNIRS) and electroencephalography (EEG) systems (Stuart et al., 2018). fNIRS is a valid and feasible neuroimaging technique to measure cortical activity and reproduce reliable and consistent findings with functional magnetic resonance imaging (fMRI) results (Bulgarelli, et al., 2018; Ferrari & Quaresima, 2012). It measures the hemodynamic response of neuronal cortical tissues by detecting oxyhemoglobin and deoxyhemoglobin that present different absorption wavelength properties in the near-infrared spectrum (Ferrari & Quaresima, 2012; Herold, et al., 2017).

Some lifestyles, such as low physical activity levels and poor sleep quality, are associated with a decline in postural control performance. Physical activity has been reported as an important factor in improving postural stability, and it can reduce fall rates in older people by improving their balance (Sherrington et al., 2011; Thomas, K. & Magal, 2014). Sleep quality disorders result in postural control impairment in healthy young adults (Furtado et al., 2016) and older people, which may increase the risk of falls in the elderly (Robillard et al., 2011). A study reported that acute sleep loss interferes negatively with balance stability under single-task performance (quiet standing posture) in adults, causing an increase in the center of pressure (CoP) displacement in anterior-posterior and medial-lateral directions, total displacement and total area (Siu et al., 2015). In the assessment of postural balance, CoP is considered the gold standard measure (Chen et al., 2021). Furthermore, the study data suggest that postural control changes may be more evident during challenging conditions, such as dual-task (Siu et al., 2015). Still, a previous study showed a correlation between postural performance and sleep quality in the last 24h in adults with fibromyalgia; however, no correlation was found in the control group (Akkaya et al., 2013).

Previous research showed that sleep duration (≥ 7 hours) is associated with higher cortical oxygenation in the frontal area during verbal fluency tasks (Kato et al., 2017); and sleep quality influences the functional connectivity of brain areas and brain activity level during verbal working memory tasks (Bu et al., 2018) in older people.

Some studies found a relationship between a higher (VO_{2max}) fitness level and increased prefrontal cortex oxygenation while performing a cognitive task in younger and older women (Dupuy et al., 2015). Others showed a positive effect of acute moderate aerobic exercise on brain activation during cognitive task performance in older people (Hyodo et al., 2012). Greater prefrontal cortex oxygenation was also found in higher cardiorespiratory fitness individuals when performing a cognitive task than the lower-fit individuals (Goenarjo et al., 2021).

A systematic review of the effects of exercise on cerebral oxygenation in healthy people using functional near-infrared spectroscopy showed that prefrontal oxygenation increased among moderate and hard exercise intensities. However, the cerebral oxygen levels at very hard exercise intensities dropped (Rooks et al., 2010).

Earlier research revealed that physically active people present a better postural performance than sedentary people (Lelard & Ahmaidi, 2015); furthermore, physical activity improves balance, strength, coordination, functional ability, and gait performance (Skelton, 2001). On the other hand, the association between the level of physical activity and postural control has shown contradictory results in some studies. For example, no correlation between the level of physical activity and postural control was found in sedentary or non-sedentary overweight adults (Delfa-de la Morena et al., 2021).

Although the literature suggests that exercise has various health benefits (Warburton et al., 2006) and that sleep disorders negatively affect health (Chow, 2020), less is known about the correlation between physical activity and sleep quality on postural control and brain activation under dual-task performance. In addition, the results found in some studies differ from each other. So, it is important to understand the effect of lifestyle habits (sleep quality and physical activity) on postural control and brain activation. For that reason, this study evaluated the postural control and hemodynamic response between different tasks, and analyzed the associations between physical activity levels and sleep quality with static postural control performance and oxy and deoxyhemoglobin concentrations in the prefrontal cortex area under dual-task conditions in young adults. We hypothesized that: (i) a poor sleep quality is associated with worse performance in the postural control under DT conditions; (ii) a lower level of physical activity is associated with poorer performance in the postural control under DT conditions; (iii) the changes in oxy and deoxyhemoglobin concentrations during the dual-tasks performance are related with sleep quality; (iv) the level of physical activity is associated with oxy and deoxyhemoglobin concentrations changes under dual-tasks conditions.

METHODOLOGY

The study's sample number was determined using the G*power software (Franz Faul, Edgar Erdfelder, Axel Buchner, Universität Kiel, Germany, version 3.1.9.6) with a power of 0.80, a correlation effect size of 0.50, and a significance level of 0.05. Therefore, a minimum of 29 individuals was needed.

After checking the eligibility criteria, thirty-four healthy young adults (22 males and 12 females) were recruited through the dissemination of the study on social networks (see table 7.1 for participants' characteristics). Exclusion criteria included any history of cardiovascular, neurological, musculoskeletal, and respiratory diseases, surgery in the lower limbs (last six months), cognitive or physical disorders, vestibular and/or visual impairments without correction, use of medication that influences the neuromuscular system, and age superior to 35 years. Written informed consent was obtained from all participants prior to the study.

All procedures were carried out under the Declaration of Helsinki and were approved by the Ethics Committee of the Polytechnic Institute of Coimbra (approval number: 27_CEPC2/2019).

Table 7.1. Participant's characteristics (mean ± SD).

Variables	**Sample n = 34**
Age (years)	22.91 ± 3.90
Height (m)	1.71 ± 0.09
Body mass (kg)	73.42 ± 16.19
BMI (Kg/m^2)	24.75 ± 4.05

BMI, body mass index.

Tasks protocol

All tasks were performed with fNIR device placed in the prefrontal cortex area. Before participants performed each task, the brain activation baseline was recorded for 10 s. The participants performed twice each task during 60 s with a rest period of 45 s for CoP and fNIR data collection (Herold et al., 2017). No instructions were given regarding which task to prioritize during the dual-task, and conditions were randomized. The participants used their own smartphones (Tandon et al., 2021) and held them as usual to maintain ecological validity. Lastly, the participants completed the IPAQ and PSQI questionnaires to collect data about the level of physical activity and sleep quality, respectively.

In the postural task (single-task), the participants stood comfortably on the force plate with their feet shoulder-width apart, eyes open, and arms along the trunk for 60 s (quiet standing posture) (Carpenter et al., 2001; Onofrei et al., 2020).

The participants performed two dual tasks for 60 s: keep the postural task while performing a cognitive task (cog-DT), and keep the postural task while performing a secondary motor task (mot-DT).

The cog-DT consisted in keeping a quiet standing posture while performing adding and subtracting calculations with one or two digits (e.g., 15+53=?; 3+?=91) or memorizing each figure's color, number, and image (e.g., five, purple, flowers; two, blue, planes) displayed on the participant's smartphone screen. In addition, participants were asked to perform the cognitive task while sitting in a chair as a cognitive single-task. According to the cognitive processes involved, these cognitive tasks are classified in the same category (Bayot et al., 2018). The participants verbalized the answer when performing dual-task, and the percentage of correct responses was calculated to determine cognitive task performance during ST and DT.

The mot-DT consisted in keeping a quiet standing posture while typing randomly on the smartphone keyboard at a self-selected pace. In addition, participants performed the secondary motor task while sitting in a chair as a secondary motor single-task. The number of taps on the smartphone keyboard was recorded by the number of characters written to determine motor secondary task performance during ST and DT.

Level of Physical activity and sleep quality assessment

The International Physical Activity Questionnaire-Short Form (IPAQ-SF) assessed the physical activity level. It is a self-administered questionnaire that includes nine items to assess the intensity of physical activity in MET-min/week over the last seven days (Craig et al., 2003). The physical activity score was performed based on the IPAQ instrument protocol (Sjostrom et al., 2005).

The Pittsburg Sleep Quality Index (PSQI) assessed sleep quality and disturbances over the previous month. The PSQI consists of 19 items that measure seven domains of sleep: subjective sleep quality, sleep latency, sleep duration, usual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction. The global sleep quality score is the sum of the seven domains and ranges from 0 to 21; a global score above 5 indicates poor sleep quality (Buysse et al., 1989).

Center of pressure - linear analysis

A Bertec® force plate model FP4060-07-1000 (Bertec Corporation, 6171 Huntley Road, Suite J Columbus, OH 43229 USA) with 1000Hz frequency was used to measure the total excursion of the center of pressure (TOTEX CoP), the displacements of the center of pressure in anterior-posterior (CoP-AP) and medial-lateral (CoP-ML) directions, the mean total displacement velocity of CoP (MVELO CoP), the mean displacement velocity of CoP in anterior-posterior (MVELO CoP-AP) and medial-lateral (MVELO CoP-ML) directions, 95% confidence ellipse sway area (CEA), and the amplitude of the center of pressure in anterior-posterior (A-AP) and medial-lateral (A-ML) directions. All CoP data were filtered using a 7th Butterworth with a 50 Hz low-pass filter, and they were processed after the assessment with a Matlab routine (version R2020b, The Mathworks, Inc.).

fNIR data acquisition and analysis

A fNIR100A-2 (Biopac System Inc., USA) device was used to measure the oxy and deoxyhemoglobin concentrations changes (unit in μ mol/L) in the prefrontal cortex area. This device presents 16 optodes with a 2.5 cm source-detector separation that record light intensity with two wavelengths, 730 and 850 nm, at a frequency of 2Hz. The Biopac software was used for data acquisition and analysis. Initially, a visual inspection was performed to eliminate low-quality channels. Then, the raw files were filtered with a 20th Hamming, 0.1 Hz, low-pass FIR filter to remove high-frequency noise, long-term drift, and cardiac and respiratory cycle effects (Ayaz et al., 2010; Izzetoglu et al., 2010). After, a Sliding-window Motion Artifact Rejection (SMAR) algorithm (window size=10 s, upper threshold=0.025 nm, lower threshold=0.003 nm) was run to remove motion artifacts (Ayaz et al., 2010). The changes in light absorption were converted to changes in concentration of oxy-Hb and deoxy-Hb using the modified Beer-Lambert Law concerning a ten seconds local baseline recorded at the beginning of data collection (Herold et al., 2017).

Dual-task cost

The dual-task cost (DTC) was calculated for postural control and secondary tasks performance through the following equation (1) and it expresses the percentage change in performance during dual-task (DT) relative to single-task (ST) (Doumas et al., 2008):

$$\mathrm{DTC} = \frac{\mathrm{DT} - \mathrm{ST}}{\mathrm{ST}} * 100\% \tag{1}$$

The DTC for postural control performance was calculated for all CoP variables (TOTEX CoP, CoP-AP, CoP-ML, MVELO CoP, MVELO CoP-AP, MVELO CoP-ML, CEA, A-AP, and A-ML). The single-task indicates the postural control performance during the postural task, and the dual-task indicates the postural control performance while performing the postural task simultaneously with a cognitive (cog-$\mathrm{DTC}_{\mathrm{CoP\ variable}}$) and secondary motor single-task (mot-$\mathrm{DTC}_{\mathrm{CoP\ variable}}$). A high $\mathrm{DTC}_{\mathrm{CoP\ variable}}$ value indicates a poorer performance in the postural control (worse postural stability) under dual-task than the single-task (Doumas et al., 2008).

Regarding cognitive task performance, the cognitive DTC (cogDTC) was calculated using the same formula. The single-task indicates the average percentage of correct responses in the seated position, while the DT indicates the average percentage of correct responses during the postural task. In the motor DTC (motDTC), the single-task indicates the average number of characters written on the smartphone keyboard in the seated position, while the DT indicates the average number of characters written on the smartphone keyboard during the postural task.

A cogDTC and motDTC positive indicates a better performance of secondary tasks during the dual-task than ST (Doumas et al., 2008).

Statistical analysis

The IBM SPSS Statistics 25.0 software for Windows (SPSS, Inc., Chicago, Ill, USA) was used to analyze all data. Descriptive data were presented as mean and standard deviation (SD). The normal distribution of the parameters was calculated through the Shapiro–Wilk test. Since the variables were not normally distributed, the values were presented as the median and interquartile range (IQR).

The Friedman test was used to compare the center of pressure variables and the hemodynamic response ([oxy-Hb] and [deoxy-Hb]) between the different tasks (postural task versus cog-DT versus mot-DT). When the result of the Friedman test was significant, we used the Bonferroni correction for multiple pairwise comparisons.

We calculated the dual-task cost for postural control and secondary task performances separately to obtain comparable results; for that, we used the Wilcoxon signed-rank test to analyze the difference between the cog-$DTC_{CoP\ variable}$ and mot-$DTC_{CoP\ variable}$.

The Spearman's correlation was used to analyze the relationships between the level of physical activity (IPAQ total score), sleep quality (PSQI total score), postural control and secondary tasks performances (through cog-$DTC_{CoP\ variable}$ and mot-$DTC_{CoP\ variable}$, cogDTC and motDTC, respectively), and hemodynamic response (by the oxy and deoxy-Hb concentrations values during cog-DT and mot-DT performance). Spearman's rho coefficient (r_s) ranges between -1 and 1;

a value close to -1 or 1 represents a very strong association between the variables. The significance level was set at the level of $p < 0.05$.

RESULTS

Physical activity level and sleep quality

The results of the IPAQ in MET-min/week and PSQI questionnaires are represented in Table 7.2. The IPAQ score revealed that most young adults have a high level of physical activity (55.9%), 32.4% have a moderate and 11.8% have a low level of physical activity. The young adults presented a good sleep quality according to the average PSQI total score (5.32 ± 2.92).

Table 7.2. IPAQ and PSQI scores, mean ± SD.

Outcomes	**n = 34**
Physical activity	
IPAQ total score (MET-min/week)	3314.1 ± 2853.9
Walking (MET-min/week)	754.6 ± 905.0
Moderate-intesity PA (MET-min/week)	618.2 ± 563.1
Vigorous-intensity PA (MET-min/week)	1941.2 ± 2136.4
Sleep quality	
PSQI total score	5.32 ± 2.92

IPAQ-SF, International Physical Activity Questionnaire-Short Form; PSQI, Pittsburg Sleep Quality Index.

Static postural control

The linear analysis of the center of pressure showed significant differences for all CoP variables (total excursion, displacements of the CoP in anterior-posterior and medial-lateral directions, mean total displacement velocity of CoP, mean displacement velocity of CoP in anterior-posterior and medial-lateral directions, 95% confidence ellipse sway area, and the amplitude of the center of pressure in anterior-posterior and medial-lateral directions) between the postural task, cog-DT and mot-DT ($p < 0.001$, see Table 7.3). There was a significant increase in all CoP variables from the postural task to both dual-tasks conditions. *Post hoc* analyses with Bonferroni correction showed differences in all CoP variables ($p < 0.05$) between postural task and cog-DT, and postural task and mot-DT.

However, no significant differences between cog-DT and mot-DT were found (*p* > 0.05 for all CoP variables).

Table 7.3. Comparisons of CoP - linear analysis among postural task (single-task) and the two dual-tasks (cog-DT and mot-DT), median (IQR).

Outcomes	**Single-task**	**Cog-DT**	**Mot-DT**	***p*-value**[1]
TOTEX CoP	2431.8 (2204.4-2890.4)	2638.6 (2424.0-3166.2)	2582.8 (2246.4-3130.1)	<0.001
CoP-AP	1841.5 (1668.1-2193.1)	2029.8 (1825.7-2345.6)	1953.1 (1636.1-2316.0)	<0.001
CoP-ML	1224.2 (1097.8-1442.3)	1303.3 (1204.3-1499.7)	1327.1 (1156.6-1587.6)	<0.001
CEA	219.5 (141.8-388.3)	670.1 (313.3-1818.0)	526.3 (236.3-1090.0)	<0.001
A-AP	28.0 (20.8-37.1)	48.4 (35.1-77.0)	37.5 (29.2-49.0)	<0.001
A-ML	16.1 (12.0-24.3)	31.5 (17.6-49.7)	27.1 (17.9-60.4)	<0.001
MVELO CoP	486.4 (440.9-578.1)	527.8 (484.8-633.3)	516.6 (449.3-626.1)	<0.001
MVELO CoP-AP	368.3 (333.6-438.7)	406.0 (365.2-469.2)	390.6 (327.2-463.2)	<0.001
MVELO CoP-ML	244.9 (219.6-288.5)	260.7 (240.9-300.0)	265.4 (231.3-317.5)	<0.001

TOTEX CoP, total excursion of the center of pressure (mm); CoP-AP, displacement of the center of pressure in anterior-posterior direction (mm); CoP-ML, displacement of the center of pressure in medial-lateral direction (mm); CEA, 95% confidence ellipse sway area (mm^2); A-AP, amplitude of the center of pressure in anterior-posterior direction (mm); A-ML, amplitude of the center of pressure in medial-lateral direction (mm); MVELO CoP, mean total velocity displacement of CoP (mm/s); MVELO CoP-AP, mean velocity displacement anterior-posterior of CoP (mm/s); MVELO CoP-ML, mean velocity displacement medial-lateral of CoP (mm/s); ST, single-task - keep a quiet standing posture; cog-DT, keep a quiet standing posture while performing a cognitive task; mot-DT, keep a quiet standing posture while performing a secondary motor task.

[1] Friedman test

Oxyhemoglobin and deoxyhemoglobin concentrations

The changes in oxy and deoxyhemoglobin concentrations in the prefrontal cortex during postural task and dual-tasks (cog-DT and mot-DT) performance are presented in figure 7.1.

There were differences in oxy and deoxyhemoglobin concentrations between the postural task and the two dual tasks (*p* = 0.038 and *p* = 0.003, respectively). *However, post hoc* analysis showed a significant difference in the oxyhemoglobin concentration only between the postural task (single-task) and cog-DT (*p* = 0.033) (increase in [oxy-Hb] during cog-DT compared to the postural task). Concerning the [deoxy-Hb], we found significant differences between the postural task and cog-DT ($p = 0.033$), and between the postural task and mot-DT ($p = 0.003$).

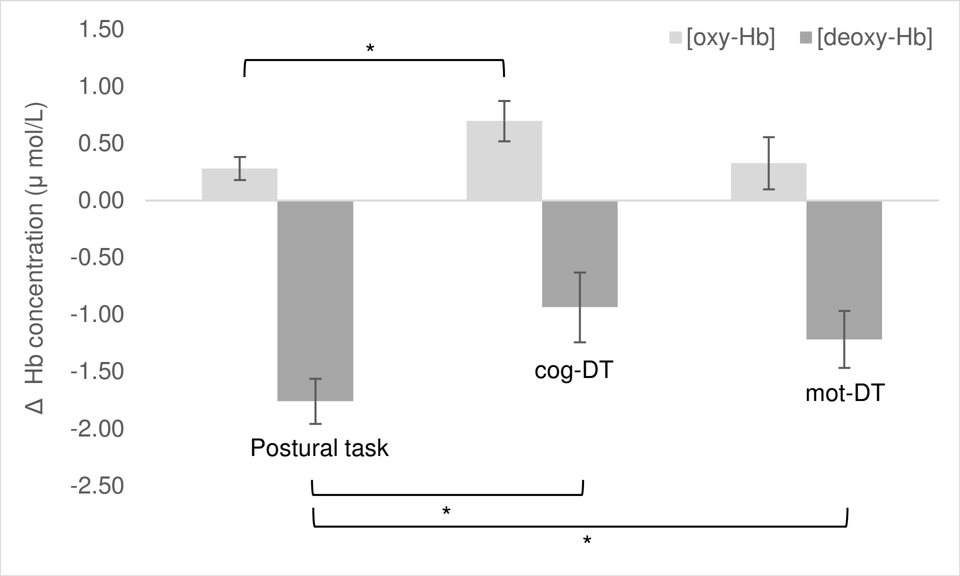


Figure 7.1. Changes in hemoglobin concentrations in the prefrontal cortex during postural task and the two dual-tasks performance.

The *y*-axis displays the hemoglobin concentration changes (median values and standard errors (error bars)). The oxyhemoglobin concentration, [oxy-Hb], is indicated by the light grey bar, and the deoxyhemoglobin concentration, [deoxy-Hb], by the dark grey bar.

