COMENIUS UNIVERSITY IN BRATISLAVA

FACULTY OF MATHEMATICS, PHYSICS AND INFORMATICS

# THE INFLUENCE OF CONCURRENT COGNITIVE TASKS ON BALANCE, STEP INITIATION AND GAIT IN HEALTHY YOUNG ADULTS

Master's thesis

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**Bc. Ondrej Spevák**

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Master's thesis

Study program: 9.2.11. Cognitive Science

Field of study: Cognitive Science

Supervisor: RNDr. Barbora Cimrová, PhD.

**Bratislava, 2014** **Bc.Ondrej Spevák**

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# THESIS ASSIGNMENT

**Name and Surname:** Bc. Ondrej Spevak
**Study programme:** Cognitive Science (Single degree study, master II. deg., full time form)
**Field of Study:** 9.2.11. Cognitive Science
**Type of Thesis:** Diploma Thesis
**Language of Thesis:** English
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**Title:** The Influence of Concurrent Cognitive Tasks on Balance, Step Initiation and Gait in Healthy Young Adults

**Aim:** 1. Evaluate the influence of concurrent cognitive tasks on the static and dynamic postural control in young adults.
2. Verify the theories based on previous studies.

**Literature:** Winter DA, "Human balance and posture control during standing and walking," Gait Posture, 3, 193-214, 1995.
Woollacott M and Shumway-Cook A, "Attention and the control of posture and gait: a review of an emerging area of research," Gait and Posture, 16, 1-14, 2002.
Echt KV, Wolf SL, Rogers WA, Hall CD, "Cognitive and Motor Mechanisms Underlying Older Adults' Ability to Divide Attention While Walking," Physical Therapy, 91, 1039-1050, 2011.

**Annotation:** Human locomotion is an activity carried out on daily basis by healthy, as well as balance-impaired persons and as such, it represents a significant part of our everyday lives. According to the recent studies, human locomotion is not a pure motor function but it is tightly connected to cognitive processes, such as attention and executive function.

**Keywords:** locomotion, gait, cognition, dual tasking, motor-cognitive interference

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Abstract

The aim of this thesis was to process data and investigate whether cognitive-motor interference will be shown. We have used data of 23 participants acquired during standing, initiating a step and walking under single and dual task conditions. Cognitive tasks loading spatial and verbal working memory were performed concurrently with motor tasks. Results of RM-ANOVA performed on the data support the view of motor function dependent on cognition, or to be more specific working memory. In addition, we have calculated effect sizes of both concurrent tasks during each motor task. Results of this study will further represent data of control group in the research of cognitive-motor interference in patients with multiple sclerosis.

**Keywords:** Locomotion; Gait; Cognition; Dual tasking, Motor-cognitive interference

Abstrakt

Cieľom tejto práce bolo spracovanie vstupných dát a skúmanie motoricko-kognitívnej interferencie. Použili sme data 23-och participantov namerané počas státia, chôdze a inicializácie kroku počas vykonávania konkurennčných kognitívnych úloh. Boli použité konkrétne konkurenčné úlohy zaťažujúce verbálnu, alebo priestorovú pracovnú pamäť, vykonávané spoločne s motorickými úlohami. Výsledku testu RM-ANOVA sú zhodné s tvrdením o motorickej činnosti ovplyvnenej kogníciou, alebo presnejšie, pracovnou pamäťou. Navyše, vypočítali sme veľkosť efektu oboch konkurenčných úloh vykonávaných pri každej z uvedených motorických činností. Výsledky tejto štúdie budú následne použité ako data kontrolnej skupiny vo výskume zaoberajúcom sa motricko-kognitívnou interferenciou pacientov so sklerózou multiplex.

**Kľúčové slová:** pohyb, chôdza, kognícia, konkurentné úlohy, motoricko-kognitívna

# Foreword

This study is concerned with interference of cognition and motor functions. Phenomenon was already approached and great influence in the field of clinical application was achieved. Beside for the patients, this topic is also of interest for healthy people and gaining the knowledge about locomotion, which is rather complex task, could be considered another benefit of this and similar studies.

The research was initiated by the Department of Neurology of University Medical Centre in Ljubljana. The core equipment used was treadmill system for gait analysis, available in the Laboratory for gait and movement disorders. After very rich introductory phase with the topic, I decided to continue working with the data gathered and contribute to the research.

Main paradigm used in the study was dual-task paradigm with help of which we maintain to gather the data suitable for further evaluations in the field of motor-cognitive interference.
The thesis could be of value for expanding research registered in the field.

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# Tables and figures

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# 1. Introduction

## 1.1. Topic overview

Research presented in this thesis is oriented toward the phenomenon of the interference between human locomotor system and cognition. Although it might seem there is no need for research or space for discovery in the field of human walking, after performing empirical study in this thesis, we are strongly assured this is not the case. On the contrary, this area of research is still only at the beginning and more and more discrepancies waiting to be solved are arising with the expansion of the explorations concerned with the topic. The locomotor task that is probably most often noticed and performed is none other than walking. It is perceived by a majority of people as something completely normal and available by default. In a scientific way, walking is recognized as a very complex task requiring multitude systems simultaneously. This is one of the reasons why even a simple task such as standing is rather complex to model and simulate. On the other hand, children learning to walk perceive this task with ease, not minding the complexity. Although locomotion is one of the main matters of the thesis, cognitive domain, no less significant, will also be addressed. As a matter of fact, our research could be considered the interface of these two phenomena.

## 1.2. Motivation

Human locomotion influenced by cognition, the main phenomenon this study is concerned with, is an activity carried out on daily basis by healthy, as well as balance-impaired persons and as such, it represents a significant part of our everyday lives. Quality of life is thus strongly dependent on the ability to walk and maintain balance. Instability and falls are some of the consequences of reduced postural control. Fall induced injuries constitute high costs and a major public-health concern of elderly, with an increasing trend in the future[1]. Study of Winter [2] presented striking number of deaths due to falls in elderly population, even when compared to deaths of young people caused by motor vehicle accidents, resulting in 185.6 and 21.5 per 100 000 deaths respectively. According to the recent studies, human locomotion is not a pure motor function but it is tightly connected to cognitive processes [3][4]. Previous research identified two cognitive functions - attention and executive function as the main cognitive influencers of gait [4][5]. Recent studies have suggested that quality and speed of walking are affected if cognitive tasks are performed concurrently [6]. As it was emphasized in the papers studied, additional research in the area of cognitive and motor tasks interference would be of great significance for improving our understanding of the phenomenon, as well as for clinical purposes[3][7].

### 1.3. Impact

Conformed to the literature [3], devaluation in the balance competence was understood as an age-related issue, prevalent in older adults, explained by a decrease in sensory or motor system functions. Several studies [3][4] suggest this is not the only reason and argument for the theory of attention as inseparable cognitive resource needed for proper balance control. This is still an insufficiently explored area and researchers highlight the necessity of future research on this topic. Our study contributes to this debate by considering the cognitive-motor interference. We would be honored if this thesis represented at least one step in the way of approaching improvements, mainly relating to the patients with specific types of pathology (such as Multiple sclerosis or Parkinson's disease) and elderly population. This and similar studies have the potential of bringing fruitful results in the field of early diagnosis of balance-impairments, prevention of falls and fall-induced injuries, and rehabilitation.

### 1.4. Objectives

This study is primarily focused on evaluating the influence of concurrent cognitive tasks on the static postural control, step initiation and gait in healthy young adults. Our research was oriented towards exploration of the effects of different cognitive tasks on motor performance. Verification of theories based on the previous studies could also be considered as one of the objectives.

## 2. Background

The way humans walk is characterized by specific features. Approaching this phenomenon and further discussion requires understanding of these features, as well as basic means of measurements and major findings, which will be introduced in this chapter.

## 2.1. Walking and gait overview

Human walking is defined as a method of locomotion involving the use of the two legs alternately, to provide both support and propulsion with at least one foot being in contact with the ground at all times, excluding running [8][9]. Besides running, this definition also eliminates some forms of pathological gait (e.g. crutch-walking) that are commonly considered a form of walking [8]. In line with this definition, walking is understood as an act of motion with above stated characteristics.

One of the core aspects of human walk is bipedalism. It can be defined as a type of terrestrial locomotion characterized by the alternative use of two feet only. A habitual use of this form of gait is one of the features that separates humans from other primates [10] and it is treated as the major hominin adaptation that evolved approximately five million years ago [11][12]. Available facts, in most cases obtained from fossils, encouraged a heated debate on the evolution of human bipedalism, supporting several alternative and often contradictory theories. The way bipeds locomote undoubtedly brings a lot of advantages when compared to our quadruped ancestors. On the other hand, this adaptation required some compromises including high pressure on the spine causing lower back pain, decreased pelvis width, which is the reason for births nowadays resulting in children being born less developed when compared to children who were in the womb for 10 months, as it used to be the case in the past, and higher demands on the balance control system in general [2][11] [12].

It is essential to explain the difference between walking and gait, as these terms are often interchangeable. In the definition of walking, there is no specification of the way walking is performed and this is certainly not caused by the lack of diversity of walking patterns. On the contrary, a wide variety of the ways walking is performed is the reason for introducing the term gait. It describes the manner or style of walking [8]. Naturally, gait is frequently related to quadrupeds due to their ability of various styles of walking. Although normal gait provides a norm for evaluation, it is useful to realize that it refers to both sexes, variation of ages as well as a wide assortment of body geometry [8].

## 2.2. Revision of gait evaluation methods

Walking is a voluntary movement that involves the brain, spinal cord, peripheral nerves, muscles, bones and joints. Analyses of a process of this complexity require an interdisciplinary approach engaging anatomy, physiology and biomechanics [8]. This thesis is oriented mostly toward a biomechanical approach combined with neuropsychology, which will become apparent in the following chapters.

A valuable overview of gait evaluation methods and a brief review trough time was given in the books of Whittle [8], and Hausdorff [13] starting with descriptive studies in 1680s, continuing to the first kinematic measurements in 1870s, when also the term center of gravity was popularized, followed by force plate introduction in 1920s. Electromyography (EMG) resulted from muscle activity studies which started in 1940s. Ten years later mechanical analyses were presented, following by mathematical modeling in 1970s. Authors [8][13] continue to describe the major expansion in the field, that was noticed in 1980s, caused by clinical application of gait studies. The science of biomechanics, a study approaching biological systems by the methods typical for mechanical engineering[8], presented the most relevant mechanical aspects of gait analysis, including time, mass, force, center of gravity and moments of force and motion. Measuring these variables is also useful for secondary calculations of lengths of steps or strides, and cadences among the others.

Both authors [8][13] recognize a division of the methods used to perform gait evaluations. Two broad categories presented are low (also including no-tech) and high-tech referring to technical complexity, which is usually closely related to the cost increase, often resulting in the unavailability of equipment in the laboratories. The first category is characterized by self-reports and performance-based measures, especially observation. High-tech category includes EMG known as the measurement of the electrical activity of a contracting muscle, as well as force plates used to measure the ground reaction forces during standing, initiating a step, walking across it or performing other motor tasks. Motion capture systems that record a complete description of the gait kinematics in digital form, a metabolic function used to determine the energy cost of walking, or treadmills, which are used for prolonging walking times and increasing speeds when compared to walkways, are also classified as high-tech methods of gait assessment. Combining these approaches leads to highly sophisticated equipment, as it is the case with force plates built into a treadmill, which were also used for performing the empirical study in this thesis.

## 2.3. Role of cognition in gait

Gait performance is dependent on subject's anatomy, but this is not the only factor that influences it. The role of cognitive functions on gait until recent years stayed in shadow. Classical view on gait considered it rather automated motor activity with minimal higher-level cognitive demands [14]. The actual concept advocates multitude neuropsychological effects on gait [14], which triggered expansion of the research in the field, incorporating biomechanics, brain imaging, neuropsychology, physics and physiology.

## 2.4. Literature overview

Numerous studies discussed a cognitive-motor interference (CMI), confirming the importance of the research considered with the topic. Despite the fact that the effect of various concurrent cognitive tasks on gait were assessed, these tasks can be organized in the general categories. Al-Yahia et al. [7] reviewed 66 relevant studies, and presented 5 subgroups of cognitive tasks used with healthy participants, including discrimination and decision making, mental tracking, reaction time, verbal fluency and working memory. The effect of these tasks was evaluated on five outcome measures, namely speed, cadence, stride length, stride time, and stride time variability. A slightly different approach in analyzing the studies concerned with the interference between attention and gait resulted in the categorization of the experiments by focusing on either young adults or fall prone elders, examining aging-effect on the interference, and last category consisted of clinical studies [3]. Results of the studies of  in young adults, which are the most relevant category for our thesis, are presented in the next chapter.

