# Computerized dynamic posturography in ballet dancers

by

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**A dissertation submitted in fulfilment of the requirements for the degree**

**M Communication Pathology**

In the Departmentof Speech-Language Pathology and Audiology at the

UNIVERSITY OF PRETORIA

FACULTY OF HUMANITIES

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November 2016

**UNIVERSITY OF PRETORIA**

**FACULTY OF HUMANITIES**

**RESEARCH PROPOSAL & ETHICS COMMITTEE**

# DECLARATION

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# Acknowledgements

I was blessed with an amazing support system through my years of postgraduate study. I would like to thank the following people who assisted me through the process of completing this project:

First and foremost, I need to thank God for granting me the ability, and opportunity, to study. I have been blessed more than I could ever deserve. This project has only been possible through him, and He has provided me with a support system to carry me through all the trials and doubts that I had.

To my husband, Fouché, thank you for the thousands of talks we had over the last three years. You kept me positive, motivated me and guided my thoughts when I was overwhelmed with academic tasks, work and planning our wedding. The spiritual guidance you provided kept me centered. Thank you for being my academic and personal sounding board and assisting with the technical difficulties I had to overcome with MS Word and Excel.

My mother, Rialette, who inspired me to become an audiologist and assisted with my patient case load when I needed to complete academic tasks. Thank you for being the best mentor, employer, and mother that a person can aspire to be. I also need to give thanks to my father, Ignatius, whose academic knowledge and experience was invaluable during the academic process.

To my supervisor, Prof Vinck. Thank you for providing technical and statistical expertise throughout this project. The combination of your audiological and statistical knowledge made you invaluable. Thank you for supervising my pre- and postgraduate research projects.

To my second supervisor, Dr. Maes. Thank you for your technical expertise in this project, as well as your willingness to assist with patient related queries outside of this project.

Dr. Heinze, my third supervisor, thank you for teaching me how to be an audiologist. You have been pivotal in my studies since my first year at the University of Pretoria, and inspired my passion for the vestibular field. Thank you for again adding your expertise to this project.

Lastly, Carlien, my housemate and co-postgraduate student, who shared all her knowledge concerning master’s degree admin, who taught me how to keep track of everything since our first year at university and who held my hand when organising my wedding. Thank you for keeping me sane since 2009.

## Abstract

Balance is the ability to maintain an individual's centre of mass over his or her base of support while standing. Ballet dancers have better balance than non-dancer control groups as they presented with better sensory-motor integrative skills when required to maintain a given posture for a longer period. To evaluate functional balance abilities, assessing individuals with above average balance abilities may provide valuable information about function. The balance of trained ballet dancers ($N_1$) was investigated by comparing Sensory Organisaiton Test (SOT), Motor Control Test (MCT) and Limits of Stability (LOS) test results to matched non-trained individuals ($N_2$). A quasi-experimental and two group design was used. Ten matched trained ballet dancers ($N_1$) and 10 untrained individuals were included in the study. Trained ballet dancers ($N_1$) had an average of 16.6 (± 4.24) years of experience, while non-trained individuals ($N_2$) had none. No significant dufferences in demographic data was present between groups. Both groups reflected good overall balance and similar sensory organization. No differences in reflex latencies and weight symmetry of the left or right leg was present. Trained ballet dancers ($N_1$) reflected higher response strength for medium forward translations (p.05) with the left leg, indicating poorer amplitude scaling in response to platform translations than those of non-trained individuals ($N_2$). In non-trained individuals ($N_2$), there was less variation in the response strength between legs. Research indicated that stretch reflex amplitude was attenuated as load stability was reduced. Co-contraction was also heightened as stability was reduced, but not enough to oppose the induced instability, probably due to feed-forward strategies instead of rapid involuntary feedback. Trained ballet dancers ($N_1$) were able to extend further out of their Centre of Pressure (COP) than non-trained individual ($N_2$) during forward ($p<.05$) and right forward ($p<.05$) movements. It was concluded that that for forward and right forward movements, ballet dancers used the feedback they received during the movements better than non-trained individuals ($N_2$), resulting in a better awareness of where to go in space and how to reach that position after a subsequent attempt. This difference may be as a result of continuous training. Ballet training exercises can be

used to rehabilitate individuals with impaired limits of stability. Further studies should be done on exactly which ballet training exercise results in increased limits of stability.

## Key Words

Ballet dancers

Computerised Dynamic Posturography

Equilibrium Score

Limits of Stability Test

Maximum excursion

Motor Control Test

Postural Response Strength

Sensory Organization Test

Somatosensory

## List of abbreviations and acronyms

| | |
|---|---|
| ADT | Adaptation Test |
| A-P sway | Anterior-Posterior sway |
| BMI | Body Mass Index |
| COP | Centre of Pressure |
| COG | Centre of Gravity |
| CDP | Computerized Dynamic Posturography |
| DASA | Dance Association of South Africa |
| EQL | Equilibrium |
| LOS | Limits of Stability test |
| H/M | Maximum Hoffman reflex amplitude ratio |
| MCT | Motor Control Test |
| RAD | Royal Academy of Dance |
| RWS | Rhythmic Weight Shift Test |
| SOT | Sensory Organization Test |
| VCR | Vestibulo-Collic Reflex |
| VOR | Vestibulo-Ocular Reflex |
| VSR | Vestibulo-Spinal Reflex |

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# Computerized dynamic posturography in ballet dancers

## Chapter 1

## 1 INTRODUCTION

Balance can be defined as the ability to maintain an individual's centre of mass over his or her base of support while standing (Nashner, Shupert, & Horak, 1988). Adequate balance control requires a multisensory integration of visual, vestibular and somatosensory information (Simmons, 2005a). Combining this sensory information by using the central nervous system is termed sensory organisation (Nashner et al., 1988). This sensory information from the different input systems is centrally processed in the vestibular nuclei and the cerebellum and coupled to motor output reflexes to maintain eye, head, and body stabilization. Eye stabilization is generated through the vestibulo-ocular reflex (VOR) (Dodge, 1903; Barnes, 1980). Head and upper trunk stabilizationis generated through the vestibulo-collic reflex (VCR) (Peng, Hain, & Peterson, 1999). Postural balance control of the mid and lower extremities is generated through the vestibulo-spinal reflex (VSR) (Barnes, 1980). To better understand the exact mechanism of this complex balance control system, it would be illuminating to examine individuals presenting with exceptionally good balance performance.

Research suggests that gymnasts have better postural stability then individuals with no gymnastic training (Carrick, Oggero, Pagnacco, Brock, & Arikan, 2007). The authors further concluded that methodology not associated with the motor task may contribute to an increase in sport performance and a resulting decrease in the probability of injury (Carrick et al., 2007). Synchronized figure skaters also reflected better weight distribution the controls, but reflected lower stability (Alpini, Mattei, Schlecht, & Kohen-Raz, 2008). Variations in vestibulo-ocular parameters were observed in figure skaters, possibly as a result of habituation, but this was dependant on the discipline of figure skating (Alpini, Botta, Mattei, & Tornese, 2009). Ramsay and Riddoch (2001) demonstrated that increased practice can improve a sensory-motor skill in ballet dancers. The balance of motor abilities of ballet dancers has been studied extensively.

Research established that professional ballet dancers have better balance than non-dancer control groups as they presented with better sensory-motor integrative skills when required to maintain a given posture for a longer period (Crotts, Thompson, Nahom, Ryan, & Newton, 1996). They maintained greater stability than non-dance trained participants while using a single leg to balance on a foam surface, with or without visual input. Several reasons have been put forward to explain the exceptional balance displayed by ballet dancers.

Usually, the sensory perception of turning and spinning stimulates the vestibular system and elicits the VOR as well as a self-perception of movement and response to try and stop one from falling (Nigmatullina, Hellyer, Nachev, Sharp, and Seemungal,. 2013). One reason suggested by Nigmatullina et al,. (2013), is that repeated training changes the brain structure of dancers in significant and anatomically observable ways. Grey matter in lobules VIII and IX, forming part of the vestibular cerebellum, reflected significant reductions. Whole brain white matter analysis reflected a white matter cluster where the relationship for the perceptual time constant and fractional anisotropy was the same for ballet dancers and matched controls. This was measured by diffusion tensor imaging and voxel-based morphometry. The result is that the usual tight link between perception and reflex is uncoupled, and the sensation of vertigo is weakened. Nigmatullina et al. (2013) suggested that the uncoupling of the reflex and perception thereof is a reflection of vertigo resistance that dancers experience. Another postulated a reason why ballet dancers do not perceive dizziness is that they seem to possess the ability to suppress their automatic and perceptual VOR responses to rapid spinning (Osterhammel, Terkildsen, & Zilstorff, 1968).

Theoretically, classical ballet dancers only reflected better postural control than control groups in conditions measured where their eyes were open (Hugel, Cadopi, Kohler, & Perrin, 1999). Golomer, Crémieux, Dupui, Isableu, and Ohlmann (1999a) measured the degree of dependence on vision for postural control and perception. They noted that ballet dancers were more stable and less dependent on vision for postural control. This was because of ballet strengthening the accuracy of proprioceptive inputs and shifts sensory-motor dominance from vision to proprioception. Golomer, Dupui, Séréni, and Monod (1999b) assessed the involvement of vision in regulating dynamic equilibrium in children and adults. Vision made the largest contribution to reducing low frequency oscillations, but visual dependence differed according to age. Bruyneel, Mesure, Paré, and Bertrand (2010), who noted that age and vision influence the balance of ballet dancers, confirmed this. Also, Bruyneel et al. (2010), determined that adolescent and adult dancers had fewer oscillations when relying on visual input during anterior, lateral and posterior limb movements. The authors attributed this to visual dependence. Similarly to Golomer et al. (1999b), Bruyneel et al. (2010) noted that eighteen year olds were more visually dependant. Research into the importance of visual input for postural control established that ballet dancers only performed better when their eyes were open (Hugel et al., 1999). This is in contrast to the research by Golomer et al. (1999a), who theorized that a more developed motor program is established by reducing body oscillations resulting from hip and ankle instabilities through dance training. Training strengthened the accuracy of proprioceptive input and therefore shifted the pattern of dominance from vision to proprioception.

Differences in the procedures used to assess the use of vision in dancers could attribute to the different test results. Hugel et al. (1999) assessed dancers using a posturography platform. Two different procedures were used. During the first, a dancer was standing with both feet on the force plate. Their sway was assessed with eyes open and closed. During the second assessment, participants were assessed on demi-point with eyes open and closed as well as during unipodal demi-pointe with eyes open. In contrast to the posturography platform used by Hugel et al. (1999), Golomer et al. (1999a) assessed participants on a stabilometer consisting of a seesaw platform with a cylindrically curved base. This base is connected to a pivot (Golomer et al., 1999a). On this stabilometer, participants were not able to stand still.

It was required of them to constantly adjust posture to maintain balance (Golomer et al., 1999a). Their anterior-posterior sway was assessed during eyes open and closed conditions. Dancers had to rely on different skills during the two types of assessments.

Golomer, Rosey, Dizac, Mertz and Fagard (2009) reflected that proprioceptive inputs are strengthened by training, resulting in ballet dancers relying more on proprioceptive input. Simmons (2005a) established that dancers were less stable than non-dancer controls when somatosensory information was made unreliable as dance training results in a shift in sensory weighting from visual to somatosensory information. These results validate the fact that dancers rely predominantly on somatosensory information to maintain postural control. Research further indicated that professional dancers strengthen the accuracy of proprioceptive inputs, shifting the dominance from that of vision to proprioception (Golomer et al., 1999a). Schmit, Regis, and Riley (2005) also noted that ballet dancer's skilled balance control could be as a result of training. This was further demonstrated by Ramsay and Riddoch, (2001) where they determined that ballet dancers revealed greater accuracy in position matching tasks of the upper limbs (the shoulder and elbow joints). This implies that mass and continuing training have the ability to improve a sensory motor skill (Ramsay & Riddoch, 2001). To understand the effect of training, the working of the somatosensory system needs to be described.

The VSR pathway consists of three neuronal arcs. The first is the lateral vestibulospinal tract, originating from the ipsilateral lateral vestibular nucleus (Barnes, 1980; Herdman, 2007). The second is the medial vestibulospinal tract, the origin of which can be found in the contralateral medial, superior and descending vestibular nuclei (Barnes, 1980; Herdman, 2007). Lastly, the VSR pathway is made up of the reticulospinal tract (Barnes, 1980) (Herdman, 2007). This tract receives sensory input from the vestibular nuclei as well as all the other sensory and motor systems that are responsible for maintaining balance (Herdman, 2007). Furthermore, Allum and Shepard (1999) summarized that proprioceptively triggered short and long latency reflexes originate from the triceps surae muscle originating from the ankles.

These reflexes in the lower leg dictate responses elicited from either translations or rotations of a support surface. Long latency neuromuscular responses occurred with an onset time of around 100ms, whereas the short latency neuromuscular responses were present at 40ms -50ms. The proprioceptive function of individuals matures around the age of three to four years old (Steindl, Kunz, Schrott-Fischer, & Scholtz, 2006). Young dancers were less stable than adult dancers until the age of 17 years as a result of undergoing a growth spurt (Bruyneel et al., 2010; Golomeret al., 1999b).

There are various techniques to measure postural control. Bruyneel et al. (2010) used a force plate (without a visual surround) in which visual information was either available or denied. Another technique employed by Golomer et al. (1999a) and (Golomer et al., 1999b), assessed participants on the platform of a seesaw with a cylindrically curved base; a stabilometer. Four experimental conditions were included in the protocol, eyes open and closed for both anteroposterior and lateral tilts. Tilts were measured via an angular accelerometer. Lastly, computerized dynamic posturography (CDP), and specifically the sensory organization test (SOT) can be used. The SOT, the motor control test (MCT) and the limits of stability test (LOS) are test protocols available on the CDP equipment. Participants are asked to stand on a force plate enclosed by a visual surround. Postural control is measured during six conditions (Simmons, 2005a).

By making use of the SOT, Simmons (2005a) provided information about the contribution of the vestibular, the visual and the somatosensory system in ballet dancers. Simmons (2005a) did not include other functional tests to measure the effect and carry-over of dancers’ improved balance systems on everyday tasks. There was no extension of research to assess the functioning of the long loop pathways using the MCT, therefore structural integrity was not assessed. This pathway includes the peripheral nerves, the descending and ascending spinal pathways as well as brain structures responsible for interpreting the information from the VSR (NeuroCom, 2005).

In a subsequent publication, Simmons (2005b) continued his research by publishing dorsiflexion results obtained from the same group of dancers previously assessed. The technique he used is the adaptation test (ADT), where a participant is asked to stand on a force plate surrounded by a visual field (NeuroCom, 2005), which rotates 8° upward at a rate of 50° per second. Electrodes are strapped parallel to a participant's gastrocnemius and anterior tibialis muscle of each leg. Electromyogenic (EMG) impulses were then recorded. He found that ballet dancers have comparable short latency and medium latency neuromuscular responses as non-trained controls, whereas the average activation time for long latency neuromuscular responses was significantly faster, as well as more consistent than controls. Simmons (2005a) and Simmons (2005b) also did not make use of the Limits of Stability (LOS) test to evaluate the ballet dancers and control group's ability to move safely, swiftly and smoothly through their full limits of stability set at 100% (NeuroCom, 2005). Adding this assessment will provide information concerning voluntary motor control.