Postural task, keep a quiet standing posture; cog-DT, keep a quiet standing posture while performing a cognitive task; mot-DT, keep a quiet standing posture while performing a secondary motor task.

* $p < 0.05$ (Friedman test with Bonferroni correction for multiple comparisons).

Dual-task cost

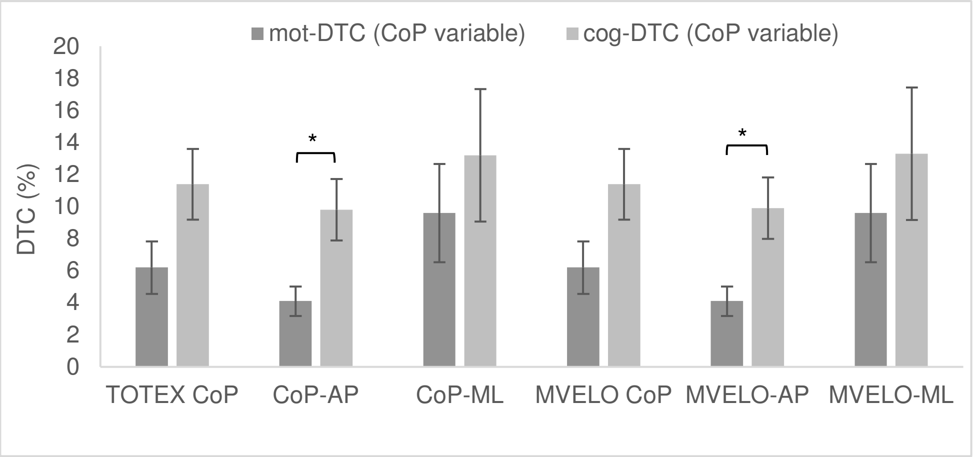
Postural control performance

For all CoP variables, the mean of the cog-DTC was higher than the mot-DTC (see figure 7.2); however, both DTC values indicated a worst postural control performance under dual-task than the single-task.

The difference between cog-DTC and mot-DTC was significant for the displacement of the center of pressure in anterior-posterior direction ($p = 0.016$), mean velocity displacement anterior-posterior of CoP ($p = 0.016$), and amplitude of the center of pressure in anterior-posterior direction ($p = 0.038$). There were no differences among the other DTC CoP variables ($p > 0.05$).

Secondary tasks performance

There was an improvement in the cognitive and motor secondary task performance during dual-task than cognitive and motor secondary single-task performance in the seated position (mean of cogDTC = 13.91% and motDTC = 13.93%).



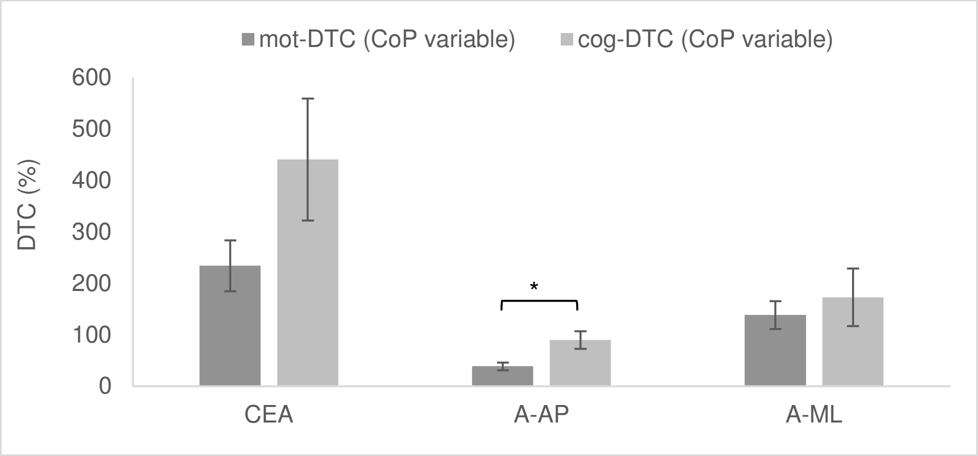


Figure 7.2. Mean percentage of motor and cognitive dual-task cost for CoP variables. DTC, dual-task cost for TOTEX CoP, total excursion of the center of pressure; CoP-AP, displacement of the center of pressure in anterior-posterior direction; CoP-ML, displacement of the center of pressure in medial-lateral direction; CEA, 95% confidence ellipse sway area; A-AP, amplitude of the center of pressure in anterior-posterior direction; A-ML, amplitude of the center of pressure in medial-lateral direction; MVELO CoP, mean total velocity displacement of CoP; MVELO CoP-AP, mean velocity displacement anterior-posterior of CoP; MVELO CoP-ML, mean velocity displacement medial-lateral of CoP during keep a quiet standing posture while performing a cognitive task (cog-DTC) and keep a quiet standing posture while performing a secondary motor task (mot-DTC). Error bars represent standard errors.

* $p < 0.05$: Comparision between cog-DTC and mot-DTC (Wilcoxon signed-rank test).

Relationship between physical activity level and sleep quality with postural control performance under dual-task

The analysis revealed a moderate, positive and significant correlation between the sleep quality and the cog-DTC for the mean displacement velocity of CoP in the medial-lateral ($r_s = 0.422$, $p = 0.013$) and the displacements of the center of pressure in the medial-lateral direction ($r_s = 0.422$, $p = 0.013$). There was a strong, positive and significant correlation between sleep quality and cog-DTC for the amplitude of the center of pressure in the medial-lateral direction ($r_s = 0.579$, $p < 0.001$). However, there were no significant relations between the other outcomes ($p > 0.05$) (see table 7.4).

Table 7.4. Relationship between physical activity level and sleep quality with the interference of cognitive and motor tasks on the postural control performance (DTC).

Outcomes	**IPAQ-SF total score**		**PSQI total score**	
	Spearman's rho	*p*-value	Spearman's rho	*p*-value
cog-DTC TOTEX CoP	0.029	0.870	0.241	0.169
cog-DTC CoP-AP	-0.047	0.794	0.040	0.821
cog-DTC CoP-ML	0.068	0.702	**0.422**	**0.013**
cog-DTC CEA	-0.066	0.711	0.320	0.065
cog-DTC A-AP	-0.048	0.790	0.139	0.432
cog-DTC A-ML	-0.085	0.633	**0.579**	**<0.001**
cog-DTC MVELO CoP	0.029	0.870	0.241	0.169
cog-DTC MVELO CoP-AP	-0.047	0.794	0.040	0.821
cog-DTC MVELO CoP-ML	0.068	0.702	**0.422**	**0.013**
cogDTC	0.024	0.894	-0.152	0.392
mot-DTC TOTEX CoP	0.136	0.444	0.078	0.661
mot-DTC CoP-AP	0.092	0.604	-0.112	0.529
mot-DTC CoP-ML	0.055	0.759	0.223	0.205
mot-DTC CEA	0.078	0.661	0.016	0.928
mot-DTC A-AP	0.019	0.916	-0.281	0.107
mot-DTC A-ML	0.078	0.661	0.140	0.431
mot-DTC MVELO CoP	0.136	0.444	0.078	0.661
mot-DTC MVELO CoP-AP	0.092	0.604	-0.112	0.529
mot-DTC MVELO CoP-ML	0.055	0.759	0.223	0.205
motDTC	-0.041	0.817	0.141	0.425

DTC, dual-task cost for TOTEX CoP, total excursion of the center of pressure; CoP-AP, displacement of the center of pressure in anterior-posterior direction; CoP-ML, displacement of the center of pressure in medial-lateral direction; CEA, 95% confidence ellipse sway area; A-AP, amplitude of the center of pressure in anterior-posterior direction; A-ML, amplitude of the center of pressure in medial-lateral direction; MVELO CoP, mean total velocity displacement of CoP; MVELO CoP-AP, mean velocity displacement anterior-posterior of CoP; MVELO CoP-ML, mean velocity displacement medial-lateral of CoP during keep a quiet standing posture while performing a cognitive task (cog-DTC) and keep a quiet standing posture while performing a secondary motor task (mot-DTC).

IPAQ-SF, International Physical Activity Questionnaire-Short Form; PSQI, Pittsburg Sleep Quality Index; cogDTC, dual-task cost for cognitive task performance; motDTC, dual-task cost for motor secondary task performance.

Bold values with $p < 0.05$. Spearman's correlation test.

Relationship between physical activity level and sleep quality with hemodynamic response performance under dual-task

There were no significant relations between the level of physical activity and the [oxy-Hb] and [deoxy-Hb] changes during both dual-task performances ($p > 0.05$) (see table 7.5). In addition, there was no association between sleep quality and the [oxy-Hb] and [deoxy-Hb] changes during both dual-task performances and single-task ($p > 0.05$) (see table 7.5).

Table 7.5. Relationship between physical activity level and sleep quality with hemodynamic response performance under single and dual-task conditions.

Outcomes	**IPAQ-SF total score**		**PSQI total score**	
	Spearman's rho	*p*-value	Spearman's rho	*p*-value
cog-DT [oxy-Hb]	0.091	0.610	0.168	0.342
cog-DT [deoxy-Hb]	-0.212	0.230	-0.085	0.633
mot-DT [oxy-Hb]	-0.040	0.824	-0.078	0.660
mot-DT [deoxy-Hb]	-0.208	0.237	-0.033	0.852
ST [oxy-Hb]	-0.156	0.378	0.257	0.142
ST [deoxy-Hb]	-0.186	0.292	-0.196	0.265

IPAQ-SF, International Physical Activity Questionnaire-Short Form; PSQI, Pittsburg Sleep Quality Index; cog-DT [oxy-Hb] and cog-DT [deoxy-Hb], oxy and deoxyhemoglobin concentration change during keeping a quiet standing posture while performing a

cognitive task (cog-DTC); mot-DT [oxy-Hb] and mot-DT [deoxy-Hb], oxy and deoxyhemoglobin concentration change during keeping a quiet standing posture while performing a secondary motor task (mot-DTC); ST, single-task (postural task).
Spearman's correlation test.

DISCUSSION

The present study analyzed the differences between the postural task (quiet standing posture) and two dual-tasks (cognitive DT, cog-DT and motor DT, mot-DT), to investigate the associations between physical activity level and sleep quality with the postural control and response hemodynamic performance under dual-task conditions in young adults.

There was an increase in all CoP variables results from the postural task to both dual-task conditions, revealing a decrease in postural control during dual-task performance.

The results showed differences between postural task and cog-DT and between postural task and mot-DT in all CoP variables. The dual-task interference was higher during cog-DT than mot-DT, since the cog-DT presents higher DTC values for all CoP variables, showing that during cog-DT the postural control performance was worse than the postural task. The differences between cog-DTC and mot-DTC occurred in the CoP displacement in the anterior-posterior direction, mean velocity displacement anterior-posterior of CoP, and CoP amplitude in the anterior-posterior direction.

Regarding the cerebral oxygenation in the prefrontal cortex, our results showed a significant increase in [oxy-Hb] from the postural task to the cog-DT and differences in the [deoxy-Hb] from the postural task to cog-DT and mot-DT. However, no correlations were found between hemodynamic response, physical activity level and sleep quality. These data suggest that the increase in brain activation during the cognitive dual-task is not directly related to good sleep quality and higher physical activity that characterizes this sample. During the cognitive dual-task condition, the young adults increased their cognitive task performance and decreased postural control performance compared to postural task, suggesting a cognitive priority trade-off pattern (Plummer et al., 2013). Thus, we suggest that the increase of cerebral oxygenation in the prefrontal cortex from postural task to cognitive dual-task performance can be due to the cognitive function of each individual. Previous research found an increase in oxy-Hb during cognitive dual-task and a correlation between oxy-Hb values and cognitive function (e.g., working memory, attention, executive function) (Ohsugi et al., 2013).

Young adults had a high level of physical activity and good sleep quality; however, when we evaluated the correlation between these factors with postural control performance, by the dual-task cost, and the hemodynamic response, by the oxy and deoxyhemoglobin concentrations in the prefrontal cortex under both dual-tasks conditions, only sleep quality was correlated with postural control in the variables, mean displacement velocity of CoP in the medial-lateral direction, displacement and amplitude of CoP in the medial-lateral direction, during the cog-DT performance, suggesting that poor sleep quality is associated with postural control deterioration in the medial-lateral direction of the CoP under cognitive dual-task performance.

The thalamus has a role in integrating and processing various sensory and motor information (Huguenard & McCormick, 2007). Previous studies suggest that the posterolateral thalamus (ventral posterior and lateral posterior nuclei) is involved in the control of upright standing posture (Karnath et al., 2000), and the thalamic structures also have a role in the circadian rhythm of sleep and wakefulness (Jan et al., 2009). A study reported that 24h sleep deprivation caused a decrease in regional cerebral glucose metabolic rate in the thalamus, prefrontal, and posterior parietal cortices using positron emission tomography (Thomas, M. et al., 2000). Besides, it was found an association between the central nervous system and motor fatigue. During motor fatigue, the subcortical areas (e.g., thalamus, basal ganglia areas) are less active, affecting the motor control processing (Hou et al., 2016). Thus, in our research, we consider that the correlation found between sleep quality and postural control performance during the cognitive dual-task may be due to the role of the thalamus in sleep regulation and postural control. Furthermore, the postural control impairments caused for 24h of sleep deprivation can be associated with mental fatigue due to sleeplessness in young adults (Ma et al., 2009); and mental fatigue impairs physical performance and postural control (Fletcher et al., 2021; Ma et al., 2009). Therefore, poor sleep quality can result in less activation of the thalamic structures and mental and motor fatigue, contributing to declined motor performance under cognitive dual-task.

Young adults preferentially prioritize their balance control over cognitive performance when experiencing foot-placement disturbances by adopting an ankle and hip strategy to maintain balance in the static bipedal posture (Small & Neptune, 2022); however, some studies suggest that after ankle muscle fatigue, they change the ankle strategy to the hip strategy to control balance in the postural standing (Paillard, 2012). Hip muscle fatigue causes more postural sway than ankle muscle fatigue (Paillard, 2012) and more oscillation of the center of pressure in the medial-lateral direction than anterior-posterior direction (Sarabon & Hirsch, 2016). Our results showed a higher cog-DTC in displacement, mean velocity displacement, and amplitude of CoP in the anterior-posterior direction than the mot-DTC, and a relationship between sleep quality and the displacement, mean velocity displacement, and amplitude of CoP in the medial-lateral direction under cognitive dual-task performance. So, the motor strategy adjustment, muscle fatigue, and increased attentional demands during the cognitive dual-task performance can explain the additional postural control impairment in the medial-lateral direction of CoP and its relationship with sleep quality in young adults. To consolidate this assumption, we recommend studies that assess muscle activity to understand the changes in postural strategies during dual-task conditions.

There is a lack of evidence about the effects of exercise or physical activity programs on static and dynamic postural control improvements during dual-task in the elderly (Gobbo et al., 2014). In another study, there was no correlation between exercise capacity (determined by the incremental shuttle walking test) and balance performance during the one-legged stance test in older adults (Hayashi et al., 2012). Furthermore, moderate to high levels of physical activity appear to benefit cognitive function in middle age groups and older people (over 38 years old), but not in young adulthood, according to the prefrontal cortex activity measured by electroencephalogram during a cognitive single-task performance (Berchicci et al., 2013). Our results also found no direct relationship between physical activity level, postural control performance and hemodynamic response under dual-task conditions in young adults.

The strength of our study was to analyze the correlation between sleep quality and physical activity level with postural control performance and brain activity during dual-task conditions. However, our study has some limitations as sleep quality and physical activity level were subjectively assessed by questionnaires. So, in future studies, we recommend using objective measures to assess sleep and physical activity to understand better the relationship between these lifestyles in postural control performance and hemodynamic response under dual-task conditions in young adults and other age groups or clinical conditions. Furthermore, the lack of studies related to the aim of the present study limits the discussion of the results, so more studies using a similar approach and methodology should be performed.

This study found a moderate to strong association between subjective sleep quality and postural control in young adults, showing their postural control performance during daily cognitive tasks is compromised as a result of low sleep quality. Our results can orient the planning of strategies to prevent injuries or falls, and improve postural control during dual-task conditions. The dual-task training, for example, may be used as an intervention strategy once it can contribute to improving sleep quality (Demirdel & Erbahc, 2020) and postural control performance (Bustillo-Casero et al., 2017).

CONCLUSION

The cognitive dual-task presented a greater decrease in postural control performance (displacement, velocity, and amplitude of CoP in anterior-posterior directions) and activation of the prefrontal cortex than the motor dual-task and single-task. The differences found in the postural control during dual-task performance do not correlate with the level of physical activity. However, good sleep quality was associated with better postural control performance in the medial-lateral direction during cognitive dual-task. The hemodynamic response during the dual-task performance did not correlate with the level of physical activity or sleep quality. We recommend more studies to assess the relationship between sleep and physical activity level with postural control and hemodynamic response performance under dual-task conditions.

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Conflicts of Interest

The authors declare no conflict of interest.

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CHAPTER IX – Study VIII: Influence of cognitive and motor tasks using smartphone during gait: EMG and gait performance analysis – Dual-task study

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ABSTRACT

Previous studies reported changes in spatiotemporal gait parameters during the dual-task performance while walking using a smartphone compared to walking without a smartphone. However, studies that assess muscle activity while walking and simultaneously performing smartphone tasks are scarce. So, this study aimed to assess the effects of motor and cognitive tasks using a smartphone while simultaneously performing gait on muscle activity and gait spatiotemporal parameters in healthy young adults. Thirty young adults (22.83 ± 3.92 years) performed five tasks: walking without a smartphone (single-task, ST); typing on a smartphone keyboard in a sitting position (secondary motor single-task); performing a cognitive task on a smartphone in a sitting position (cognitive single-task); walking while typing on a smartphone keyboard (motor dual-task, mot-DT) and walking while performing a cognitive task on a smartphone (cognitive dual-task, cog-DT). Gait speed, stride length, stride width and cycle time were collected using an optical motion capture system coupled with two force plates. Muscle activity was recorded using surface electromyographic signals from bilateral biceps femoris, rectus femoris, tibialis anterior, gastrocnemius medialis, gastrocnemius lateralis, gluteus maximus and lumbar erector spinae. Results showed a decrease in stride length and gait speed from the single-task to cog-DT and mot-DT ($p < 0.05$). On the other hand, muscle activity increased in most muscles analyzed from single- to dual-task conditions ($p < 0.05$). In conclusion, performing a cognitive or motor task using a smartphone while walking promote a decline in spatiotemporal gait parameters performance and change muscle activity pattern compared to normal walking.

Key-words: muscle activity; spatiotemporal gait parameters; smartphone; dual-task.

INTRODUCTION

Dual-task paradigm is an approach used to assess the performance and interference between the tasks; when people perform two tasks concurrently, the performance of one or both tasks can be compromised (Woollacott & Shumway-Cook, 2002). For example, it is much frequent for people to do various activities or tasks simultaneously using a smartphone while walking. Previous studies reported that performing tasks using smartphones while walking decreases gait performance, such as decreased gait speed, stride length, and cadence (Crowley et al., 2019; Kim et al., 2020; Tan et al., 2022), increased stride width and double support time (Parr et al., 2014; Tan et al., 2022), compared to walking without a smartphone. These changes in gait performance due to smartphone use while walking can compromise pedestrian safety (Schwebel et al., 2012; Stavrinos et al., 2011), causing an increase in the risk of injuries and accidents for pedestrians (Nasar & Troyer, 2013). However, a recent review about smartphone use's effects on gait characteristics reported that few studies evaluated muscle activation on gait during dual-task (Tan et al., 2022). Furthermore, other research that assesses muscle activity under dual-task conditions is also scarce and shows controversial results (Abbud et al., 2009; Majlesi et al., 2017). For example, under dual-task performance (cognitive-task while walking), a lower muscle activation pattern was found than during normal walking (Abbud et al., 2009); in another study, no changes in muscle activity were found between single- and dual-task during walking (Majlesi et al., 2017).