## 2.5. Major findings

Many studies confirmed a significant decrease in gait speed, and stride length, as well as a reduction in gait cadence, while stride time and stride time variability were significantly increased under dual-task when compared to single-task condition in healthy participants [7]. Values shown in Figure 1 depict strong effects of influence of working memory domain on gait, calculated as the difference of means (except for variability) between single and dual task conditions. Strategy of slowing down under dual task condition follows from above stated, and it was noted that changes in gait speed could differentiate between healthy participants and patients with neurological disorders, as this parameter is considered an indicator of functional performance [7].

| Gait parameter | Greatest MD | Lowest difference |
|---|---|---|
| **Speed (m/s)** | -0.12  for verbal fluency | -0.02 for discrimination and decision-making |
| **Cadence (steps/min)** | −11.67 for working memory | - 0.45 for reaction time |
| **Stride length (m)** | −0.12 for working memory | −0.05 for mental tracking |
| **Stride time (s)** | 0.09 for verbal fluency | 0.02 for working memory |
| **Stride time variability** | 0.49 for mental tracking group | 0.34 for working memory group |

**Figure  1 Effect sizes of cognitive task on gait, according to [7]**

Summary of the studies concerned with cognitive-motor interference focusing on young adults, presented in [3], dealt with the demonstration of postural control dependence on attention. In the first explored study [15], it was hypothesized, and also confirmed, that balance task will interfere with a spatial (Brooks spatial memory task), but not a verbal (remembering similar sentences) memory task. The next study [16] focused on attentional demands during different postural tasks performance, concluding that postural tasks are attentionaly demanding and demands directly increase with task complexity. It presents no change in gait parameters, not complying with the next study [17], in which significant, but very small changes were detected. The whole part concerned with CMI in young adults was concluded with a suggestion that postural control might be attentionaly demanding, with the stronger effect characteristic for the tasks of higher complexity.

## 2.6. Hypothesis

Presented findings showed influence of working memory task on gait related parameters. Our aim is to further explore this phenomenon, presenting thus null hypothesis, that there is no difference between various (visual, verbal) forms of working memory on motor performance.

# 3. Empirical study

## 3.1. Essential concepts

In order to conduct the experiment, which will provide relevant data we had to consider the most suitable methodology. As we were dealing with phenomenon encapsulating two domains i.e. cognitive and motor, we encountered new methodological issue. The decision to use already verified dual-task paradigm was made. Essential concepts relevant to the both domains and methods are described below.

### 3.1.1. Basic definitions

Anteroposterior (AP)

In the studies concerned with gait analyses, anatomical terms denoting direction are often used. The term anterior describes the direction to the front while posterior to the back in reference to the body [8]. Anteroposterior thus referrers to front-back (e.g. as of COP excursion).

Mediolateral (ML)

The term medial describes a position (usually of body part) towards the midline of the body (e.g. big toe in relation to foot), and lateral means the exact opposite i.e. away from the midline (e.g. little toe) [8]. Additionally, the term mediolateral is used to denote left-right direction.

Posture

Posture is commonly understood as the way the body is positioned during dynamic or static motor tasks. Winter [2] defines the posture as the orientation of the body (or any of its segments) in relation to the gravitational vector, and explains it is an angular measure from the vertical. Postural control was defined as the control of the body’s position in space for the purposes of balance and orientation [3].

Balance

The term describing body posture dynamics in order to prevent falling, related to the inertial forces acting on it [2] is called balance. In general, balance is presumed to be the ability to move or retain the position without losing control.

Center of pressure (COP)

Center of pressure is understood as a single point, depicting all the pressures over the surface of the foot in contact with the ground [2]. It is defined as the point beneath the foot through which it can be assumed that the ground reaction force is passing [8]. Based on the statements above, COP of only one foot on the ground will be beneath it, moving someplace between the feet, if both are in contact with the surface. Whether the dynamic or static motor task is being performed, the trajectories of the COP in both, the anteroposterior, and mediolateral direction can be assessed. The process of calculating the COP from the data measured by the force plates, as well as formulas, that we have used are presented in the chapters below.

### 3.1.2. Working memory (WM)

One of the core working memory characteristic is its limited capacity, especially important for the CMI concept. WM is understood as temporary storage of information providing an interface between perception, long-term memory and action and could be recognized in two forms, verbal and visuospatial [18]. Both of the WM subcategories are characterized by finite capacity. Verbal WM is often explained by phonological loop model proposing an explanation of the ability to store information for a few seconds, which could be dependent on the articulatory rehearsal process that takes place in the real time [18]. The capacity of visuospatial, or spatial to be more specific, WM could be assessed using Brooks spatial memory task described below. Working memory is tightly related to attention and executive functions.

### 3.1.3. Gait qualities

The objective of this section is to propose concise explanation of elemental gait parameters that include temporal as well as distance factors.

Gait cycle (Stride)

Gait cycle, in literature frequently called stride, consists of two steps and it represents a basic unit in gait assessment. It is defined as the time interval between two consecutive occurrences of one of the repetitive events of walking, for which initial contact of one foot is usually taken [8][9]. Two phases are distinguished during a single gait cycle. The first, stance or support phase, comprises of a period of the foot being in contact with the ground, beginning with the initial contact and ending with toe off, followed by the transition to the second, or swing phase, specified by the foot in the air in order to move the limb [9]. The stance phase comprises some 60% of a gait cycle, while the remaining 40% is period of the swing phase.

The gait cycle is formed by the following seven repetitive events: initial contact, opposite toe off, heel rise, opposite initial contact, toe off, feet adjacent and tibia vertical [8], all of which are illustrated in Figure 2, as well as swing and stance phase subdivisions.
During the gait cycle, the period of double and single support is distinguished as shown in Figure 2. Both feet on the ground, one in initial contact and other in toe off state, are recognized as a double support. During the swing phase of one foot, the other is in the

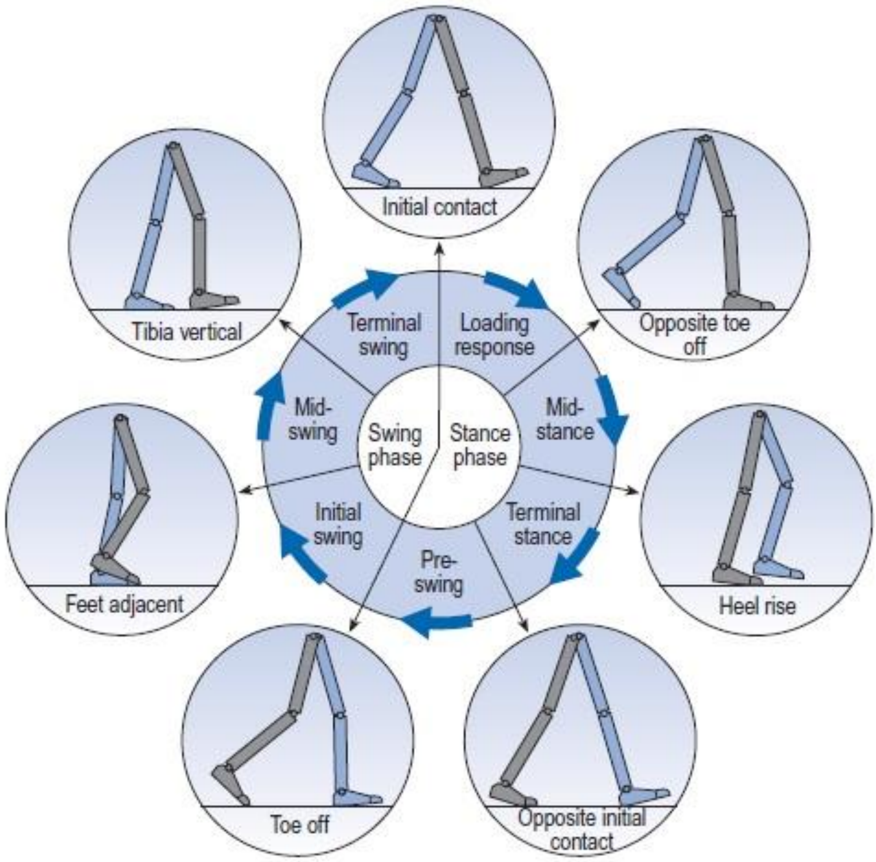



**Figure 2 Gait cycle (right leg is shown in gray color), reprinted from [8].**

single support phase, differentiating right and left support phase in accordance with the foot on the ground [9]. Double support occurs at approximately 10% of the gait cycle.

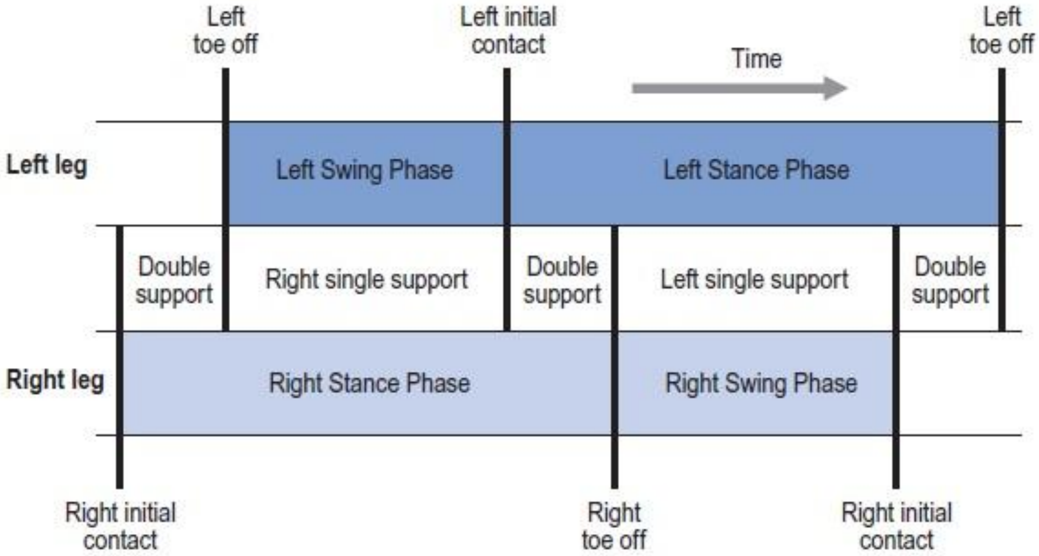



**Figure 3 Single and double support time during a gait cycle, reprinted from [8]**

Gait cycle time (Stride time)

From the above stated definition, it becomes evident, that stride (or gait cycle) time is the time duration from the initial heel contact of one foot to the next one of the same foot [16] (see figure 1). It can be calculated using the formula: $\text{cycle time }(s) = \text{time }(s) \times 2/(\text{steps counted})$, where reciprocal number of steps is multiplied by 2 due to the fact that two steps form a stride [8].

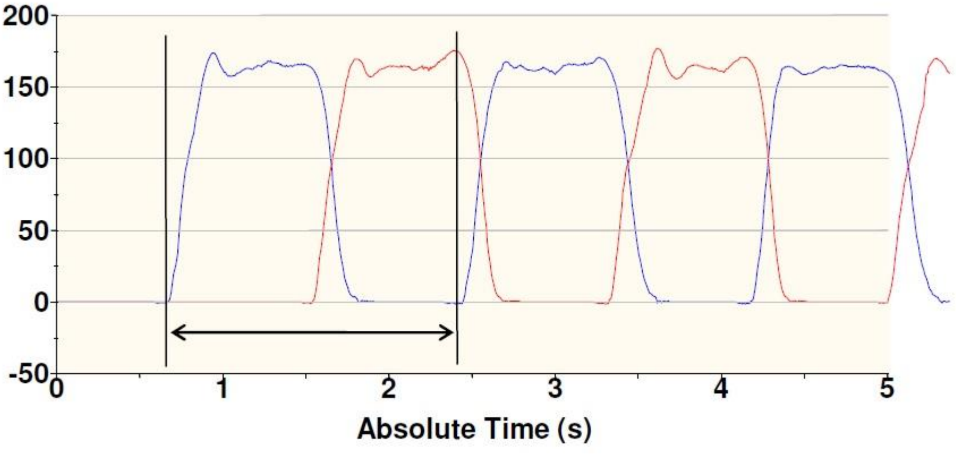



**Figure 4 Force vs. time of the gait cycle, reprinted from [19]**

Gait cycle length (Stride length)

In general, the length of the gait cycle consists of two step lengths [9]. It can be measured directly by counting the strides performed on the distance established before. An indirect method requires additional parameters, using the next formulae [8]: $\text{stride length (m)} = \text{speed (m/s)} \times \text{cycle time (s)}$ or $\text{stride length (m)} = \text{speed (m/s)} \times 2 \times 60 \div \text{cadence (steps/min)}$ or $\text{stride length (m)} = \text{distance (m)} \times 2 \div \text{steps counted}$. It is assumed, that gait cycle length might be controlled by the cortico-basal ganglia circuit, through the thalamus [7].

Base of support (BOS)

Base of support represents stride width, wherefore it is often also called like that. It has been defined as the horizontal stride width during the double support phase when the center of gravity of the whole body remains within BOS [20].

Cadence

Measure units of cadence are steps per minute, which directly reveal the essence of this parameter. Cadence states how many steps were made for a given time interval, which is usually in the range of seconds. Therefore, the following formula converts them to minutes multiplying by 60 and it looks as follows: $\text{cadence (steps/min)} = \text{steps counted} \times 60 \div \text{time (s)}$ [8]. Neural correlate of cadence is brainstem and spinal cord mechanisms [7], which are then controlled by higher nervous system structures.