It should be noted that posturography does not provide any information with regards to the aetiology of a balance disorder (Furman, 1994). It provides functional information about an individual's balance abilities. This testing procedure indicates how a balance disturbance may affect activities of daily living. Lastly, Furman (1994) further explains that posturography provides a functional measure that assists with forecasting of the benefits that an individual may experience with therapeutic intervention, such as physical therapy.

Extending the study of balance by also including additional tests, such as MCT and LOS, will help to determine whether carry-over of skills was achieved while training takes place. In the light of the research above, it would be beneficial to quantify the effect that training of the somatosensory system can have on everyday functional tasks to determine if it can be used to improve function. Taube Gruber & Gollhoffer ., (2008) reported that training balance is beneficial for prevention of injuries as well as rehabilitation in respect to posture, strength, specifically of the flexor and extensor femoral muscles (Heitkamp, Horstmann, Mayer, Weller, & Dickhuth, 2001) and hamstrings (Myer, Ford, Brent, & Hewett, 2006), as well as jumping. This was relevant for athletes as well as elderly adults (Taube et al,. 2008). Taube et al. (2008) clarified further that the primary neural adaptations were shown to be found at different sites of the central nervous system. When looking at task specific spinal reflex adaptation, the soleus Hoffmann's reflex (H-reflex) gain was inhibited in trained dancers during stance (Mynark & Koceja, 1997). Taube, Gruber, Beck, Faist, Gollhoffer and Schubert. (2007) determined that it is not only the task but also the phase of movement essential for training related H-reflex modulation. They assessed participants during a rapid posterior displacement of a support surface. No adaptations were visible for spinally generated short latency neuromuscular responses, but, in contrast to this, long latency neuromuscular responses reflected significantly reduced maximum Hoffman reflex amplitude ratios (H/M-ratios). Concerning supraspinal adaptations, numerous supraspinal structures are used to control upright posture. These would be the basal ganglia, cerebellum, and brainstem (Lalonde & Strazielle, 2007; Visser & Bloem, 2005). The motor cortex also plays an important role in maintaining postural control (Beloozerova, Sirota, Swadlow, Orlovsky, Popova, & Deliagina, 2003). Descending from the motor cortex to the spinal motor neurones, a direct monosynaptic corticospinal pathway is present (Fetz, Cheney, Mewes, & Palmer, 1989). Improved cortical plasticity was shown as a result of training (Taube et al., 2007). High task specificity was noted in the plasticity of the spinal, corticospinal and cortical pathways (Taube et al., 2008).

Golomer et al. (1999a) and Simmons (2005a) determined that trained ballet dancers ($N_1$) predominantly rely on somatosensory information to maintain balance control during static tasks. The purpose of this study is, therefore, to investigate how ballet dancers use sensory information and motor control strategies during automatic and voluntary movements to maintain postural control. If trained ballet dancers ($N_1$) have better balance then untrained individuals, ballet training exercises could possibly be used as rehabilitation exercises for individuals with impaired function. The study looked at whether the skills developed by training is transferred into everyday activities. The study aimed to draw a comparison between the CDP outcome parameters of trained $N_1$ ballet dancers and non-trained individuals ($N_2$) to determine the nature and extent of the difference(s) between the two groups.

# Chapter 2

# 2 METHODOLOGY

## 2.2 Aims

### *2.2.1 Main aim*

To compare the postural control of trained ballet dancers ($N_1$) to that of non-trained individuals ($N_2$).

### *2.2.2 Sub-aims*

Leedy & Ormrod (2010), explained that the primary problem should be separated into manageable sub-problems. In order to achieve the main aim, the following sub aims needed to be achieved:

1. To evaluate and compare the automatic postural control of trained ballet dancers ($N_1$) and non-trained individuals ($N_2$).
2. To evaluate and compare the voluntary postural control of trained ballet dancers ($N_1$) and non-trained individuals ($N_2$).

## 2.3 Research design

According to Leedy and Ormrod (2010), a specific plan is required to guide researchers in a purposeful way to acquire all the relevant data needed. A quasi-experimental and two group design was followed during this research project (Leedy & Ormrod, 2010). A two group design was deemed appropriate as the researcher divided her subjects into two groups, one group whom received ballet training throughout their lives and another with no training (Leedy & Ormrod 2010). All tests were conducted in a clinical context as specialised equipment was used to obtain measurements.

Independent variables of the project consisted of the different groups of participants, namely the trained ballet dancers ($N_1$) and non-trained individuals ($N_2$). Dependent variables, therefore, were outcome variables of the tests. The outcome measures assessed during the SOT was the amount of anterior-posterior sway during each trial, the position of a participant's COG placement as well as an indication of each participant's strategy used to maintain and regain balance. The outcome measures of the MCT focussed on latency, strength symmetry and weight symmetry of reflexes during each trial. Lastly, outcome measures of the LOS were velocity, reaction time and directional control of movements as well as a participant's endpoint and maximum excursion in a direction.

## 2.4 Ethical considerations

Ethical clearance was obtained from the research ethics committee of the Faculty of Humanities at the University of Pretoria on 21 April 2015, before contacting and collecting data (Appendix A). Leedy and Ormrod (2010) reflected that when human participants are the focus of research, ethical implications should be closely considered. The following ethical considerations were taken into account during the project (Leedy & Ormrod, 2010).

### *2.4.1 Informed consent*

Informed consent (Appendix B) was obtained from each participant before enrolling them into the study. The nature of the study was explained to each participant in writing as well as verbally to assure that they were informed of the nature and components that the study would take. Participants were informed via the informed consent letter that participation in the project is voluntary. They were able to withdraw at any time or refuse participation without negative consequences (Leedy & Ormrod, 2010).

### *2.4.2 Confidentiality*

Confidentiality was maintained by providing each participant with a unique code for the duration of the study. By assigning a code, it ensured anonymity during statistical analysis procedures. No participant's name was used when recording the results. The identity of each participant was only known to the researcher. The data concerning each participant was therefore captured in such a way that confidentiality was ensured.

### *2.4.3 Avoidance of harm*

Researchers should not expose participants to unnecessary physical or emotional harm (Leedy & Ormrod, 2010). Participants were protected from being harmed during the study by strapping them into an appropriately sized harness, mounted onto the metal frame of the NeuroCom Smart Equitest®. A selection of harness sizes ranging from small to large was available. Participants were counselled throughout the test procedure with regards to what was expected of them and what will occur next as changes in the force plates, and visual surround may have caused slight discomfort.

### *2.4.4 Honesty*

Participants had, and will continue to have access to their results at any moment. The results of the study will be made public by publishing it in a scientific journal as well as in a master's degree dissertation. During this process, the data was checked by a supervisor and co-supervisors. It will also be peer reviewed before publication in a journal.

### *2.4.5 Storage of data*

In accordance with the policy of the University of Pretoria, data will be archived in the Department of Speech-Language Therapy and Audiology for 15 years. This will be available in hard copy and in a digital format. To maintain confidentiality, no identifying information of participants will be available in these files.

## 2.5 Sampling method and sampling size

Two groups were enrolled in the study. A trained ballet dancer group, consisting of ten participants and an untrained group, also made up of ten matched participants.

Nonprobability sampling was used to select participants, as the researcher could not guarantee that all elements of the population were represented in the study population (Leedy & Ormrod, 2010). Purposive sampling was used to select participants as the participants needed to fit a definite set of criteria based on the judgement of the researcher (Leedy & Ormrod, 2010). Similar Body Mass Index (BMI) ranges were present between the trained ballet dancer and non-trained individual ($N_2$) (Table 1). If a trained ballet dancer was underweight, the matched control also had to reflect a BMI of under 18.5, or between 18.5- 25 for normal weight individuals. Non-trained individuals ($N_2$) reflected slightly higher BMI ranges than the trained ballet dancers ($N_1$), with the mean BMI values being 20.17 and 18.73 ($p>.05$) respectively.

## 2.6 Study population

Twenty participants aged 18-30 participated in the study; ten were experienced ballet dancers, and ten had no formal ballet or alternative dance training. The two groups were matched concerning gender, height and BMI range.

Participants were referred to the researcher by dancers known to the researcher and community ballet schools. The non-trained individual ($N_2$) group was enlisted through posts on social media or referral from individuals known to the researcher.

Demographic data was gathered through a questionnaire (Appendix C). The data is presented in Table1. The average years of ballet experience was 16.6 years (minimum= 10 yrs., maximum= 22yrs.) for trained ballet dancers ($N_1$), and 0 for non-trained individuals ($N_2$). Four participants indicated that they dance on an intermediate level. One participant reported being rated on an advanced foundation level; three participants are performing on advanced 1 level, and the remaining two dancers participate on advanced 2. Two of the previously mentioned participants have also completed their teacher’s exams and currently practice as ballet teachers. The table below presents a summary of the biographical data of the study participants.

**Table 1: Summary of biographical data of trained ballet dancers ($N_{1=10}$) matched to Non-trained individuals ($N_{2=10}$)**

| Trained ballet dancers ($N_1$) | Age | Height (cm) | BMI | Non-trained individuals ($N_2$) | Age | Height (cm) | BMI |
|---|---|---|---|---|---|---|---|
| **Ballet dancer 1** | 23 | 173 | 21,05 | **Non-trained individual 1** | 20 | 173 | 16,04 |
| **Ballet dancer 2** | 23 | 178 | 15,47 | **Non-trained individual 2** | 24 | 178 | 17,99 |
| **Ballet dancer 3** | 18 | 177 | 18,51 | **Non-trained individual 3** | 29 | 177 | 19,15 |
| **Ballet dancer 4** | 20 | 165 | 20,57 | **Non-trained individual 4** | 19 | 165 | 20,2 |
| **Ballet dancer 5** | 20 | 163 | 19,57 | **Non-trained individual 5** | 20 | 163 | 24,46 |
| **Ballet dancer 6** | 22 | 170 | 21,11 | **Non-trained individual 6** | 24 | 170 | 22,49 |
| **Ballet dancer 7** | 25 | 162 | 18,29 | **Non-trained individual 7** | 20 | 162 | 19,05 |
| **Ballet dancer 8** | 25 | 178 | 21,15 | **Non-trained individual 8** | 20 | 178 | 22,09 |
| **Ballet dancer 9** | 25 | 158 | 19,23 | **Non-trained individual 9** | 25 | 158 | 18,43 |
| **Ballet dancer 10** | 20 | 163 | 19,57 | **Non-trained individual 10** | 25 | 163 | 21,83 |
| **Mean (SD)** | 22.1 ± 2,51 | 168.7 ± 7.45 | 19,45 ± 1.75 | **Mean (SD)** | 22,6 ± 3,27 | 168,7 ± 7.45 | 20,17 ± 2.52 |

### 2.7 Participant selection criteria

Criteria only applicable to the trained professional group were years of experience in a certain school of dance, years of dance experience and level of experience. The level of experience is how far they have completed their exams e.g. Intermediate foundation or advanced 2. This is their competence level, whereas the years of experience is how many years they have participated in ballet. Criteria only applicable to the non-trained individual ($N_2$) group were their highest sporting achievement. Ramsay and Riddoch (2001) determined that practice can improve a motor sensory skill, possibly influencing the current research. Vestibular screening results were also documented on the biographical questionnaire and screening form (Appendix C).

### *2.7.1 General inclusion and exclusion criteria*

#### *2.7.1.1 Age*

Adolescents were used. All participants needed to be older than 18 years and younger than 30 years old. The reason for age as an inclusion criterion is that the visual, as well as the vestibular afferent system, matures between the age of 15 to 16 years (Steindl et al., 2006). Participants were required to be 18 years or older to be included in the study, as to allow them to have gained enough ballet experience. It was also previously found that young dancers (12- 17 years old) are less stable than adult ballet dancers, as they experienced more falls and presented with an increase in mediolateral oscillations (Bruyneel et al., 2010). Participants were required to be younger than 30 years old to exclude the potential impact of aging on their vestibular and somatosensory systems.

#### *2.7.1.2 Medical conditions*

Participants with a history of adhesions or abnormalities in, or around the joints as well as serious anatomical or muscle limitations were excluded from the study. (Koutedakis & Jamurtas, 2004). No prior diagnoses of autoimmune diseases affecting the joints, known anatomical anomalies of the joints and no history of epilepsy were required. Participants selected for this study could not present with a prior history of serious injuries to the hips, knees or ankles for which surgery or medical treatment was required. Participants were also excluded if they presented with a history of previous head injuries, such as concussion or closed head injuries.

#### *2.7.1.3 Function of the vestibular system*

Only participants without a history of vertigo, dizziness and imbalance were included in the study. To ensure normal vestibular function, bedside vestibular evaluations were performed (Appendix C). This consisted of spontaneous and gaze evoked nystagmus, smooth pursuit, saccades, fixation suppression, head impulse, headshake and dynamic visual acuity (DVA) tests. The Dix-Hallpike positioning, static positional, limb coordination, and Romberg stance tests were also performed on each participant. When assessing visual acuity during head movements, static visual acuity was determined electronically prior to completing the DVA test. Apparatus used for the DVA was the CDP equipment's DVA protocol as a mounted screen is available.

#### *2.7.1.4 Muscle fatigue*

Participants were required to refrain from physical exercise such as jogging, cycling, swimming or dancing 12 hours before participation in research to exclude the effect of muscle fatigue on the test results.

### ***2.7.2 Inclusion criteria for trained professional dancers***

Participants included in the study either had to follow one of three ballet dance school streams available in South Africa. These are Royal Academy of Dance (RAD), Dance Association of South Africa's (DASA) and Cecchetti. Participants who are studying ballet through the RAD needed to be at an intermediate level or higher. In accordance to DASA as well as Cecchetti's ranking system, ballet dancers were included if they were ranked at an advanced level. This allowed participants in the experimental group to have gained ample experience as to have mastered most, if not all, ballet moves through the years.

#### *2.7.2.1 Dance experience*

Trained ballet dancers ($N_1$) had to have no less than ten years of experience as a ballet dancer.

### *2.7.1 Inclusion criteria for non-trained individuals ($N_2$)*

#### *2.7.1.1 Dance experience*

Non-trained individuals ($N_2$) were included in the study when they had no classical or alternative dance experience

#### *2.7.1.2 Sporting experience*

Non-trained individuals ($N_2$) were included when they did not have any experience as a semi-professional sport’s person in any discipline. The author defined this as participation in sport on a provincial level. The table below presents an overview of the criteria for a trained professional dancer and a non-trained individual ($N_2$) to be included in their respective groups.

**Table 2:** Inclusion criteria for trained ballet dancers **($N_{1=10}$)** and non-trained individuals **($N_{2=10}$)**

| **Criterion** | **Trait** | **Included (✓) or excluded (×)** | |
|---|---|---|---|
| **All participants (n=20)** | | | |
| **Age** | 18-30 years old | <18 | × |
| | | >18 | ✓ |
| | | <30 | ✓ |
| **Visual abilities** | Uses glasses | Tested while using glasses | |
| | Does not use glasses | No limitation | |
| **Medical conditions** | Adhesions or abnormalities in, or around the joints | × | |
| | Serious anatomical or muscle limitations | × | |
| | Autoimmune diseases affecting the joints | × | |
| | Known anatomical anomalies of the joints | × | |
| | Epilepsy | × | |
| **Function of the vestibular system** | Normal | ✓ | |
| | Abnormal | × | |
| **Previous injuries** | Serious injuries to the hips, knees or ankles | × | |
| | Head injury | × | |
| **Muscle fatigue** | Exercise on day | × | |
| **Trained professional dancers** ($N_{1=10}$) | | | |
| **Years of dance experience** | >10 years | ✓ | |
| **School of Dance** | Cecchetti | Advanced | ✓ |
| | DASA | Advanced | ✓ |
| | RAD | Intermediate level or higher | ✓ |
| **Non-trained individuals** ($N_{2=10}$) | | | |
| **Dance experience** | None | ✓ | |
| **Sporting experience** | Provincial | × | |
| **Physical characteristics** | Gender | Female | |
| | BMI range | Similar to matched trained professional dancers | |
| | Height | Same as matched trained professional dancers | |

## 2.8 Apparatus and procedures and measures

### *2.8.1 Measures*

A case history was obtained from each participant using a biographical questionnaire (Appendix C) The case history used in the current study focussed on aspects about all participants such as age, previous injuries, medical conditions, visual abilities, sporting experience as well as physical exercise on the day of data collection.