The surface electromyographic (sEMG) is an efficient technique for measuring muscle activity during gait (Drost et al., 2006; Roetenberg et al., 2003). Furthermore, the information provided by lower limb muscle activity can help understand better the neuromuscular behavior during gait (Schmitz et al., 2009). Thus, this study aims to analyze the changes in muscle activity and spatiotemporal gait performance during walking while concurrently performing a cognitive and secondary motor task using a smartphone in healthy young adults. Thus, we hypothesized that: (1) Young adults present a decline in spatiotemporal gait parameters performance (e.g., lower speed gait, increased stride width) when performing a cognitive task on their smartphone while walking than when performing a secondary motor task while walking and normal walking (single-task); (2) walking while performing different tasks on a smartphone would change the muscle activity pattern in lower limbs compared to the single-task; (3) the dual-task cost (DTC) of spatiotemporal gait parameters is higher in cognitive dual-task (worst gait performance) than motor dual-task conditions relative to the single-task performance; (4) the DTC of muscle activity is greater in motor dual-task compared to cognitive dual-task.

Methodology

In order to calculate the necessary sample size, an *a priori* power analysis was conducted using G*power software (Franz Faul, Edgar Erdfelder, Axel Buchner, Universität Kiel, Kiel, Germany, version 3.1.9.6) (Erdfelder et al., 1996). According to the study design, a minimum of 18 subjects was needed to achieve a large effect size (Cohen's $f = 0.40$) with $\alpha = 0.05$ and a power of 0.95.

Thirty healthy young adults (22 males and 8 females), between 18 and 35 years, without neurological, respiratory, musculoskeletal, vestibular and cardiac diseases participated in this study (sample characteristics in table 8.1). All participants gave informed written consent following the principles of the Declaration of Helsinki. This study was approved by the Ethics Committee of the Polytechnic Institute of Coimbra.

Table 8.1. Anthropometric and demographic characteristics of the sample (mean ± SD).

Variables	**Sample, n = 30**
Age (years)	22.83 ± 3.92
Height (m)	1.73 ± 0.08
Body mass (Kg)	75.77 ± 16.17
Body Mass Index (Kg/m^2)	25.15 ± 4.23

Tasks Protocol

Participants performed the following tasks for 60s, twice with the rest 45s between each task: (1) Single-task (ST, primary motor task): the participants were asked to walk for 60s at their preferred normal pace without smartphone use on a 8-m walkway; (2) Cognitive single-task: in the seated position, the participants performed a cognitive task displayed on the smartphone screen based on the mental tracking/working memory tasks category (arithmetic and memory tasks) (Bayot et al., 2018). To avoid typing on the smartphone, the participants were instructed to verbalize their responses; (3) Secondary motor single-task: the participants were instructed to type randomly on the smartphone keyboard in the seated position; (4) Cognitive dual-task (cog-DT): the participants were asked to walk while simultaneously performing a cognitive task on the smartphone; (5) Motor dual-task (mot-DT): the participants were asked to walk while simultaneously typing on the smartphone keyboard.

The tasks were performed in randomized order, and no instructions were given regarding which task to prioritize while performing the dual-task. Participants used their smartphones and held them with their preferred hand to maintain a condition similar to real life and ecological validity. The number of correct answers was recorded during cognitive single-task and cog-DT. The number of taps on the smartphone keyboard was recorded in secondary motor single-task and mot-DT to assess the secondary task performance. The spatiotemporal gait parameters and sEMG from bilateral lumbar erector spinae muscles and six lower limb muscles were recorded during single-task and dual-tasks conditions.

Spatiotemporal gait acquisition and analysis

An optical motion capture system (Qualysis AB, Göteborg, Sweden) with ten Oquos® Optoelectronic cameras of high speed and a resolution of 1.3 to 12 megapixels with a 200 Hz measurement frequency coupled with two force plates (Bertec Corporation, OH 43229 USA; AMTI, USA) was used for 3D gait analysis. According to Wilken et al. (Wilken et al., 2012), one experienced researcher placed fifty-three reflecting markers on defined anatomical landmarks. Furthermore, marker clusters were placed on the thighs and shanks to improve segment tracking. Spatiotemporal gait parameters were collected using Qualisys Track Manager v2.15 software (Qualisys AB, Götebor, Sweden) and processed using the Visual 3D software (C-Motion, USA). The marker data were filtered with 6-Hz Butterworth low-pass filter. In this study, the spatiotemporal gait variables assessed during single and dual-task conditions were: stride length, stride width, cycle time and gait speed.

Muscle activity acquisition and analysis

Surface electromyography (sEMG) signals from the muscles were recorded using a telemetric equipment (PLUX, Lisbon, Portugal) with Bluetooth connectivity. Before electrode placement, the skin was meticulously prepared to improve the signal collected. Then, active surface electrodes (Al/AgCl, rectangular shape 30mm x 22 mm) using the AMBU BlueSensor N (AMBU, Ballerup, Denmark) were placed bilaterally on the following muscles: biceps femoris (BF), rectus femoris (RF), tibialis anterior (TA), gastrocnemius medialis (GM), gastrocnemius lateralis (GL), gluteus maximus (GMax) and lumbar erector spinae (LES), according to Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) (Hermie J Hermens et al., 2000). The EMG data were sampled at 1000 Hz and processed by a routine in the Matlab software (version R2020b, The Mathworks, Inc.). The EMG signal was digitally filtered (20–490 Hz), then full-wave rectified, and low-pass filtered at 12 Hz fourth-order Butterworth digital filter. The procedures described by Konrad (Konrad, 2006) and Hermens et al. (H. J. Hermens et al., 1999) to evaluate maximal voluntary contraction (MVC) were used. During the maximal isometric efforts, all participants were verbally encouraged, and to avoid fatigue, a 2 min rest period was allowed between repetitions. To determine the EMG_{MAX} have performed three isometric repetitions of 3 to 4 s for each muscle.

Statistical Analysis

The descriptive data related to sample characteristics were presented as mean ± SD (standard deviation). The Shapiro–Wilk test was used to test the normality distribution. Since not all variables were normally distributed, the EMG and spatiotemporal gait data were analyzed using non-parametric tests; and their values were presented as median and interquartile range (IQR). We used the formula (Doumas et al., 2008): DTC (dual-task cost) = [(dual-task – single-task)/singe-task]*100 to determine the cognitive and motor interference in muscle activity and spatiotemporal gait parameters during cognitive and motor dual-task relative to single-task for each participant. The single-task indicates the gait and muscle activity performance through spatiotemporal gait parameters and EMG data of each muscle in walking; the dual-task indicates the performance of these outcomes in walking while simultaneously performing cognitive and motor secondary tasks. The DTC was calculated separately for muscle activity and gait performance in both dual-tasks: cognitive dual-task cost (cog-DTC) and motor dual-task cost (mot-DTC). The differences between the motor DTC (mot-DTC) and cognitive DTC (cog-DTC) were assessed using Wilcoxon signed-rank test. Friedman test with Bonferroni *post-hoc* pairwise comparisons was used to assess the differences between the tasks in muscle activity and spatiotemporal gait parameters.

All analyses were performed using IBM-SPSS 25.0 software, and the significance level was set at $p < 0.05$.

Results

Young adults reported an average of 4.28 ± 3.37 hours per day of smartphone use, and 6.9% reported previous falls or tripping while using their smartphone. While performing tasks with smartphone use, most participants held the smartphone with both hands. However, there were no differences in spatiotemporal gait parameters and muscle activity between participants who held the smartphone with one or both hands ($p > 0.05$).

The spatiotemporal gait analysis showed significant differences in gait speed ($p < 0.001$) and stride length ($p = 0.012$) between the single-task, cog-DT and mot-DT (see table 8.2). There was a significant decrease in these variables from the single-task to both dual-task conditions. However, no significant differences ($p > 0.05$) were found in the cycle time and stride width parameters (see table 8.2).

Post hoc analyses with Bonferroni correction showed differences in gait speed between single-task and cog-DT ($p < 0.001$) and between single-task and mot-DT ($p = 0.043$); however, no significant differences ($p > 0.05$) were found between cog-DT and mot-DT in gait speed. In stride length were found differences between single-task and cog-DT ($p = 0.014$). However, no significant differences ($p > 0.05$) were found between single-task and mot-DT and between cog-DT and mot-DT in stride length.

Table 8.2. Spatiotemporal gait parameters during the tasks performed – median values (IQR).

	ST	mot-DT	cog-DT	*p*-value[1]
Speed (m/s)	1.08 (0.98–1.20)	0.98 (0.88–1.15)	0.94 (0.89–1.05)	< 0.001*
Stride Length (m)	0.90 (0.78–1.15)	0.78 (0.72–0.93)	0.78 (0.67–0.95)	0.012*
Stride Width (m)	0.13 (0.11–0.15)	0.13 (0.12–0.16)	0.15 (0.11–0.16)	0.648
Cycle Time (s)	0.86 (0.66–1.07)	0.82 (0.70–1.02)	0.82 (0.71–1.05)	0.131

ST, single-task; mot-DT, motor dual-task; cog-DT, cognitive dual-task. [1] Friedman test; * *p*-value < 0.05.

During the single-task were found differences in muscle activity (% MVC) between each muscle's left and right sides (TA, GM, GL, RF, BF, GMax and LES: $p < 0.05$), showing less muscle activity on the right side muscles compared to the left side muscles. However, during both dual-task conditions, there were no differences in muscle activity (% MVC) between the left and right sides of each muscle ($p > 0.05$).

The comparison between single-task, cog-DT and mot-DT muscle activity (% MVC) *post hoc* analyses with Bonferroni correction is presented in Figure 8.1. Muscle activity increases significantly from the single-task to dual-task conditions in the right side's TA, GM, GL, RF, BF, GMax and LES (all $p < 0.05$), and decreases in left GMax ($p < 0.05$). On the left side, the TA and GM activity increases significantly from the single-task to mot-DT ($p < 0.05$); however, no differences were found between single-task and cog-DT ($p > 0.05$). Left RF activity decreases from single-task to cog-DT ($p < 0.05$); however, there were no differences in left RF activity between single-task and mot-DT ($p > 0.05$).

There were no differences ($p > 0.05$) between single and dual-task in the left side's GL, BF and LES activity. No differences were found in muscle activity bilaterally between mot-DT and cog-DT ($p > 0.05$).

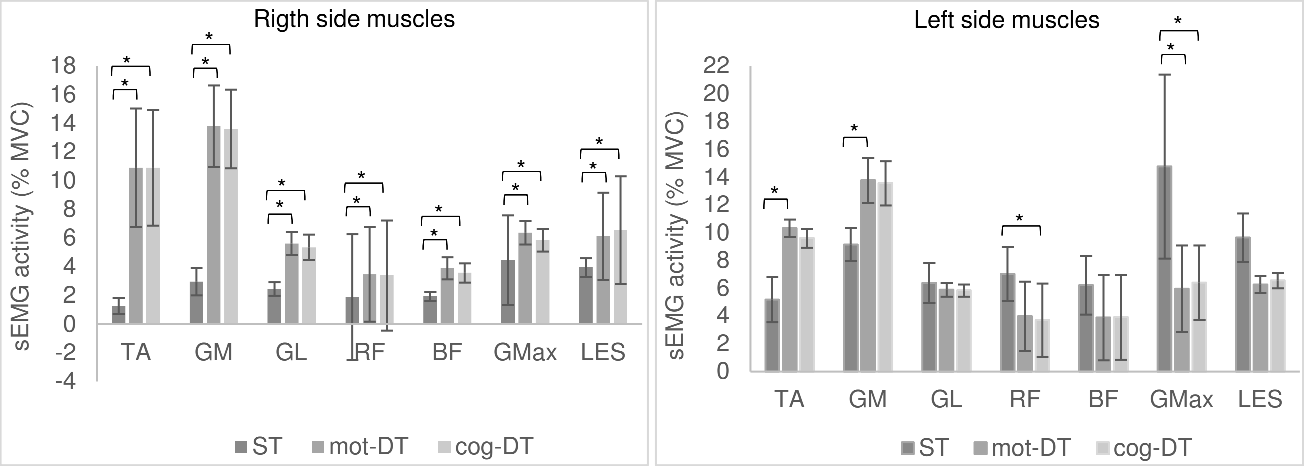

Figure 8.1. Comparison between muscle activity (% MVC) during single and dual-tasks conditions.

ST, single-task; mot-DT, motor dual-task; cog-DT, cognitive dual-task; EMG. The y-axis displays the median values of the surface electromyographic activity (% MVC, maximum voluntary contraction) measured in the TA, tibialis anterior; GM, gastrocnemius medialis; GL, gastrocnemius lateralis; RF, rectus femoris; BF, biceps femoris; GMax, gluteus maximus and LES, lumbar erector spinae. Error bars represent standard error.

* *p*-value < 0.05 using Friedman test with Bonferroni correction for multiple comparisons.

Dual-task Cost

Table 8.3 shows the results obtained for the cognitive and motor dual-task cost and the differences found between both dual-task costs in spatiotemporal gait parameters and muscle activity. Cognitive and motor dual-task costs showed a decrease in gait performance when young adults simultaneously performed cognitive or secondary motor tasks while walking than single-task. However, differences were only found in the dual-task cost between cog-DT and mot-DT in gait speed ($p = 0.011$), showing that the cognitive task interferes more negatively with gait performance than the secondary motor task relative to the single-task. In addition, there were no differences between cognitive and motor DTC in stride length, stride width and cycle time.

Differences were found between cog-DTC and mot-DTC in TA bilaterally, right GM, and right RF, showing that muscle activity was greater during the mot-DT than cog-DT relative to the single-task performance ($p < 0.05$). On the other hand, in left RF, the muscle activity performance was less during both dual-task relative to the ST, with differences between cog-DTC and mot-DTC ($p < 0.05$), showing an inferior RF activity in cog-DT than mot-DT. However, there were no differences between cog-DTC and mot-DTC ($p > 0.05$) in GL, BF, GMax, and LES of both sides and left GM activity.

Table 8. 3. Comparison between mot-DTC and cog-DTC, median values (IQR).

		mot-DTC (%)	**cog-DTC (%)**	***p*-value[1]**
Spatiotemporal gait parameters				
Speed (m/s)		-6.93 (-14.52–(-0.07))	-10.83 (-17.60–(-1.46))	0.011*
Stride Length (m)		-8.67 (-19.77–6.12)	-10.03 (-20.63–0.89)	0.491
Stride Width (m)		3.33 (-8.77–18.84)	3.05 (-10.34–26.93)	0.975
Cycle Time (s)		1.85 (-12.16–16.16)	5.55 (-12.50–15.00)	0.517
Muscle activity (sEMG)				
Tibialis Anterior	Left	0.89 (0.03–2.84)	0.77 (0.10–2.79)	0.003*
	Right	8.06 (5.50–15.93)	8.06 (4.85–14.55)	0.010*
Gastrocnemius Medialis	Left	0.40 (0.01–0.97)	0.30 (-0.14–1.10)	0.069
	Right	3.40 (1.76–6.33)	3.28 (1.70–5.95)	0.037*
Gastrocnemius Lateralis	Left	-0.14 (-0.55–0.37)	-0.11 (-0.56–0.29)	0.581
	Right	1.50 (0.68–2.27)	1.16 (0.60–2.59)	0.315

Rectus Femoris	Left	-0.42 (-0.65–0.16)	-0.44 (-0.66–0.08)	0.012*
	Right	0.66 (0.23–1.26)	0.57 (0.19–0.98)	0.014*
Biceps Femoris	Left	-0.14 (-0.65–0.14)	-0.24 (-0.65–0.28)	0.262
	Right	0.79 (0.26–1.69)	0.60 (0.17–1.50)	0.382
Gluteus Maximus	Left	-0.63 (-0.75–0.05)	-0.61 (-0,76–(-0.01))	0.443
	Right	0.37 (0.11–0.89)	0.34 (0.08–0.85)	0.284
Lumbar Erector Spinae	Left	-0.33 (-0.61–0.20)	-0.35 (-0.56–0.25)	0.905
	Right	0.54 (0.25–1.20)	0.55 (0.21–1.25)	0.060

sEMG, surface electromyography (% MVC, maximum voluntary contraction); mot-DTC, motor dual-task cost; cog-DTC, cognitive dual-task cost. * *p*-value < 0.05; [1] Wilcoxon signed test.

Concerning the secondary tasks performance, there was an increase in secondary tasks performance from single-task to dual-task conditions. Differences were found (*p* = 0.001) between the average percentage of correct answers between cognitive single-task (sitting position, 70.35% ± 21.49%) and cog-DT (82.79% ± 16.51%). However, no differences were found (*p* = 0.558) between the average number of taps on the smartphone keyboard in the seated position (480.50 ± 131.94) and during mot-DT (495.50 ± 140.66).

DISCUSSION

The main purpose of this study was to assess changes in spatiotemporal gait parameters and muscle activity during walking while concurrently performing cognitive and motor taks on a smartphone compared to normal walking. Furthermore, we explored the dual-task cost between cognitive and mot-DT. Our results showed a decrease in gait speed and stride length from single-task to motor-DT and cog-DT, revealing a reduction in gait performance during dual-task conditions. The decline in gait performance was more evident from single-task to the cog-DT (differences in gait speed and stride length) than single-task to the mot-DT (differences only in gait speed). When we calculated the dual-task cost, differences between cog-DTC and mot-DTC were only observed in the gait speed, showing a greater decline in gait performance under the cog-DT than the mot-DT condition relative to the single-task gait performance.

The cognitive performance increases from the cognitive single-task to cog-DT; on the other hand, the gait speed and stride length decrease from normal walking to cog-DT, leading to a decrease in gait performance during cog-DT. Thus, there was an improvement in cognitive task performance and a deterioration of gait performance in the cog-DT relative to single-task performance, showing that young adults adopted a cognitive priority trade-off pattern while performing a cognitive task on a smartphone simultaneously with walking (Plummer et al., 2013). Although this pattern was similar in mot-DT, the changes in the performance of typing on a smartphone keyboard and spatiotemporal gait parameters in mot-DT relative to single-task performance were not significant; the only difference between single-task and mot-DT was in gait speed. The cognitive motor-interference pattern depends on various factors like as task type, the difficulty level of the task, and performer characteristics (e.g., motor and cognitive skills, motivation, concentration, and fear of failing) (Tomporowski & Qazi, 2020). For that reason, young adults may have adopted a cognitive priority trade-off pattern, possibly because they felt more challenged and focused on demonstrating success in the added task than on walking performance.

On the other hand, muscle activity increased in most muscles analyzed from the single-task to the cog-DT and mot-DT (bilateral TA and GM, right side's GL, RF, BF, GMax, and LES), suggesting a greater overload on muscle activity during the cog-DT and mot-DT compared to the single-task. However, no differences in muscle activity were found between cog-DT and mot-DT. The differences between cog-DTC and mot-DTC were only found in the right GM, TA, and RF bilaterally, which the mot-DTC was superior to the cog-DTC in TA bilaterally, GM, and RF of the right side, showing that typing on a smartphone keyboard represents a higher cost in muscle activity than smartphone cognitive task relative to the muscle activity performance in the single-task.

These results suggest that the gait and muscle activity changes during dual-task conditions promoted a decline in gait performance and greater muscle activation compared to normal walking in young adults. However, performing a cognitive task using a smartphone while simultaneously walking appears to cause more gait impairments than typing on a smartphone keyboard. According to capacity sharing theory (Pashler, 1994), the gait speed and stride length changes during a cog-DT compared to the single-task and mot-DT can be related to the inability to share attentional resources between two tasks (cognitive and motor tasks) under cog-DT condition. Furthermore, the competition of tasks by shared neural networks can also explain cog-DT results once there is a neural network interconnection between gait speed control areas and the prefrontal cortex, which plays an essential role in cognitive function (Al-Yahya et al., 2011).