Speed

In gait analyses, speed is measured in a standard way, by dividing the distance with the time of the subject's walk, $\text{speed (m/s)} = \text{distance (m)} \div \text{time (s)}$. According to [8], 6-10 meters in the middle of walking is a suitable distance for speed calculations. Whittle [8] also points out the incorrect usage of the term velocity, in literature often used as a substitute for speed, and explains that velocity is a vector and as such, it should also contain the direction parameter. Although cadence and stride length might be related to gait speed, these are probably controlled by different mechanisms, and as such not directly tied to gait speed, which is presumed to be controlled by the cortico-basal ganglia circuit, through the thalamus [7].

### 3.1.4. Dual-task paradigm

Different concepts of attentional limitations were proposed. Bottleneck reffers to the concept of sequentially executed mental operations which thus cannot be processed simultaneously [21]. Another model, called capacity sharing allows for more processing pools that opearate in parallel, but share the capacity. Next one, called crosstalk, proposes joint processing of similar operations. Whichever model was used, the fact that our cognition is limited seems to be supported many times in various studies in the field of cognitive-motor interference [6][4][3].

The main concept of dual task paradigm is to load the both assessed domains and track the interference effect. In our study, this was applied in the field of motor control, represented by the posturography, step initiation and walking, performed simultaneosly with cognitive tasks that required working memory capacity. These data were always compared to single task (ST) condition, in order to estimate the differences.

## 3.2. Methods

Experiment was performed at the Department of Neurology of University Medical Centre in Ljubljana. The core equipment used was treadmill system for gait analysis, available in the Laboratory for gait and movement disorders enabled acquiring of the distribution of pressure during several motor tasks under both, single and dual condition. The study was approved by the local ethics committee and all the participants signed an informed consent before the experiment. All the details are provided in the following sections.

### 3.2.1. Experiment design

The design of the experiment was based on the above described dual-task paradigm, consisting thus of two concurrently performed tasks. Figure 5 depicts a combination of motor tasks, painted in green, with the exception of single mental task, the one lacking a motor, symbolized with 'Ø' sign in light green. In the second row, pertinent concurrent cognitive tasks (Brooks and 2-back) are shown. Similarly to motor-tasks, light blue squares with the symbol Ø, represent complementary task only, or the lack of the actual task in other words.

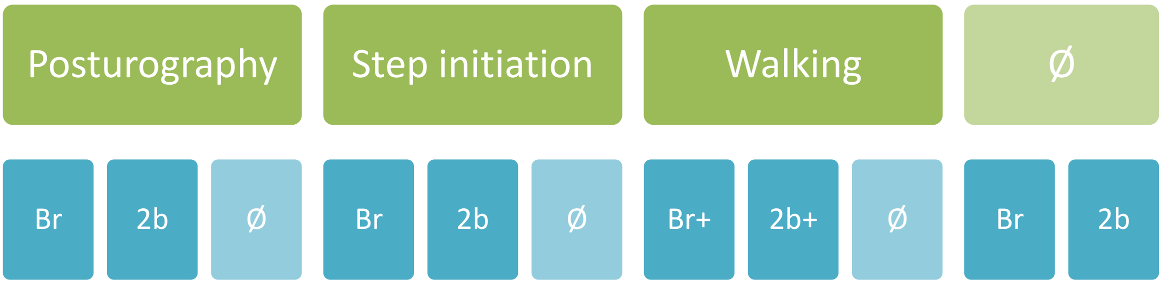



**Figure 5 Experiment design scheme**

The objective of the presented design was acquiring data in such a way to provide the information about motor-cognitive interference. Every motor task thus has to be performed under both, single and dual condition. In addition, the influence of more than one mental task type was measured, bringing the possibility of comparing the effect between them too. A walking task introduced a new parameter when compared to others, speed. The experiment has been designed with an intention to provide a wide variety of meaningful data, also by manipulating the speed in combination with each cognitive task during walking. Detailed description of the performed tasks is given in the next chapter.

### 3.2.2. Tasks

The experiment always started with a familiarization phase where general explanation of all the tasks was given, continuing with measuring the time a participant needed to handle the distance of 80 meters by walking at a comfortable pace, which was used for determining the subject's natural speed. The walking speed under dual conditions was also measured. Concurrent cognitive tasks were randomized and participants were instructed to walk at the preferred speed and not to hurry (Sunday walk across the park was used as an example.). Before performing the cognitive task, participants received detailed instructions. Wireless headphones were used during all the trials in order to preserve equal conditions. Every trial lasted for two minutes. Speeds measured, means of which are presented in Figure 13, were subsequently set on a treadmill. Constant speed of treadmill's belt was kept during every trial in order to prevent the strategy of slowing down while walking under dual task condition, which is typical for walking on static surfaces [22]. Our presumption was that walking over ground and on a treadmill is comparable.

#### 3.2.2.1. Cognitive tasks

All of the necessary instructions during the cognitive tasks in the whole experiment were given in the Slovene language in the form of canned sounds played trough wireless headphones.

Brooks spatial cognitive task. (Br)

This cognitive task was used for loading visuospatial working memory capacity. Before the task started, participants were informed about the required output of this concurrently performed cognitive task in the form of eight numbers written to the matrix in the order specified during the task. The staring position of the number one was always square with coordinates 2,2 in the matrix with fixed size of 4 x 4 as shown in the Figure 6. After each new trial, the experimenter made sure that the participants knew where the starting position was and repeated the matrix dimensions. During the task, instructions were given on where to put the next number in the imagined matrix through the headphones. After finishing, subjects were asked to write the numbers, which required them to remember the positions. This task was used similarly as in study of Kerr et al described in [3]. All trials that were used in our experiment can be found in Appendix 4.

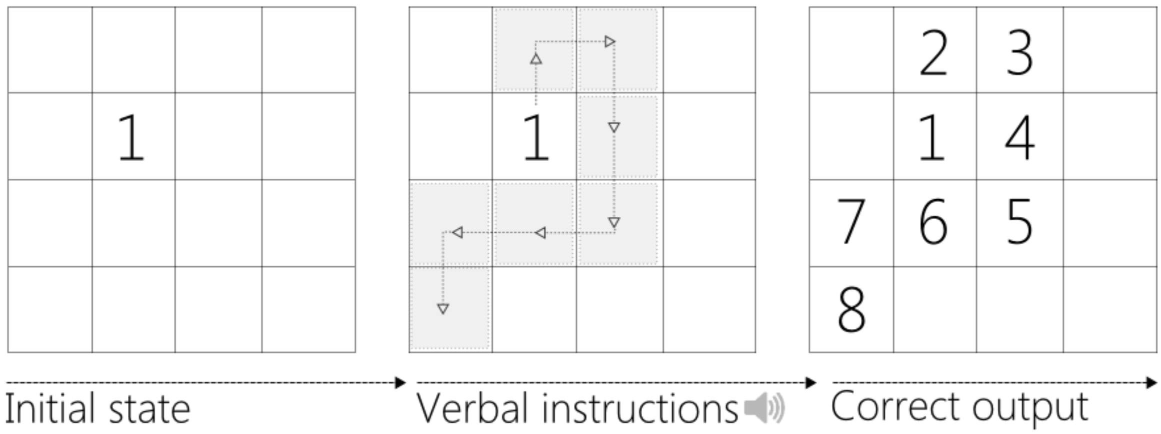



**Figure 6 Flow of the Brooks spatial memory task**

2-back cognitive task. (2b)

2b represents N-back task. which is used for accessing the verbal part of working memory. It is a parametric paradigm and in our study 2 was chosen as parameter value, calling it therefore 2-back task. This parameter represents the number of stimuli a subject is required to remember in order to provide the desired output. In our experiment, participants were required to monitor series of 30 numbers, that were presented through the headphones, and to respond whenever the presented stimuli was the same as the presented 2 steps before as indicated in the Figure 7 by the numbers in red. Appendix 5 holds all the trial used for our study.

5 7 1 8 **1** 4 8 7 **8** **7** 5 5 3 **5** 6 9 **6** 7 **6** 2 4 **2** **4** 9 9 **9** 3 1 8 **1**

**Figure 7 2-back task trial example**

We chose these two cognitive tasks to define which domain of working memory interacts with motor functions.

Empty motor task represents single mental task condition (Me)

In this block of our experiment participants carried out the two above mentioned cognitive tasks, while sitting on the chair with their eyes closed and headphones on their heads as it is presented in Figure 8.

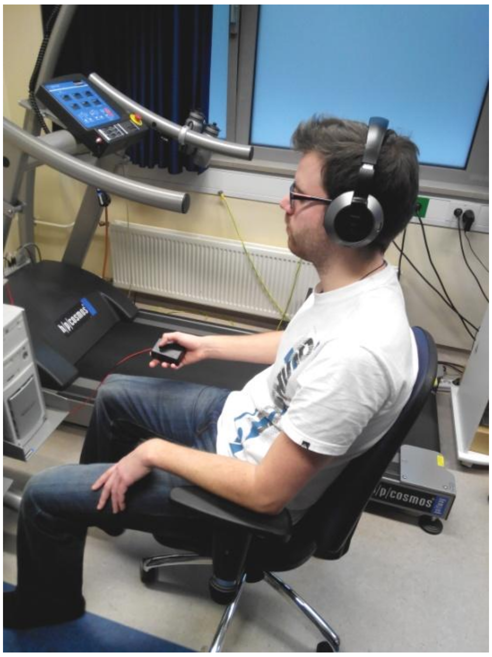


**Figure 8 Performing the single mental task**

3.2.2.2. Posturography (Po)

The main objective of this task was quantifying the vertical forces acting on the surface during the subjects' performance of upright stance in static condition. The participants were instructed to step on the treadmill, put their feet together, hands into relaxed position along the body and head in the position as if looking forward, but with eyes closed (see Figure 9). This task, called posturography, consisted of three trials, as depicted in Figure 5.

**Figure 9 Subjects performing posturography task**

Assessed parameters included sway in both ML and AP directions, speed and path of the COP, as well as cognitive task outcome for dual-tasking condition.

#### 3.2.2.3. Step initiation (Si)

As it has been customary with other motor tasks performed in the experiment, this one was also combined with each of the used cognitive task. The motor task performed in this block was making a step forward or backward based on the position of the subject on the treadmill. In contrast to other blocks, this one was controlled by the indicator in the form of red LED light located on the wall in front of the treadmill allowing so direct visibility to it from the perspective of the participants (indicated by the red dots in Figure 10). It was used only for the purposes of this motor task, in order to prevent stepping in the rhythm of cognitive task instructions played trough the headphones, which was observed during the pilot study. The light was manipulated by the custom-made switching script that ran on the Raspbery Pi computer and was synchronized with the E-prime application. It was used to indicate the start of the step. The experimenter instructed the participants to step up on the backside of the treadmill, placing them so to the center of the rare force plate, in order to move to the next one after performing the following step. They were asked to assume a position of feet they are feeling comfortable in, as opposed to the specified requirements in the posturography block. The light in both on and off state was demonstrated.

Anticipatory postural adjustments (APA) represent the mechanism that acts just before the step initiation and it is responsible for adjusting the center of body mass by changing the position of the COP in reverse [23]. APAs are shown in Figure 21 on the second graphs, starting at the left blue marker and ending at the second.

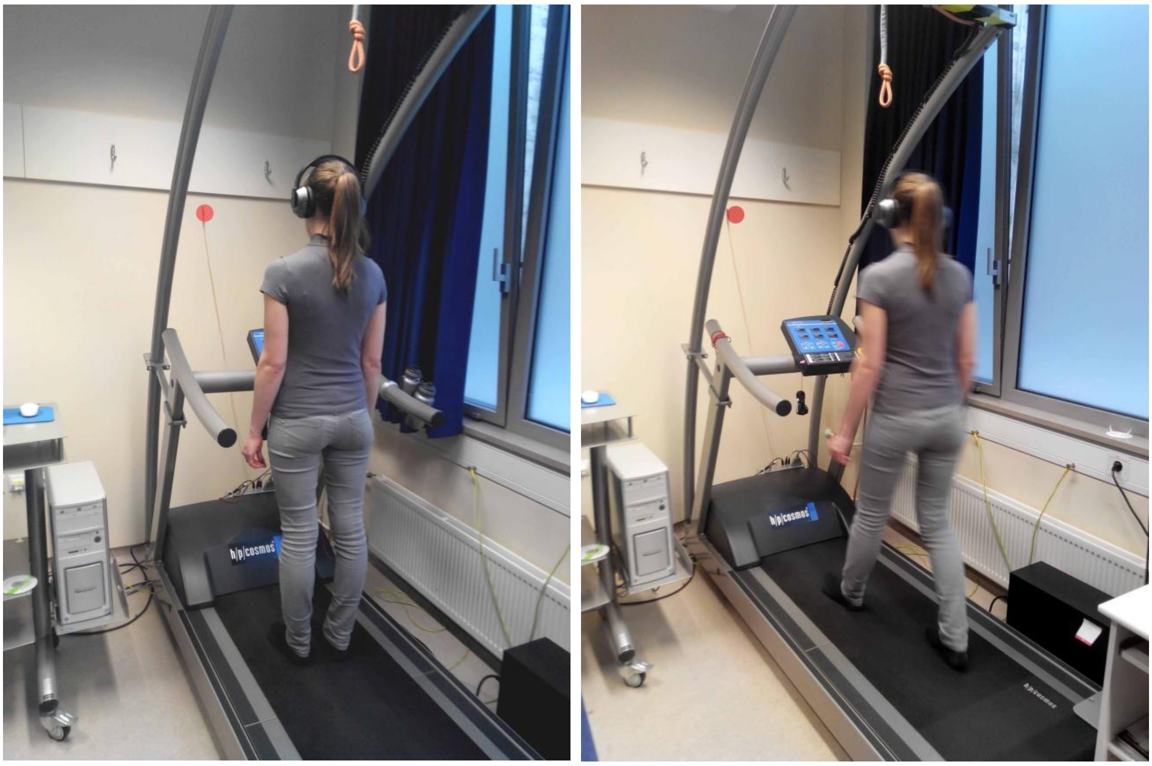


**Figure 10 Step initiation task environment**

3.2.2.4. Walking (G)

As the name of the task discloses, the motor task performed in this block was walking. The subjects were always beforehand instructed to follow the cognitive task. Specific instructions for how the participants should walk were purposely not given. A minimum time of 5 minutes, or more if participants required so, was used for letting them walk on the treadmill. After they confirmed that they are feeling comfortable, the trial was started. Three initially measured speeds were used in this block, each with appertain cognitive task. A single task condition requiring only the motor task was also performed three times, combined with all three initial speeds. Standard cognitive tasks set was used. The subjects were required to walk without support, thus the usage of handles installed on the treadmill was forbidden. Headphones were used in each trial.