### *2.8.2 Apparatus*

Computerized Dynamic Posturography (CDP) equipment (The NeuroCom Smart Equitest®) was used to assess postural control and functional balance abilities of the experimental and control groups. The NeuroCom Smart Equitest® used was installed in August 2013 under licence of Amtronix (Pty) Ltd. The equipment automatically calibrates the force plates every time that it starts up.

### *2.8.3 Procedures*

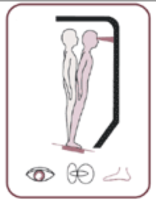
Participants were tested at a private audiology practice in Pretoria. All participants were assessed using corrected vision if appropriate. Participants were strapped into a fitted harness according to their height before commencement of the testing procedures. This harness is anchored to the equipment to prevent injury in case of loss of balance by a participant. The three tests mentioned below were completed afterwards. Testing procedures lasted around an hour. For the SOT, four trials were allowed for each one of the six conditions assessed.

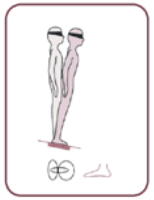
The SOT, MCT and LOS tests were selected as a test battery as voluntary and automatic postural control was assessed (Vervoort, Nackaerts, Mohammadi, Heremans, Verschueren, Niewboe and Vercruysse,. 2013). The SOT was selected as it assesses the ability to integrate sensory (visual, vestibular and somatosensory) information (Vervoort et al., 2013). The MCT assesses automatic postural reactions in forward and backward directions. The LOS assesses the ability to voluntary shift the COG to eight different directions, instead of just from left to right and forward and backward, such as the Rhythmic Weight Shift (RWS) test (Vervoort et al., 2013).

#### *2.8.3.1 Procedures and description of the SOT test*

Table 3 illustrates the six conditions of the SOT, along with the effect of the force plate and visual surround on the ability to use sensory information to maintain postural control.

**Table 3:** Sensory Organisation Test (SOT) procedures and description

| **Procedure of SOT** (Tusa, 2000) | **Figure *** | **System of Reliance** | **Unavailable System** |
|---|---|---|---|
| **Six sensory organization tests were performed.** | | | |
| **Condition 1**<br>During condition one, the participant stood on the force plate, eyes open. |  | All systems available (baseline) | All systems active |
| **Condition 2**<br>While assessing condition two, the participant w stood on the force plate with her eyes closed. |  | Reliance on the somatosensory and vestibular system. | Visual input removed |
| **Condition 3**<br>The visual surround moved during condition three, while the force plates remained stable. |  | Reliance on the somatosensory and vestibular system. | Visual system made unreliable |
| **Condition 4**<br>During condition four the force plates moved, but the visual surround remained stable. |  | Reliance on the visual and vestibular system. | Somatosensory system made unreliable |

| **Procedure of SOT** (Tusa, 2000) | **Figure *** | **System of Reliance** | **Unavailable System** |
|---|---|---|---|
| **Condition 5**<br>As with the previous condition, condition five was assessed with moving force plates, but the participant's eyes were closed, denying visual input. |  | Reliance on vestibular input only. | Visual and somatosensory system removed |
| **Condition 6**<br>Lastly during condition six, the force plates and the visual surround moved. Participants were required to maintain postural stability. |  | Reliance on vestibular input only. | Visual and somatosensory system removed |

*Figures in table Accessed 5-12-2016 from http://balanceandmobility.com/for-clinicians/computerized-dynamic-posturography/cdp-protocols/

Table 4 gives a description of the outcome variables of the Sensory Organisation Test (SOT)

**Table 4:** Definitions, descriptions, and calculations of Sensory Organisation Test (SOT) outcome variables

| **Outcome variables** | **Descriptions of test outcomes** | **Formulae** |
|---|---|---|
| **Equilibrium scores** | Equilibrium scores were calculated by comparing the theoretical maximum A-P COG displacement to the theoretical sway stability limit of 12.5° (Simmons, 2005a; Vanicek, Strike, McNaughton, & Polman, 2009). Simmons (2005a) explains that this is illustrated as a percentage value, with 100% reflecting no sway, and 0% indicating a fall. Each 10 points on the equilibrium score, therefore, represented 1.25° of actual sway by a participant. The equilibrium score is calculated by using the following formula (Vanicek et al., 2013): | $\frac{12.5^\circ - (\Theta_{CT}\max - \Theta_{CT}\min)}{12.5^\circ}\ x\ 100$<br>$\Theta_{CT} = Participant's\ s\ calculated\ maximum\ anterior - posterior\ COG\ displacement\ for\ condition\ C\ and\ trial\ T$ |
| **Composite score** | The composite score was calculated by adding the average scores of condition 1 and condition 2 to the sum of the three equilibrium scores of condition 3-6 and then dividing this total value by fourteen. This calculation is Illustrated through the following formula (Guskiewicz, Riemann, Perrin, & Nashner, 1997). | $Composite\ Score = \frac{\frac{\sum_{T=1}^{3} X_{1T}}{3} + \frac{\sum_{T=1}^{3} X_{2T}}{3} + \sum_{C=3}^{6}\sum_{T=1}^{3} X_{CT}}{14}$<br>$X_{CT} = Equilibrium\ score\ for\ Condition\ C\ and\ Trial\ T$ |
| **Strategy scores** | The strategy score is a difference score expressed as a percentage. This score includes the difference between the maximum and minimum sheer forces generated by the subject, divided by a constant representing the theoretical sheer force difference in normals and normalized. Strategy scores were computed by comparing the peak-to-peak amplitude of horizontal shear force with the maximum possible sheer force of 11.4kg (Vanicek et al., 2009). The higher the score, the greater the use of an ankle strategy rather than a hip strategy. A hip- or ankle dominant strategy can be used to maintain balance across the six sensory conditions of the SOT. | |

#### *2.8.3.2 Procedures and description of the MCT*

During this assessment, the force plates made three small, three medium and three large random backwards transitions. This process was repeated while the equipment made forward transitions (NeuroCom, 2005). Participants were asked to maintain their balance control. Long latency neuromuscular responses of the peripheral nerves, the descending and ascending spinal pathways and brain structures responsible for interpreting the information from the VSR was measured (NeuroCom, 2005). The outcome variables are described in Table 5.

**Table 5:** Definitions and descriptions of Motor Control Test (MCT) outcome variables

| **Outcome variables** | **Descriptions of test outcomes** |
|---|---|
| **Response latency** | The response latency is a measurement of the time elapsed between the onset of support surface translation and the point where the participant actively resisted induced sway (Vanicek et al., 2009). While performing the MCT, the force plates of the NeuroCom Smart Equitest® make small, medium and large backward and forward translations. |
| **Weight Symmetry** | Weight symmetry was assessed by looking at the distribution of body weight over each limb (Vanicek et al., 2009). Scores nearing 100 represents equal weight distribution (NeuroCom, 2005). |
| **Strength Symmetry** | The strength symmetry indicates symmetry of the relative response strength for each foot (Ikai, Kamikubo, Takehara, Nishi, & Miyano, 2003). |
| **Response Strength** | Active responses in each direction and the size of the translation induced by the platform was measured. Low response strength represented adequate amplitude scaling in response to platform translations on the NeuroCom Smart Equitest® (Vervoort et al., 2013). |

#### *2.8.3.3 Procedures and description of the LOS test*

Participants were required to stand with both feet planted on the stationary force plates. They were instructed to shift their centre of gravity to their maximum limits of stability (the position just before falling over) for eight different conditions/positions (NeuroCom, 2005). A “go” signal was visually provided by the NeuroCom Smart

Equitest® on a mounted screen as a stimulus to commence with movement. The ability of a participant to move safely, swiftly and smoothly through their full limits of stability set at 100% was assessed. The test also measured their directional control, movement velocity, maximum excursion as well as reaction time to a stimulus (NeuroCom, 2005). For the LOS, the COP trajectory concerning height, titled "normalized COP," was utilised to estimate the sway angle of the center of mass (Gyllensten, Hui-Chan, & Tsang, 2010). The outcome variabes of the LOS are described in Table 6.

**Table 6:** Definitions and descriptions of Limits of Stability (LOS) test outcome variables

| **Outcome variables** | **Descriptions of test outcomes** |
|---|---|
| Directional Control | When measuring directional control, the smoothness of displacement of the normalized COP to each of the eight target positions was assessed. The amount of off-target movement was compared to the amount of on-target movement of the normalized COP (Gyllensten et al., 2010). |
| Movement Velocity | Movement velocity is defined as the average speed of COP movement in degrees per second (Gyllensten et al., 2010). |
| Reaction Time | The mean reaction time of a movement from the COG towards a target set either forward, right forward, right, right backward, backward, left backward, left, and left forward was measured. |
| Endpoint Excursion | The endpoint is considered to be the point at which the first movement toward the target discontinues and subsequent corrective movements begin (NeuroCom, 2005). The endpoint was determined when the initial COP movement speed reached 0 or a deviation from the target of the COP (Gyllensten et al., 2010; Nashner, 1994). |
| Maximum Excursion | Maximum excursion is determined by measuring the furthest distance travelled by the COP, without falling (Nashner, 1994) |

## 2.9 Data analysis

The NeuroCom Smart Equitest® allows researchers to select data to be produced in either a graphical or numerical format. Numerical data was selected for this study. This was transferred to a MS Excel spread sheet to simplify data analysis.

Descriptive and inferential statistics were used to summarise and analyse the obtained data. Regarding descriptive statistics mean values were analysed to compare and contrast the experimental and control groups.

The Wilcoxon signed rank test was used to analyse the data through IBM SPSS version 23.0. This non-parametric statistical hypothesis test allows for data that does not meet the normality requirement. It is used to assess whether the ranks of the population mean differ when comparing two related or matched samples or repeated measurements of a single sample (i.e. it is a paired difference test). It can be used as an alternative to the paired Student's t-test, t-test for matched pairs, or the t-test for dependent samples when the population cannot be assumed to be normally distributed (Lowry, 2014). A significance level of $p < 0.05$ was used for the analysis of the study.

Regarding inferential statistics, an average score across three trials for each of the six SOT conditions was calculated. These scores were used to determine whether there was a statistically significant difference between the trained and untrained groups in terms anterior-posterior sway (A-P sway), force and centre of gravity position as measured by the SOT. Possible significant differences were also calculated for the average composite score of matched participants.

The Wilcoxon signed rank tests were performed to determine if a significant difference was present in mean performance data for the MCT. This was measured during small, medium and large translations of the left and the right leg about latency, weight and strength symmetry as to determine the reflexive functioning of the automatic long loop pathways (this is a pattern of short and medium latency electromyogenic responses in the stretched triceps surae muscle and a long latency response in its antagonist muscle, the anterior tibialis (Allum and Shepard,.1999)). between trained ballet dancers ($N_1$) and non-trained individuals ($N_2$). Lastly, the Wilcoxon signed rank test utilized to assess if there is a statistical significance in and between the following parameters measured during the LOS in the forward, right forward, right, right backwards, backwards, left backwards as well as left and left forward positions between the experimental and control group.

- The reaction time (in seconds) after a command was given to move.
- The difference in movement velocity (deg/sec).
- The difference in percentage (%) of maximum excursion from their COG.
- The endpoint of their first movement out a participants COG.
- The percentage (%) of directional control towards the listed positions.

## 2.10 Reliability and validity

Validity in research refers to the extent to which an instrument used measures what it is supposed to measure (Leedy & Ormrod, 2010). Reliability refers to the consistency of the instrument in measuring a variable if no change is made (Leedy & Ormrod, 2010). Care was taken with regards to malleolar alignment on the force plates so not to reflect false negative or positive results. The researcher ensured visually the malleolus was always aligned on the T-line of the force plate. Tests were repeated if participants changed their foot placement during the test trial. Objective tests were used during the study to assure that the data is not influenced by perceptions of the participant and/or the researcher.

No pilot study was done as research in this study was based on prior research by Simmons (2005a) and Simmons 2005b). Test-retest variability of the SOT has been established in normal patients. (Black, 2001). Consistent SOT sway deficits were reflected in abnormal patients during repeat tests (Black, 2001). Validity of the SOT has also been established. “Patients with peripheral vestibular deficits, especially bilateral, and severe loss of vestibular function consistently demonstrate sway amplitudes above 95% confidence intervals of normal subjects or falls on sensory organization tests (SOTs) 5 and 6 (Black 2001).

### 2.11 Bias

Bias is defined as anything, be it an influence, condition or a set of conditions that can distort the data (Leedy & Ormrod, 2010). Computerized Dynamic Posturography (CDP) objectively quantifies the performance of the systems responsible for maintaining balance. The SOT is sensitive to functional impairments. Participants were also not able to affect the results of the MCT as a reflexive pathway is stimulated by the sudden movement of the force plates. Care was taken when obtaining the case history of participants so not to let a specific tone of voice influence answers. A specific set of questions was used when taking the case history (Appendix C).

# Chapter 3

## 3 RESULTS

The study aimed to compare the Computerized Dynamic Posturography (CDP) outcome parameters of a group of trained ballet dancers ($N_1$) and a group of matched non-trained individuals ($N_2$) to determine the nature and extent of the difference(s) between the two groups.

## 3.2 Automatic Postural Control: Sensory Organisation Test (SOT)

As part of the SOT, the following analysis was performed: Equilibrium Score (ES), Sensory Analysis (SRS).

### *3.2.1 Equilibrium Score and composite score*

The table below presents the results of the statistical analysis performed on the Equilibrium and Composite scores of the trained ballet dancers ($N_1$) and non-trained individuals ($N_2$).

**Table 7:** Equilibrium (EQL) and composite scores of trained ballet dancers **($N_{1=10}$)** and non-trained individuals **($N_{2=10}$)**

| Equilibrium Score | | | |
|---|---|---|---|
| | **p-value** | **Trained Ballet Dancers ($N_1$) (Mean)** | **Non-Trained Individuals (Mean) ($N_2$)** |
| **EQL 1** | 0.91 | 95.10 (±1.18) | 94.97 (±1.92) |
| **EQL 2** | 0.20 | 93.87 (±1.16) | 92.77 (±2.35) |
| **EQL 3** | 0.09 | 93.87 (±2.09) | 92.60 (±2.18) |
| **EQL 4** | 0.72 | 87.73 (±4.91) | 87.37 (±2.73) |
| **EQL 5** | 0.22 | 73.13 (±5.80) | 74.77 (±4.00) |
| **EQL 6** | 0.95 | 74.33 (±5.37) | 74.27 (±6.31) |
| **EQL Composite score** | 0.40 | 84.70 (±1.49) | 83.90 (±2.33) |

Equilibrium scores were calculated by comparing the theoretical maximum A-P COG displacement to the theoretical sway stability limit of 12.5°. The composite score was calculated using a formula, described in Table 3. This provides an average balance score for an individual. Table 8 illustrates the mean equilibrium score results for trained ballet dancers ($N_1$) and non-trained individuals ($N_2$). Higher ES scores represent the better ability to maintain postural control.