Most young adults held smartphones with both hands while performing cog-DT and mot-DT, reducing arm swing movement and leading to more constraints during dual-task conditions. The arm swing movement plays an important role in walking because it decreases the metabolic cost of gait (Collins et al., 2009), reduces body angular momentum about the vertical axis (S.M. Bruijn et al., 2008), and helps recover gait stability face of a balance perturbation (Sjoerd M Bruijn et al., 2010). A study reported a decrease in gait speed, stride length, and cadence during walking with constraint arm swing than normal walking without restrictions (Koo & Lee, 2016). Thus, the compromise of arm swing movement during both dual-task conditions can explain the decrease in gait speed and stride length during dual-task compared to the single-task performance.

A study showed a reduced gait speed, a decrease in neck range of motion (head relative to the thorax) in all planes, a higher rotation of the head relative to global space, increased head flexion, and a higher deviation from a straight path during reading and tying text while walking compared to the normal walking (Schabrun et al., 2014). Thus, postural alterations arising from tasks performed with the smartphone while walking can be factors responsible for decreasing gait speed. Furthermore, while performing a cognitive task using a smartphone, more attention is needed than typing on a smartphone keyboard, so gait speed was lower during cog-DT compared to the mot-DT and single-task.

The alteration of the field of view when engaging with a smartphone appears to result in adopting a more cautious gait pattern, such as reducing gait speed and stride length, compared to walking without a smartphone (Timmis et al., 2017), which can explain the decrease in stride length between cog-DT and single-task, and between mot-DT and single-task in our study. However, the increased cognitive demand during cog-DT can have affected gait performance even more than mot-DT, contributing to differences between cog-DTC and mot-DTC in gait speed relative to single-task.

A study assessed the right lower limb muscle activity (gluteus maximus and medius, biceps femoris, rectus femoris, gastrocnemius (medial and lateral), tibialis anterior, and soleus) in young adults performing walking while texting on a smartphone (Lee & Jeon, 2021). It showed a decrease in gait speed and tibialis anterior, gastrocnemius, rectus femoris, gluteus maximus and medius muscle activity during dual-task compared to walking without smartphone use. Our results showed a muscle activation pattern different from the data of this study (Lee & Jeon, 2021); however, we assessed muscle activity bilaterally. Bilateral tibialis anterior and gastrocnemius medialis, right side's biceps femoris, rectus femoris, gastrocnemius lateralis, gluteus maximus and lumbar erector spinae increased their activity from single-task to both dual-task conditions. Nevertheless, the left rectus femoris muscle activity decreased from single-task to cog-DT, and the left gluteus maximus muscle activity decreased from single-task to both dual-task conditions. The changes in muscle activity observed during dual-task conditions can result from a central nervous system adaptation to overcome the instability inherent or biomechanical disadvantages in response to task demands. A previous study (Agostini et al., 2015) showed an increase in ankle muscle co-contractions in the load response and mid-stance of gait during texting while walking in young adults. It was suggested that this increase could be due to the need for greater ankle stabilization when body weight is transferred from one leg to the other (Agostini et al., 2015). On the other hand, the increase in muscle activity from single-task to cog-DT and mot-DT can lead to a higher energy expenditure of walking during the dual-task performance and consequently promote muscular fatigue and increase the risk of falls during walking (Hallal et al., 2013; Mian et al., 2006).

This study had some limitations, as we did not consider joint ranges of motion analysis, the eye behavior, and EMG analysis in the different phases of the gait cycle, which could provide additional information to understand better the changes in muscle activity and spatiotemporal gait parameters during smartphone use in dual-task conditions. In future studies, it is recommended to assess eye tracking, postural analysis, and EMG pattern in each gait phase.

Our results showed a decrease in walking optimization during dual-task conditions that can compromise gait stability and dynamic balance. It should be noted that 6.9% of young adults who participated in the study reported falling or tripping due to smartphone use while walking. Nonetheless, the changes observed in spatiotemporal gait parameters and muscle activity during the dual-task conditions can be understood as adaptation strategies of motor control to surrounding environmental and dual-task conditions to minimize the risk of falling or tripping.

CONCLUSION

Adding a smartphone cognitive task or typing on a keyboard while walking changes muscle activity patterns and decreases the performance of spatiotemporal gait compared to normal walking in young adults.

When performing a cognitive task using a smartphone while walking, young adults presented a greater decrease in gait performance (less gait speed and stride length) than the motor dual-task and single-task. Muscle activity increased from single-task to both dual-task conditions in most muscles analyzed, especially in the tibial anterior and gastrocnemius medialis (ankle stabilizer muscles). Thus, the smartphone cognitive task appears to interfere more negatively with gait and muscle activity performance than typing on the keyboard smartphone, possibly due to inadequate capacity to divide the attentional resources among two tasks when young adults perform a cognitive dual-task.

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Conflicts of Interest

The authors declare no conflict of interest.

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CHAPTER X: Study IX – The role of sleep quality and physical activity level on gait speed and brain hemodynamics changes in young adults – a dual-task study

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ABSTRACT

Walking requires attentional resources, and the studies using neuroimage techniques have grown to understand the interaction between cortical activity and motor performance. Previous studies reported a decline in gait performance and changes in the prefrontal cortex (PFC) activity during a dual-task performance compared to walking only. Some lifestyle factors, such as sleep and physical activity (PA) levels, can compromise walking performance and brain activity. Nonetheless, the studies are scarce. This study aimed to assess gait speed and hemodynamic response in the PFC during a cognitive dual-task (cog-DT) compared to walking only, and to analyze the correlation between PA and sleep quality (SQ) with gait performance and hemodynamic response in the PFC during a single task (ST) and cog-DT performance in young adults. A total of 18 healthy young adults (mean age ± SD = 24.11 ± 4.11 years) participated in this study. They performed a single motor task (mot-ST)—normal walking—and a cog-DT—walking while performing a cognitive task on a smartphone. Gait speed was collected using a motion capture system coupled with two force plates. The hemoglobin differences (Hb-diff), oxyhemoglobin ([oxy-Hb]) and deoxyhemoglobin ([deoxy-Hb]) concentrations in the PFC were obtained using functional near-infrared spectroscopy. The SQ and PA were assessed through the Pittsburg Sleep Quality Index and International Physical Activity Questionnaire-Short Form questionnaires, respectively. The results show a decrease in gait speed ($p < 0.05$), a decrease in [deoxy-Hb] ($p < 0.05$), and an increase in Hb-diff ($p < 0.05$) and [oxy-Hb] ($p > 0.05$) in the prefrontal cortex during the cog-DT compared to the single task. A positive correlation between SQ and Hb-diff during the cog-DT performance was found. In conclusion, the PFC's hemodynamic response during the cog-DT suggests that young adults prioritize cognitive tasks over motor performance. SQ only correlates with the Hb-diff during the cog-DT, showing that poor sleep quality was associated with increased Hb-diff in the PFC. The gait performance and hemodynamic response do not correlate with physical activity level.

Keywords: simultaneous tasks, physical activity, cognitive, speed gait, sleep, fNIR, prefrontal cortex.

INTRODUCTION

It is common to perform two tasks simultaneously in everyday life, such as walking while playing a game on a smartphone, walking while talking to other people, or maintaining a standing posture while reading a newspaper. The capacity to perform two tasks concurrently is called the dual-task paradigm (Macpherson, 2018). However, generally, when people perform two tasks simultaneously, the attention is divided between both tasks, which can result in a decline in the performance of one or both tasks due to the limited ability to share attentional resources (Bayot et al., 2018; Huang & Mercer, 2001; Plummer & Eskes, 2015).

Previous studies reported that walking requires attentional resources and is not just an automated motor activity (Bayot et al., 2018; Woollacott & Shumway-Cook, 2002; Yogev-Seligmann et al., 2008). Thus, studies that assessed gait performance when simultaneously performing cognitive or motor secondary tasks showed a decline in gait performance in dual-task conditions. For example, a reduction in gait speed during walking when performing a secondary task compared to normal walking was observed in young adults (Beurskens et al., 2016; Mirelman et al., 2014; Schabrun et al., 2014), older adults (Beurskens & Bock, 2013; Freire Júnior et al., 2017), and in neurological diseases (Hunter et al., 2018; Liu et al., 2018).

The prefrontal cortex plays an essential role in executive functions and gait control (Fuster, 2001; Suzuki et al., 2004). Furthermore, neuroimaging studies have grown to understand brain activity resulting from the interaction between motor and cognitive task performance. Some neuroimaging techniques used to assess the cognitive resources and brain regions involved in walking performance under dual-task conditions are functional magnetic resonance imaging (fMRI) (Bürki et al., 2017), positron-emission tomography (PET) (Szturm et al., 2021), electroencephalography (EEG) (Possti et al., 2021), and functional near-infrared spectroscopy (fNIRS) (Herold et al., 2017). fNIR has advantages over others because it is portable and can be used during motion and in natural environments (Herold et al., 2017; Scholkmann et al., 2014). In addition, it measures the changes in oxy and deoxyhemoglobin concentrations associated with neural activity (Quaresima & Ferrari, 2019; Villringer & Chance, 1997). A systematic review showed that increased brain activity could lead to more walking impairments due to the use of more attentional resources during a dual-task, especially in older adults with neurological diseases (Bishnoi et al., 2021). Another study using fNIR concluded that walking while performing a cognitive task increased brain activation in prefrontal regions and decreased gait performance compared to normal walking in healthy young adults (Mirelman et al., 2014).

The attentional demands during walking while performing a secondary task (Al-Yahya et al., 2011) can depend on the task's type and complexity and the subjects' age (Woollacott & Shumway-Cook, 2002). However, some lifestyles can compromise walking performance and brain activity, such as sleep quality and physical activity; nevertheless, studies are scarce. Existing studies suggest that the oxyhemoglobin was higher after a whole night's sleep than at the beginning of the night (Oniz et al., 2019). Others reported that sleep plays an important role in the processes of learning and memory (Gudberg & Johansen-Berg, 2015); that physical activity benefits the executive function (Berchicci et al., 2013), and gait speed (McMullan et al., 2020) and that sedentarism (Willey et al., 2017), poor sleep quality, and more than 8 hours of sleep duration (Wang & Zou, 2022) can be associated with lower gait speed.

Gait speed is considered the sixth "vital sign" because it is easily measurable and provides essential information about the functional status (Fritz & Lusardi, 2009; Montero-Odasso et al., 2005). Moreover, gait speed can be correlated with cognitive impairment and the risk of falls (Dyer et al., 2020; Peel et al., 2019). For that reason, we consider it important to investigate gait speed and neural activity during dual-task conditions in young adults to obtain more knowledge about the interaction between motor and cognitive task performance, and its relationship with sleep quality and physical activity, to detect early signs of impairments. Therefore, this study aims to assess the changes in gait speed and hemodynamics response on the prefrontal cortex resulting from the addition of a cognitive task during walking (cognitive dual-task) compared to normal walking (single task). Furthermore, we also in-tend to determine the correlation between sleep quality and physical activity level with gait performance and brain hemodynamics changes during the dual-task. We hypothesized that: (i) the young adults would demonstrate a reduction in gait speed and an increase in hemodynamics response in the prefrontal cortex during the performance of a dual-task compared to a single task; (ii) sleep quality and physical activity level would correlate with gait performance and brain hemodynamics changes during a dual-task in young adults.

METHODOLOGY

Participants

A total of 18 healthy young adults, aged between 18 and 35 years, voluntarily participated in this study and signed the informed consent form (sample characteristics are in Table 9.1). They reported having no known history of cardiovascular, musculoskeletal, neurological, vestibular, or cognitive disorders or of taking medications. The Ethics Committee of the Polytechnic Institute of Coimbra approved the study (27_CEPC2/2019).

Table 9.1. Sample's socio-demographic characteristics.

Variables	**Sample n = 18**
Age (years)	24.11 ± 4.11
Height (m)	1.74 ± 0.07
Body mass (Kg)	79.92 ± 14.24
Body Mass Index (Kg/m^2)	26.36 ± 4.13

Procedure

We considered it important to use tasks similar to everyday life; therefore, as the smartphone is a massively used electronic device that can modify gait behavior (Bovonsunthonchai et al., 2020), in this study, in the dual-task condition, the participants performed the cognitive task using a smartphone while walking. Based on previous studies (Crowley et al., 2016; Krasovsky et al., 2021; Takeuchi et al., 2016; Tan et al., 2022), the tasks protocol used in this research is the following:

Single motor task (mot-ST)—The participants were instructed to walk at a self-selected preferred walking speed and regularly pace back and forth along an 8 m walkway for 60 s.

Single cognitive task (cog-ST)—The participants performed a cognitive task on a smartphone based on working memory tasks (Bayot et al., 2018) and verbalized their responses while sitting on a chair for 60 s.

Cognitive dual-task (cog-DT)—The participants were instructed to walk while simultaneously performing a cognitive task on a smartphone for 60 s.

The gait performance (gait speed) and hemodynamics changes in the prefrontal cortex were collected during the single task and cognitive dual-task. The cognitive task performance was measured through the percentage of correct answers collected during cognitive single- and dual-task conditions. The motor task performance was deter-mined through the collection of gait speed and hemodynamics changes in the pre-frontal cortex during normal walking and the cognitive dual-task. Each task was per-formed for 60 s, twice with 45 s rest. The young adults were not given any instructions regarding which task to prioritize during the cog-DT and performed the tasks randomly to minimize the learning factor. To maintain ecological validity, the participants performed the cognitive single- and dual-task with their usual smartphone and held it with their preferred hand or both hands.

Instruments and Data Analysis

Gait speed data were collected with ten Oquos® Optoelectronic cameras of high speed and a resolution of 1.3 to 12 megapixels, with a 200 Hz measurement frequency, coupled with two force plates (Bertec Corporation, Columbus, OH 43229 USA; AMTI, Watertown, MA, USA) using an optical motion capture system (Qualysis AB, Göteborg, Sweden) and the Qualisys Track Manager v2.15 software (Qualisys AB, Götebor, Sweden). According to Wilken et al. (2012), 53 reflective markers on defined anatomical landmarks were placed by one experienced researcher. Furthermore, marker clusters were placed on the thighs and shanks to improve segment tracking quality. Gait speed data were filtered with a 6-Hz Butterworth low-pass filter and processed using the Visual 3D software (C-Motion, Germantown, MD, USA).

The hemodynamic changes in the prefrontal cortex were recorded using fNIR100A-2 (Biopac System Inc., Goleta, CA, USA) equipment attached to the forehead. This fNIR device has 16 recording channels with a source–detector separation of 2.5 cm and records at a frequency of 2 Hz, detecting infrared light wavelengths at 730 nm and 850 nm. Cognitive Optical Brain Imaging (COBI) was used for data acquisition, and the fNIRSoft professional software for data processing (Biopac software). After a visual inspection to remove low-quality channels, the raw signals were filtered using a low-pass finite impulse response (FIR) filter, with an order of 20 Hamming, and a cut-off frequency of 0.1 Hz (Ayaz et al., 2010; Herold et al., 2018; Izzetoglu et al., 2010) to eliminate confounding physiological noise. Next, the motion artifacts were removed using a sliding-window motion artifact rejection (SMAR) algorithm (Ayaz et al., 2010). The changes in oxyhemoglobin ([oxy-Hb]) and deoxyhemoglobin ([deoxy-Hb]] concentrations relative to a 10 s baseline were recorded according to the modified Beer–Lambert Law (Herold et al., 2018). The hemoglobin difference (Hb-diff = [oxy-Hb] – [deoxy-Hb]) was also extracted for the assessment of the hemodynamics response in the prefrontal cortex.

Sleep quality was assessed using the Pittsburg Sleep Quality Index (PSQI). This self-report questionnaire assesses sleep quality over the previous month. A global score above 5 indicates poor sleep quality. The global sleep quality score ranges from 0 to 21 (Buysse et al., 1989). The Portuguese version of the PSQI presents adequate validity and reliability (Cronbach's α of 0.70) for assessing sleep quality (João et al., 2017) such as other PSQI versions (Backhaus et al., 2002; Bertolazi et al., 2011).

Physical activity level was assessed using a self-report questionnaire, the International Physical Activity Questionnaire-Short Form (IPAQ-SF). It assesses the intensity of physical activity in MET-min/week over the last seven days (Craig et al., 2003). The physical activity score was obtained according to the IPAQ instrument protocol (Sjostrom et al., 2005).

Statistical analysis

The descriptive variables, such as the sample's socio-demographic characteristics, the IPAQ-SF and PSQI total scores, were presented as mean and ± SD (standard deviation), and the physical activity level was presented as frequencies. The Shapiro–Wilk test confirmed the non-normality of the data. The Wilcoxon signed-rank test was used to compare gait speed, cognitive task performance, [oxy-Hb], [deoxy-Hb] and Hb-diff between single- and dual-task performance. The data were presented as the median and interquartile range (IQR).

The Spearman's rho test was used to correlate sleep quality and physical activity level with gait performance and hemodynamics changes in the prefrontal cortex during motor single-task and cognitive dual-task conditions.

All analyses were performed using IBM-SPSS 25.0 software and the significance level was set at $p < 0.05$.

RESULTS

Gait speed and hemodynamic changes in the prefrontal cortex

The difference in walking performance and hemodynamics changes in the prefrontal cortex between normal walking and the cognitive dual-task are represented in Table 9.2.

When we added a cognitive task to the motor task of walking, a decrease in gait speed, a decrease in [deoxy-Hb], an increase in [oxy-Hb], and a higher Hb-diff in the prefrontal cortex were found compared to normal walking. Only in the oxyhemoglobin concentration were no differences found between normal walking and the cog-DT.

Table 9.2. Gait performance and hemodynamics changes in the prefrontal cortex between normal walking and cognitive dual-task condition.

Outcomes	**Motor Single-task**	**Cog-DT**	***p*-value**^{1}
Gait speed (m/s)	1.05 (0.94–1.18)	0.95 (0.90–1.10)	0.006 *
[oxy-Hb] (μ mol/L)	0.18 (-0.41–0.73)	0.30 (-0.57–0.73)	0.501
[deoxy-Hb] (μ mol/L)	-1.09 (-1.27–(-0.31))	-1.41 (-2.02–(-0.79))	0.039*
Hb-diff (μ mol/L)	0.92 (0.22–1.59)	1.27 (0.54–2.80)	0.039*

[oxy-Hb], oxyhemoglobin concentration; [deoxy-Hb], deoxyhemoglobin concentration; Hb-diff, difference between oxy and deoxyhemoglobin concentrations; cog-DT, cognitive dual-task. * $p < 0.05$: Comparison between motor single-task and cognitive dual-task (Wilcoxon signed-rank test).

Cognitive task performance

There was an increase in cognitive task performance from the single cognitive task (cognitive task on a smartphone in a seated position) to the cognitive dual-task (walking while performing a cognitive task on a smartphone). The median percentage of correct responses increased from the single cognitive task (58.33

(42.13–69.91)%) to the cognitive dual-task (78.70 (64.35–96.30)%); this difference was significant ($p < 0.001$).

Relationship between physical activity and sleep quality with gait performance and hemodynamics response under single- and dual-task conditions

Young adults presented a total IPAQ-SF score of 3701.06 ± 3460.345 MET-min/week and a total PSQI score of 5.18 ± 3.28. Concerning the physical activity level, according to the IPAQ-SF, 41.2% have a high level of physical activity, 41.2% have a moderate physical activity, and 17.6% have a low level of physical activity.

The analysis showed a moderate, positive, and significant correlation between sleep quality and the Hb-diff during cog-DT performance. However, there were no significant relationships between the other outcomes analyzed ($p > 0.05$) (see Table 9.3).

Table 9.3. Relationship between IPAQ-SF and PSQI total scores with gait performance and hemodynamics response under single- and dual-task conditions.