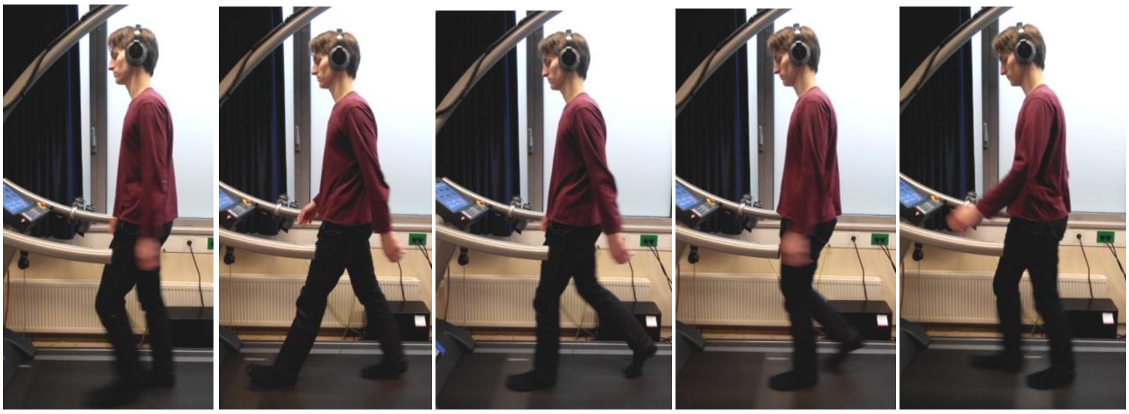


**Figure 11 Walking task setting**

Gait parameters that were acquired during the performance of this part of the experiment consisted of stride and step time, base of support, stride length, double support time, progress angle and cadence. Although belt speed was set according to initially measured natural speed, it was monitored again due to potential small changes caused by the standard physical features of walking as resistance.

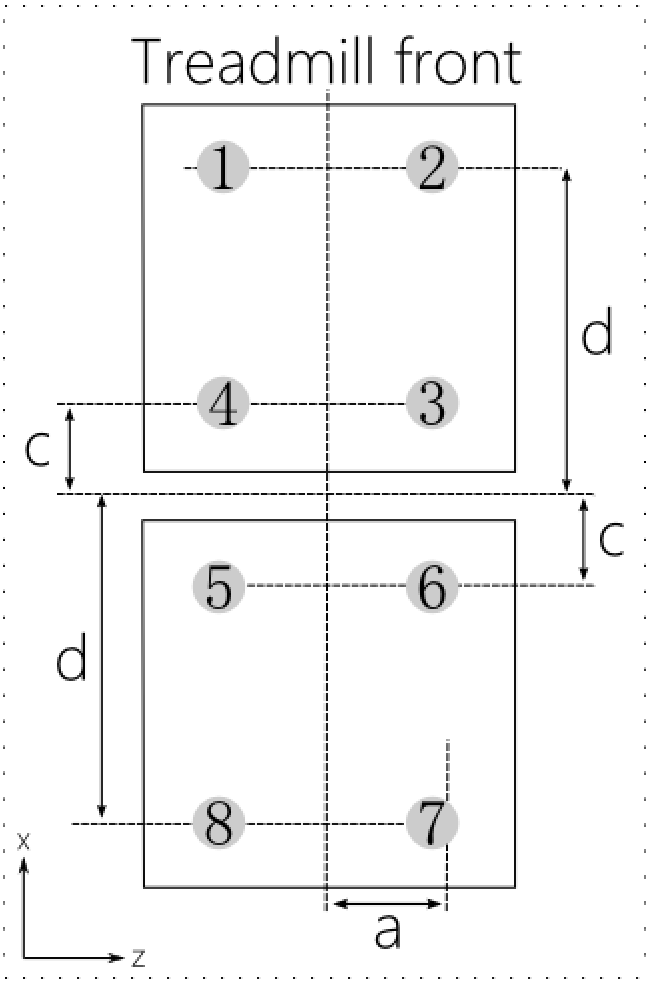
## 3.2.3. Setting

The aim of this chapter is to provide an overview of the experiment setting, including hardware and software equipment used for performing the experiment.

### 3.2.3.1. Apparatus

The core equipment used for the data acquisition was a treadmill (H/P/cosmos Kistler Gaitway) with the dimensions of running surface 1500 × 500 mm. Recordings of ground reaction forces in vertical, anteroposterior and mediolateral directions were made using two force plates, installed beneath the treadmill's moving belt, first in front of the treadmill and second in the rear. Both were equipped with four force sensors situated in the plate's corners, marked with a number, always starting from the upper left corner as depicted in Figure 12. COP calculations were done using the data from the sensors and dimensions of the plates, which are described in chapter 3.3.

Additional hardware included two PCs for running the software for cognitive tasks and Gaitway software separately, as well as Raspberry Pi for additional scripts. Wireless headphones were used in order to present the cognitive tasks to the subjects. A custom-made button was also used as the interface for evaluating 2b tasks.




Distances depicted

a = 30.632 cm

c = 3.0150 cm

**Figure 12 Force plates scheme according to manual [19]**

3.2.3.2. Software

Gaitway Software (Kistler, type: 2813M01-A20, version: 2.0.9.0) was used for gathering the data from the treadmill, which was controlled by the experimenter using the default application H/P/ Cosmos para control (H/P/cosmos sports & medical gmbh, build: 20007-11-27.0028, version: 201). Custom Python application, which ran on the Raspberry Pi computer, was made in the laboratory and it served to control the LED light in the step initiation motor task for indicating the step start command. The core application, synchronizing all the equipment, also used for instructing the cognitive tasks and following the procedure flow, was E-Prime (Psychology Software Tools, Inc., version: 2.0 Professional).

### 3.2.4. Subjects

Thirty-seven participants were recruited for the experiment. Four of the 37 original participants' data were dropped from this sample due to technical difficulties during the data acquisition. Data from 23 females and 10 males were used in the study. Subjects mean age was 25.5 ± 2.5 years (range 21 - 35), weighed 65.7 ± 11 kg and were 173.1 ± 8.5 cm high. The majority of the participants were studying at the time the experiment was conducted and others already had postgraduate degrees. All subjects were either solely native Slovenes or bilingual.

### 3.2.5. Output

The experiment produced different types of output data. First, printed protocols (see Appendix 1) of every participant, consisting of signed consent, basic information about the subject, specific trials scheme, as well as Brooks spatial memory task results. Next, files generated in accordance with the treadmill sensors and button output in two formats, gaux and exp, which will be talked about in detail in the following chapters, as they required considerable degree of post processing in order for the  usable data to be extracted. A part of the data collection of every subject were also sounds recorded as the output of the story tasks.

The mean preferred walking speed, measured while performing Brooks spatial memory and N-back task, was 1.29 ± 0.44 and 1.31 ± 0.44 m/s respectively. The single task condition mean speed was 1.33 ± 0.19 m/s.

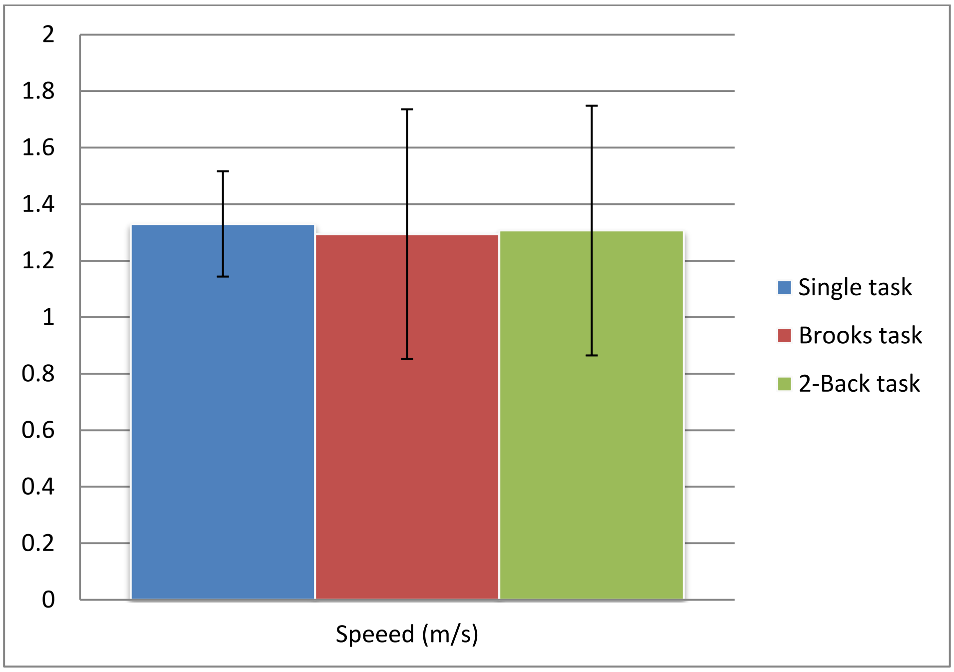



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**Figure 13 Means of preferred speeds under single and dual task condition (with standard deviation)**

## 3.3. Data preprocessing

This chapter is meant to explain the process of extracting the data from output files consisting of raw values only, in order to prepare them for analysis. It is organized according to performed tasks. Algorithms were developed for extracting the data of each motor, as well as 2-back tasks outputs. They were implemented in Matlab. (MathWorks, version: 7.12.0.635), chosen for its ability to relatively easily deal with large matrices, which was the structure of our data.

**Figure 14 Gaux file structure**

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| | | Vertical force plate1 | | | | Vertical force plate 2 | | | | | | Auxiliary data (2b) | | | | | |
| Sample | Time (s) | Sensor 1 | Sensor 2 | Sensor 3 | Sensor 4 | Sensor 5 | Sensor 6 | Sensor 7 | Sensor 8 | Belt speed | | N sounds | P sounds | Button (-) | | | |
| 0.00 | 0.00 | -0.02 | 0.00 | -0.02 | 0.00 | 0.78 | 0.87 | 0.43 | 0.55 | 0.00 | | 0.01 | 0.00 | -0.32 | | | |
| 1.00 | 0.01 | -0.02 | 0.00 | -0.02 | 0.00 | 0.78 | 0.87 | 0.43 | 0.55 | 0.00 | | 0.00 | 0.00 | -0.31 | | | |
| 2.00 | 0.02 | -0.02 | 0.00 | -0.02 | 0.00 | 0.78 | 0.87 | 0.43 | 0.55 | 0.00 | | 0.00 | 0.00 | -0.31 | | | |
| 3.00 | 0.03 | -0.02 | 0.00 | -0.02 | 0.00 | 0.78 | 0.87 | 0.43 | 0.55 | 0.00 | | 0.00 | 0.00 | -0.31 | | | |
| | | | | | | | | | | | | | | | | | |
| 11999.00 | 119.99 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.01 | 0.00 | | 0.00 | 0.00 | -0.31 | | | |

### 3.3.1. File structure

As it was reported above, output files that required post processing were exported from Gaitway software in two formats, first with a .gaux (Gaitway Auxiliary File) file extension, and file with the .exp (exported) extension. Apart from small differences, structure (illustrated in Figure 14) of both files was similar, containing raw voltage data. The table below shows matrix of 18 columns and 12000 rows, which store the core information. In addition, files also contained headers and footers, structure of which varied among two file formats, thus it had to be eluded by the Matlab scripts as it was not of relevance for further processing. Columns of the matrix represent variables, starting with sample number and time in seconds. Data were acquired at the 100 Hz interval, creating so 6000 rows for each minute of recording. Trials in our experiment had a duration of two minutes, generating thereby 12000 rows in the file. Columns 3-6 serve as a force plate no. 1 data holders, beginning with the first sensor and ending with the fourth one. In like manner, columns 7-10 represent sensors of the second force plate. Succeeding column consists of the speed of the belt values. The remaining three columns, 13-15, were used for auxiliary data acquisition, as there is an option to use available free channels for these purposes. In our experiment, they were fitted with the data of 2b task, column 13 represents false cues, 14th the correct ones, ending with the output from the button distinguishing between pressed and released state. Auxiliary data were discrete nature, ranging from less then 1, or greater then 3 Volts, for absent and present sound state respectively, which applies for both, channel of correct (positive) and incorrect (negative) sounds. Discrete nature was symptomatic for 15$^{th}$ column as well, representing button presses, with a range of values above -0.3 V for pressed state, and below -1 V for released button

### 3.3.2. Common preprocessing features

Even though a specific explanation of data processing of each task follows in the next sections, some of the general concepts that were common for all of them are gathered here.