Figure 1 illustrates the mean equilibrium scores (peak amplitude of A-P sway) for the six conditions of the SOT for the two groups. The mean equilibrium scores (ES) of trained ballet dancers ($N_1$) and non-trained individuals ($N_2$) were above the normative range (>70) (NeuroCom, 2005), indicating good overall balance in both groups. No significant differences (p>.05) between trained ballet dancers ($N_1$) and non-trained individuals ($N_2$) were reflected for conditions 1 to 6, indicating no difference in postural stability and preference between the two groups. The mean equilibrium composite scores did not reflect significant differences (p>.05) between the two groups either.

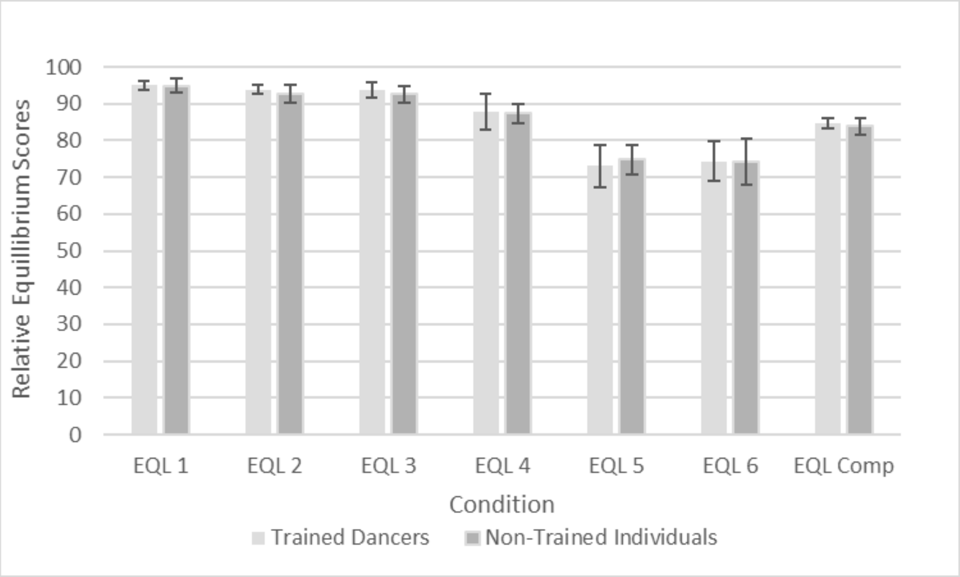


**Figure 1: Mean Equilibrium score (ES) results**

### *3.2.2 Strategy Analysis*

The table below presents the results of the statistical analysis of the strategy scores of the trained ballet dancers ($N_1$) and non-trained individuals ($N_2$).

**Table 8:** Strategy Scores of trained ballet dancers **($N_{1=10}$)** and non-trained individuals **($N_{2=10}$)**

| **Strategy Score** | | | |
|---|---|---|---|
| | **p-value** | **Trained ballet dancers ($N_1$) (Mean)** | **Non-trained individuals ($N_2$) (Mean)** |
| **EQL 1** | 0.53 | 98.90 (±0.39) | 98.83 (±0.24) |
| **EQL 2** | 0.20 | 98.97 (±0.51) | 98.80 (±0.36) |
| **EQL 3** | 0.11 | 99.10 (±0.52) | 98.83 (±0.36) |
| **EQL 4** | 0.80 | 87.97 (±3.14) | 87.37 (±3.43) |
| **EQL 5** | 0.22 | 80.57 (±5.29) | 79.57 (±4.44) |
| **EQL 6** | 0.26 | 82.80 (±4.45) | 80.43 (±5.23) |

The strategy score includes the difference between the maximum and minimum sheer forces generated by the subject, divided by a constant representing the theoretical sheer force difference in normals and normalized (Vanicek et al., 2009). The higher the score, the greater the use of an ankle strategy rather than a hip strategy. Scores approaching 100 indicate the predominant use of ankle strategy, whereas scores near 0 indicate hip stategy. Scores inbetween indicate the use of both strategies. Table 8 represents the mean strategy score values for trained ballet dancers ($N_1$) compared to non-trained individuals ($N_2$). The Wilcoxon signed rank test was used to determine whether differences in the strategy participants use to maintain balance was present.

No statistically significant differences were found regarding the strategy participants used to maintain postural control (Figure 2) for conditions 1 to 6. Both groups predominantly used an ankle dominant strategy to maintain balance, which shifted to a strategy with a hip dominant component as the difficulty of the conditions increased.

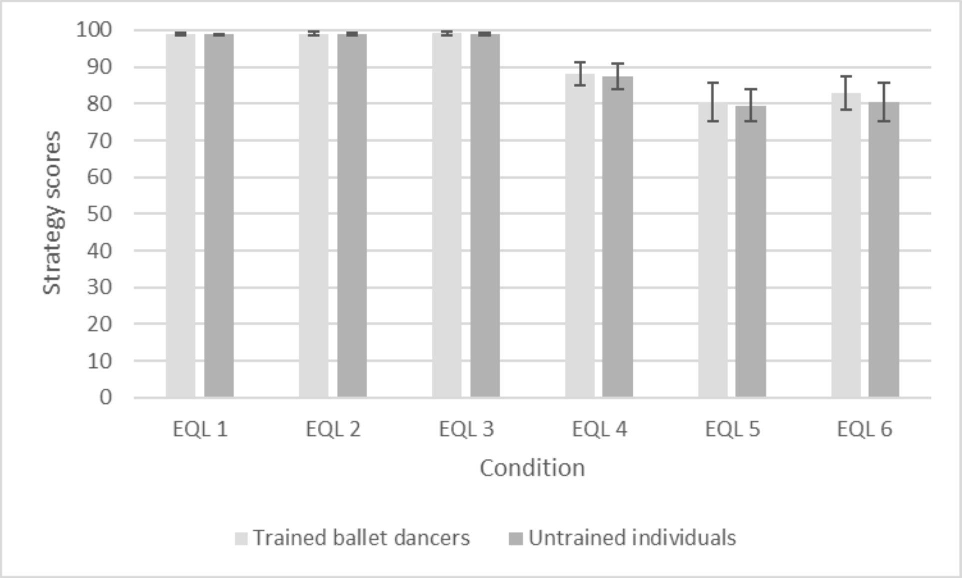


**Figure 2: Mean strategy scores for the Sensory Organisation Test (SOT).**

## 3.3 Automatic Postural Control: Motor Control Test (MCT)

As part of the MCT, the following analysis was performed: Postural Response Latency, Weight symmetry, Strenght symmetry and Response strenght.

### *3.3.1 Postural Response Latency*

The table below presents the results of the statistical analysis of the Postural Response Latency of the left and right legs of the trained ballet dancers ($N_1$) and non-trained individuals ($N_2$).

**Table 9:** Postural Response Latency of trained ballet dancers **($N_{1=10}$)** and non-trained individuals **($N_{2=10}$)** for the left and right leg.

| **Postural Response Latency** | | | |
|---|---|---|---|
| **Left leg** | | | |
| | **p-value** | **Trained Ballet Dancers ($N_1$) (Mean)** | **Non-trained Individuals ($N_2$) (Mean)** |
| **Small Backward** | 0.16 | 127.00 (±8.23) | 123.00 (±12.52) |
| **Medium Backward** | 1.00 | 120.00 (±8.16) | 120.00 (±8.16) |
| **Large Backward** | 1.00 | 119.00 (±8.76) | 119.00 (±8.76) |
| **Small Forward** | 0.43 | 135.00 (1±7.16) | 130.00 (±9.43) |
| **Medium Forward** | 0.21 | 134.00 (±15.78) | 131.00 (±14.49) |
| **Large Forward** | 0.60 | 127.00 (±11.60) | 124.00 (±10.75) |
| **Right leg** | | | |
| **Small Backward** | 0.25 | 130.00 (±4.71) | 125.00 (±12.69) |
| **Medium Backward** | 0.24 | 124.00 (±9.66) | 119.00 (±8.76) |
| **Large Backward** | 0.48 | 122.00 (±6.32) | 120.00 (±8.16) |
| **Small Forward** | 0.17 | 138.00 (±16.19) | 130.00 (±8.16) |
| **Medium Forward** | 0.59 | 131.00 (±13.70) | 129.00 (±12.87) |
| **Large Forward** | 0.62 | 126.00 (±12.65) | 124.00 (±8.43) |

The response latency is a measurement of the time elapsed between the onset of support surface translation and the point where the participant actively resisted induced sway (Vanicek et al., 2009). Table 9 represents the mean postural response latency differences between trained ballet dancers ($N_1$) and non-trained individuals ($N_2$).

Figure 3 and Figure 4 illustrates the response latencies during translations of the force plate. Statistical testing did not indicate significant differences between ballet dancers and non-dancers for forward or backward translations. The latency of the left and right leg for small, medium and large forward translations is represented in Figure 3 and Figure 4. The boxes represent interquartile ranges (Q25 and Q75), median values and error bars indicating the non-outlier range. An algorithm determines the latency composite score for each participant across the six trials of the left and right leg. The Wilcoxon signed rank test was again used to determine differences between matched participants. No statistically significant difference was present between latency composite scores, confirming no gross response latency differences between the two groups.

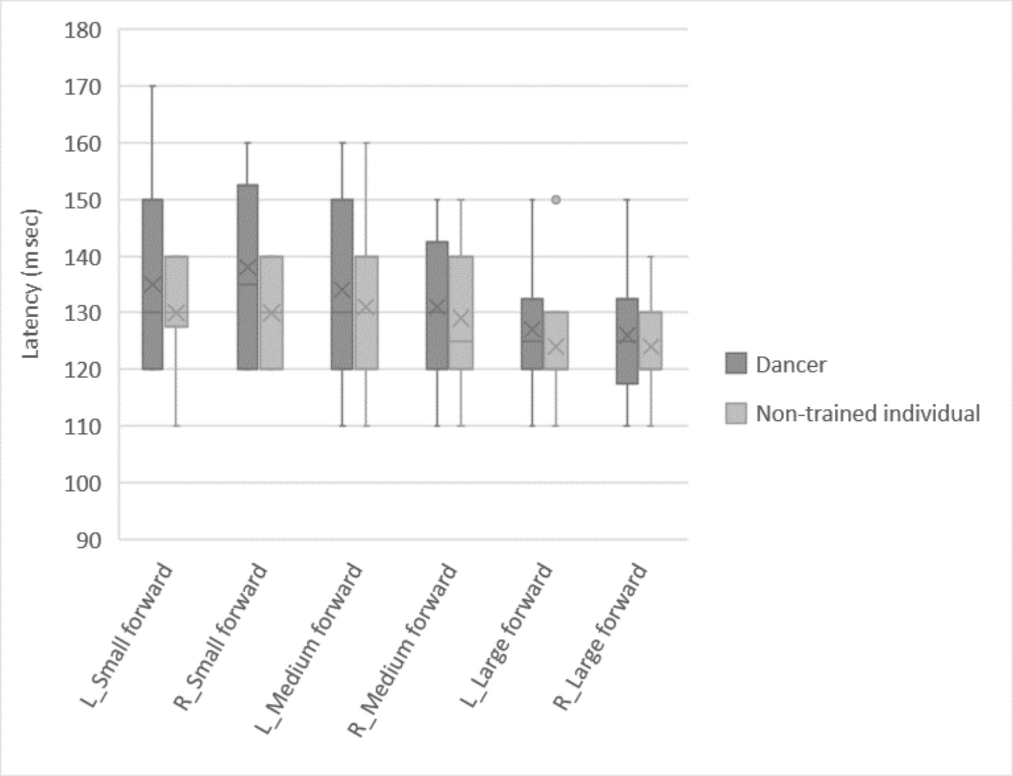


**Figure 3: Group differences in the Motor Control Test (MCT) performance per condition.**

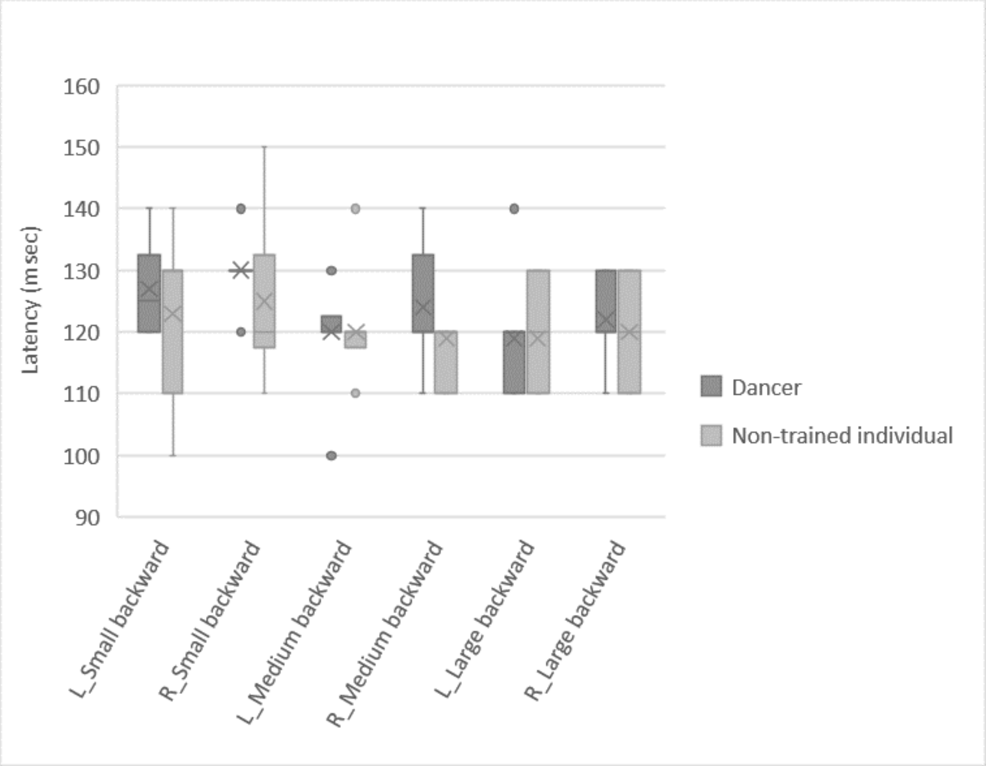


**Figure 4: Group differences in the Motor Control Test (MCT) performance per condition.**

### *3.3.2 Weight symmetry*

The table below presents the results of the statistical analysis of the weight symmetry scores of the trained ballet dancers ($N_1$) and non-trained individuals ($N_2$).

**Table 10:** Weight symmetry scores of trained ballet dancers **($N_{1\text{-}10}$)** and non-trained individuals **($N_{2=10}$)**.

| **Weight Symmetry** | | | |
|---|---|---|---|
| | **p-value** | **Trained Ballet Dancers ($N_1$) (Mean)** | **Non-trained Individuals ($N_2$) (Mean)** |
| **Small Backward** | 0.34 | 98.30 (±5.74) | 100.50 (±4.97) |
| **Medium Backward** | 0.58 | 98.40 (±5.52) | 99.60 (±6.90) |
| **Large Backward** | 0.77 | 98.90 (±6.44) | 99.20 (±6.56) |
| **Small Forward** | 0.47 | 100.50 (±4.30) | 98.70 (±4.92) |
| **Medium Forward** | 0.92 | 99.50 (±5.52) | 100.50 (±4.65) |
| **Large Forward** | 1.00 | 100.50 (±6.38) | 100.30 (±3.89) |

Weight symmetry is the distribution of body weight over each limb (Vanicek et al., 2009). Table 11 represents the difference between the mean weight symmetry scores between trained ballet dancers ($N_1$) and non-trained individuals ($N_2$). Statistical analysis (using the Wilcoxon signed rank test) of weight symmetry results for small, medium and large backwards and forward translations reflected no significant differences ($p>.05$). Figure 5 illustrates the weight symmetry during translations of the force plate for small, medium and large backward and forward translations. The boxes represent interquartile differences (Q25 and Q75), median values and error bars indicating a range.