Outcomes	**IPAQ-SF total score**		**PSQI total score**	
	Spearman's rho	*p*-value	Spearman's rho	*p*-value
cog-DT [oxy-Hb]	0.392	0.119	0.326	0.202
cog-DT [deoxy-Hb]	-0.100	0.701	-0.258	0.318
cog-DT Hb-diff	0.235	0.363	**0.522**	**0.032**
mot-ST [oxy-Hb]	0.109	0.688	0.002	0.996
mot-ST [deoxy-Hb]	0.156	0.564	-0.294	0.269
mot-ST Hb-diff	0.085	0.753	0.253	0.344
Gait speed: cog-DT	−0.243	0.348	0.301	0.241
Gait speed: mot-ST	−0.191	0.462	0.133	0.610

IPAQ-SF, International Physical Activity Questionnaire-Short Form; PSQI, Pittsburg Sleep Quality Index; [oxy-Hb], oxyhemoglobin concentration (μ mol/L); [deoxy-Hb], deoxyhemoglobin concentration (μ mol/L); Hb-diff, difference between oxy and deoxyhemoglobin concentrations (μ mol/L); gait speed, m/s; cog-DT, cognitive dual-task; mot-ST, motor single-task.

Spearman's correlation test. Bold values with $p < 0.05$.

DISCUSSION

This study investigated the influence of cognitive task on gait speed performance and the hemodynamics response in the prefrontal cortex while walking (cognitive dual-task) compared to normal walking, and the association between physical activity level and sleep quality with gait performance and hemodynamics response in the pre-frontal cortex under normal walking and cognitive dual-task conditions in young adults.

Our results show that, when a cognitive task is added to walking, a decline in gait speed and changes in prefrontal cortex activation are detected, suggesting that both tasks share neural networks (Fuster, 2001; Suzuki et al., 2004) and that more attentional resources to perform the tasks are needed. Furthermore, the young adults showed that they allocated more attentional recourses to perform the cognitive task to the detriment of walking performance, because they demonstrated an improvement in the cognitive task performance from the cog-ST to the cog-DT, verified by the increase in the percentage of correct answers. The hemodynamics response increased in the prefrontal cortex from normal walking to the cognitive dual-task, showing an increase in Hb-diff and a decrease in deoxyhemoglobin concentration. Although the oxyhemoglobin concentration also increased from the mot-ST to the cog-DT, no differences were found between the two conditions, which may be related to the fact that the participants verbalized their answers during the cognitive task performance. The reduction in oxyhemoglobin can result from a decrease in cerebral blood flow and cerebral oxygenation as a consequence of hypocapnia caused by verbalization (F Scholkmann et al., 2013).

Similar to our research, a decrease in gait speed and higher prefrontal activation from normal walking to the cognitive dual-task was observed in other studies. For example, a study using fNIR showed that young adults, when performing a cognitive dual-task, decreased gait performance and increased activation in the prefrontal area than in normal walking (Mirelman et al., 2014). In addition, a review paper reported that most studies showed increased prefrontal activity during dual-task performance compared to usual walking (Vitorio et al., 2017). Another systematic review reported that gait control requires cognitive resources, and there is generally a decline in gait performance when there is simultaneous involvement of cognitive tasks while walking (Al-Yahya et al., 2011). Concerning the tasks used in our study, a systematic review that analyzed the influence of tasks performed using a smartphone while walking showed a decline in gait performance in dual-task conditions in most studies assessed (Tan et al., 2022).

Regarding the correlation analysis between physical activity and sleep quality, only a correlation between sleep quality and the difference in hemoglobin during the cog-DT was found. This correlation suggests that poor sleep quality is associated with a greater difference in hemoglobin in prefrontal cortex activation in dual-task conditions. We suppose that this may be due to a compensatory mechanism resulting from a higher mental effort (amount of cognitive resources allocated to perform a task (Paas & Merrienboer, 1994) and consequent overload in the recruitment of cognitive resources, leading to lower system efficiency caused by poor sleep quality. In children, it appears that the worst dual-task performance is associated with disrupted sleep, a higher quantity of REM (rapid eye-movement) sleep related to lower gait variability, and a higher cognitive performance associated with a greater quantity of slow-wave sleep (Möhring et al., 2019). Another study showed that poor sleep quality was related with a slower normal walking speed in adults (Wang & Zou, 2022). In addition, a decrease in gait speed and higher gait variability were associated with a lower sleep efficiency during a dual-task but not while performing a single task in older people (Agmon et al., 2016).

Although no correlations were found in this study between physical activity and gait performance and hemodynamics response, some studies report that moderate-to-vigorous-intensity physical activity improves gait speed (over 50 years) (McMullan et al., 2020). In addition, another study reported that moderate-to-high levels of physical exercise positively affect executive functions in middle-aged and older individuals (Berchicci et al., 2013). A study in young adults suggested that good sleep quality was associated with higher gait speed in single-task conditions, but did not investigate during dual-task condition (Kasović et al., 2021).

In this study, we used self-reported questionnaires to assess sleep quality and physical activity, which may have conditioned our results in the correlation tests. Thus, we considered this a limitation of this study together with the small sample size. Therefore, we recommended future studies that objectively measure these outcomes and correlate them with gait performance and brain activity during performing tasks. Furthermore, in the cognitive dual-task used in this study, most young adults reduced the swing movement of their arms, and their field of vision decreased due to manipulating the smartphone, which may have contributed to the decrease in gait speed. Therefore in addition to the tasks used in this study, we also suggest performing cognitive tasks without a smartphone to better understand the influence of cognitive tasks on gait speed under dual-task conditions. Another limitation was that we did not monitor blood pressure or breathing cycle, considering that these parameters can influence fNIR measurements (Kirilina et al., 2012; Scholkmann et al., 2014). Future studies should consider these parameters.

Our study contributed to understanding the interaction between motor and cognitive performance under dual-task conditions and how activity in the prefrontal cortex changes. Moreover, it showed that sleep quality might interfere with hemodynamic response in the prefrontal cortex during dual-task conditions. In this way, implementing strategies to improve sleep quality can be helpful to the functioning of the prefrontal cortex. For example, moderate physical activity can be a tool to enhance sleep quality (Wang et al., 2021).

Furthermore, facing the changes in motor and cognitive performance from normal walking to the cognitive dual-task and the increased risk of injury due to smartphone use reported in other research (Nasar et al., 2013; Haolan et al., 2021), dual-task training can be used to reduce the interference between motor and cognitive performance, minimizing the risk of injuries or falls (Pang et al., 2018).

CONCLUSION

The hemodynamic response in the prefrontal cortex during a cog-DT suggests that young adults prioritize cognitive tasks over motor performance and allocate more attentional recourses in the cognitive task than gait performance. The gait speed decreases, the hemoglobin difference in the prefrontal cortex increases, and the deoxyhemoglobin concentration decreases during a cognitive dual-task compared to normal walking. Sleep quality only correlates with the Hb-diff during the cog-DT, showing that poor sleep quality was associated with increased Hb-diff in the prefrontal cortex. The gait performance and hemodynamics response do not correlate with the physical activity level. Future studies that objectively assess physical activity and sleep quality are recommended to investigate and clarify the correlation between these factors with gait speed performance and brain activity. Implementing clinical practices that improve sleep quality and motor and cognitive performance during dual-task conditions can help optimize the interaction between motor and cognitive systems.

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Conflicts of Interest

The authors declare no conflict of interest.

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CHAPTER XI – FINAL CONSIDERATIONS

LIMITATIONS AND RECOMMENDATIONS

Although specific limitations of each study were presented in the corresponding study chapter, some relevant limitations are described below.

Based on previous studies, the baseline task used was a single-task without smartphone use; however, this task could be considered a limitation of this thesis because the head positions during the single- and dual-task conditions were different. The head position was in neck flexion (forward head posture) during smartphone use in the cognitive and motor dual-tasks, contributing possibly to different variations in the CoP between the single- and the dual-tasks, which can explain the differences in the CoP behavior between tasks.

Another limitation could be due to the effect of verbalizing involved in the cognitive dual-task, which could have further influenced CoP behavior. In addition, the respiratory frequency was not controlled, which could have altered CoP displacement. Therefore, future studies are recommended to clarify the influence of verbal tasks on CoP behavior, as the effects of verbalization and cognitive task are unclear.

Although we processed the fNIR data, we could have added complementary measures (e.g., blood pressure, heart rate, respiratory cycle, etc.) to monitor systematic changes since oxyhemoglobin is sensitive to physiological changes.

The sample size and the data resulting from the assessment of sleep quality and physical activity level can have conditioned the results since most of the sample presented good sleep quality and a moderate physical activity level. Furthermore, sleep quality and physical activity level were subjectively assessed by questionnaires. So, in future studies, we recommend using objective measures to assess sleep and physical activity to understand better the relationship between these lifestyles in postural control performance and hemodynamic response under dual-task conditions in young adults and other age groups or clinical conditions.

In future studies, it would also be interesting to include the muscular synergy analysis, joint ranges of motion analysis, non-linear measures in gait study, a multichannel fNIR device to cover other brain regions beyond the prefrontal cortex to assess the interaction between the prefrontal cortex and the brain motor-network areas. Furthermore, we also recommend dual-task studies in pathological conditions and other age groups.

PRATICAL IMPLICATIONS

Given the consequences of aging, it is important to study the younger populations for early detection and intervention in cognitive and motor changes in order to minimize the impact of aging. Furthermore, postural control is fundamental for the performance of multiple activities of daily living. This thesis contributes to a better understanding of the influence between the cognitive and motor systems on dua-task performance and postural control maintenance based on the measurement of results using the dual-task paradigm. It constitutes a more sensitive measure in detecting predictors of cognitive and motor changes and in identifying individuals' motor and cognitive abilities. Using the dual-task paradigm can improve motor and cognitive performance, improve the performance of athletes, reduce the risk of falls/injuries, and minimize motor and cognitive deterioration at more advanced ages. Thus, the changes observed in the center of pressure behavior, spatiotemporal gait parameters, muscle activity, and prefrontal cortex activation during the dual-task conditions add information about the neurophysiological alterations that occur during dual-task conditions in young adults. Furthermore, the data obtained can provide a reference for other studies, which may, in the future, allow the creation of normative data to identify early warning signs related to motor and cognitive impairments.

FINAL CONCLUSIONS

The main conclusions resulting from each study are described below.

Chapter II: Few studies assessed the influence of different difficulty levels while simultaneously performing two motor tasks, such as keeping a static standing posture or walking while performing a secondary motor task. Gait is the primary motor task more analyzed in dual-task studies. Nonetheless, the static and dynamic postural control parameters analyzed in this review were negatively affected during motor dual-task conditions compared to the motor single-task performance, regardless of age or clinical condition. However, more studies need to evaluate the interference in performance between two motor tasks.

Chapter III: Differences in the center of pressure behavior during single- and dual-task between good and poor quality sleep groups in healthy young adults were not found. However, were observed intra-group changes in total excursion of the CoP, the displacements of the CoP in anterior-posterior and medial-lateral directions, the mean total velocity displacement of CoP and the 95% confidence ellipse sway area during cognitive dual-task compared to the single-task performance, resulting in a greater oscillation and compromise of the postural control in static standing posture during cognitive dual-task, independently of the sleep quality.

Chapter IV: Both linear and nonlinear analyses were able to detect changes in postural control performance between single- and dual-task conditions. Performing cognitive or motor tasks while using a smartphone impairs similar oscillations of CoP during static standing posture and causes lower complexity and greater regularity in the center of pressure sway compared with single-task performance in young adults. However, the dual-task cost for the total excursion, displacement in the anterior-posterior direction, mean total velocity and mean anterior-posterior velocity of CoP was greater during the cog-DT than the mot-DT. Thus the cognitive task demand while keeping a static standing posture causes a higher increase in body oscillation compared to the single-task and motor dual-task performance. Consequently, there was less efficacy in static postural control maintenance during cognitive dual-task.

Chapter V: The increase in the cognitive demands (different difficulty levels tasks) negatively affected the performance of the postural task when performing them concurrently, compared to keeping a static standing posture (single-task). However, there were no differences in dual-task costs between the easy and difficult cognitive dual-task conditions. Furthermore, there were no differences in hemodynamic response in the frontal cortex between the easy cognitive dual-task and the single-task. Thus, in general, keeping a static standing posture while performing a difficult cognitive task contributed to a greater influence on postural sway and activation of the prefrontal cortex than single-task performance.

Chapter VI: Using nonlinear analysis of CoP during motor dual-task conditions with different difficulty levels, we found changes in postural control complexity from postural single-task (keeping a static standing posture) to motor dual-task conditions. The results suggested that performing a difficult motor dual-task (keeping a static standing posture while simultaneously typing on a smartphone keyboard) represents less effectiveness in postural control, less complexity and adaptability of the dynamic system of CoP displacement than postural single-task and easy motor dual-task.

Chapter VII: During keeping a static standing posture while simultaneously performing a cognitive task on a smartphone, there were changes in co-contraction index patterns of the lower limb muscles, decreased muscle activity, and increased prefrontal cortex activity compared to the single-task. These results can suggest that young adults allocated more attentional resources to the cognitive task over the motor task under cognitive dual-task conditions.

Chapter VIII: Poor sleep quality was associated with a worse postural control performance in CoP-ML, MVELO CoP-ML and A-ML parameters under cognitive dual-task conditions in static standing posture position. The motor and cognitive dual-task costs and hemodynamic response during motor and cognitive dual-task conditions do not correlate with physical activity level. Furthermore, the hemodynamic response during the motor and cognitive dual-task performance did not correlate with the level of physical activity or sleep quality.

Chapter IX: Adding a cognitive task or typing on a smartphone keyboard while walking changes muscle activity patterns and decreases the performance of spatiotemporal gait compared to normal walking in young adults. Muscle activity increased from single-task to both dual-task conditions in most muscles analyzed, especially in ankle stabilizer muscles. Nonetheless, walking while simultaneously performing a cognitive task on a smartphone showed less gait speed and stride length than the motor dual-task and single-task.

Chapter X: As the gait speed decrease, the hemoglobin difference in the prefrontal cortex increases, and deoxyhemoglobin concentration decreases from normal walking to cognitive dual-task. Cognitive dual-task triggered a greater prefrontal cortex activation, suggesting that young adults prioritized the cognitive task over motor performance and allocated more attentional recourses in the cognitive task than gait performance. Sleep quality only correlates with the hemoglobin difference in the prefrontal cortex under the cognitive dual-task performance, showing a positive correlation. No correlations were found between physical activity and gait speed performance and hemodynamic response in the prefrontal cortex.

In **general conclusion**, healthy young adults, when performing a cognitive-dual task, showed a decrease in static postural control performance, greater regularity and lower complexity in the center of pressure displacement, more prefrontal cortex activation, decreased muscle activity in a static standing posture and increased during gait, lower gait speed and lower stride length compared with the motor dual-task and single-task conditions.

The hemodynamics responses in the prefrontal cortex increased and the gait speed decreased from normal walking to cognitive dual-task. A moderate and positive correlation was found between sleep quality and hemoglobin difference in the prefrontal cortex while walking with simultaneously performing a cognitive task. Furthermore, poor sleep quality was associated with a worse postural control performance in displacement, mean velocity and amplitude of center of pressure in medial-lateral directions under cognitive dual-task conditions. No correlations were found between physical activity and the speed gait performance, the center of pressure behavior, and hemodynamic response in the prefrontal cortex during static and dynamic tasks.

These changes could possibly be due to inadequate capacity to divide the attentional resources among two tasks, which leads to the adoption of different strategies and compensatory mechanisms to minimize the risk of falls or trips when performing a dual-task, and to the task performer characteristics. We recommend future studies that explore the dual-task effect in other kinetic and kinematic gait parameters, other age groups, and diseases to clarify and better understand the changes in motor control and brain activity during dual-task conditions.

Appendixes

APPENDIX A – Postural control during motor dual-task in young adults with different levels of physical activity

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INTRODUCTION

Center of pressure (CoP) is an objective measure to assess postural control. A higher displacement of the CoP position can express a decline in postural control. Previous studies have demonstrated that a sedentary lifestyle affects balance negatively and increases the risk of falling. In addition, most activities of daily living involve performing two or more tasks concurrently. Thus, while performing a dual or multi-tasks, it is essential to maintain an adequate postural control to prevent the risk of falls and injuries.

OBJECTIVE

The main goal of this study was to compare the center of pressure displacement between healthy young adults with different levels of physical activity during motor dual-task performance.

METHOD

After checking eligibility criteria, 35 healthy young adults (23.09 ± 3.97 years, mean ± SD) were recruited to perform a motor dual-task: maintaining quiet upright standing posture while performing a concurrent motor task – answer the smartphone, during 60 s. The total excursion of the center of pressure (TOTEX_CoP), the displacement anterior-posterior (CoP-AP), and medial-lateral (CoP-ML) of the center of pressure were recorded by Bertec® force plate, and the data was assessed with a Matlab routine. To analyze center of pressure excursions in different levels of physical activity, the International Physical Activity Questionnaire (IPAQ) – short version was used to assess physical activity levels. Then, the participants were divided into three groups: sedentary (n = 5), minimally active (n = 13), and highly active (n = 17). Statistical analyses were performed using IBM-SPSS (version 25.0). To compare center of pressure displacement between different levels of physical activity during motor dual-task was used the Kruskal-Wallis test. The significance level was set at $p < 0.05$, and the data were shown as the median and interquartile range (IQR).

RESULTS

A tendency for a higher total displacement of the center of pressure was observed in the sedentary group (TOTEX_CoP: 3110.67 (2466.54-3908.73) mm) compared to the physically active groups (minimally active - TOTEX_CoP: 2600.75 (2500.34-3205.97) mm; highly active - TOTEX_CoP: 2712.99 (2499.01-3275.84) mm), but differences were not statistically significant between the three groups ($p > 0.05$). The same happened in the anterior-posterior and medial-lateral center of pressure displacement ($p > 0.05$).

CONCLUSIONS: Physically active young adults did not present less postural oscillation than sedentary young adults during motor dual-task performance. The small sample in each physical activity group could have contributed to the lack of statistical significance. Therefore, we suggest more studies that assess the influence of the level of physical activity on postural control.

Keywords: center of pressure; postural control; motor dual-task; physical activity; young adults.

Thematic axis: Quality of Life and Health in an interdisciplinary perspective.

APPENDIX B – Prefrontal cortex oxygenation and sleep quality in cognitive dual-task - fNIR study

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BACKGROUND

Previous studies suggest that poor sleep quality negatively affects the executive function of the prefrontal cortex and, consequently, the impairment of learning abilities. The aim of this study was to compare the oxygenated hemoglobin concentration ([HbO2]) during cognitive dual-task with subjective sleep quality in young adults.

METHODS

Thirty-two healthy young adults (age= 23.13 ± 3.92years, mean ± SD) were recruited according to the eligibility criteria. Using functional near-infrared spectroscopy (fNIR), oxygenated hemoglobin concentration ([HbO2]) was measured during quiet standing while performing a concurrent cognitive task - arithmetic and memory tasks (cognitive dual-task). The quality of sleep was assessed by the Pittsburgh Sleep Quality Index (PSQI). After data processing, the Mann-Whitney test was used for comparison and the statistical significance level was set to $p < 0.05$.

RESULTS

There were 59.4% of participants with a global PSQI score ≤5 (good sleep quality) and 40.6% with a score >5 (poor sleep quality). No differences were observed in the mean of [HbO2] in the prefrontal cortex during cognitive dual-task in young adults with good and poor sleep quality ($p > 0.05$).

CONCLUSION

The results of this study do not support the possibility of increases in the hemodynamic response on the prefrontal cortex be expected due to a good sleep, once the sleep quality appears not to have a significant effect on [HbO2] in young adults during the performance of cognitive dual-task.

APPENDIX C – Analysis of hemodynamics response in prefrontal cortex during motor and cognitive dual-task - fNIR study

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Background

Most of the processes occurring in the human body, need brain oxygenation. Motor and cognitive systems require neural resources and during a dual-task performance the demand on the brain increases. This study aimed to analyse the brain activation in static postural control during motor and cognitive dual-tasks.