All of the algorithms were implemented in Matlab (MathWorks, version: 7.12.0.635 ) and the majority of the input data was obtained from the treadmill. The core monitored quantity was Center of Pressure. COP computations were performed according to the following formulas, given in Kistler treadmill manual [19], implemented in Matlab scripts. The formulas below contain the constants (a, d, c) representing the distances as specified in Figure 12. F in the formula stands for measured value of particular sensor.

Forces acting on the front plate only, in the anteroposterior plane were calculated as a division of summed values of the sensors 1, 2, 3 and 4 as follows: $AP = (d \times F1 + d \times F2 + c \times F3 + F4)/(F1 + F2 + F3 + F4)$. Mediolateral excursions of COP were determined the following way: $ML = ((-a \times (F1 - F2 - F3 - F4)))/(F1 + F2 + F3 + F4)$. Pressure acting on rare plate was estimated succeeding way: $AP = -(c \times F5 + c \times F6 + d \times F7 + d \times F8)/(F5 + F6 + F7 + F8)$ and $ML = (-a \times (F5 - F6 - F7 + F8))/(F5 + F6 + F7 + F8)$.

Tasks requiring foot contact on both force plates (step initiation) were evaluated by using the next formulas for AP and ML COP respectively: $AP = ((d \times F1 + d \times F2 + c \times F3 + c \times F4) - (c \times F5 + c \times F6 + d \times F7 + d \times F8))/(F1 + F2 + F3 + F4 + F5 + F6 + F7 + F8)$ and $ML = (-a \times (F1 - F2 - F3 + F4 + F5 - F6 - F7 + F8))/(F1 + F2 + F3 + F4 + F5 + F6 + F7 + F8)$.

### 3.3.3. Posturography

Measurements performed during this block of the experiment were gathered in a standard gaux file. We were interested in analyzing the data acquired in the middle of each posturography trial. In accordance with this, the proposed algorithm first read the whole input file and subsequently excluded the first and last 15 seconds of the recording, focusing only at the motor task performed in the middle 90 seconds. Thereafter, computations of COP were started and plotted on the 6 graphs, where the experimenter could check if they fit the expected criteria. As participants were standing on rare plate only during this task, the data obtained by the sensors 1 to 4 were expected to be at their baseline values around zero, represented by the 4 flat lines trough the time as shown in Figure 15. In contrast with these almost flat lines, the next graph should clearly display movement caused by the

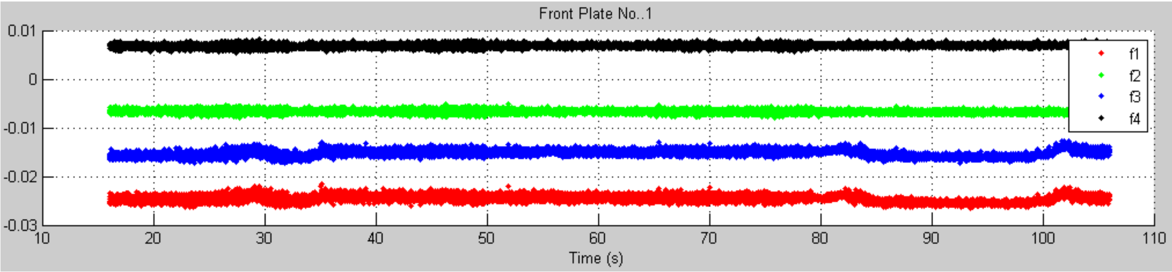


**Figure 15 Values of front force plate sensors during posturography task**

subject standing in the center of rare force plate. Figure 16 depicts values of the 2nd force plate sensors. Calculations of mediolateral sway are presented in the next graph and the expected values are shown in Figure 17, followed by AP sway depicted in the Figure 18. Total COP calculations were plotted in the next graph and standard graph looked like the one in Figure 19. In case of undamaged file, the evaluator could start other calculations, and save them to the output file.

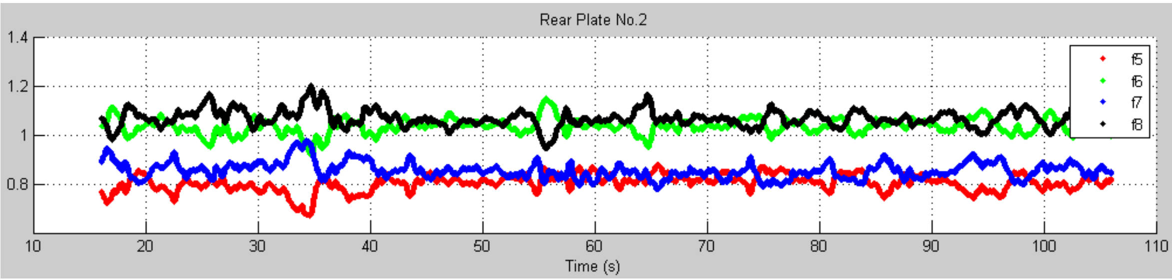


**Figure 16 Example of sensors values of rare plate in posturography task**

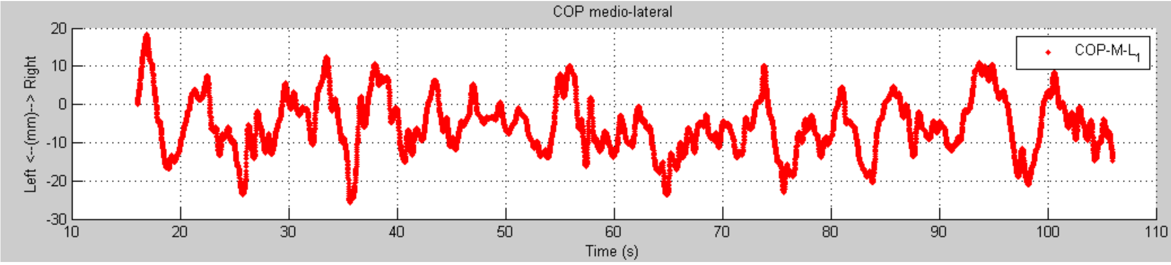


**Figure 17 ML sway during standing**

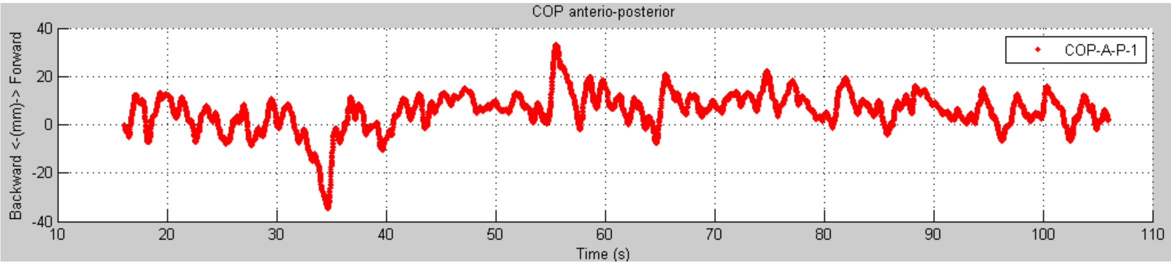


**Figure 18 Expected AP sway in posturography task**

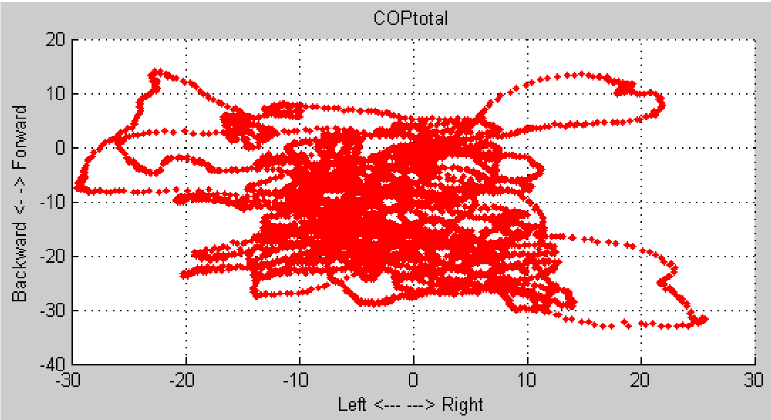


**Figure 19 Total COP during standing**

## 3.3.4. Step initiation

The nature of data acquired during the step initiation tasks required human intervention during post-processing, which conditioned the development of the interactive script. The implemented algorithm dealt with the input data of all 8 sensors as step was initiated on one and ended on the other force plate. After reading the file, program computes AP values of the whole trial as depicted in Figure 20. It is important to point out that one trial was composed of 12 steps in average and all were written in one file. As we wanted to analyze only steps made towards the front, we wrote the function *find_patterns*, which subsequently isolated them and executed the division of data. The separation points are indicated by the blue dots in Figure 20. Afterwards, data of separated step were plotted in 6 graphs showing 1st and 2nd force plate's sensors values, ML changes in COP, followed by AP (see Figure 21) and two graphs representing COP values of one and both plates. Now the algorithm expects 5 markers in the plots, representing start of the step, start of the

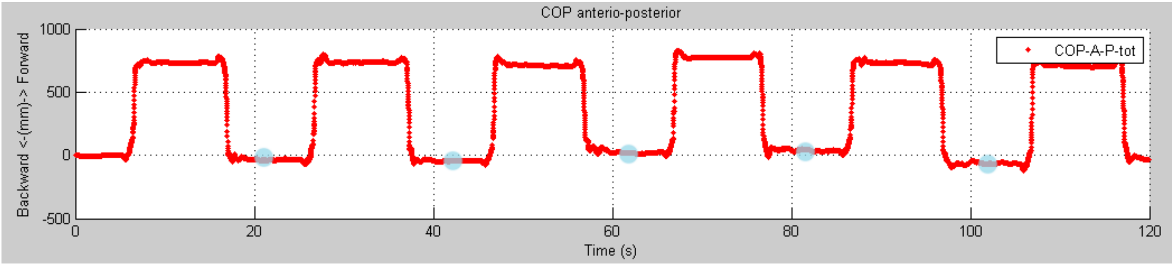


**Figure 20 AP COP values during SI trial**

APA, end of the APA, steady state after the finished movement and the finished step as indicated by the blue dots in Figure 21. When markers are carefully set, calculations will be performed based on them. The following parameters are some of the data subsequently written to the output file: APA start time, swing foot off time, after APA steadystate, APAduration, StepLength, COP path.

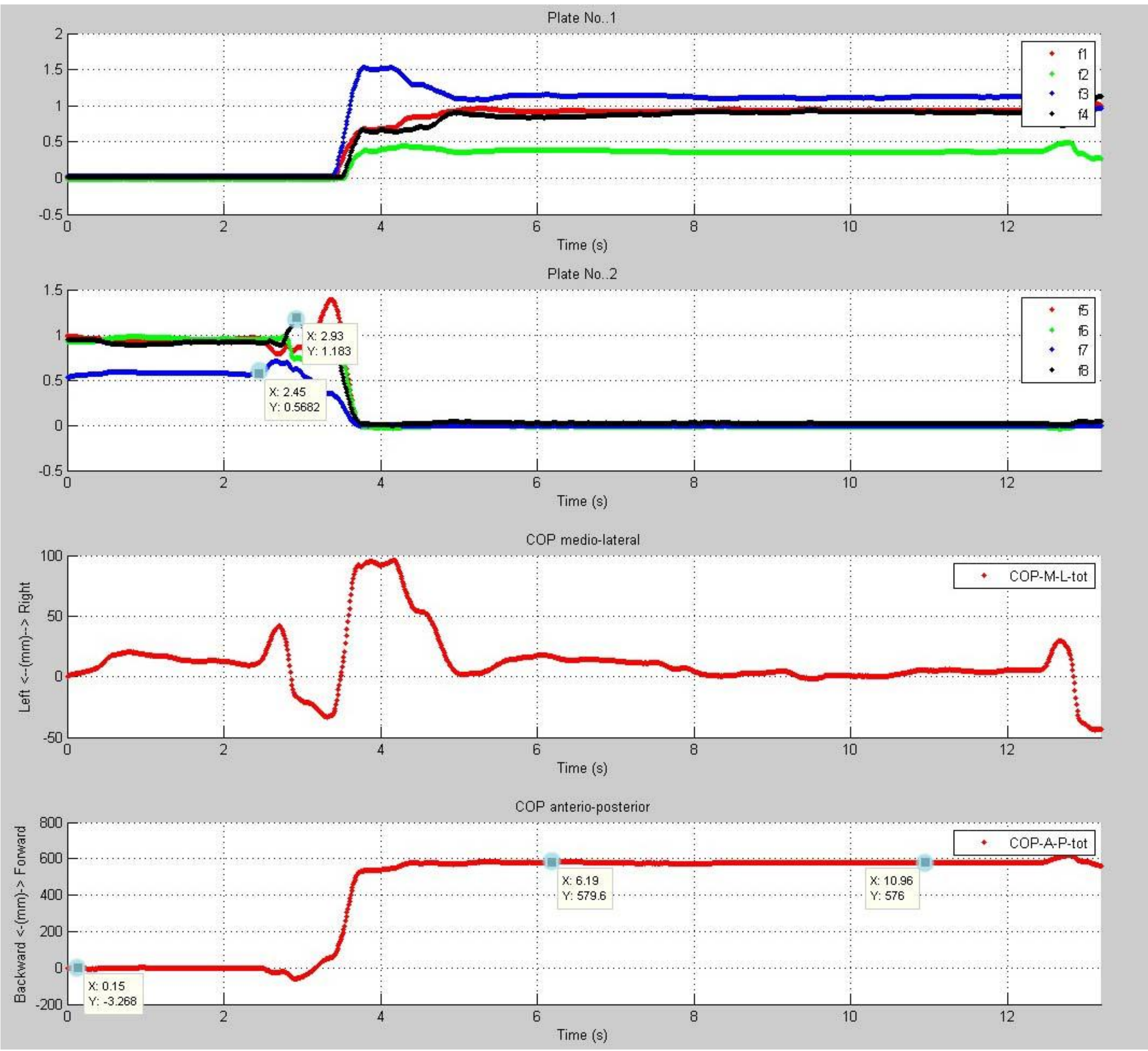


**Figure 21 Interactive environment of SI script**

## 3.3.5. Gait

Commercially available Gaitway software was used for assessment of gait related parameters.