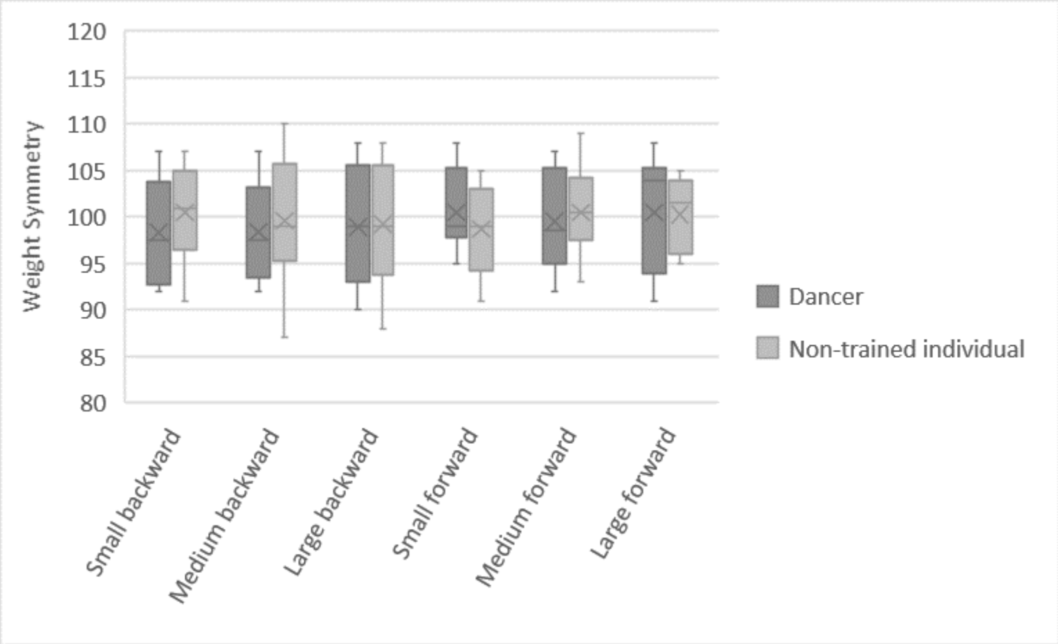


**Figure 5: Group differences in the Motor Control Test (MCT) performance per condition.**

### *3.3.3 Strength Symmetry*

The table below presents the results from the statistical analysis of the Strength Symmetry scores of trained ballet dancers ($N_1$) and non-trained individuals ($N_2$).

**Table 11:** Strength Symmetry scores of trained ballet dancers **($N_{1=10}$)** and non-trained individuals **($N_{2=10}$)**

| **Strength Symmetry** | | | |
|---|---|---|---|
| | **p-value** | **Trained Ballet Dancers ($N_1$) (Mean)** | **Non-trained Individuals ($N_2$) (Mean)** |
| **Small Backward** | 0.14 | 87.10 (±12.32) | 98.30 (±17.51) |
| **Medium Backward** | 0.21 | 91.90 (±12.19) | 101.40 (±13.66) |
| **Large Backward** | 0.76 | 93.40 (±8.51) | 95.40 (±15.83) |
| **Small Forward** | 0.34 | 92.00 (±16.87) | 100.20 (±15.29) |
| **Medium Forward** | 0.02* | 92.00 (±9.60) | 104.40 (9.34) |
| **Large Forward** | 0.02* | 92.10 (±7.13) | 102.40 (±5.70) |

The strength symmetry indicates symmetry of the relative response strength for each foot (Ikai et al., 2003). Table 11 and Figure 6 illustrates the mean strength symmetry of the left and right leg for small, medium and large backward and forward translations. The boxes represent interquartile ranges (Q25 and Q75), median values and error bars indicating a non-outlier range.

Ballet dancers reflected strength symmetry responses significantly smaller for medium forward ($p<.05$) as well as large forward ($p<.05$) translations compared to non-trained individuals ($N_2$) (Figure 6). No significant difference was present for small forward translations. Regarding all backwards translations, similar function was reflected between the two groups and no significantly different responses was present between the matched participants.

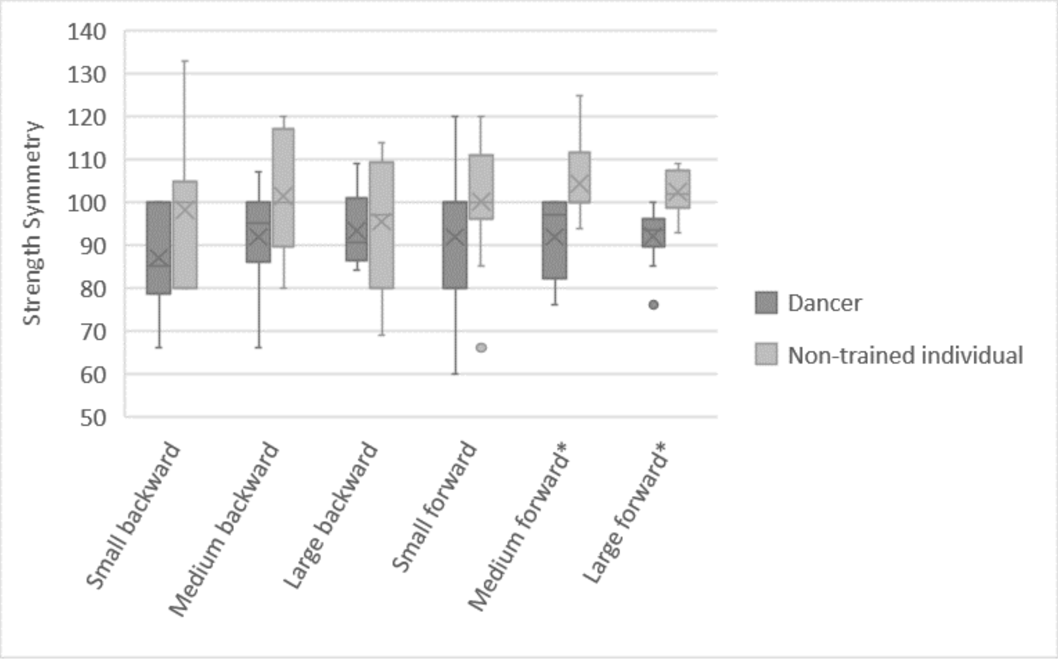


**Figure 6: Group differences in the Motor Control Test (MCT) performance per condition.**

### *3.3.4 Response strength*

The table below presents the results of the statistical analysis of the Response Strength score of the trained ballet dancers ($N_1$) and non-trained individuals ($N_2$).

**Table 12:** Response strength scores of trained ballet dancers **($N_{1=10}$)** and non-trained individuals **($N_{2=10}$)** for the left and right leg

| **Amplitude Scaling** | | | |
|---|---|---|---|
| **Left leg** | | | |
| | **p-value** | **Trained Ballet Dancers ($N_1$) (Mean)** | **Non-trained Individuals ($N_2$) (Mean)** |
| **Small Backward** | 0.22 | 3.00 (±1.15) | 2.40 (±1.51) |
| **Medium Backward** | 0.12 | 5.70 (±2.16) | 4.60 (±2.17) |
| **Large Backward** | 0.88 | 9.20 (±3.77) | 9.30 (±4.30) |
| **Small Forward** | 0.68 | 2.90 (±1.60) | 2.70 (±1.42) |
| **Medium Forward** | 0.02* | 6.50 (±1.90) | 5.00 (±2.26) |
| **Large Forward** | 0.17 | 9.10 (±2.60) | 7.70 (±2.41) |
| **Right leg** | | | |
| **Small Backward** | 0.87 | 2.10 (±0.88) | 2.20 (±1.14) |
| **Medium Backward** | 0.22 | 5.00 (±2.16) | 4.50 (±1.51) |
| **Large Backward** | 0.88 | 8.40 (±3.95) | 8.20 (±3.65) |
| **Small Forward** | 0.43 | 2.30 (±0.67) | 2.90 (±1.85) |
| **Medium Forward** | 0.68 | 5.60 (±1.65) | 5.30 (±1.83) |
| **Large Forward** | 0.79 | 8.00 (±2.71) | 7.90 (±2.13) |

The active responses in each direction and the size of the translation induced by the platform was measured. (Vervoort et al., 2013). Table 12 compares the mean amplitude scaling results between trained ballet dancers ($N_1$) and non-trained individuals ($N_2$). Data was analysed using the Wilcoxon signed rank test. Figure 7 and 8 represents the response strength of the left and right leg for small, medium and large forward and backward translations. The boxes represent interquartile ranges (Q25 and Q75), median values and error bars indicating non-outlier range.

No significant differences were observed in the right leg. Trained ballet dancers ($N_1$) reflected higher response strength for medium forward translations with the left leg, indicating inferior amplitude scaling in response to platform translations that that of non-trained individuals ($N_2$) ($p<.05$) (Figure 7). No further significant differences were observed for small and large forward and small, medium and large backwards translations with the left leg. No significant differences were present in response strength results for forward or backward translations using the right leg (Figure 8).

Both groups reflected low amplitude scaling during the trials of the MCT, but as the size of the movement increased, the response strength also increased, indicating poorer function.

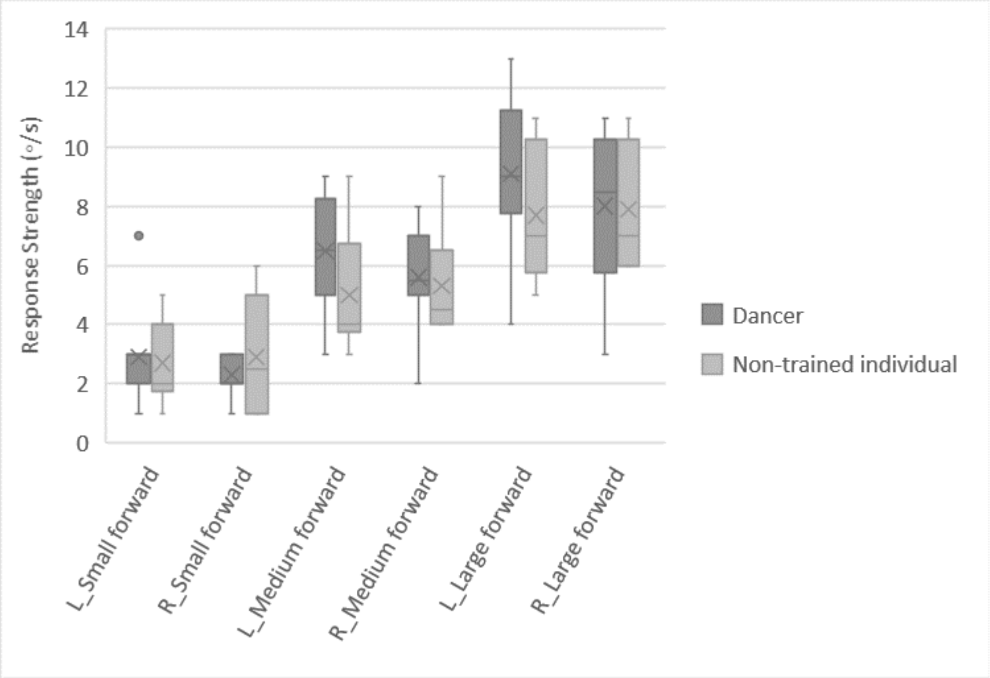


**Figure 7: Group differences in the Motor Control Test (MCT) performance per condition.**

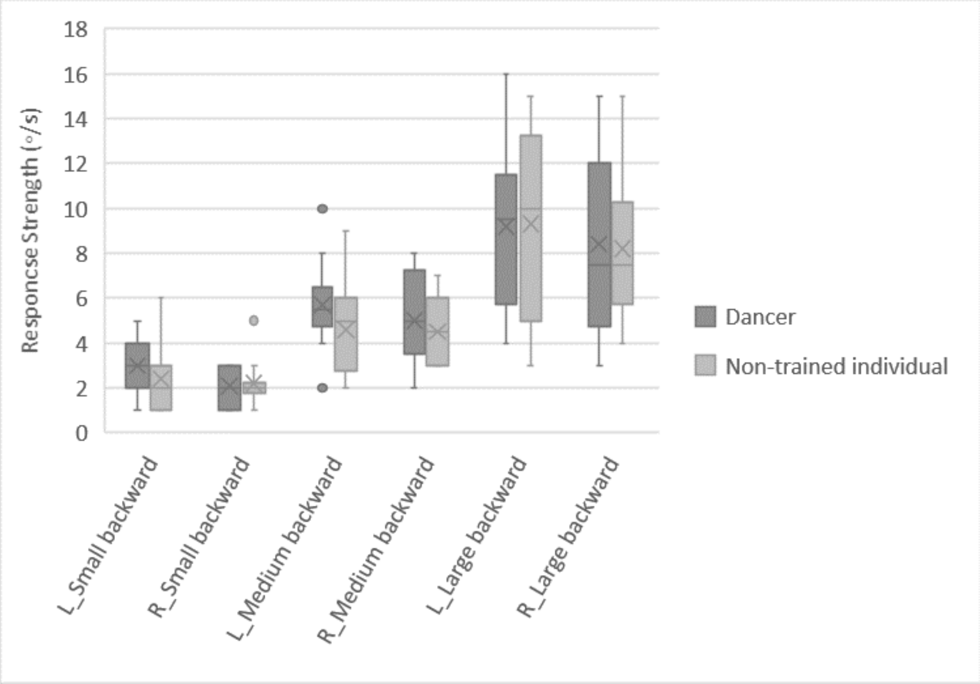


**Figure 8: Group differences in the Motor Control Test (MCT) performance per condition.**

## 3.4 Voluntary Postural Control: Limits of Stability Test (LOS)

As part of the LOS test the following analysis was performed: Directional Control, Movement Velocity, Reaction Time, Endpoint Excursion (EE) and Maximum Excursion (ME).

### *3.4.1 Directional Control*

The table below presents the results from the statistical analysis of the Directional Control scores of trained ballet dancers ($N_1$) and non-trained individuals ($N_2$) for eight measured movement directions.

Table 13**:** Directional Control scores of trained ballet dancers **($N_{1=10}$)** and non-trained individuals **($N_{2=10}$)** for eight measured movement directions.

| **Directional Control** | | | |
|---|---|---|---|
| | **p-value** | **Trained Ballet Dancers ($N_1$) (Mean)** | **Non-trained Individuals ($N_2$) (Mean)** |
| **Forward** | 0.41 | 92.10 (±3.28) | 93.00 (±3.74) |
| **Right Forward** | 0.33 | 90.90 (±4.04) | 89.30 (±3.02) |
| **Right** | 0.11 | 78.40 (±7.92) | 85.60 (±6.35) |
| **Right Backward** | 0.72 | 74.70 (±15.54) | 75.70 (±8.94) |
| **Backward** | 0.80 | 83.50 (±7.79) | 82.50 (±9.42) |
| **Left Backward** | 0.28 | 73.40 (±10.88) | 70.10 (±10.07) |
| **Left** | 1.00 | 86.00 (±3.86) | 85.80 (±3.61) |
| **Left Forward** | 0.67 | 87.10 (±9.23) | 86.60 (±8.81) |

Directional control is the smoothness of displacement of the normalized COP to each of the eight target positions. (Gyllensten et al., 2010). Table 13 illustrates the difference in directional control between trained ballet dancers ($N_1$) and non-trained individuals ($N_2$). Statistical analysis, using the Wilcoxon signed rank test, indicated no significant difference (p>.05) in the performance of trained professional dancers compared no non-trained individuals ($N_2$) for all eight positions.