Methods

Using Functional near-infrared spectroscopy (fNIR), brain activity (oxygenated hemoglobin concentration ([HbO2]), deoxygenated hemoglobin concentration ([HHb]), oxygenation difference hemoglobin concentration changes (HbOxy= HbO2 – HHb), total hemoglobin (HbTotal= HbO2 + HHb)) were measured in thirty-three young adults (age=23.12±3.86 years, mean ± SD) during three conditions: in a postural task, quiet standing (single motor task), quiet standing while performing a concurrent motor task – answer the smartphone (motor dual-task) and quiet standing while performing a concurrent cognitive task - arithmetic and memory tasks (cognitive dual-task). After data processing, the Wilcoxon signed-rank test was used for comparison.

Results

We found increased [HbO2] in young adults while performing cognitive dual-task compared to the single motor task and motor dualtask ($p < 0.05$). HbOxy differences between cognitive and motor dual-task were found ($p < 0.05$). No significant differences between single and motor dual-task in [HbO2] were observed.

Conclusion

Hemodynamic activity in the prefrontal cortex was significantly increased in cognitive dual-task compared to the single motor task. Pre-frontal hemodynamics appear not to be influenced by the number of motor tasks performed while the opposite occurs for the cognitive ones which may arise because the demand in the prefrontal cortex is greater in cognitive tasks while during the motor tasks the [HbO2] is recruited elsewhere.

APPENDIX D – The effect of smartphone use on gait velocity

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ABSTRACT

The use of smartphone has increased amongst all ages and it use during walking causes serious injuries. Understanding the motor control processes of gait while using a smartphone seems to be of high practical relevance. The aim of this study was to analyze the gait velocity while using a smartphone in young adults. Fifteen healthy young adults (age= 21.27 ± 3.03 years, mean±SD) were recruited. The gait velocity was assessed in two conditions: walking at a normal pace and velocity (single motor task) and walking while texting on smartphone (motor dual-task), using the Qualisys® Motion Capture System. Compared to walking without using a smartphone, the subjects walked at slower velocity when using a smartphone ($p < 0.05$). In conclusion, the use of smartphone has a negative impact on gait velocity, suggesting the risk of falls and injuries in young adults, also, can be an indicator of more evident gait changes in old age.

INTRODUCTION

Many daily activities require the performance of multiple tasks and involve the integration of cognitive and motor skills (Plummer et al., 2013). Thus, efficient postural control is fundamental to the success of most daily tasks.

Changes in the gait patterns during concurrently cognitive or motor tasks performed have been reported and related to an increased risk of falls (Hausdorff et al., 2008).

Gait velocity is associated with balance and functional ability and it has been considered a predictor of health status (Fritz et al., 2009), functional decline, and a clinical indicator of well-being, frailty, and mortality (Studenski et al., 2011). For this reason, the gait velocity is an important study parameter.

The smartphone has become a device most used in our daily lives and amongst all ages. Using smartphones during walking increases pedestrians' risk of accidents, injuries, or death. (Nasar & Troyer, 2013).

Waking while using a smartphone may affect motor control and response capacity, due to the dual-task effect compromising gait efficiency and safety. So, this study aimed to compare gait velocity in young adults when walking while using a smartphone and walking freely.

MATERIALS AND METHODS

Subjects were 15 healthy young adults (age= 21.27 ± 3.03 years, height=169 ± 10 cm; body mass index= 23.06 ± 3.39, mean ± SD). The sample characteristics are presented in table 1.

Table 1. Sample characteristics (mean and standard deviations (SD).

Parameters	Mean	SD
Age (years)	21.27	3.03
Height (Cm)	169	10
Body mass (Kg)	68.49	16.19
BMI (Kg/m^2)	23.06	3.39

The inclusion criteria for this study were: healthy young adults (18 – 35 years). Exclusion criteria included (1) diseases or injuries that affect the musculoskeletal, nervous, and cardiorespiratory system, (2) being on medication, (3) recent surgeries (less than two months) that interfere with gait, (4) abnormalities or not corrected-to-normal vision, (5) vestibular disorders.

After checking the eligibility criteria fifteen young adults were recruited. All procedures were done in compliance with the Declaration of Helsinki and after a detailed description of the objective and research methodology, all participants signed informed consent. This study was approved by the Ethics Committee of the Polytechnic of Coimbra (approval number: 27_CEPC2/2019).

A questionnaire was used to assess the sociodemographic characteristics of the participants and to extract some data about usual smartphone use.

All participants underwent anthropometric measurements (weight and height) before performing motor tasks. Then, they were instructed to walk in two conditions during 60 s: walking at normal pace and velocity (single motor task) and walking while typing on a smartphone (simulate texting on the smartphone) with preferred hand or both hands according to what they were used to (motor dual-task). Each participant repeated twice each task, with one minute rest period between trials. All participants performed 3 gait cycles before data collection, allowing them to stabilize gait velocity.

No priority was given to texting and walking tasks. The participants were instructed to use their personal smartphone and their normal method of texting on the smartphone while natural walking.

The gait velocity analysis was performed using Qualysis® Motion Capture System (Qualysis AB, Kvarnbergsgatan 2, 411 05 Göteborg, Sweden) with 10 Oquos® Optoelectronic cameras high speed and resolution of 1.3 to 12 megapixels with a 200Hz measurement frequency, which simultaneously followed the movements of 69 reflective markers on the full-body model according to the IOR skin marked protocol in a previously calibrated volume with an error less 0.7 mm (fig.1). The reflective markers were always fixed with a double-side tape onto landmarks on the participants' skin by the same researcher. The gait velocity was measured from the marker on the xiphoid process and data processing was performed using Qualysis Track Manager software (Qualysis AB, Sweden).

The statistical analysis in this study was conducted using IBM-SPSS 25.0 software. Quantitative data are reported as mean ± SD. The Shapiro-Wilks test was used to confirm the normal distribution of all continuous variables. The equality of variances was assessed by computing Levene´s test. The gait velocity differences between motor single and dual-task were assessed by a paired t-test. The statistical significance level was set to $p < 0.05$.

Figure 1. Data collection.

RESULTS

Most participants reported regular smartphone use for an average of 2 to 4 hours per day and all participants type on the smartphone with both hands. The gait velocity was 1.39 m/s on single motor task (only walking) and in the motor dual-task (walking while texting on the smartphone) the gait velocity was 1.29 m/s. Walking while texting on the smartphone (motor dual-task) significantly decreased gait velocity ($p < 0.05$) comparatively to only walking (single motor task) (fig.2).

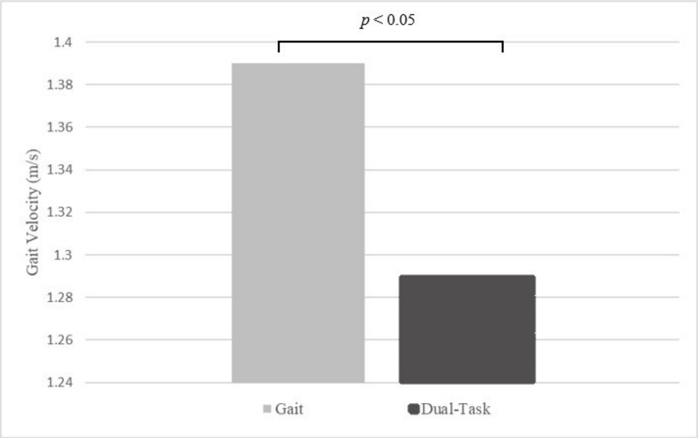

Figure 2. Comparison of gait velocity between single motor task (gait) and motor dual-task.

DISCUSSION

The main purpose of this study was to investigate changes in gait velocity caused by smartphone use during motor dual-task. Results demonstrated a gait velocity decreased during walking while texting on a smartphone compared to a simple walking task (single task).

Results are consistent with previous studies that reported decreased gait velocity and changes in other spatiotemporal gait parameters during smartphone use (Jeon et al., 2016; Licence et al., 2015).

Lamberg et al. (2012) found a gait velocity decrease of 16% and 33% when participants walk while talking on a cell phone compared to only walking and when they walk while texting on a cell phone, respectively. These results show a decrease in gait velocity in the dual-task performance compared to a single task. During walking the arm movement is used as a strategy to increase the dynamic stability of the gait (Punt et al., 2015). When texting the smartphone with both hands the upper limbs are positioned in front of the trunk, which reduces and limits the natural movement of the trunk and arms, contributing to reduce the ability to walk maintaining dynamic balance (Schabrun et al., 2014). For this reason, the pedestrian accidents, the risk of falls, and musculoskeletal injuries are greater.

The smartphone use during the gait performance causes limitations of body movement and decreased visual information from the environment, contributing to changes in gait pattern (decreased gait velocity).

The present research adds valuable information to the knowledge around the effects of smartphone use on gait velocity in young adults: it is essential to prevent changes in gait caused by the use of a smartphone and to pay attention to the impact on the fall risk, pedestrian accidents, and musculoskeletal injuries. The reduction of gait velocity while texting on a smartphone in young adults can be a predictor of more evident gait changes and a marker of neurodegeneration and pedestrian injuries in old age.

CONCLUSION

Walking while texting on a smartphone modifies gait performance. The use of smartphones has a negative impact on gait velocity in young adults, suggesting an increased risk of falls, pedestrian accidents, and injuries.

We suggest specific training that included simultaneously motor and cognitive tasks to improve dual-task performance in both young and older people.

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APPENDIX E – Center of pressure velocity analysis: Comparison between standing posture and cognitive dual-task in young adults

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ABSTRACT

Center of pressure (CoP) analysis is often used to assess postural control and understand motor control mechanisms while simultaneously performing different tasks (Chen, Liu, Xiao, Liu & Wang, 2021). The CoP velocity can be considered an indicator of the efficiency of the postural control, and it is a sensitive measure to detect changes in postural control (Palmieri et al. 2002, Roma et al. 2021). The purpose of this study was to evaluate the center of pressure velocity during quiet standing posture and cognitive dual-task in young adults. Thirty-six young adults (23.08 ± 3.92 years) participated in this study. Each subject was requested to perform two tasks: standing quietly (single task – ST) and keeping a quiet standing posture while playing a mental game based on arithmetic or memory tasks in their smartphone (cognitive dual-task – cog-DT) on a force plate during 60 s. The mean total velocity of CoP (MVELO_CoP), the mean anterior-posterior and medial-lateral velocities of CoP (MVELO_CoP-AP and MVELO_CoP-ML, respectively) were acquired through the Bertec® force platform and the data assessed with a Matlab routine. Statistical analyses were performed using IBM-SPSS (version 25.0), and the level of significance was set at $p < 0.05$. To compare CoP velocity between single and cognitive dual-task was used the related-sample Wilcoxon signed-rank test. The data were presented as the median and interquartile range (IQR). The MVELO_CoP (Cog-DT: 509.41 (453.83-603.70) mm/s vs ST: 481.40 (439.66-561.25) mm/s; $p < 0.000$), MVELO_CoP-AP (cog-DT: 389.62 (349.89-454.85) mm/s vs ST: 368.85 (330.20-431.38) mm/s; $p < 0.000$), and MVELO_CoP-ML (cog-DT: 252.53 (224.13-305.83) mm/s vs ST: 243.53 (215.31-280.97) mm/s; $p < 0.000$) increased during the cognitive dual-task compared to single-task performing.

The results suggest that maintaining a quiet posture while playing a mental game on the smartphone decreases young adults' ability to control upright posture compared to maintaining quiet standing posture only. Furthermore, these apparent changes in a young sample may predict more significant changes in postural control in old age, namely, more risk of falls.

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Poster ID: S19

Center of pressure velocity analysis:

Comparison between standing posture and cognitive dual-task in young adults

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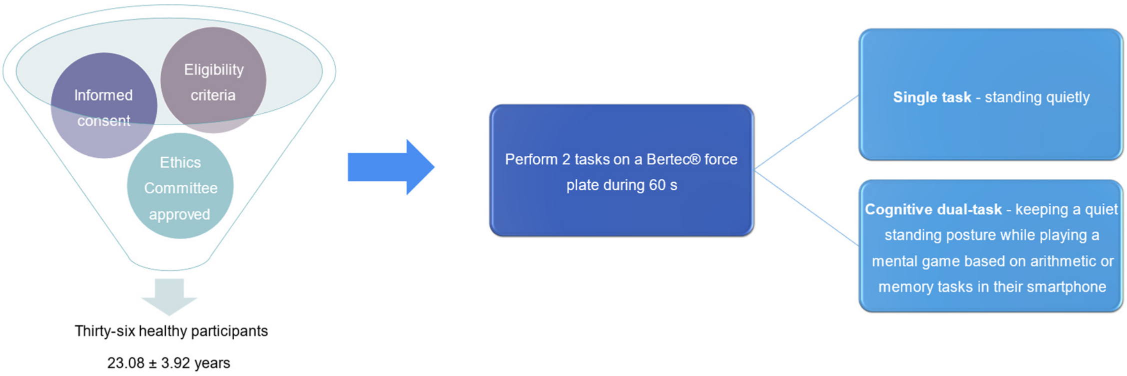
Introduction

Center of pressure (CoP) analysis is often used to assess postural control and understand motor control mechanisms while simultaneously performing different tasks. The CoP velocity can be considered an indicator of the efficiency of the postural control, and it is a sensitive measure to detect changes in postural control.

The purpose of this study was to evaluate the center of pressure velocity during quiet standing posture and cognitive dual-task in young adults.

Methodology



Informed consent

Eligibility criteria

Ethics Committee approved

Thirty-six healthy participants

23.08 ± 3.92 years

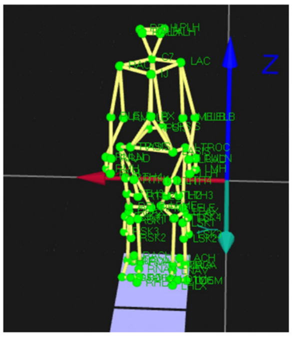
Perform 2 tasks on a Bertec® force plate during 60 s

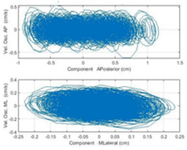
Single task - standing quietly

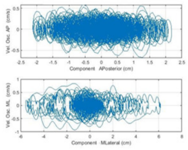
Cognitive dual-task - keeping a quiet standing posture while playing a mental game based on arithmetic or memory tasks in their smartphone

Results

Fig.1. Statokinesigram : Center of pressure velocity in anterior-posterior (AP) and medial-lateral (ML) directions between single and cognitive dual-task: related-sample Wilcoxon signed-rank test. The data were presented as the median and interquartile range.







	Single Task	**Vs.**	**Cognitive dual-task**
CoP velocity	481.40 (439.66-561.25) mm/s	$p < 0.000$	509.41 (453.83-603.70) mm/s
CoP-AP velocity	368.85 (330.20-431.38) mm/s	$p < 0.000$	389.62 (349.89-454.85) mm/s
CoP-ML velocity	243.53 (215.31-280.97) mm/s	$p < 0.000$	252.53 (224.13-305.83) mm/s

Conclusions

The results suggest that maintaining a quiet posture while playing a mental game on the smartphone decreases young adults' ability to control upright posture compared to maintaining quiet standing posture only. Furthermore, these apparent changes in a young sample may predict more significant changes in postural control in old age, namely, more risk of falls.

References

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Roma, E.; Gobbo, S.; Bullo, V.; Spolaor, F.; Sawacha, Z.; Duregon, F.; Bianchini, G.; et al. Influence of age on postural control during dual task: a center of pressure motion and electromyographic analysis. *Aging Clinical and Experimental Research*. 2021.

APPENDIX F – Brain activation changes during cognitive dual-task: comparison between young adults with different levels of physical activity

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Current Status: Accepted for oral presentation at the Annual Meeting Coimbra Health School 2021.

BACKGROUND

Previous studies suggest that physical activity can modify the hemodynamic response and cerebral oxygenation. The aim of this study was to compare the oxygenated hemoglobin concentration ([HbO2]) during cognitive dual-task between young adults with different levels of physical activity.

METHODS

Thirty-two participants (age= 23.13 ± 3.92 years, mean ± SD) were subjected to a cognitive dual-task, consisting of quiet standing while performing a concurrent cognitive task (arithmetic and memory tasks). The subjects used functional near infrared spectroscopy (fNIRS) during task performance, where oxygenated hemoglobin concentration ([HbO2]), deoxygenated hemoglobin concentration ([HHb]), and total hemoglobin (HbTotal= HbO2 + HHb) were measured in the prefrontal cortex. The International Physical Activity Questionnaire (IPAQ) – short version – was used to assess the levels of subjects' physical activity. After data processing, the Kruskal-Wallis test was used for comparison.

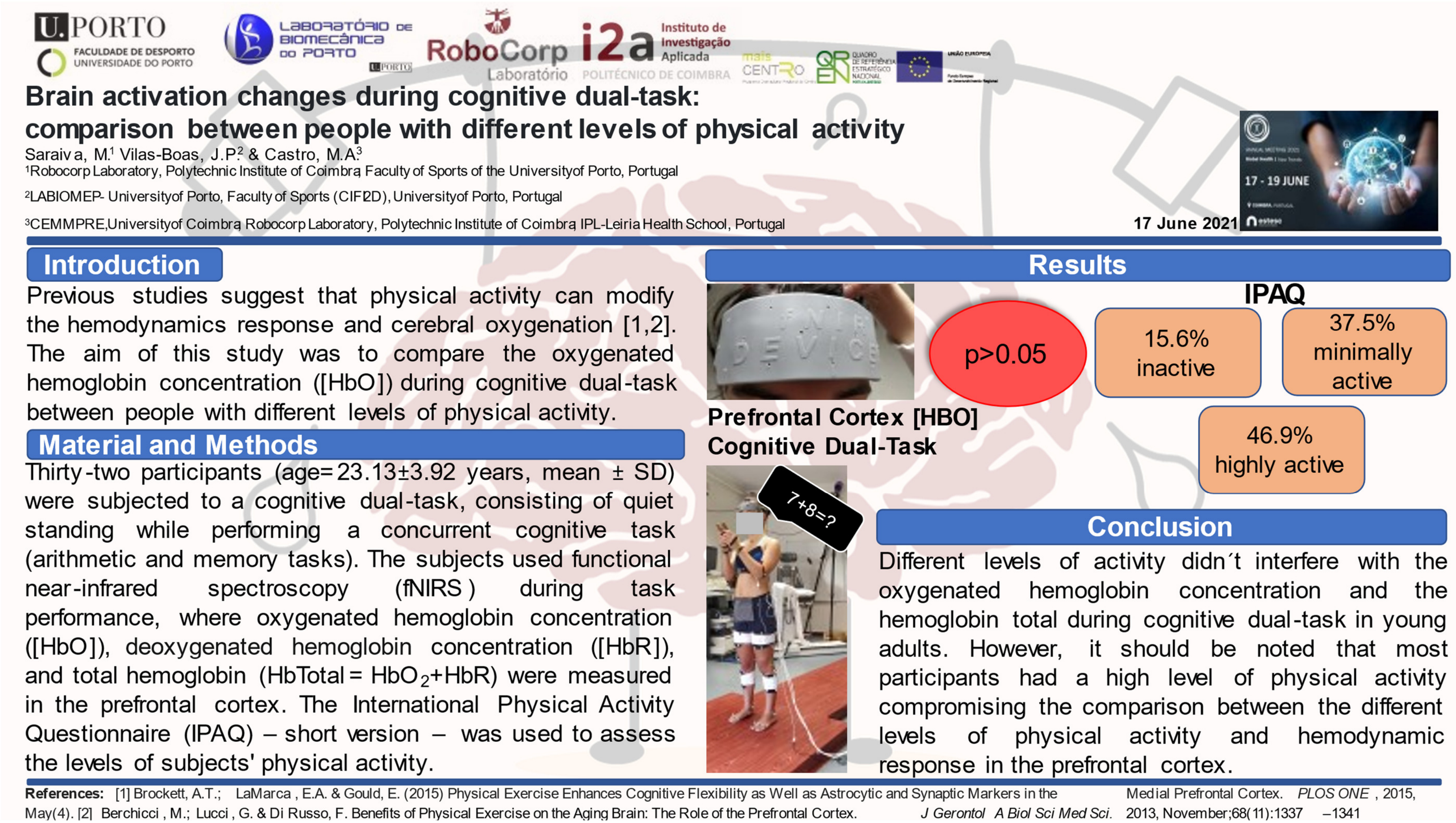
RESULTS

According to IPAQ, in this sample, 46.9% are highly active, 37.5% minimally active and 15.6% inactive. No association between levels of physical activity and oxygenated hemoglobin concentration ($p > 0.05$) in young adults was found during cognitive dual-task. Hemoglobin total did not differ between the different levels of physical activity during cognitive dual-task.