## 3.3.6. Concurrent cognitive tasks

Two cognitive tasks were used in our experiment. Participants' answers concerned with the Brooks spatial memory task were reported filling an empty matrix printed on a paper and therefore evaluated manualy.

2b tasks data were captured in Gaitway auxiliary files using the channels 13 to 15. As it was indicated in Figure 14, these data consist of three variables, particularly, negative sounds, positive sounds and output from the button used, respectively. Sounds were reproduced using wireless headphones delineating within task input for participants. If the presented number was correct in the sense of 2b task assignment, a positive signal was recorded and vice versa for negative sounds. A presence of a signal was conceived as the value greater than 3 V and absence as less than 1 V. A button was considered pressed if the value did not not exceed -1 V. Data of these variables were used as an input for the 2b analyses. The algorithm written in Matlab (evaluate2b.m) first isolated the beginnings of both sounds and subsequently controlled the state of the button during and 300 samples after them (doublecheck this). The output consists of the number of correct, missing and wrong reactions written to the Microsoft office Excel file.

## 3.4. Summary and outputs

In the previous chapter, we have provided an overview of the data post-processing and presented the amount of work required for raw data manipulation in the thesis. This part was essential and inevitable for further analyses, considering its output in the form of a robust file consisting of usable data representing the experiment itself.

# 4. Results

## 4.1. Statistical analyses

The phase described in the previous chapter provided us with usable data that could be additionally analyzed. The repeated-measures analyses of variance (RM-ANOVA) were performed on the data of each motor task. Cognitive tasks were set as within-subject factor, always consisting of a single motor, Brooks spatial memory and 2-back task. The gender of the participants was set as between-subject factor. The aim of this chapter is to present the results of the statistical analysis.

### 4.1.1. Posturography

Results of RM-ANOVA performed with the data acquired during the posturography task (see Appendix 2) revealed significant main effect of factor Cognitive tasks on following parameters: COP path length ($F = 3.653$, $df1 = 1$, $df2 = 62$, $p = 0.32$), as well as of approximate entropy ($F = 5.692$, $df1 = 1$, $df2 = 62$, $p = 0.005$) and standard deviation ($F = 5.395$, $df1 = 1$, $df2 = 62$, $p = 0.007$) of anteroposterior sway. Pairwise comparisons showed

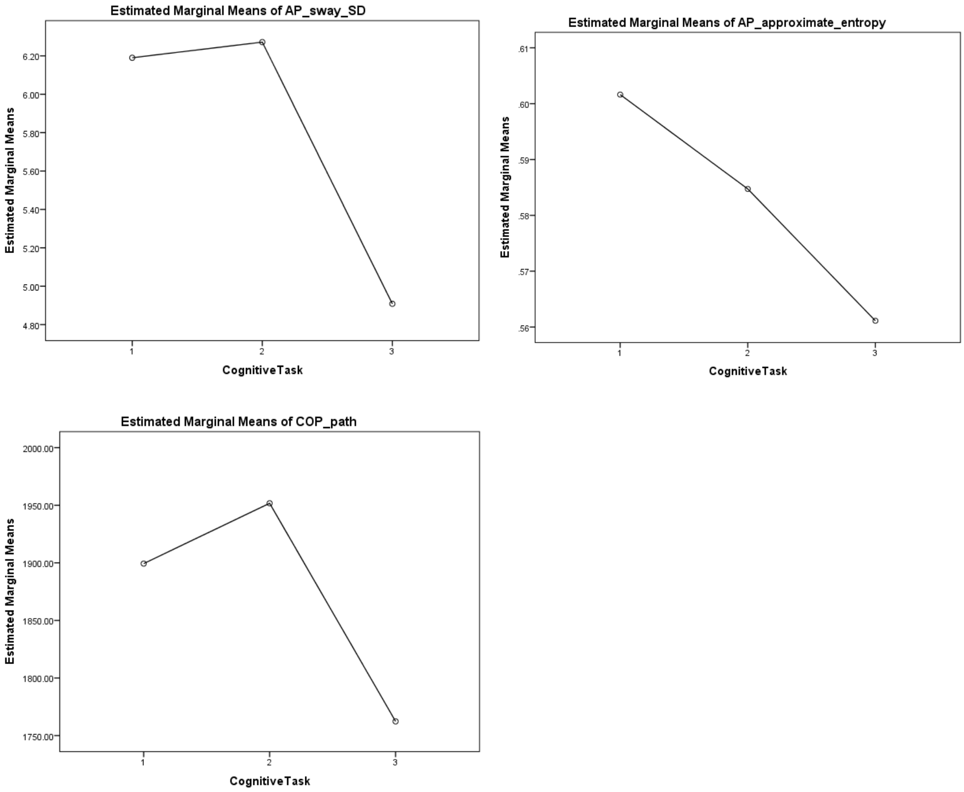


**Figure 22 Significant parameters in posturography task**

| Measure | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| **ML_sway_amplitude** | 38.312 | 2.738 | 32.729 | 43.896 |
| **ML_sway_SD** | 5.893 | .341 | 5.198 | 6.589 |
| **ML_approximate_entropy** | .579 | .017 | .544 | .615 |
| **AP_sway_amplitude** | 36.406 | 2.726 | 30.846 | 41.967 |
| **AP_sway_SD** | 5.790 | .320 | 5.137 | 6.443 |
| **AP_approximate_entropy** | .582 | .018 | .546 | .619 |
| **Maximum_COP_speed** | 142.263 | 26.061 | 89.111 | 195.415 |
| **COP_path** | 1871.139 | 71.214 | 1725.897 | 2016.382 |

**Figure 23 Posturography, means**

significant ($p < 0.001$) differences in COP path, standard deviation of sway in AP direction and also in the approximate entropy, between 2b task and both other cognitive task conditions (single motor task and Brooks task). for standard deviation of sway in AP direction and additionally revealed significance ($p = 0.013$) also between Brooks and 2b tasks. The approximate entropy also significantly ($p = 0.003$) differed between single condition and 2-back, as well as ($p = 0.023$) Brooks and 2-back task. The same pattern was observed with the length of the COP path ($p = 0.024$ and $p = 0.007$).

Considering gender differences in posturography task, statistically significant differences were found only for ML approximate entropy ($F = 4.364$, df1 = 1, df2 = 31, $p = 0.045$) and standard deviation of sway in anteroposterior direction ($p = 0.049$). Marginal means are depicted in Figure 23.

### 4.1.2. Step initiation

The repeated-measures analyses of variance of step initiation (attached in Appendix 3) data tracked the effects of cognitive tasks on duration, amplitude of ML and AP excursion of anticipatory postural adjustments. Among the monitored parameters were also the maximal speed of the COP, as well as its path length. The length of the step made by a participant toward the front of the treadmill was also included in ANOVA. Univariate tests pointed out to significant effect of cognitive tasks on both AP ($F = 15.842$, df1 =1, df2 = 60, $p < 0.001$) and ML ($F = 7.623$, df1 =1, df2 = 60, $p = 0.001$ ) sway amplitudes, but also on maximal speed of the COP ($F = 14.494$, df1 =1, df2 = 60, $p = 0.000$) and COP path length ($F = 8.215$, df1 =1, df2 = 60, $p= 0.001$). No significant effect was found for the APA duration and step length parameters. Tests of between-subjects effects declared significance only for maximal ML deviation of APA ($F = 17.037$, df1 =1, df2 = 30, $p = 0.000$) and COP path length ($F = 13.297$, df1 =1, df2 = 30, $p = 0.001$).

Total significant differences were detected between all the tasks in APA mediolateral (means: ST = 33.586 ± 1.808; Br = 37.111 ± 1.825; 2b = 40.114 ± 2.256) and anteroposterior deviation amplitude (ST = 36.167 ± 3.467; Br = 42.407 ±2.361; 2b = 48419 ± 2.752), as well as for maximal COP speed (ST: 725.216 ± 32.808; Br = 824.302 ± 35.382; 2b = 891.337 ± 39.604). COP path length significantly varied between single (mean = 166.622 ± 5.582) and dual task conditions (Br = 179.486 ± 5.988; 2b = 183.340 ± 7.373). Significant differences between sexes were observed in APA ML amplitude (p <

0.001) and COP path length (p = 0.001). Figure 27 shows significantly influenced motor parameters of step initiation by cognitive tasks.

| Measure | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| **APA_duration** | .575 | .013 | .548 | .602 |
| **APA_ML_amplitude** | 36.949 | 1.719 | 33.439 | 40.459 |
| **APA_AP_amplitude** | 42.331 | 2.610 | 37.001 | 47.661 |
| **Max_COP_speed** | 813.618 | 31.267 | 749.762 | 877.474 |
| **Step_length** | 501.040 | 17.798 | 464.692 | 537.387 |
| **COP_path_length** | 176.483 | 5.852 | 164.532 | 188.433 |

**Figure 24 Means of step initiation tasks**

### 4.1.3. Walking

RM-ANOVA performed with the data gathered during walking tasks under single and dual task conditions with appropriately adjusted speeds in accordance to each concurrent task affirmed the effects stated below. Univariate tests results pointed out to significant concurrent cognitive task effect on stride length (F = 10.647, df1 =1, df2 = 32, p < 0.001), stride time (F = 8.314, df1 =1, df2 = 32, p = 0.001), step time (F = 8.022, df1 =1, df2 = 32, p = 0.002), as well as on cadence (F = 9.184, df1 =1, df2 = 32, p = 0.001), not confirming

| Measure | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| **StrideLength** | 126.344 | 3.305 | 119.337 | 133.351 |
| **Double_support_time** | .131 | .003 | .126 | .137 |
| **Stride_time** | 1.021 | .014 | .991 | 1.050 |
| **Step_time** | .507 | .007 | .493 | .522 |
| **Cadence** | 118.088 | 1.615 | 114.665 | 121.510 |

**Figure 25 Marginal means of walking tasks**

the effect on double support time during walking. Pairwise comparisons reported statistically significant effect for stride length between single task condition and Brooks spatial working memory task ($p = 0.009$) and 2-back ($p < 0.001$), with no significant differences detected in influence of stride length between two cognitive tasks. Double support time effect was significant ($p = 0.041$) only in single motor tasks when compared to Brooks task results. The next gait parameter monitored was stride time, showing significant differences between concurrent task-free condition and both cognitive tasks (Br: $p = 0.005$, 2b: $p = 0.001$) while walking. The same effect was shown for step time (Br: $p = 0.01$, 2b: $p = 0.02$) and cadence (Br: $p = 0.004$, 2b: $p = 0.001$). Motor related parameters with statistically significant effects are shown in Figure 26.