Figure 9 illustrates the amount of intended movement towards a target, given as a percentage value, during a movement from the COG position to a point set at 100% LOS either forward, right forward, right, right backward, backward, left backward, left and left forward.

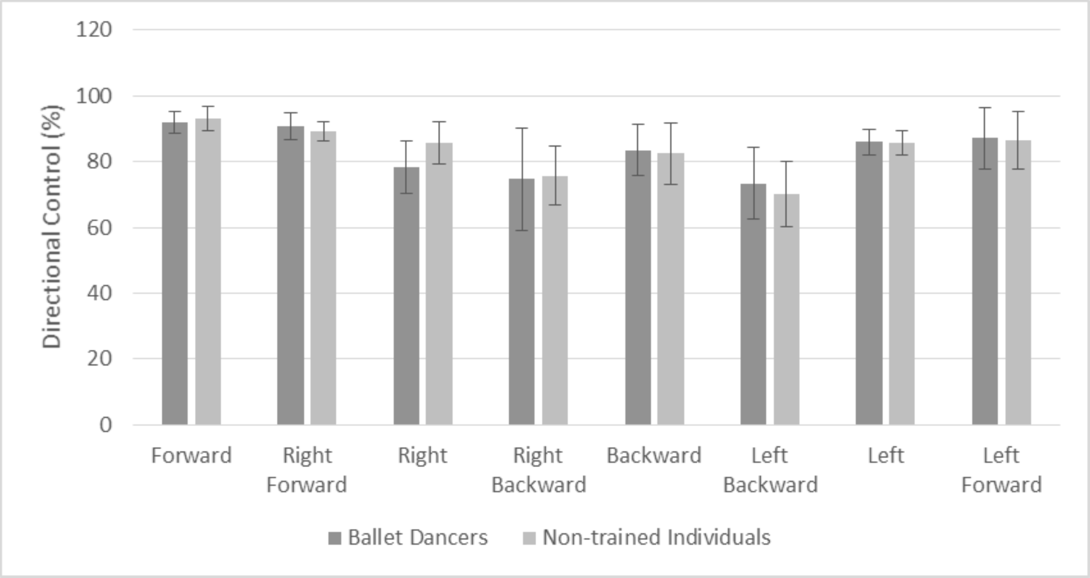


**Figure 9: Group differences in mean directional control (%)**

### *3.4.2 Movement Velocity*

The table below presents the results of the statistical analysis of the Movement Velocity scores of the trained ballet dancers ($N_1$) and non-trained individuals ($N_2$) for eight measured movement directions.

**Table 14:** Movement Velocity scores of trained ballet dancers **($N_{1=10}$)** and non-trained individuals **($N_{2=10}$)** for eight measured movement directions.

| **Movement Velocity** | | | |
|---|---|---|---|
| | **p-value** | **Trained Ballet Dancers ($N_1$) (Mean)** | **Non-trained Individuals ($N_2$) (Mean)** |
| **Forward** | 0.01* | 4.57 (±2.12) | 2.75 (±0.84) |
| **Right Forward** | 0.03* | 5.53 (±2.14) | 3.44 (±1.16) |
| **Right** | 0.88 | 4.70 (±1.91) | 4.72 (±1.97) |
| **Right Backward** | 0.92 | 4.15 (±2.07) | 4.37 (±1.99) |
| **Backward** | 0.57 | 2.26 (±0.70) | 2.36 (±0.70) |
| **Left Backward** | 0.88 | 3.96 (±1.73) | 4.05 (±1.85) |
| **Left** | 0,58 | 4,58 (±1,77) | 5.19 (±2.10) |
| **Left Forward** | 0,45 | 4,73 (±2,54) | 4.71(±1.33) |

Movement velocity is the average speed of COP movement in degrees per second (Gyllensten et al., 2010). The difference in movement velocity between trained ballet dancers ($N_1$) and non-trained individuals ($N_2$) is demonstrated in Table 14. Data was analysed using the Wilcoxon signed rank test. Figure 10 illustrates the velocity during a movement from the COG position to eight targets (forward, right forward, right, right backward, backward, left backward, left and left forward) set at 100% LOS.

Trained dancers reflected a highly significant (p<.05) difference in the average velocity of movement from their COG towards a target during forward movements, as well as significantly (p<.05) better performance during right forward movements than that of matched non-trained individuals ($N_2$). Mean velocity values for trained dancers for movements forward (4.57deg/sec) and right forward (5.53deg/sec) was higher than for the non-trained individuals ($N_2$) (2.75deg/sec) and (3.44deg/sec) respectively (Figure 10). No significant difference in average velocity was present during right, right backwards, backwards, left backwards, left and left forward movement positions. Large standard deviation ranges were present for both groups during all movement directions.

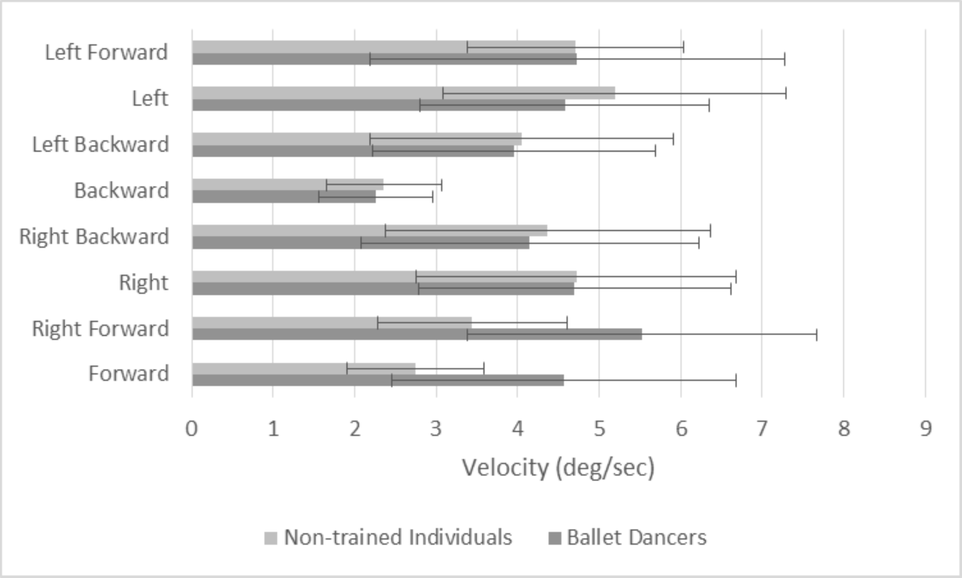


**Figure 10: The difference in mean movement velocity (deg/sec) between trained ballet dancers ($N_{1=10}$) and matched non-trained individuals ($N_{2=10}$) during an intended movement from the Centre of Gravity (COG) position towards a target set at 100% Limits of Stability (LOS).**

### *3.4.3 Reaction Time*

The table below presents the results of the statistical analysis of the Reaction Time scores of the trained ballet dancers and non-trained individuals ($N_2$) for eight measured movement directions.

**Table 15:** Reaction time scores of trained ballet dancers **($N_{1=10}$)** and non-trained individuals **($N_{2=10}$)** for eight measured movement directions.

| **Reaction Time** | | | |
|---|---|---|---|
| | **p-value** | **Trained Ballet Dancers ($N_1$) (Mean)** | **Non-trained Individuals ($N_2$) (Mean)** |
| **Forward** | 0.88 | 0.88 (±0.45) | 0.84 (±0.29) |
| **Right Forward** | 0.04* | 0.62 (±0.23) | 0.91 (±0.35) |
| **Right** | 0.72 | 0.77 (±0.28) | 0.87 (±0.43) |
| **Right Backward** | 0.15 | 0.54 (±0.14) | 0.71 (±0.32) |
| **Backward** | 0.26 | 0.72 (±0.23) | 0.66 (±0.26) |
| **Left Backward** | 0.24 | 0.75 (±0.23) | 0.91(±0.35) |
| **Left** | 0.58 | 0.67 (±0.16) | 0.71 (±0.20) |
| **Left Forward** | 0.29 | 0.61 (±0.15) | 0.72 (±0.31) |

The reaction time is the movement from the COG towards a target. The difference in reaction time between trained ballet dancers ($N_1$) and non-trained individuals ($N_2$) is illustrated in Table 15. Data was analysed using the Wilcoxon signed rank test.

A significant difference ($p<.05$) was present in the reaction time (the time from the command to move, and the participant's first movement) for right forward movements. Figure 11 demonstrates that trained ballet dancers ($N_1$) (0.61sec ±0.22) reflected a faster average reaction time for movements forward and towards the right, then non-trained individuals ($N_2$) (0.91sec ±0.35). No significant results were obtained for the other movement directions. Large standard deviation ranges were present for both groups during all movement directions. *

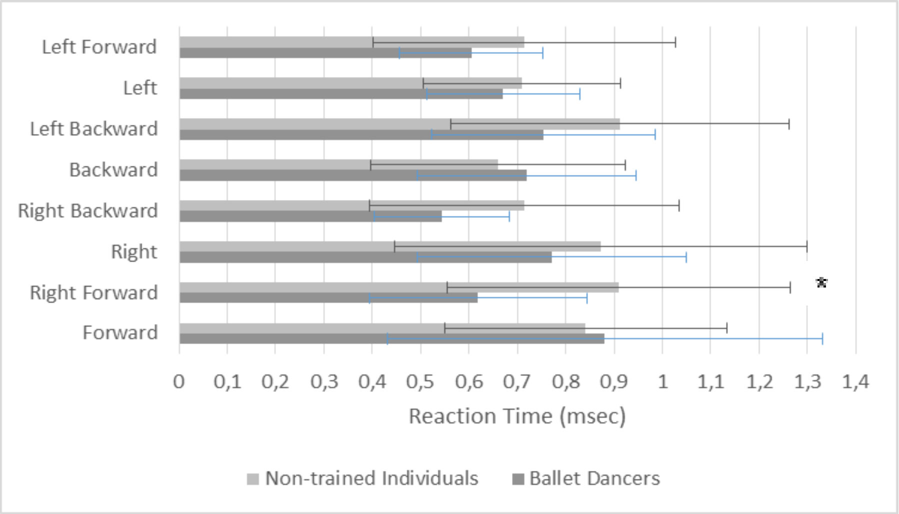


**Figure 11: Mean Reaction Time (sec) of trained ballet dancers $(N_{1=10})$ compared to non-trained individuals $(N_{2=10})$ during voluntary movements from the Centre of Gravity (COG) position towards a target set at 100% Limits of Stability (LOS).**

### *3.4.4 Endpoint Excursion*

The table below presents the results of the statistical analysis of the Endpoint Excursion scores of the trained ballet dancers ($N_1$) and non-trained individuals ($N_2$) for eight measured movement directions.

**Table 16:** Endpoint Excursion scores of trained ballet dancers $(N_{1=10})$ and non-trained individuals $(N_{2=10})$ for eight measured movement directions.

| **Endpoint Excursion** | | | |
|---|---|---|---|
| | **p-value** | **Trained Ballet Dancers ($N_1$) (Mean)** | **Non-trained Individuals ($N_2$) (Mean)** |
| **Forward** | 0.92 | 80.20 (±22.32) | 81.40 (±12.41) |
| **Right Forward** | 0.12 | 99.70 (±9.10) | 88.10 (±13.26) |
| **Right** | 0.33 | 78.60 (±8.10) | 74.90 (±8.75) |
| **Right Backward** | 0.51 | 87.00 (±12.61) | 82.50 (±12.44) |
| **Backward** | 0.07 | 61.30 (±14.09) | 51.10 (±12.22) |
| **Left Backward** | 0.65 | 85.20 (±16.83) | 82.90 (±11.88) |
| **Left** | 0.03* | 85.70 (±9.21) | 74.50 (±12.20) |
| **Left Forward** | 0.44 | 98.60 (±11.21) | 93.90 (±8.05) |

The endpoint is when the initial COP movement speed reached 0 or a deviation from the target of the COP (Gyllensten et al., 2010; Nashner, 1994). Table 16 compares the difference between the endpoint excursion of trained ballet dancers ($N_1$) and non-trained individuals ($N_2$). Data was analysed using the Wilcoxon signed rank test.

Illustrated in Figure 13 is the percentage COP displacement towards a target set at 100% LOS. During voluntary leftwards movements, there was a significant difference ($p<.05$) in the ability of ballet dancers to maximally complete the distance of the first movement towards the target set at 100% limits of stability. Trained ballet dancers ($N_1$) could move an average of 85.7% (±9.21%), compared to 74.5% (±12.20%) in non-trained individuals ($N_2$). A trend towards significance was also noted for backwards movements, with results bordering significance at p=0,066. No significant difference was present for trained dancers and non-trained individuals ($N_2$) about their ability to maximize the original endpoint excursion ($p<.05$) for forward, right forward, right, right backward and left backward movement directions.

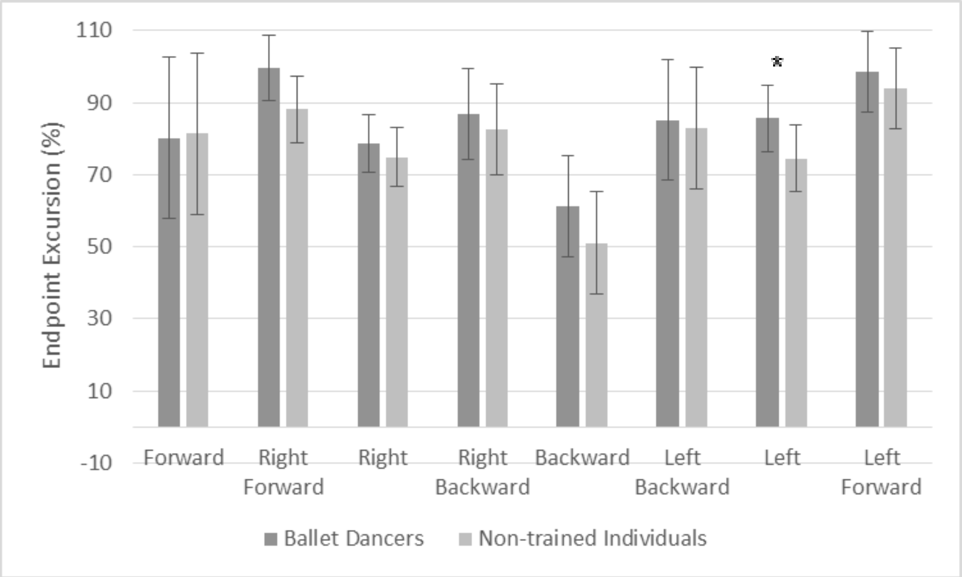


**Figure 12: Percentage (%) movement out of the Centre of Gravity (COG) to the point at which the first movement toward the target discontinues between trained ballet dancers ($n_{1=10}$) and non-trained individuals ($n_{2=10}$)**

### *3.4.5 Maximum Excursion*

The table below presents the results of the statistical analysis of the Maximum Excursion scores of the trained ballet dancers and non-trained individuals ($N_2$) for eight measured movement directions

**Table 17:** Maximum Excursion scores of trained ballet dancers **($N_{1=10}$)** and non-trained individuals **($N_{2=10}$)** for eight measured movement directions.

| **Maximum Excursion** | | | |
|---|---|---|---|
| | **p-value** | **Trained Ballet Dancers ($N_1$) (Mean)** | **Non-trained Individuals ($N_2$) (Mean)** |
| **Forward** | 0.05* | 101.80 (±4.05) | 91.90 (±10.95) |
| **Right Forward** | 0.05* | 106.20 (±6.41) | 97.30 (±7.65) |
| **Right** | 0.47 | 91.80 (±7.07) | 87.80 (±9.51) |
| **Right Backward** | 0.08 | 99.50 (±7.35) | 94.00 (±4.64) |
| **Backward** | 0.15 | 80.10 (±8.62) | 74.20 (±9.75) |
| **Left Backward** | 0.06 | 99.90 (±7.52) | 90.00 (±11.54) |
| **Left** | 0.07 | 92.50 (±8.83) | 87.20 (±5.39) |
| **Left Forward** | 0.22 | 105.00 (±6.83) | 100.40 (±5.19) |

Illustrated in Figure 13 is the maximum distance that trained dancers were able to achieve from their Centre of Gravity (COG) position towards a target set at 100% Limits of Stability (LOS). The maximum excursion is the furthest distance travelled by the COP, without falling (Nashner, 1994). The difference in the maximum excursion is compared (Table 17) between trained ballet dancers ($N_1$) and non-trained individuals ($N_2$). Analysis of the maximum distance that trained dancers were able to achieve from their COG position towards a target using the Wilcoxon signed rank test, reflected significant differences for forward ($p<.05$) and right forward ($p<.05$) movement directions. A trend towards significance was noted for left backwards movements ($P<.05$). No statistically significant difference was present during rightwards, right backwards, backwards, left, and left forward movement directions.