CONCLUSION

These findings suggest that different levels of activity don´t interfere with the oxygenated hemoglobin concentration and the hemoglobin total during cognitive dual-task in young adults. However, it should be noted that most participants had a high level of physical activity compromising the comparison between the different levels of physical activity and hemodynamic response in the prefrontal cortex.

Keyword's: cognitive dual-task, physical activity, prefrontal cortex, cerebral oxygenation, fNIR.



Brain activation changes during cognitive dual-task: comparison between people with different levels of physical activity

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17 June 2021

Introduction

Previous studies suggest that physical activity can modify the hemodynamics response and cerebral oxygenation [1,2]. The aim of this study was to compare the oxygenated hemoglobin concentration ([HbO]) during cognitive dual-task between people with different levels of physical activity.

Material and Methods

Thirty-two participants (age=23.13±3.92 years, mean ± SD) were subjected to a cognitive dual-task, consisting of quiet standing while performing a concurrent cognitive task (arithmetic and memory tasks). The subjects used functional near-infrared spectroscopy (fNIRS) during task performance, where oxygenated hemoglobin concentration ([HbO]), deoxygenated hemoglobin concentration ([HbR]), and total hemoglobin (HbTotal = HbO_2+HbR) were measured in the prefrontal cortex. The International Physical Activity Questionnaire (IPAQ) – short version – was used to assess the levels of subjects' physical activity.

Results

Prefrontal Cortex [HBO]
Cognitive Dual-Task

p>0.05

IPAQ

15.6% inactive

37.5% minimally active

46.9% highly active

Conclusion

Different levels of activity didn´t interfere with the oxygenated hemoglobin concentration and the hemoglobin total during cognitive dual-task in young adults. However, it should be noted that most participants had a high level of physical activity compromising the comparison between the different levels of physical activity and hemodynamic response in the prefrontal cortex.

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APPENDIX G – Motor task performance during smartphone use on static and dynamic postural control in young adults

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Current Status: Accepted for oral presentation at the Annual Meeting Coimbra Health School 2021.

BACKGROUND

Performing two or more tasks simultaneously is frequently associated with a performance decline in one or both tasks. The smartphone use while walking was associated with increased physical demands related to manipulation of the smartphone. The aim of the study was to compare motor tasks performances using a smartphone during static postural control and gait in young adults.

METHODS

Thirty-six healthy participants (age= 23.25 ± 4.04 years, mean ± SD) were instructed to perform two different motor tasks using a smartphone while walking and standing. The motor tasks consisted of typing on the smartphone keyboard (texting a message) and taking the smartphone out of the bag, bringing it to the ear and puting it back in the bag (answer the smartphone). The performance of each motor task was assessed by the number of characters written in the message and the number of times the smartphone was answered during walking and quiet standing position.

RESULTS

The motor tasks performance was greater during quiet standing position than walking. The number of characters in the message during the typing on the smartphone while walking task was lower compared to the typing on the smartphone while standing task ($p = 0.005$). The number of times the smartphone was taken out of the bag, brought to the ear and put back in the bag was greater during quiet standing position than walking task ($p = 0.004$).

CONCLUSION

The motor tasks performance, answering the phone or texting, was worst during the gait, which can represent that the gait requires more attentional resources, head control and dynamic stability.

Keyword's: motor dual-task, motor performance, motor skills, smartphone.

Motor task performance during smartphone use on static and dynamic postural control in young adults

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17 June 2021

Introduction

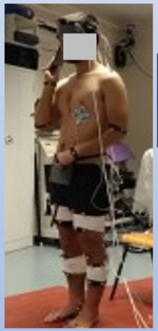
Performing two or more tasks simultaneously is frequently associated with a performance decline in one or both tasks [1]. The smartphone use while walking was associated with increased physical demands related to manipulation of the smartphone [2]. The aim of the study was to compare motor tasks performances using a smartphone during static postural control and gait in healthy young adults.

Material and Methods

Thirty-six healthy participants (age=23.25±4.04 years, mean ± SD) were instructed to perform two different motor tasks using a smartphone while walking and standing. The motor tasks consisted of typing on the smartphone keyboard (texting a message) and taking the smartphone out of the bag, bringing it to the ear and putting it back in the bag (answer the smartphone). The performance of each motor task was assessed by the number of characters written in the message and the number of times the smartphone was answered during walking and quiet standing position.

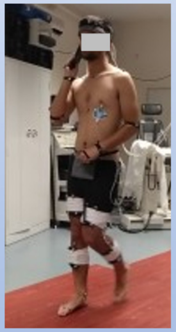
Results

Standing posture while aswering the smartphone VS **Walking while aswering the smartphone**



MTP1=31.0±10.9

p-value = 0.004



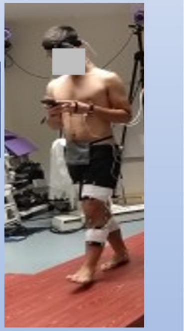
MTP1=28.0±10.2

Motor Task Perfomance (MTP1): Number of times the smartphone was answered

Standing posture while texting a message VS **Walking while texting a message**

MTP2=525.8±149.3

p-value = 0.005



MTP2=485.4±148.0

Motor Task Perfomance (MTP2): Number of characters written in the message

Conclusion

The motor tasks performance, answering the phone or texting, was worst during the gait, which can represent that the gait requires possibly more attentional resources, head control and dynamic stability.

References: [1] Woollacott, M. & Shumway-Cook A. Attention and the control of posture and gait: a review of an emerging area of research. *Gait Posture*. 2002; 16:1–14. [2] Marone, J.R., Patel, P.B., Hurt, C.P., Grabiner, M.D. Frontal plane margin of stability is increased during texting while walking. *Gait Posture*. 2014; 40:243–6.

ANNEXES

ANNEX A – Informed Consent

Consentimento informado

(de acordo com a Declaração de Helsínquia da Associação Médica Mundial)

Por favor, leia com atenção a seguinte informação. Se achar que algo está incorreto ou que não está claro, não hesite em solicitar mais informações.

Título do estudo: O efeito da dupla tarefa no controlo postural estático e dinâmico em atividades da vida diária e a sua relação com a qualidade do sono e a atividade física em adultos jovens.

Enquadramento: Trabalho de investigação para a obtenção do grau de Doutor em Fisioterapia na Faculdade de Desporto da Universidade do Porto, sob a orientação da professora Doutora Maria António Castro e co-orientação do professor Doutor João Paulo Vilas-Boas .

Explicação do estudo: O objetivo principal deste estudo é avaliar o efeito de tarefas cognitivas e motoras no controlo postural estático e na marcha em jovens adultos, utilizando o telemóvel. Pretende-se também verificar se existem relações entre o nivel de atividade física e a qualidade do sono no desempenho de duas tarefas realizadas simultaneamente. Para a concretização deste estudo, será necessário uma única avaliação, com duração aproximada de 60 min. Serão recolhidos dados relacionados com o nivel de atividade física, qualidade do sono, da atividade eletromiográfica, cerebral, da marcha e do equilíbrio estático.

Condições e financiamento: O estudo mereceu parecer favorável da Comissão de Ética. Toda a explicação, procedimentos e objetivos do estudo é fornecida de forma clara e esclarecedora. Garante-se a ausência de qualquer risco à integridade física e psicológica e ainda o direito de recusar a qualquer altura a sua participação no estudo, sem que isso possa ter, como efeito, qualquer prejuízo na assistência que lhe é prestada. A sua participação é voluntária e não lhe será cobrado qualquer custo que daí advenha. Todos os dados recolhidos são confidenciais e servirão única e exclusivamente para a realização deste estudo e publicação de artigos que resultem deste estudo.

Confidencialidade e anonimato: Garante-se o anonimato, a confidencialidade e o uso exclusivo dos dados recolhidos para o estudo.

Agradeço a sua colaboração para a conctretização do presente estudo. Obrigada!

O investigador, ____
Data: ____/ ____/ _____ Assinatura: ___________________
Contactos: _________________

Se concorda com a proposta que lhe foi feita, queira assinar este documento.
Nome do participante: ____

Declaro ter lido e compreendido este documento, bem como as informações verbais que me foram fornecidas pelo investigador. Foi-me garantida a possibilidade de, em qualquer altura, recusar participar neste estudo sem qualquer tipo de consequências. Desta forma, aceito participar neste estudo e permito a utilização dos dados, que de forma voluntária forneço, confiando em que apenas serão utilizados para esta investigação e nas garantias de confidencialidade e anonimato que me são dadas pelo investigador.

Data: ____/ ____/ _____ **Assinatura:** ___________________________

Este documento é composto por 2 páginas e feito em duplicado: uma via para o investigador e outra para o participante.

ANNEX B – Individual Questionnaire

Trabalho de investigação para obtenção de grau de Doutor em Fisioterapia

Titulo: O efeito da dupla tarefa no controlo postural estático e dinâmico em atividades da vida diária e a sua relação com a qualidade do sono e a atividade física em adultos jovens.

Nome: ____ Código Inv.: ____
Data de Nascimento: ___/ ______/ ______ Género: Feminino: ☐
Idade: _____ Masculino: ☐
Localidade: ___________________________
Tlm: _____________________ e-mail:_______________________________________
Profissão: ________________________________
Habilitações Literárias: 12º ano ☐
Licenciatura ☐ Se não concluída, identifique o ano do curso:
1º ano ☐ 2º ano ☐ 3º ano ☐ 4º ano ☐
Mestrado ☐ Doutoramento ☐ Outro ☐ ______________

Informação clínica

(Indique se tem alguma das seguintes condições.)

Doenças Cardiovasculares	Sim ☐ Não ☐	
Doenças Respiratórias	Sim ☐ Não ☐	
Doenças Metabólicas	Sim ☐ Não ☐	
Doenças/Lesões Neurológicas	Sim ☐ Não ☐	
Doenças/Lesões Músculo-Esqueléticas	Sim ☐ Não ☐	
Fez alguma cirurgia nos últimos 6 meses?	Sim ☐ Não ☐	Se sim, onde? _______________________
Doenças Mentais/ Psicológicas	Sim ☐ Não ☐	
Alterações da acuidade visual	Sim ☐ Não ☐	Se sim: Corrigida ☐ Sem correção ☐
Alterações da acuidade auditiva	Sim ☐ Não ☐	Se sim: Corrigida ☐ Sem correção ☐
Outras condições	Sim ☐ Não ☐	Quais?:_____________________________
Encontra-se medicado?	Sim ☐ Não ☐	Refira a sua medicação: ____________________________________ ____________________________________

Outras observações:

Dados Antropométricos (Material de recolha de dados de acordo com o material disponível)		
Peso (Kg):	**Altura (cm):**	**IMC (Kg/cm^2):**

Estilos/ Hábitos de vida

Pratica exercício físico?	Sim ☐ Não ☐ Se sim, quantas vezes e onde? 1x/semana ☐ 2-3x/semana ☐ 4-6x/semana ☐ Diariamente ☐ Ginásio ☐ Lazer/exterior ☐ Desporto de competição ☐
Considera fazer uma alimentação saudável?	Sim ☐ Não ☐
Hábitos tabágicos	Sim ☐ Não ☐
Em média quantas horas dorme/dia?	____________
Toma medicação para adormecer?	Sim ☐ Não ☐
Quanto tempo demora para adormecer a maioria das vezes?	≤ 30 min ☐ > 30 min ☐
Geralmente, costuma acordar mais que uma vez por noite?	Sim ☐ Não ☐
Como classificaria a sua qualidade de sono?	Muito boa ☐ Boa ☐ Má ☐ Muito má ☐
Utiliza o telemóvel 60/30 minutos antes de adormecer?	Sim ☐ Não ☐
Em média, quantas horas utiliza o telemóvel/dia? _______	Em que situações o utiliza mais o seu telemóvel? Falar ☐ Escrever mensagens ☐ Jogar ☐ Ouvir música ☐ Ver vídeos/filmes ☐ Internet ☐ Outros ☐
Já sofreu alguma queda, tropeçou, desequilibrou-se, ou teve algum acidente por causa do uso do telemóvel?	Sim ☐ Não ☐

Obrigada pela sua colaboração!

ANNEX C – International Physical Activity Questionnaire – IPAQ Short Portuguese Version

Estamos interessados em conhecer os níveis de actividade física habitual dos Portugueses. As suas respostas vão ajudar-nos a compreender o quanto activos somos. As questões referem-se ao tempo que dispende na actividade física numa semana. Este questionário inclui questões acerca de actividades que faz no trabalho, para se deslocar de um lado para outro, actividades referentes à casa ou ao jardim e actividades que efectua no seu tempo livre para entretenimento, exercício ou desporto. As suas respostas são importantes. Por favor responda a todas as questões mesmo que não se considere uma pessoa activa.

Obrigado pela sua participação

Ao responder às seguintes questões considere o seguinte:

Actividade física vigorosa *refere-se a actividades que requerem muito esforço físico e tornam a respiração muito mais intensa que o normal.*
Actividade física moderada *refere-se a actividades que requerem esforço físico moderado e torna a respiração um pouco mais intensa que o normal.*

Ao responder às questões considere apenas as actividades físicas que realize durante pelo menos 10 minutos seguidos.

1a Habitualmente, por semana, quantos dias faz actividades físicas **vigorosas** como levantar e/ou transportar objectos pesados, cavar, ginástica aeróbica ou andar de bicicleta a uma velocidade acelerada?

___ dias por semana
___ Nenhum (passe para a questão **2a**)

1b Quanto tempo costuma fazer actividade física vigorosa por dia?

____ horas ___ minutos

2a Normalmente, por semana, quantos dias faz actividade física **moderada** como levantar e/ou transportar objectos leves, andar de bicicleta a uma velocidade moderada ou jogar ténis? Não inclua o andar/caminhar.

_______ dias por semana
_______ Nenhum (passe para a questão **3a**)

2b Quanto tempo costuma fazer actividade física moderada por dia?

____ horas ___ minutos

3a Habitualmente, por semana, quantos dias **caminha** durante pelo menos 10 minutos seguidos? Inclua caminhadas para o trabalho e para casa, para se deslocar de um lado para outro e qualquer outra caminhada que possa fazer somente para recreação, desporto ou lazer.

____ dias por semana
____ Nenhum (passe para a questão **4a**)

3b Quanto tempo costuma caminhar por dia?

____ horas ___ minutos

3c A que passo costuma caminhar?

_____ Passo **vigoroso**, que torna a sua respiração muito mais intensa que o normal;
_____ Passo **moderado**, que torna a sua respiração um pouco mais intensa que o normal;
_____ Passo **lento**, que não causa qualquer alteração na sua respiração;

As últimas questões referem-se ao tempo que está sentado diariamente no trabalho, em casa, no percurso para o trabalho e durante os tempos livres. Estas questões incluem o tempo em que está sentado numa secretária, a visitar amigos, a ler ou sentado/deitado a ver televisão.

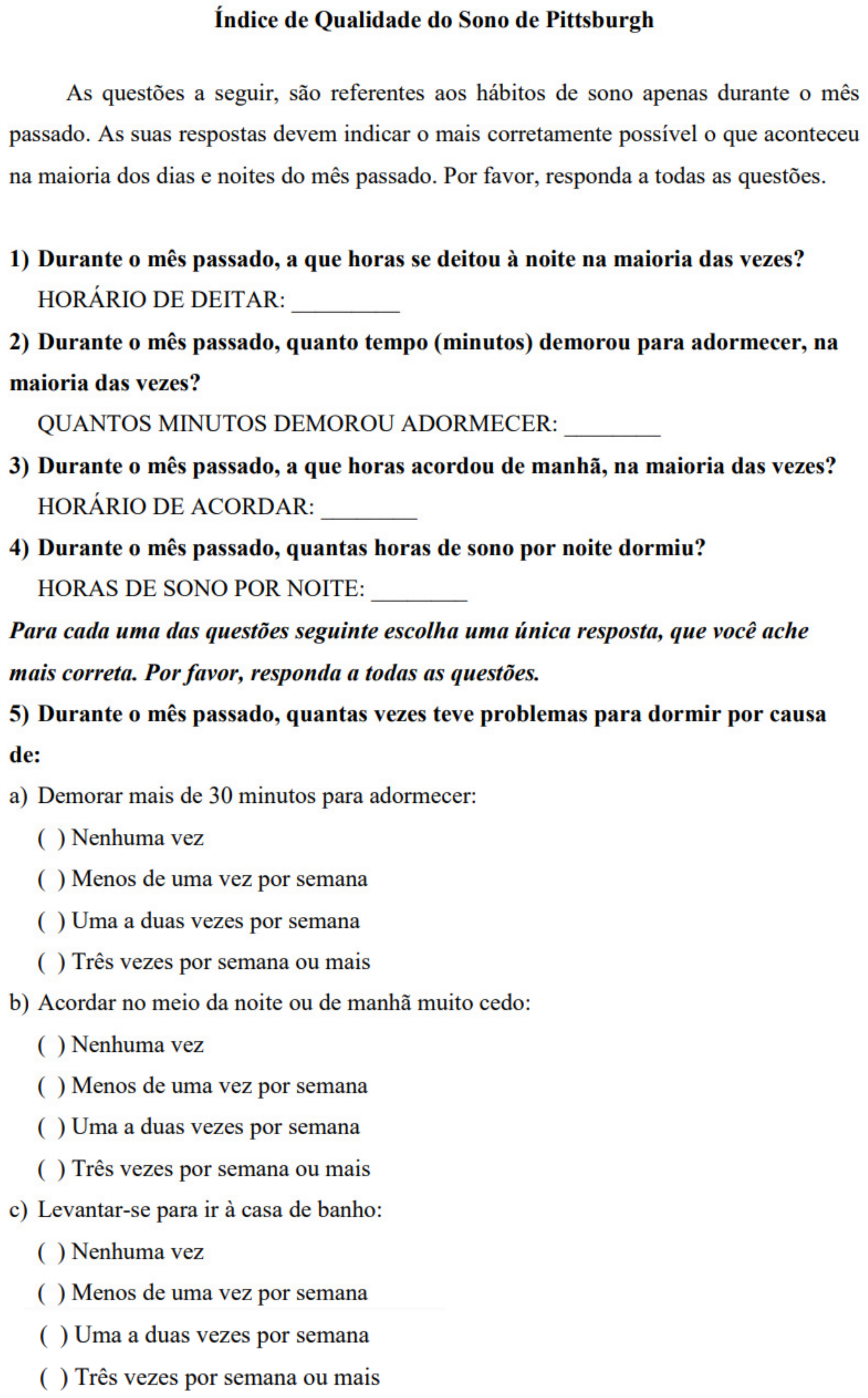
4a Quanto tempo costuma estar sentado num **dia de semana**?

____ horas ___ minutos

4b Quanto tempo costuma estar sentado num **dia de fim-de-semana**?

____ horas ___ minutos

ANNEX D – Pittsburgh Sleep Quality Index – PSQI Portuguese Version



Índice de Qualidade do Sono de Pittsburgh

As questões a seguir, são referentes aos hábitos de sono apenas durante o mês passado. As suas respostas devem indicar o mais corretamente possível o que aconteceu na maioria dos dias e noites do mês passado. Por favor, responda a todas as questões.