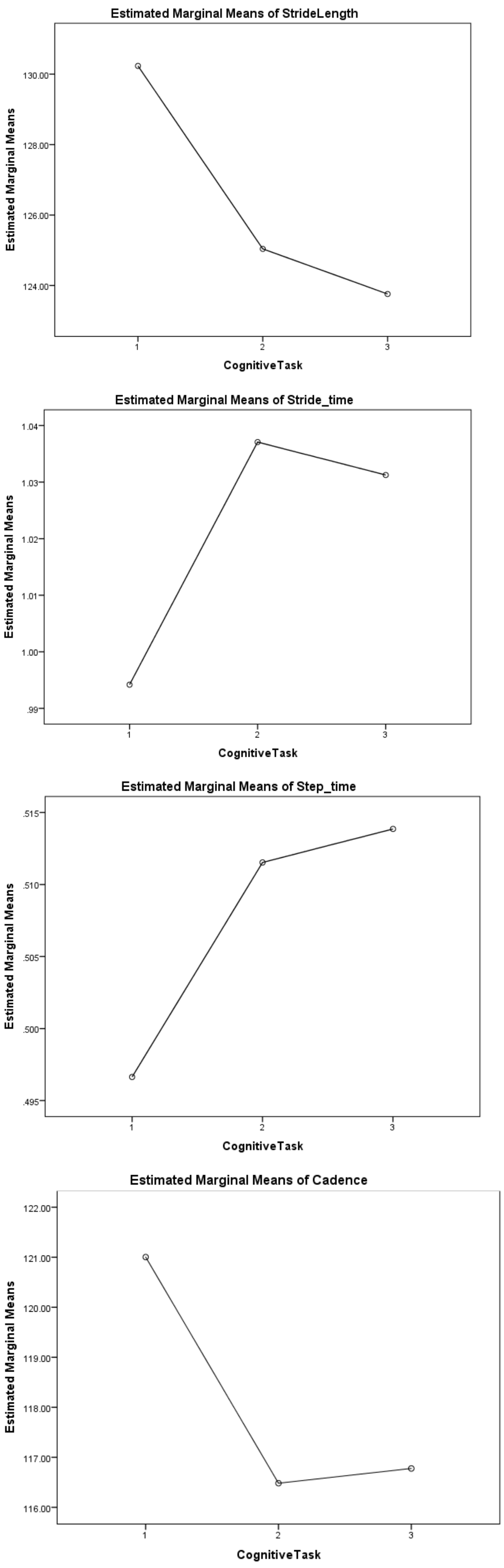


**Figure 26 Gait parameters vs. cognitive tasks**

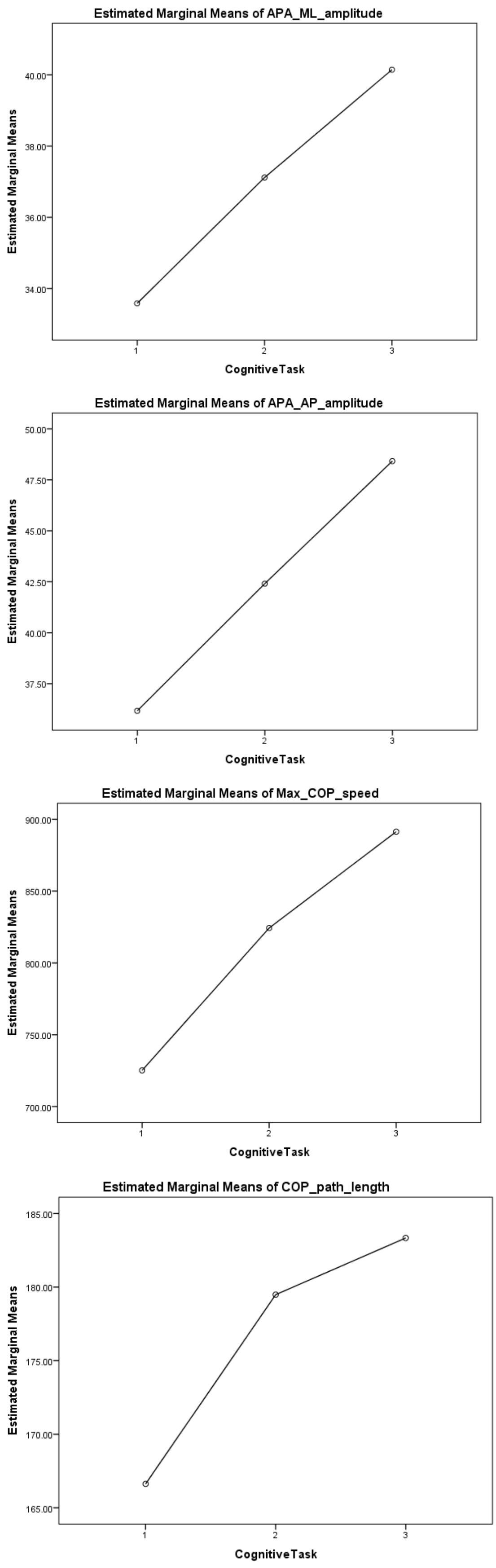


**Figure 27 Step initiation statistical significances**

## 4.2. Discussion

As it was already mentioned in this thesis, many authors incline towards the new concept of motor tasks, arguing so in the favor of cognitive-motor interference. Research in the field of working memory’s influence on initiating a step, gait, standing or performing another motor task was initiated and it is going through great expansion in the area of research per se, as well as in clinical application. Our results are consistent with the findings showing that motor tasks performance is influenced by concurrently performed tasks requiring a load of working memory.

Statistical analyses of our data acquired during posturography tasks clearly show influence of cognitive tasks on three parameters e.i. COP path length, standard deviation and approximate entropy of anetroposterior sway. A significant difference in COP path length effect between single task and 2-back condition was presented, but it was present also between Brooks spatial memory task and 2b, while on the other hand, it was not observed in comparison of Br and single motor task. Standard deviation of sway measured in AP direction followed the same pattern. Although not significant in effect size, the differences were characteristic only for the influence of single motor task when compared to 2b for ML and AP sway amplitude, as well as for standard deviation of mediolateral sway. No difference in concurrent tasks influence was recognized for ML approximate antropy or maximum speed of the COP. Pairwise comparisons revealed a significant difference in performance, dependant on genders of the participants, on ML approximate entropy and standard deviation of anteroposterior sway.

Interpreting the data of step initiation block of the experiment confirmed within-subjects effects of cognitive tasks on initiating a step for maximal deviations of APA's in both directions, as well as for COP speed and path length. Between-subjects effects were characteristic for amplitude of mediolateral excursions of APAs and COP path length. Cognitive tasks influence on step initiation parameters fully varied with statistical significance in APA ML and AP amplitude and COP speed. The duration of APAs was different in single task condition in comparison to Brooks spatial memory task, but no significant differences between other conditions were shown. COP path length varied between single and dual conditions. Nevertheless, no statistical differences were recognized between concurrent tasks.

As it was reported in the previous chapter, concurrent tasks influenced the following gait parameters: stride length and time, step time, and cadence. No significant differences between genders were found at an influence of either parameter. Stride length, time also as step time showed the expected differences between two performed conditions , but none between the two concurrent tasks. The only parameter resisting this expectancy was double support time, showing only the difference between single task condition and Brooks matrix task.

We expected to find effects of cognitive tasks influence on motor tasks. This was confirmed for each motor task as reported above, although not for every parameter monitored. In posturography task all of the significant parameters followed the same pattern. 2b task always significantly differed from other two, while there was no difference between ST and Brooks. However, step initiation trials confirmed statistically significant difference between single and dual tasking for all of the parameters. Same goes for both concurrent tasks, with exception of COP path length. All of the walking task parameters significantly differ between single and dual conditions, with no present difference between two concurrent tasks. We also aimed at exploring the differences in influence of spatial working memory task on motor-related parameters when compared to verbal working memory influence. The effect size was measured similarly to (Al-Yahya, Dawes, Smith, Dennis, Howells, & Cockburn, 2010), by calculating the difference in means between single and dual task condition. Results are presented in the following tables.

| | Posturography | | | |
|---|---|---|---|---|
| | AP_sway_SD | AP_approximate_entropy | | COP_path |
| **Br** | 0.08 | -0.02 | | 52.37 |
| **2b** | -1.28 | -0.04 | | -136.99 |
| | **Step initiation** | | | |
| | APA_ML_amplitude | APA_AP_amplitude | Max_COP_speed | COP_path_length |
| **Br** | 12.86 | 99.09 | 6.24 | 3.53 |
| **2b** | 16.72 | 166.12 | 12.25 | 6.56 |
| | **Walking** | | | |
| | StrideLength | Stride_time | Step_time | Cadence |
| **Br** | -5.19 | 0.04 | 0.01 | -4.52 |
| **2b** | -6.47 | 0.04 | 0.02 | -4.23 |

**Figure 28 Effect sizes for all motor tasks**

# 5. Conclusions

We acquired the data, processed them and additionally analyzed. Cognitive-motor interference phenomenon was confirmed for each motor task in this study. Furthermore, we calculated the effect sizes of both concurrent cognitive tasks used in our study on all three motor tasks. Although further research would be needed to explain the differences in verbal and spatial working memory influence on motor related parameters in detail, our research provided evidence that there are some.

## 5.1. Future work

Data gathered and processed in this study will be used as the data of control group of healthy participants for the research concerned with cognitive-motor interference in patients with multiple sclerosis.

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# 7. Appendices

## Appendix 1 - Protocol example

**Protokol testiranja raziskave »Vpliv sočasnih kognitivnih nalog na ravnotežje, začetek hoje in hojo pri bolnikih s klinično izoliranim sindromom«**

**1. Podatki o udeležencu:**
**1.1. Osnovni podatki:**

**Datum testiranja:**
**Zaporedna številka udeleženca:**
**Zanimanje za udeležbo na mfVEP: DA NE**

Priimek:
Ime:
Datum rojstva:
Izobrazba:

Telefon:
Telesna višina:
Telesna teža:
Opombe::

| | | število pravilnih odzivov | število napačnih odzivov |
|---|---|---|---|
| Posturografija: | N-back: | | |
| | Brooks: | | |
| | Zgodba: | | |
| Step initiation: | N-back: | | |
| | Brooks: | | |
| | Zgodba: | | |
| Hoja | N-back: | | |
| | Brooks: | | |
| | Zgodba: | | |
| Single mental task: | N-back: | | |
| | Brooks: | | |
| | Zgodba: | | |

**Čas hoje na 40 m**

| | S | Hitrost (40m/čas) |
|---|---|---|
| Samo hoja | | |
| Hoja + Brooks | | |
| Hoja + 2 Nazaj | | |

BLOK 1-8

| | | | |
|---|---|---|---|
| | | | |
| | 1 | | |
| | | | |
| | | | |

**Izjava o zavestni in svobodni privolitvi sodelujočih zdravih prostovoljcev v raziskavi: »Vpliv različnih sočasnih kognitivnih nalog na ravnotežje, začetek hoje in hojo pri bolnikih s klinično izoliranim sindromom«.**

Bolniki z multiplo sklerozo imajo pogosto težave z ravnotežjem, kar posledično pripelje do večjega števila padcev in poškodb. Ugotovili so tudi, da imajo bolniki v zelo zgodnjih stopnjah bolezni že spremenjene vzorce hoje. Vedno pogosteje ugotavljamo, da na zmožnost vzdrževanja ravnotežja vpliva tudi sočasno izvajanje miselnih aktivnosti (npr. telefoniranje, računanje, načrtovanje…), kar ljudje posamezniki vsakodnevno izvajamo. Namen naše raziskave je opredeliti vpliv sočasnega izvajanja različnih miselnih aktivnosti na ravnotežje in hojo. Podatki nam bodo pomagali pri razumevanju organizacije nadzora ravnotežja in hoje s strani živčevja ter vpliva bolezni nanj ter omogočili načrtovanje usmerjene klinične in rehabilitacijske obravnave bolnikov.

V kolikor želimo objektivno oceniti vpliv posameznih sočasnih miselnih nalog na ravnotežje in hojo pri bolnikih v začetnih stopnjah multiple skleroza, moramo v ta namen v raziskavo vključiti tudi zdrave prostovoljce.

Ob pristanku na sodelovanje v raziskavi boste opravili:

- merjenje parametrov hoje in ravnotežja v Laboratoriju za hojo in motnje gibanja na Nevrološki kliniki v Ljubljani (skupaj približno 3h).

Skupno bo to za Vas pomenilo dva obiska Nevrološke klinike. Meritve, ki jih bomo opravili so popolnoma neboleče, saj ne vključujejo invazivnih postopkov in ne predstavljajo nevarnosti za Vaše zdravje.

Za sodelovanje v raziskavi ni predvideno denarno nadomestilo.

V kolikor ste v opisani raziskavi pripravljeni sodelovati, Vas prosimo, da to potrdite s podpisom.

**IZJAVA UDELEŽENCA**

Datum:___________________

Ime in priimek: _________________________ Datum rojstva:________________________

Izjavljam, da sem seznanjen z namenom raziskave, njenimi morebitnimi koristmi in tveganji ter prostovoljno pristajam na sodelovanje v njej.