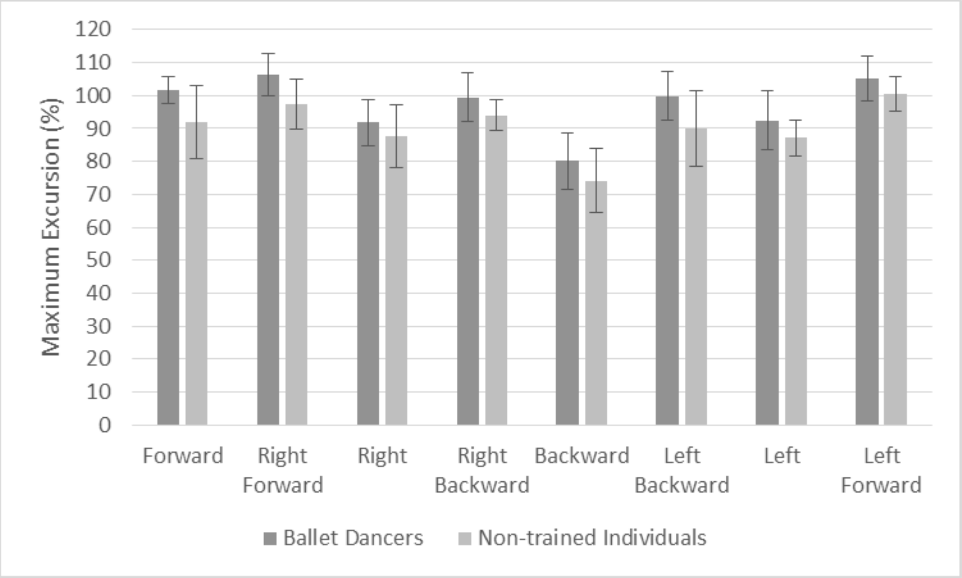


**Figure 13: Differences in mean Maximum Excursion (%) between trained ballet dancers ($N_{1=10}$) and non-trained individuals ($N_{2=10}$).**

Trained dancers were on average able to move 101.8% ±4.04% and 106.2% ±6.40% the distance of a target set at 100% LOS for forward and right forward movements (Figure 14). In comparison to this, non-trained individuals (**$N_2$**) were only able to move 91.9% ±10.9% and 97.3% ±7.64% of the distance on average. Trained dancers were able to move an average of 99.9% ±7.51% of the distance for the left backwards movement direction, compared to 90% ±11.53%.

# Chapter 4

## 4 DISCUSSION

## 4.1 Automatic Postural Control: Sensory Organisation Test (SOT)

### *4.1.1 Equilibrium Score and composite score*

No difference in the performance of trained dancers compared to non-trained individuals ($N_2$) was reflected across the SOT conditions. This stands in contrast to Simmons' (2005a) research, which found that dancers were more unstable when forced to rely on vestibular and visual input, as assessed during SOT 4. He attributed it to a shift in sensory weighting from visual towards somatosensory information. Interestingly, no significant difference was noted during SOT 4, 5 and 6 in the present research, as was found by Simmons (2005a). Trained dancers did not perform less or more proficiently than controls when forced to rely on vestibular or visual information.

Differences in the results of the two studies may be attributed to multiple causes. Firstly, different inclusion criteria were used. Simmons (2005a) ensured that his two groups had comparable cutaneous foot sensitivity by completing the Semmes-Weinstein monofilament test to both feet. He did not rule out vestibular pathology and therefore did not account for the possibility of vestibular abnormalities affecting test results. In the present research, inclusion criteria screened for vestibular abnormalities by doing the ten-minute dizziness examination (Goebel, 2001), including computerized DVA. Simmons (2005a) recruited 17 female dancers from two community dance companies. In this study, only ten matched participants could be recruited, resulting in a much smaller sample size. Simmons (2005a) research averaged 10.88 (±3.20) years of ballet training.  Years of experience in participants in the present study averaged 16,6 (± 4.24), allowing them more time to train. Simmons (2005a) also used dancers with different proficiency levels, but he did not indicate what school of dance the two community colleges offered. Dancers from different schools of ballet (DASA, cecchetti, and RAD) were used in the present study, with the different school's focus and manner of training differing slightly. Differences in clinic testing protocol may also affect results. In the present study, participants were allowed four trials, the first trial for each condition was repeated if the participant indicated that they did not concentrate fully or understand the task. Simmons (2005a) only allowed three trials. During condition 1, 2 and 3, data did approach the 100% maximum ceiling for the trained ballet dancer and matched non-trained individuals ($N_2$), It could be posited that this ceiling constrains the variance in the outcomes of the two groups, which might be the reason that there is no statistically significant difference.

Crotts et al. (1996) did a similar study using an adaptation of the foam and dome test, which is a test similar to the sharpened romberg test, with vision denied by the dome. Participants were assessed under six conditions similar to that of the SOT. Trials ran for 30 seconds, compared to 20 seconds on the SOT. Participants were scored on how long they could maintain stance on a single leg without opening their eyes (condition 2 and 5) or taking a step. Condition two would be where only vision is denied, and condition five is when vision is denied and somatosensory information is unavailable. Significant differences were present during condition 5 and 6 as well as on the composite balance score. The authors theorized that dancers can utilize information received from the vestibular and somatosensory system better, contradicting the present research. During the present study, computerized equipment was used, allowing for more objective results than Crotts et al. (1996), as the a-p sway was measured instead of the amount of time a participant could remain standing or not open their eyes. In this study, bipedal stance was used instead of standing on a single leg. Crotts et al. (1996) used a single leg, which is deemed as a more difficult task, as the base of support and integrative information for interlimb coordination is decreased compared to bipedal stance.

### *4.1.2 Strategy Analysis*

Simmons (2005a) describes that the strategy score is based on a theoretical maximum amount of shear force. For normal participants, this is 11.25Kg. A score approaching 100 indicates that slow acting postural adjustments around the ankle joints are used. He further explains that a score nearing zero indicates faster corrective movements about the hip as the maximum limits of stability of a participant is approached.

This study found trained professional dancers and non-trained individuals ($N_2$) used similar strategies for conditions 1 to 6 to maintain postural control. Matched participants used a predominantly ankle strategy to maintain postural control, which shifted to a strategy with a hip dominant component as the difficulty of the conditions increased. This was expected, as slow postural corrections around the ankle are adequate to maintain balance. The mean ES of both groups across the six conditions did not near the theoretical maximum A-P sway of 12.5°, requiring faster corrective movements around the hip as a participant’s maximum limits of stability is approached, such as when a person is nearing a fall. Slow postural corrections around the ankle joints were adequate to stabilize themselves and prevent a fall.

This stands in contrast with Simmons (2005a). He found a significant difference between groups for average strategy and that a significant shift from ankle to hip dominant strategy was present as the difficulty of tasks increased across the six conditions. Dancers also reflected greater use of a hip strategy than non-dancers during condition 5 and 6 (Simmons, 2005a). These finding in the research by Simmons (2005a) is expected, as the strategy score is dependent on the equilibrium score. Significant differences were present between groups for SOT 5 and 6 because they reflected greater A-P sway (Simmons, 2005a).

Similar to the above mentioned research, differences in results may be as a result of multiple causes. Firstly, different inclusion criteria were used. Simmons (2005a) ensured that his two groups had comparable cutaneous foot sensitivity by completing the Semmes-Weinstein monofilament test to both feet. He did not rule out vestibular pathology during this part of his research. In the present research, inclusion criteria screened for vestibular abnormalities by doing the ten-minute dizziness examination (Goebel, 2001). A smaller sample size was also used in the study. Simmons (2005a) research averaged 10.88 (±3.20) years of ballet training. Years of experience in participants in the present study averaged 16,6 (± 4.24), allowing them more time to train and may have increased their proficiency. Simmons (2005a) also used dancers with different proficiency levels, but he did not indicate what school of dance the two community colleges offered. Dancers from different schools of ballet (DASA, cecchetti, and RAD) were used in the present study, with the different school's focus and manner of training differing slightly. Differences in clinic testing protocol may also affect results. In the present study, participants were allowed four trials, the first trial for each condition was repeated if the participant indicated that they did not concentrate fully or understand the task. Simmons (2005a) only allowed three trials. During condition 1, 2 and 3, data did approach the 100% maximum ceiling for the trained professional dancer and matched non-trained individuals ($N_2$). No gross difference would, therefore, be measurable.

## 4.2 Automatic Postural Control: Motor Control Test (MCT)

### *4.2.1 Postural Response Latency*

No gross postural response latency differences were present between trained ballet dancers ($N_1$) and non-trained individuals ($N_2$). The amount of time between the onset of the support surface's translation and the point where they actively resisted induced sway was similar for trained ballet dancers ($N_1$) and non-trained individuals ($N_2$). This indicates that training did not improve the performance of the long latency neuromuscular responses of the tibialis anterior and soleus muscle during backwards and forward, small, medium and large perturbations. This further indicates that dancers were not more stable than controls, as long latency neuromuscular responses in the tibialis anterior muscle stabilizes posture (Timmann, Belting, Schwarz, & Diener, 1994).

Simmons (2005b) predicted that dancers have faster and consistent long latency neuromuscular responses than controls, possibly due to the loading of the tibialis anterior muscle. This stands in contrast to the present research, where no significant difference was present during long latency neuromuscular responses for al forward and backwards movements for either leg.

Reasons for this may be the differences in the way the researchers measured the responses. Two different test protocols were used. Simmons (2005b) calculated the average onset time of responses using electromyography (EMG) during the adaptation test (ADT) for short, medium and long latency neuromuscular responses. Force plates were rotated upward 8° at a rate of 50° per second for 5 randomly presented trials. Electrodes were placed parallel to the long axis of the anterior tibialis and medial gastrocnemius muscle of both legs. Data was then recorded using a 12-bit analogue-to-digital recorder. During dorsiflexion, such as the upward rotations, the soleus muscle is stretched (Nardone, Giordano, Corra, & Schieppati, 1988).

During the present study, the force plates translated backward and forward at random intervals, instead of rotating upward. Forward and backward translations induces stretch of the soleus (backward) and tibialis anterior (forward) muscles (Nardone et al., 1988). Research indicated that there is a difference in motor unit composition between the two sets of muscles, with slow-twitch motor units more segregated in the soleus muscle (Nardone & Schieppati, 1988). Different muscle groups, with different motor unit properties, were therefore stimulated between the two sets of research.

While translations and tilts equally stretch the soleus and tibialis anterior muscle, inducing similar early responses in the stretched muscles, consistent late responses in the agonist muscles are only induced by tilts (Nardone, Giordano, Corra, & Schieppati, 1990). In the present study, only long latency neuromuscular responses were measured indirectly using translations. Muscle or neural potentials were not directly assessed, allowing for some inaccuracies. Differences between tilts and translations, stretching the same muscles, were mostly seen in body movements, specifically the knee angles as well as in gastrocnemius length (Nardone et al., 1990).

### *4.2.2 Weight Symmetry and Strength Symmetry*

Trained ballet dancers ($N_1$) and non-trained individuals ($N_2$) both presented with symmetrical weight bearing during small, medium and large backward and forward forceplates translations. All results neared 100, indicating equal weight distribution between the two legs. No disruption in weight distribution between the left and right leg was present in either group. The strength symmetry of responses for trained ballet dancers ($N_1$) was significantly less than non-trained individuals ($N_2$) during medium and large forward translations. During medium forward translations, trained ballet dancers ($N_1$) presented with an average strength symmetry of 92 (±9.60), compared to 104.4 (±9.33) of non-trained individuals ($N_2$). On average, during large forward translations, ballet dancers reflected a strength symmetry of 92.1 (±7.12) compared to 102.4 (±5.69). The distribution of the average strength symmetry scores of ballet dancers during all trials was closer together then that of non-trained individuals ($N_2$).

Similar strength symmetry was present between groups for small forward translations. Concerning backwards translations, similar functioning was reflected between the two groups. According to the author's limited knowledge, limited research has been done on these two parameters.

### *4.2.3 Postural Response Strength*

Trained ballet dancers ($N_1$) reflected higher response strength (6.6) for medium forward translations in the left leg, indicating that the amount of angular momentum needed to counteract the sway induced by the force plate was more than that of non-dancers. Worse automatic postural control was noted in ballet dancers. A greater difference in function was reflected during average response strength measurements in ballet dancers between the two legs (Right amplitude scaling= 5.6 ±1.64, Left amplitude scaling= 6.5 ±1.90) compared to non-trained individuals ($N_2$) (Right amplitude scaling= 5.3 ±1.82, Left amplitude scaling= 5 ±2.26). In non-trained individuals ($N_2$), there was less variation in the response strength between the legs. Research indicated that stretch reflex amplitude was attenuated as load stability was reduced (Finley, Dhaher, & Perreault, 2012). Agonist-antagonist co-contraction of the amplitude of stretch reflexes was also heightened as stability was reduced, but not enough to oppose the induced instability, probable due to feed-forward strategies instead of rapid involuntary feedback (Finley et al., 2012). Feed-forward strategies are useful during predictable disturbance (Finley et al., 2012). Trained ballet dancers ($N_1$) may predict instabilities better, resulting in decreased reflex amplitudes during medium movements.

Similar amounts of angular momentum needed to counteract the sway induced by the force plate were observed for small and large forward and small, medium and large backwards translations.

Similar function was present between matched participants in the right leg. Both groups reflected low amplitude scaling during the trials of the MCT, indicating that the active responses during the movement were small. Good automatic postural control was present in both groups.

## 4.3 Voluntary Postural Control: Limits of Stability Test (LOS)

### *4.3.1 Directional Control*

The present research shows that the smoothness of displacement of normalized COP compared to target movement to off target movement was similar between trained ballet dancers ($N_1$) and non-trained individuals ($N_2$). Ballet dancers did not reflect better control of their learning trajectory than non-trained individuals ($N_2$).