1) Durante o mês passado, a que horas se deitou à noite na maioria das vezes?

HORÁRIO DE DEITAR: __________

2) Durante o mês passado, quanto tempo (minutos) demorou para adormecer, na maioria das vezes?

QUANTOS MINUTOS DEMOROU ADORMECER: _________

3) Durante o mês passado, a que horas acordou de manhã, na maioria das vezes?

HORÁRIO DE ACORDAR: _________

4) Durante o mês passado, quantas horas de sono por noite dormiu?

HORAS DE SONO POR NOITE: _________

Para cada uma das questões seguinte escolha uma única resposta, que você ache mais correta. Por favor, responda a todas as questões.

5) Durante o mês passado, quantas vezes teve problemas para dormir por causa de:

a) Demorar mais de 30 minutos para adormecer:

( ) Nenhuma vez
( ) Menos de uma vez por semana
( ) Uma a duas vezes por semana
( ) Três vezes por semana ou mais

b) Acordar no meio da noite ou de manhã muito cedo:

( ) Nenhuma vez
( ) Menos de uma vez por semana
( ) Uma a duas vezes por semana
( ) Três vezes por semana ou mais

c) Levantar-se para ir à casa de banho:

( ) Nenhuma vez
( ) Menos de uma vez por semana
( ) Uma a duas vezes por semana
( ) Três vezes por semana ou mais

d) Ter dificuldade para respirar:
( ) Nenhuma vez
( ) Menos de uma vez por semana
( ) Uma a duas vezes por semana
( ) Três vezes por semana ou mais
e) Tossir ou roncar muito alto:
( ) Nenhuma vez
( ) Menos de uma vez por semana
( ) Uma a duas vezes por semana
( ) Três vezes por semana ou mais
f) Sentir muito frio:
( ) Nenhuma vez
( ) Menos de uma vez por semana
( ) Uma a duas vezes por semana
( ) Três vezes por semana ou mais
g) Sentir muito calor:
( ) Nenhuma vez
( ) Menos de uma vez por semana
( ) Uma a duas vezes por semana
( ) Três vezes por semana ou mais
h) Ter sonhos maus ou pesadelos:
( ) Nenhuma vez
( ) Menos de uma vez por semana
( ) Uma a duas vezes por semana
( ) Três vezes por semana ou mais
i) Sentir dores:
( ) Nenhuma vez
( ) Menos de uma vez por semana
( ) Uma a duas vezes por semana
( ) Três vezes por semana ou mais

j) Outra razão, por favor, descreva: ___________________________________

Quantas vezes teve problemas para dormir por esta razão durante o mês passado?

( ) Nenhuma vez
( ) Menos de uma vez por semana
( ) Uma a duas vezes por semana
( ) Três vezes por semana ou mais

6) Durante o mês passado, como classificaria a qualidade do seu sono?

( ) Muito boa
( ) Boa
( ) Má
( ) Muito má

7) Durante o mês passado, tomou alguma medicação para dormir, receitado pelo médico, ou indicado por outra pessoa (farmacêutico, amigo, familiar) ou mesmo por sua conta? Qual (is)? _________________________________

( ) Nenhuma vez
( ) Menos de uma vez por semana
( ) Uma a duas vezes por semana
( ) Três vezes por semana ou mais

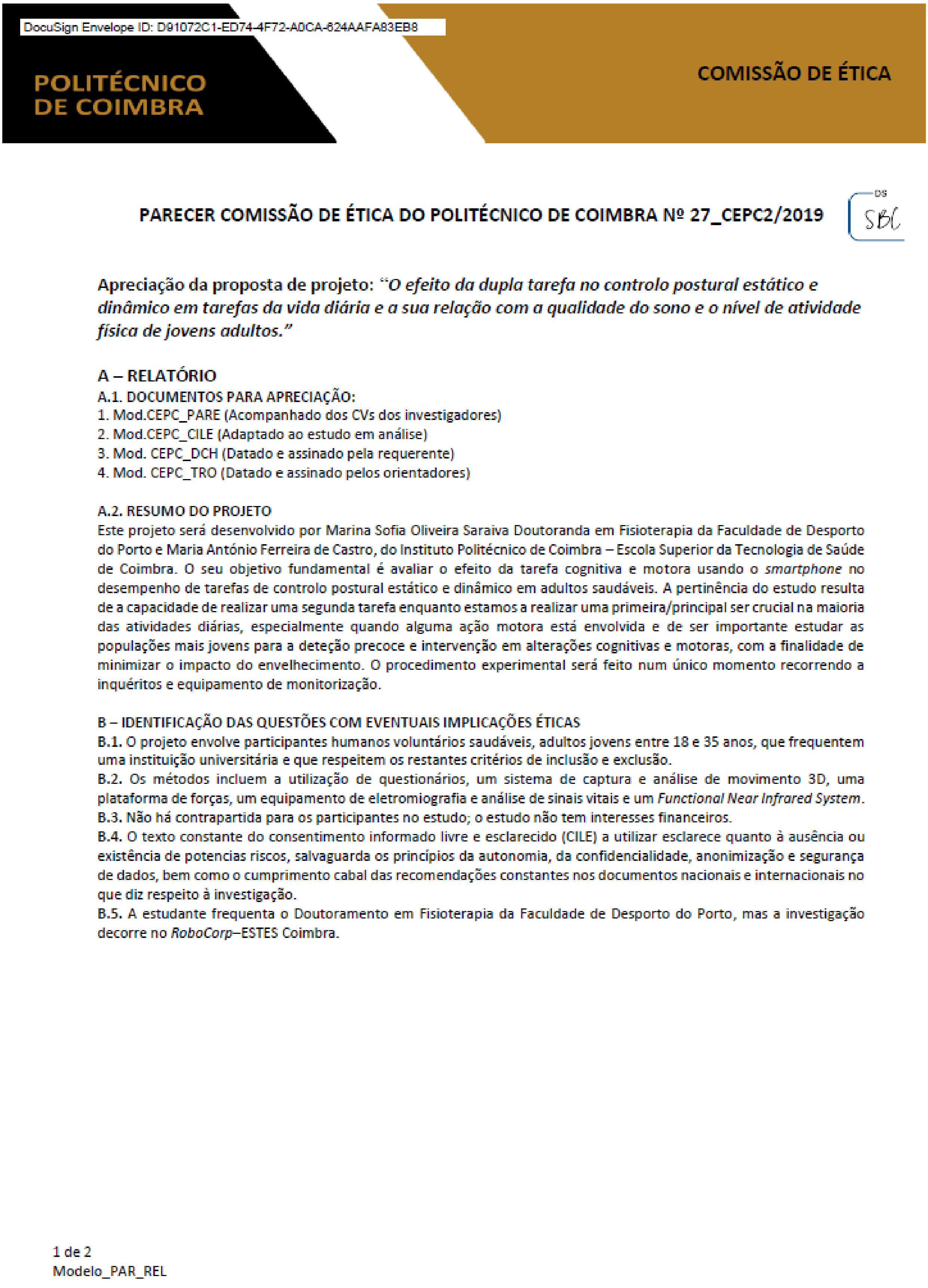
8) Durante o mês passado, se teve problemas para ficar acordado enquanto estava a conduzir, a fazer as suas refeições ou a participar noutra atividade social, quantas vezes isso aconteceu?

( ) Nenhuma vez
( ) Menos de uma vez por semana
( ) Uma a duas vezes por semana
( ) Três vezes por semana ou mais

9) Durante o mês passado, sentiu alguma indisposição ou falta de entusiasmo para realizar as suas atividades diárias?

( ) Nenhuma indisposição nem falta de entusiasmo
( ) Indisposição e falta de entusiasmo pequenas
( ) Indisposição e falta de entusiasmo moderadas
( ) Muita indisposição e falta de entusiasmo

ANNEX E – Ethics Committee of the Polytechnic of Coimbra



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POLITÉCNICO
DE COIMBRA

COMISSÃO DE ÉTICA

PARECER COMISSÃO DE ÉTICA DO POLITÉCNICO DE COIMBRA Nº 27_CEPC2/2019

DS
SBC

Apreciação da proposta de projeto: *"O efeito da dupla tarefa no controlo postural estático e dinâmico em tarefas da vida diária e a sua relação com a qualidade do sono e o nível de atividade física de jovens adultos."*

A – RELATÓRIO

A.1. DOCUMENTOS PARA APRECIAÇÃO:

1. Mod.CEPC_PARE (Acompanhado dos CVs dos investigadores)
2. Mod.CEPC_CILE (Adaptado ao estudo em análise)
3. Mod. CEPC_DCH (Datado e assinado pela requerente)
4. Mod. CEPC_TRO (Datado e assinado pelos orientadores)

A.2. RESUMO DO PROJETO

Este projeto será desenvolvido por Marina Sofia Oliveira Saraiva Doutoranda em Fisioterapia da Faculdade de Desporto do Porto e Maria António Ferreira de Castro, do Instituto Politécnico de Coimbra – Escola Superior da Tecnologia de Saúde de Coimbra. O seu objetivo fundamental é avaliar o efeito da tarefa cognitiva e motora usando o *smartphone* no desempenho de tarefas de controlo postural estático e dinâmico em adultos saudáveis. A pertinência do estudo resulta de a capacidade de realizar uma segunda tarefa enquanto estamos a realizar uma primeira/principal ser crucial na maioria das atividades diárias, especialmente quando alguma ação motora está envolvida e de ser importante estudar as populações mais jovens para a deteção precoce e intervenção em alterações cognitivas e motoras, com a finalidade de minimizar o impacto do envelhecimento. O procedimento experimental será feito num único momento recorrendo a inquéritos e equipamento de monitorização.

B – IDENTIFICAÇÃO DAS QUESTÕES COM EVENTUAIS IMPLICAÇÕES ÉTICAS

B.1. O projeto envolve participantes humanos voluntários saudáveis, adultos jovens entre 18 e 35 anos, que frequentem uma instituição universitária e que respeitem os restantes critérios de inclusão e exclusão.

B.2. Os métodos incluem a utilização de questionários, um sistema de captura e análise de movimento 3D, uma plataforma de forças, um equipamento de eletromiografia e análise de sinais vitais e um *Functional Near Infrared System*.

B.3. Não há contrapartida para os participantes no estudo; o estudo não tem interesses financeiros.

B.4. O texto constante do consentimento informado livre e esclarecido (CILE) a utilizar esclarece quanto à ausência ou existência de potencias riscos, salvaguarda os princípios da autonomia, da confidencialidade, anonimização e segurança de dados, bem como o cumprimento cabal das recomendações constantes nos documentos nacionais e internacionais no que diz respeito à investigação.

B.5. A estudante frequenta o Doutoramento em Fisioterapia da Faculdade de Desporto do Porto, mas a investigação decorre no *RoboCorp*–ESTES Coimbra.

C – CONCLUSÕES

A investigação a realizar decorre no RoboCorp–ESTES Coimbra, mas encontra-se enquadrada num Doutoramento em Fisioterapia da Faculdade de Desporto do Porto, pelo que as requerentes devem informar a respetiva Comissão de Ética da realização deste estudo. O projeto cumpre os requisitos éticos de Investigação com Seres Humanos, nomeadamente a obtenção do CILE e cumpre ainda os requisitos éticos de investigação quanto à proteção de dados pessoais. Estando salvaguardados os pressupostos éticos relacionados com a investigação, de acordo com o disposto no n.º 2 do art.º 7º do Regulamento da Comissão de Ética do IPC, não tem esta Comissão de Ética (CEIPC) nada a opor quanto ao desenvolvimento do referido projeto.

Recomendações: O Parecer desta CEIPC não dispensa outros pareceres ou autorizações, pelo que se sugere que se efetuem todos os pedidos de autorização necessários ao desenvolvimento do Estudo.

DECISÃO: DEFERIDO, por unanimidade, em reunião do dia 20 de novembro de 2019

O/A Relator/a: ABEL CARVALHO

O/A Presidente da CEIPC: SÓNIA COSTA

Assinado por: **ABEL DE OLIVEIRA MARTINS DE CARVALHO**
Num. de Identificação: BI101401272

DocuSigned by:
Sonia Brito Costa
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11/26/2019

ANNEX F – Certificate of II Congresso Internacional Interdisciplinar sobre Representações Sociais e sobre Qualidade de Vida do Vale do São Francisco – CIRSQVASF (Appendix A)

Verifique o código de autenticidade **7444868.5571201.847611.7.55502044369160532663** em https://www.even3.com.br//documentos

II CONGRESSO INTERNACIONAL INTERDISCIPLINAR SOBRE REPRESENTAÇÕES SOCIAIS E SOBRE QUALIDADE DE VIDA DO VALE DO SÃO FRANCISCO - II CIRSQVASF

I OLIMPÍADA INTERNACIONAL VIRTUAL DE CASOS CLÍNICOS DE CUIDADOS EM SAÚDE - I OLYMHEALTHCARE

CERTIFICADO

Certificamos que o trabalho intitulado **Postural control during motor dual-task in young adults with different levels of physical activity** de autoria de **Marina Solia Oliveira Saraiva, João Paulo Vilas-Boas e Maria António Castro**, foi apresentado no **II Congresso Internacional Interdisciplinar sobre Representações Sociais e sobre Qualidade de Vida do Vale do São Francisco - CIRSQVASF**, realizado em **15/12/2021** a **17/12/2021**, de modo remoto virtual.

Petrolina - PE, Brasil, 17 de dezembro de 2021.

Realização:

GIPEEF

UNIVASF
UNIVERSIDADE FEDERAL DO VALE DO SÃO FRANCISCO

Ramon Missias Moreira
Prof. Dr. Ramon Missias Moreira
Presidente do II CIRSQVASF
e da I OLYMHEALTHCARE

Proex
PRÓ-REITORIA DE EXTENSÃO

II CIRSQVASF
I OLYMHEALTHCARE

ANNEX G – Certificate of Annual Meeting 2021 Coimbra Health School (Appendix B)

ANNUAL MEETING 2021

Global Health | New Trends

17 - 19 JUNE

VIRTUAL

estesc
Politécnico de Coimbra

Certificate

We hereby certify that

Marina Saraiva

Presented the Oral Communication entitled

Prefrontal cortex oxygenation and sleep quality in cognitive dual-task – fNIR study

inserted on the **Annual Meeting - Global Health: New Trends** that took place in a virtual format from the 17th to the 19th of June 2021

Authors: Marina Saraiva; João Paulo Vilas-Boas; Maria António Castro

João José Joaquim
President of ESTeSC

Fernando Mendes
President of the Congress

Diana Martins
Coordinator

João Lima
Coordinator

ANNEX H – Certificate of Annual Meeting 2021 Coimbra Health School (Appendix C)

ANNUAL MEETING 2021

Global Health | New Trends

17 - 19 JUNE

VIRTUAL

estesc
Politécnico de Coimbra

Certificate

We hereby certify that

Marina Saraiva

Presented the Oral Communication entitled

Analysis of hemodynamics response in prefrontal cortex during motor and cognitive dual-task – fN study

inserted on the **Annual Meeting - Global Health: New Trends** that took place in a virtual format from the 17th to the 19th of June 2021

Authors: Marina Saraiva; João Paulo Vilas-Boas; Maria António Castro

João José Joaquim
President of ESTeSC

Diana Raquel Fernandes

João Pedro Marques Lima

Fernando Mendes
President of the Congress

Diana Martins
Coordinator

João Lima
Coordinator

ANNEX I – Certificate of Congresso Nacional de Biomecânica (Appendix D)

19-20 Fevereiro 2021 | Porto

Congresso Nacional de Biomecânica

ciência em movimento

CERTIFICADO DE APRESENTAÇÃO

Certifica-se que,

Marina Saraiva

Apresentou o seguinte trabalho:

"*Efeito do uso do telemóvel na velocidade da marcha*"

no 9º Congresso Nacional de Biomecânica, no dia 19 de fevereiro de 2021

A comissão organizadora:

Jorge Belinha

José Carlos Reis Campos

Elza Fonseca

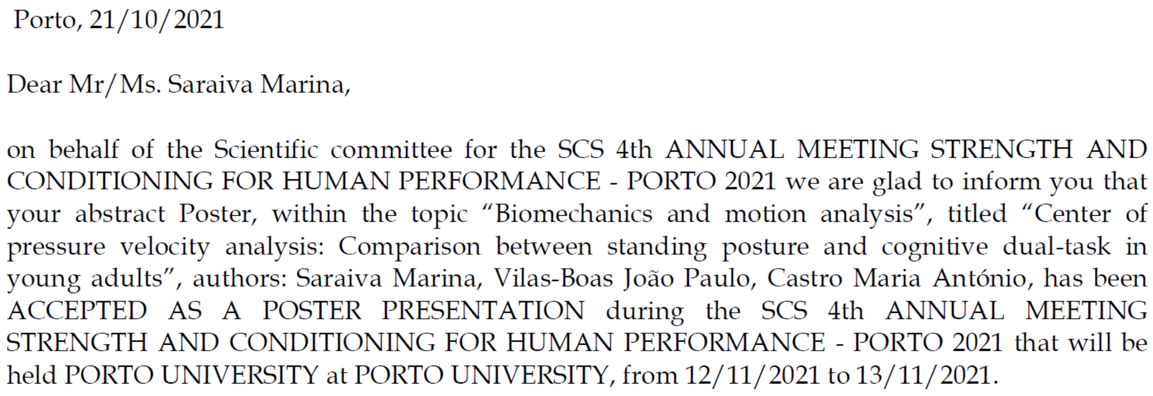
Mª Helena Figueiral

Fernanda Gentil

Susana Oliveira

Arcelina Marques

ANNEX J – Certificate of SCS 4th Annual Conference Strength and Conditioning for Human Performance (Appendix E)



Porto, 21/10/2021

Dear Mr/Ms. Saraiva Marina,

on behalf of the Scientific committee for the SCS 4th ANNUAL MEETING STRENGTH AND CONDITIONING FOR HUMAN PERFORMANCE - PORTO 2021 we are glad to inform you that your abstract Poster, within the topic "Biomechanics and motion analysis", titled "Center of pressure velocity analysis: Comparison between standing posture and cognitive dual-task in young adults", authors: Saraiva Marina, Vilas-Boas João Paulo, Castro Maria António, has been ACCEPTED AS A POSTER PRESENTATION during the SCS 4th ANNUAL MEETING STRENGTH AND CONDITIONING FOR HUMAN PERFORMANCE - PORTO 2021 that will be held PORTO UNIVERSITY at PORTO UNIVERSITY, from 12/11/2021 to 13/11/2021.

ANNEX K – Certificate of Annual Meeting 2021 Coimbra Health School (Appendix F)

ANNUAL MEETING 2021

Global Health | New Trends

17 - 19 JUNE

VIRTUAL

estesc
Politécnico de Coimbra

Certificate

We hereby certify that

Marina Saraiva

Presented the Poster Presentation entitled

Brain activation changes during cognitive dual-task: comparison between young adults with differe levels of physical activity

inserted on the **Annual Meeting - Global Health: New Trends** that took place in a virtual format from the 17th to the 19th of June 2021

Authors: Marina Saraiva; João Paulo Vilas-Boas; Maria António Castro

João José Joaquim
President of ESTeSC

Fernando Mendes
President of the Congress

Diana Raquel Fernandes Castro
Diana Martins
Coordinator

João Pedro Marques Lima
João Lima
Coordinator

ANNEX L – Certificate of Annual Meeting 2021 Coimbra Health School (Appendix G)

ANNUAL MEETING 2021

Global Health | New Trends

17 - 19 JUNE

VIRTUAL

estesc
Politécnico de Coimbra

Certificate

We hereby certify that

Marina Saraiva

Presented the Poster Presentation entitled

Motor task performance during smartphone use on static and dynamic postural control in young adults

inserted on the **Annual Meeting - Global Health: New Trends** that took place in a virtual format from the 17th to the 19th of June 2021

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Coordinator

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The end.