Podpis udeleženca:__________________________ Podpis raziskovalca:____________________

## Appendix 2 - Posturography ANOVA output

**Pairwise Comparisons**

| Measure | (I) CognitiveTask | (J) CognitiveTask | Mean Difference (I-J) | Std. Error | Sig.[b] | 95% Confidence Interval for Difference[b] Lower Bound | Upper Bound |
|---|---|---|---|---|---|---|---|
| ML_sway_amplitude | 1 | 2 | -7.409 | 7.066 | .302 | -21.820 | 7.001 |
| | | 3 | 6.013* | 1.895 | .003 | 2.149 | 9.877 |
| | 2 | 1 | 7.409 | 7.066 | .302 | -7.001 | 21.820 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | 3 | 13.422 | 7.107 | .068 | -1.074 | 27.918 |
| | 3 | 1 | -6.013* | 1.895 | .003 | -9.877 | -2.149 |
| | | 2 | -13.422 | 7.107 | .068 | -27.918 | 1.074 |
| ML_sway_SD | 1 | 2 | -.310 | .666 | .645 | -1.668 | 1.048 |
| | | 3 | .947* | .252 | .001 | .432 | 1.462 |
| | 2 | 1 | .310 | .666 | .645 | -1.048 | 1.668 |
| | | 3 | 1.257 | .641 | .059 | -.051 | 2.564 |
| | 3 | 1 | -.947* | .252 | .001 | -1.462 | -.432 |
| | | 2 | -1.257 | .641 | .059 | -2.564 | .051 |
| ML_approximate_entropy | 1 | 2 | .000 | .012 | .974 | -.026 | .025 |
| | | 3 | .020 | .012 | .115 | -.005 | .045 |
| | 2 | 1 | .000 | .012 | .974 | -.025 | .026 |
| | | 3 | .020 | .010 | .059 | -.001 | .041 |
| | 3 | 1 | -.020 | .012 | .115 | -.045 | .005 |
| | | 2 | -.020 | .010 | .059 | -.041 | .001 |
| AP_sway_amplitude | 1 | 2 | -6.571 | 7.284 | .374 | -21.427 | 8.286 |
| | | 3 | 6.260* | 2.403 | .014 | 1.358 | 11.162 |
| | 2 | 1 | 6.571 | 7.284 | .374 | -8.286 | 21.427 |
| | | 3 | 12.831 | 7.420 | .094 | -2.302 | 27.963 |
| | 3 | 1 | -6.260* | 2.403 | .014 | -11.162 | -1.358 |
| | | 2 | -12.831 | 7.420 | .094 | -27.963 | 2.302 |
| AP_sway_SD | 1 | 2 | -.081 | .525 | .878 | -1.152 | .990 |
| | | 3 | 1.282* | .326 | .000 | .617 | 1.946 |
| | 2 | 1 | .081 | .525 | .878 | -.990 | 1.152 |
| | | 3 | 1.363* | .518 | .013 | .307 | 2.420 |
| | 3 | 1 | -1.282* | .326 | .000 | -1.946 | -.617 |
| | | 2 | -1.363* | .518 | .013 | -2.420 | -.307 |
| AP_approximate_entropy | 1 | 2 | .017 | .013 | .212 | -.010 | .044 |
| | | 3 | .041* | .013 | .003 | .014 | .067 |
| | 2 | 1 | -.017 | .013 | .212 | -.044 | .010 |
| | | 3 | .024* | .010 | .023 | .003 | .044 |
| | 3 | 1 | -.041* | .013 | .003 | -.067 | -.014 |
| | | 2 | -.024* | .010 | .023 | -.044 | -.003 |
| Maximum_COP_speed | 1 | 2 | -91.127 | 78.575 | .255 | -251.382 | 69.129 |
| | | 3 | .398 | 9.821 | .968 | -19.633 | 20.429 |
| | 2 | 1 | 91.127 | 78.575 | .255 | -69.129 | 251.382 |
| | | 3 | 91.525 | 77.989 | .250 | -67.534 | 250.584 |
| | 3 | 1 | -.398 | 9.821 | .968 | -20.429 | 19.633 |
| | | 2 | -91.525 | 77.989 | .250 | -250.584 | 67.534 |
| COP_path | 1 | 2 | -52.368 | 90.042 | .565 | -236.010 | 131.273 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | 3 | 136.995* | 57.499 | .024 | 19.725 | 254.265 |
| | 2 | 1 | 52.368 | 90.042 | .565 | -131.273 | 236.010 |
| | | 3 | 189.363* | 65.510 | .007 | 55.754 | 322.972 |
| | 3 | 1 | -136.995* | 57.499 | .024 | -254.265 | -19.725 |
| | | 2 | -189.363* | 65.510 | .007 | -322.972 | -55.754 |

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

## Appendix 3 Analyses of variance of step initiation

**Pairwise Comparisons**

| Measure | (I) CognitiveTask | (J) CognitiveTask | Mean Difference (I-J) | Std. Error | Sig.[b] | 95% Confidence Interval for Difference[b] Lower Bound | Upper Bound |
|---|---|---|---|---|---|---|---|
| APA_duration | 1 | 2 | .037* | .016 | .027 | .004 | .069 |
| | | 3 | .028 | .020 | .178 | -.013 | .069 |
| | 2 | 1 | -.037* | .016 | .027 | -.069 | -.004 |
| | | 3 | -.009 | .015 | .560 | -.038 | .021 |
| | 3 | 1 | -.028 | .020 | .178 | -.069 | .013 |
| | | 2 | .009 | .015 | .560 | -.021 | .038 |
| APA_ML_amplitude | 1 | 2 | -3.531* | 1.528 | .028 | -6.652 | -.410 |
| | | 3 | -6.558* | 2.027 | .003 | -10.697 | -2.419 |
| | 2 | 1 | 3.531* | 1.528 | .028 | .410 | 6.652 |
| | | 3 | -3.027* | 1.427 | .042 | -5.942 | -.112 |
| | 3 | 1 | 6.558* | 2.027 | .003 | 2.419 | 10.697 |
| | | 2 | 3.027* | 1.427 | .042 | .112 | 5.942 |
| APA_AP_amplitude | 1 | 2 | -6.240* | 2.527 | .019 | -11.402 | -1.078 |
| | | 3 | -12.252* | 2.338 | .000 | -17.028 | -7.476 |
| | 2 | 1 | 6.240* | 2.527 | .019 | 1.078 | 11.402 |
| | | 3 | -6.012* | 1.536 | .000 | -9.149 | -2.875 |
| | 3 | 1 | 12.252* | 2.338 | .000 | 7.476 | 17.028 |
| | | 2 | 6.012* | 1.536 | .000 | 2.875 | 9.149 |
| Max_COP_speed | 1 | 2 | -99.087* | 33.253 | .006 | -166.999 | -31.174 |
| | | 3 | -166.121* | 34.276 | .000 | -236.121 | -96.121 |
| | 2 | 1 | 99.087* | 33.253 | .006 | 31.174 | 166.999 |
| | | 3 | -67.035* | 24.713 | .011 | -117.506 | -16.564 |
| | 3 | 1 | 166.121* | 34.276 | .000 | 96.121 | 236.121 |
| | | 2 | 67.035* | 24.713 | .011 | 16.564 | 117.506 |
| Step_length | 1 | 2 | .055 | 10.491 | .996 | -21.370 | 21.480 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | 3 | 11.572 | 11.567 | .325 | -12.051 | 35.196 |
| | 2 | 1 | -.055 | 10.491 | .996 | -21.480 | 21.370 |
| | | 3 | 11.517 | 7.353 | .128 | -3.500 | 26.534 |
| | 3 | 1 | -11.572 | 11.567 | .325 | -35.196 | 12.051 |
| | | 2 | -11.517 | 7.353 | .128 | -26.534 | 3.500 |
| COP_path_length | 1 | 2 | -12.863* | 4.375 | .006 | -21.799 | -3.928 |
| | | 3 | -16.718* | 4.660 | .001 | -26.234 | -7.201 |
| | 2 | 1 | 12.863* | 4.375 | .006 | 3.928 | 21.799 |
| | | 3 | -3.854 | 3.888 | .329 | -11.794 | 4.086 |
| | 3 | 1 | 16.718* | 4.660 | .001 | 7.201 | 26.234 |
| | | 2 | 3.854 | 3.888 | .329 | -4.086 | 11.794 |

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

## Appendix 4 ANOVA comparison of cognitive task effects on walking

**Pairwise Comparisons**

| Measure | (I) CognitiveTask | (J) CognitiveTask | Mean Difference (I-J) | Std. Error | Sig.[b] | 95% Confidence Interval for Difference[b] Lower Bound | Upper Bound |
|---|---|---|---|---|---|---|---|
| StrideLength | 1 | 2 | 5.194* | 1.740 | .009 | 1.505 | 8.882 |
| | | 3 | 6.474* | 1.439 | .000 | 3.423 | 9.525 |
| | 2 | 1 | -5.194* | 1.740 | .009 | -8.882 | -1.505 |
| | | 3 | 1.281 | 1.235 | .315 | -1.338 | 3.899 |
| | 3 | 1 | -6.474* | 1.439 | .000 | -9.525 | -3.423 |
| | | 2 | -1.281 | 1.235 | .315 | -3.899 | 1.338 |
| Double_support_time | 1 | 2 | -.008* | .004 | .041 | -.016 | .000 |
| | | 3 | -.004 | .003 | .143 | -.009 | .001 |
| | 2 | 1 | .008* | .004 | .041 | .000 | .016 |
| | | 3 | .004 | .004 | .304 | -.004 | .013 |
| | 3 | 1 | .004 | .003 | .143 | -.001 | .009 |
| | | 2 | -.004 | .004 | .304 | -.013 | .004 |
| Stride_time | 1 | 2 | -.043* | .013 | .005 | -.071 | -.015 |
| | | 3 | -.037* | .010 | .001 | -.057 | -.017 |
| | 2 | 1 | .043* | .013 | .005 | .015 | .071 |
| | | 3 | .006 | .011 | .611 | -.018 | .030 |
| | 3 | 1 | .037* | .010 | .001 | .017 | .057 |
| | | 2 | -.006 | .011 | .611 | -.030 | .018 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Step_time | 1 | 2 | -.015* | .005 | .010 | -.026 | -.004 |
| | | 3 | -.017* | .005 | .002 | -.027 | -.007 |
| | 2 | 1 | .015* | .005 | .010 | .004 | .026 |
| | | 3 | -.002 | .004 | .581 | -.011 | .006 |
| | 3 | 1 | .017* | .005 | .002 | .007 | .027 |
| | | 2 | .002 | .004 | .581 | -.006 | .011 |
| Cadence | 1 | 2 | 4.521* | 1.346 | .004 | 1.667 | 7.374 |
| | | 3 | 4.226* | 1.084 | .001 | 1.927 | 6.524 |
| | 2 | 1 | -4.521* | 1.346 | .004 | -7.374 | -1.667 |
| | | 3 | -.295 | 1.091 | .790 | -2.609 | 2.019 |
| | 3 | 1 | -4.226* | 1.084 | .001 | -6.524 | -1.927 |
| | | 2 | .295 | 1.091 | .790 | -2.019 | 2.609 |

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

## Appendix 5 Brooks spatial memory and 2-back task trials

**2-Nazaj naloga BLOK1** - 5 7 1 8 **1** 4 8 7 **8** **7** 5 5 3 **5** 6 9 **6** 7 **6** 2 4 **2** **4** 9 9 **9** 3 1 8 **1**

**2-Nazaj naloga BLOK2** - 6 3 **6** 5 4 **5** **4** 9 2 **9** 1 4 **1** 7 9 6 **9** 8 2 3 **2** **3** 1 8 7 **8** 8 2 **8** 5

**2-Nazaj naloga BLOK3** - 8 1 **8** **1** 7 4 4 7 **4** **7** 5 6 **5** 1 7 **1** 6 **1** 9 5 2 **5** 9 3 8 **3** 7 9 3 **9**

**2-Nazaj naloga BLOK4** - 4 5 7 **5** 1 4 8 **4** 9 3 6 **3** **6** 2 7 **2** 1 9 **1** 8 4 **8** **4** 7 6 9 **6** 8 3 **8**

**2-Nazaj naloga BLOK5** - 3 2 **3** 5 4 **5** 7 9 6 **9** **6** 2 1 **2** 3 7 **3** 8 8 **8** 7 9 2 **9** 1 5 **1** **5** 4 8

**2-Nazaj naloga BLOK6** - 9 1 **9** 8 7 **8** 3 **8** 4 3 7 **3** 1 **3** **1** 8 2 7 **2** 4 9 **4** 7 6 2 **6** **2** 4 3 5

**2-Nazaj naloga BLOK7** - 2 5 **2** 9 1 **9** 6 1 **6** 3 6 8 7 **8** 8 3 7 7 **7** 2 6 **2** **6** 4 3 **4** **3** 8 6 4

**2-Nazaj naloga BLOK8** - 7 2 **7** 6 9 **6** 1 8 **1** 7 8 3 **8** 7 5 **7** 3 2 **3** 6 5 **6** **5** 8 3 5 **3** 4 **3** 9

| | | | |
|---|---|---|---|
| | | | |
| | 1 | 2 | 3 |
| | | 5 | 4 |
| 8 | 7 | 6 | |

BLOK1

| | | | |
|---|---|---|---|
| | | | |
| 2 | 1 | | |
| 3 | 4 | 7 | 8 |
| | 5 | 6 | |

BLOK2



| | | | |
|---|---|---|---|
| | | | 8 |
| | 1 | | 7 |
| | 2 | 5 | 6 |
| | 3 | 4 | |

BLOK3

| | | | |
|---|---|---|---|
| | 2 | 3 | |
| | 1 | 4 | |
| 7 | 6 | 5 | |
| 8 | | | |

BLOK4

| | | | |
|---|---|---|---|
| | | 3 | 4 |
| | 1 | 2 | 5 |
| | | 7 | 6 |
| | | 8 | |

BLOK5

| | | | |
|---|---|---|---|
| | 2 | 3 | 4 |
| | 1 | | 5 |
| | | 7 | 6 |
| | | 8 | |

BLOK6



| | | | |
|---|---|---|---|
| 3 | 4 | 5 | |
| 2 | 1 | 6 | 7 |
| | | | 8 |
| | | | |

BLOK7

| | | | |
|---|---|---|---|
| | | | |
| | 1 | | |
| 3 | 2 | | 8 |
| 4 | 5 | 6 | 7 |

BLOK8