### *4.3.2 Movement Velocity*

The average COP movement for trained ballet dancers ($N_1$) for movements forward (4.57 deg/sec) and right forward (5.53deg/sec) was greater the non-trained individuals ($N_2$) (2.75deg/sec) and (3.44deg/sec) respectively (Figure 10). On average, trained dancers ($N_1$) moved 2.09deg/sec faster during forward, and 1.82deg/sec during right forward movements (Figure 10). Similar average COP movement was present during right, right backwards, backwards, left backwards, left and left forward movement positions.

### *4.3.3 Reaction Time*

The time from the command to move, and trained ballet dancer's (0.61sec ±0.22) first movement was significantly faster than non-trained individuals ($N_2$) (0.91sec ±0.35) for right forward movements (Figure 11). They reacted 0.30sec faster on average then matched non-trained individuals ($N_2$). The reaction time during right, right backward, backward, left, left forward and left backward movements was similar between groups.

### *4.3.4 Endpoint Excursion*

Ballet dancers were able to better pre-plan the magnitude of their movement leftward then non-trained individuals **($N_2$)**. The end of the first movement of trained ballet dancers **($N_1$)** towards a target set left was on average 11.2% further then non-trained individuals **($N_2$)**. Improvement bordering significance was reflected backwards. No difference in the ability to pre-plan the magnitude of a movement was reflected for forward, right forward, and right, right backward and left backward movement directions.

The coordination of limbs is stabilized by strengthened muscle groups, enhanced by proprioceptive feedback dancers (Kiefer, Riley, Shockley, Sitton, Hewett, Cummins-Sebree, and Haas, 2013). This contributes to movement efficiency in dancers (Kiefer et al., 2013), and may explain why trained professional dancers were able to move further out of their COG during their first movement leftward, then matched non-trained individuals **($N_2$)**. This enhanced coordination of limbs is reflected in the fact that ballet dancers presented with greater accuracy in position matching tasks of the upper- (Ramsay & Riddoch, 2001) and lower limbs (ankle, knee, and hip) (Kiefer et al., 2013) and confirms the present research

### *4.3.5 Maximum Excursion*

When standing, it has been envisaged that movements of the COG are much like an oval around a base of support, which is fixed (Nashner, Shupert, Horak, & Black, 1989). He further explained that outer boundary of this oval is the limits of stability of an individual. Maximum excursion of participants represents the corrective movement control, or feedback, after the endpoint excursion for a certain movement has been reached (Nashner, 1994). The present research reveals that trained ballet dancers ($N_1$) were able to extend out of their centre of gravity to a greater extent than non-trained individuals ($N_2$) to match their perception of the movement distance to a pre-set target, especially when moving forward and right forward. This was possible even when the base of support of trained professional dancers did not increase. Results suggest that for forward and right forward movements, ballet dancers used the feedback they received during the movements better than non-trained individuals ($N_2$), resulting in a better awareness of where to go in space and how to reach that position after a subsequent attempt (after reaching the initial endpoint).

This difference may be as a result of continuous ballet training. Ramsay and Riddoch (2001) determined that training can enhance proprioceptive awareness in the upper limbs of ballet dancers. They further clarified that this implies that training (or practice, as termed in their research), can improve a motor sensory skill (Ramsay and Riddoch,. 2001). Kinematic analysis of the lower limbs further indicated that ballet dancers were able to reproduce orientation and shape of trajectories highly accurately in comparison to gymnast controls. This demonstrates some of the rules underlying the nervous system to integrate multiple degrees of freedom of the body, enabling dancers to balance while performing complex movements with their legs (Thullier & Moufti, 2004). As previously discussed, the coordination of limbs is stabilized by strengthened muscle groups, enhanced by proprioceptive feedback. This contributes to movement efficiency in dancers (Kiefer et al., 2013). This increase in the ability of trained professional dancers to move out of their COG towards target set forward and right forward could also be attributed to the above mentioned phenomenon.

Ballet dancers also constantly receive feedback during training from visual input (looking at themselves in the mirror), as well as observing peers. This assists with special orientation. During the LOS, participants had to match their position to a visual cue provided on the screen of the NeuroCom Smart Equitest ®.

## 4.4 Critical evaluation of the study

### *4.4.1 Strengths of the study*

- A quasi experimental and two group design was followed during this research. Through the design, the experimental (trained ballet dancer ($N_1$)) and control group (non-trained individuals ($N_2$)) was matched with regards to sex, BMI range, and height, controlling for the variables above. This affected the study by assuring that biological variables could not be attributed to any differences noted.
- Functional information was obtained about the effect of training on the balance of dancers with regards to their degrees of freedom by determining the difference in reaction time, velocity, endpoint excursion, maximum excursion and directional control of trained dancers, compared to controls.
- The current research extends previous research by Simmons (2005a; Simmons, 2005b), by adding functional tests, such as the LOS test. Function was also quantified objectively through computerised measurements.
- The present study is the first South African study using CDP.

### *4.4.2 Limitations of the study*

- Participants were matched according to BMI range and not exact weight as it would have made the non-trained individual ($N_2$) group excessively difficult to acquire. It was taken into account that if a participant in the trained ballet dancer group's BMI fell within the normal category, the non-trained individual's ($N_2$) group participant also had to reflect a normal BMI score.

- A small sample size was used. Only ten participants were enrolled in the experimental group, matched with ten controls. A larger sample size may have yielded more significant data.
- Adult dancers and controls were used in the study. It would be enlightening to assess child ballet dancers as to determine at what age the noted differences start occurring, or if the dancers reflected a predisposition towards a certain way of organizing sensory information.
- Dancers on different proficiency levels, from different dance schools, as well as different schools of dance, were used. Limiting the research to a specific school of dance, such as cecchetti, is recommended in future. Dancers from the same company (e.g. Joburg Ballet) is also recommended to be used, as to ensure that participants have the same amount of experience or proficiency.

### *4.4.3 Clinical Implications*

- Ballet training strategies can be used as rehabilitation exercises to assist patients with impaired limits of stability, specifically for voluntary forward and right forward movements as it improves spatial awareness.
- Ballet training exercises can be used as rehabilitation exercise for patients with abnormal velocity of movements when moving out of their centre of gravity forward and right forward. This may be as a result of increased confidence as a result of increased special awareness during the aforementioned movements.
- Ballet training exercises can improve the relative response strength of each foot for medium and large forward movements in patients with impaired function.

### *4.4.4 Future perspectives*

Repeating the current study and increasing the sample size is recommended as to determine if results that trended towards significance become clinically significant.

It would be interesting to extend the research to children between 12 and 17 years old, participating in ballet from a young age, as to determine at what exact stage of development the aforementioned changes became clinically noticeable, as well as significant, via a longitudinal study.

Researching specific ballet training procedures as well as movements may help with creating new rehabilitation techniques and exercises to assist patients with impaired somatosensory functioning is needed.

Further research with regards to the effect that better strength symmetry for medium and large forward movements has on the balance and postural control of trained ballet dancers ($N_1$) would be beneficial, as well as why significant differences were noted between the two groups.

## 4.5 Conclusion

For automatic postural control strategies, such as the SOT, trained ballet dancers ($N_1$) used a similar strategy the non-trained individuals ($N_2$). Dancer's instability did not increase when forced to rely on visual and vestibular information. They did reflect better voluntary postural control. In conclusion, ballet dancers reflected significant better velocity, reaction time as well as maximum excursion abilities for right forward movements than untrained controls. Statistically, they also reflected results tending towards better maximum excursion abilities when extending out of their COG maximally during voluntary movements right backwards. During forward movements, ballet dancers presented with significantly better velocity and maximum excursion abilities. During leftward movements, there was a significant difference in the ability of ballet dancers to maximally complete the distance of the first movement towards the target set at 100% limits of stability. For automatic postural control strategies, such as the SOT, trained ballet dancers ($N_1$) used a similar strategy the non-trained individuals ($N_2$). The results suggest that ballet training exercises could potentially be used as rehabilitation for individuals with impaired function (such as decreased maximum limits of stability), specifically during voluntary postural control. Further study is recommended into exactly what ballet training exercise results in the aforementioned improvements in function.

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# 6 APPENDIXES

## Appendix A- Ethical approval letter

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Research Ethics Committee

21 April 2015

Dear Prof Vinck

| | |
|---|---|
| **Project:** | **Computerized dynamic posturography in ballet dancers** |
| **Researcher:** | **M Gous** |
| **Supervisors:** | **Prof B Vinck, Dr L Maes and Dr B Heinze** |
| **Department:** | **Speech-Language Pathology and Audiology** |
| **Reference number:** | **29001693 (GW20150320HS)** |

Thank you for the your response to the Committee's correspondence of 1 April 2015.

I have pleasure in informing you that the Research Ethics Committee formally **approved** the above study at an *ad hoc* meeting held on 20 April 2015. Data collection may therefore commence.

Please note that this approval is based on the assumption that the research will be carried out along the lines laid out in the proposal. Should your actual research depart significantly from the proposed research, it will be necessary to apply for a new research approval and ethical clearance.

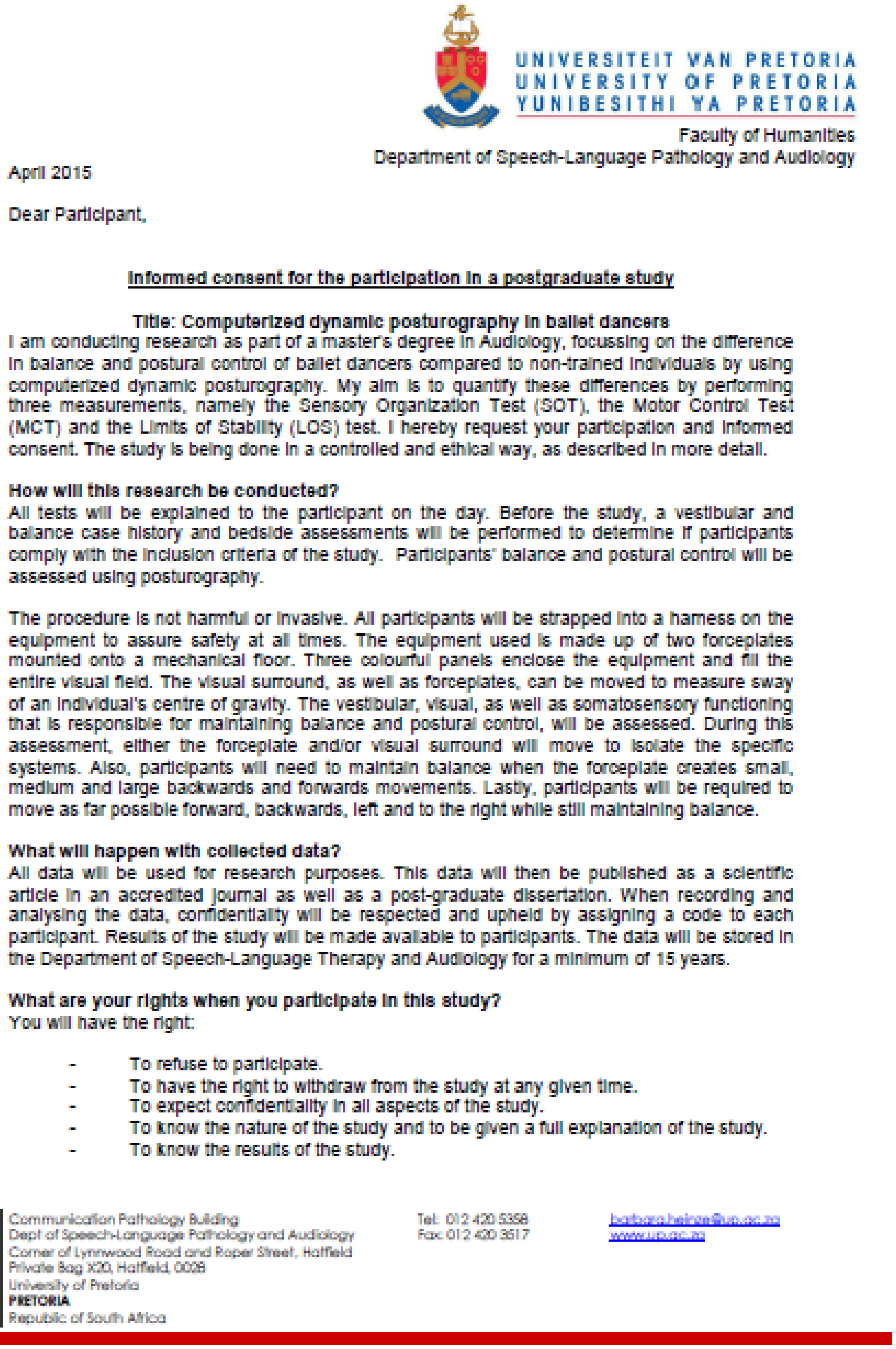
The Committee requests you to convey this approval to the researcher.

We wish you success with the project.

Sincerely

**Prof. Karen Harris**
**Acting Chair: Research Ethics Committee**
**Faculty of Humanities**
**UNIVERSITY OF PRETORIA**
**e-mail: karen.harris@up.ac.za**

Appendix B- Informed consent letter



UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA
Faculty of Humanities
Department of Speech-Language Pathology and Audiology

April 2015

Dear Participant,

**Informed consent for the participation in a postgraduate study**

**Title: Computerized dynamic posturography in ballet dancers**

I am conducting research as part of a master's degree in Audiology, focussing on the difference in balance and postural control of ballet dancers compared to non-trained individuals by using computerized dynamic posturography. My aim is to quantify these differences by performing three measurements, namely the Sensory Organization Test (SOT), the Motor Control Test (MCT) and the Limits of Stability (LOS) test. I hereby request your participation and informed consent. The study is being done in a controlled and ethical way, as described in more detail.

**How will this research be conducted?**

All tests will be explained to the participant on the day. Before the study, a vestibular and balance case history and bedside assessments will be performed to determine if participants comply with the inclusion criteria of the study. Participants' balance and postural control will be assessed using posturography.

The procedure is not harmful or invasive. All participants will be strapped into a harness on the equipment to assure safety at all times. The equipment used is made up of two forceplates mounted onto a mechanical floor. Three colourful panels enclose the equipment and fill the entire visual field. The visual surround, as well as forceplates, can be moved to measure sway of an individual's centre of gravity. The vestibular, visual, as well as somatosensory functioning that is responsible for maintaining balance and postural control, will be assessed. During this assessment, either the forceplate and/or visual surround will move to isolate the specific systems. Also, participants will need to maintain balance when the forceplate creates small, medium and large backwards and forwards movements. Lastly, participants will be required to move as far possible forward, backwards, left and to the right while still maintaining balance.

**What will happen with collected data?**

All data will be used for research purposes. This data will then be published as a scientific article in an accredited journal as well as a post-graduate dissertation. When recording and analysing the data, confidentiality will be respected and upheld by assigning a code to each participant. Results of the study will be made available to participants. The data will be stored in the Department of Speech-Language Therapy and Audiology for a minimum of 15 years.

**What are your rights when you participate in this study?**

You will have the right:

- To refuse to participate.
- To have the right to withdraw from the study at any given time.
- To expect confidentiality in all aspects of the study.
- To know the nature of the study and to be given a full explanation of the study.
- To know the results of the study.

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Should you agree to participate, please sign the attached consent form. You are welcome to contact me on marike.gous@gmail.com if any questions arise.

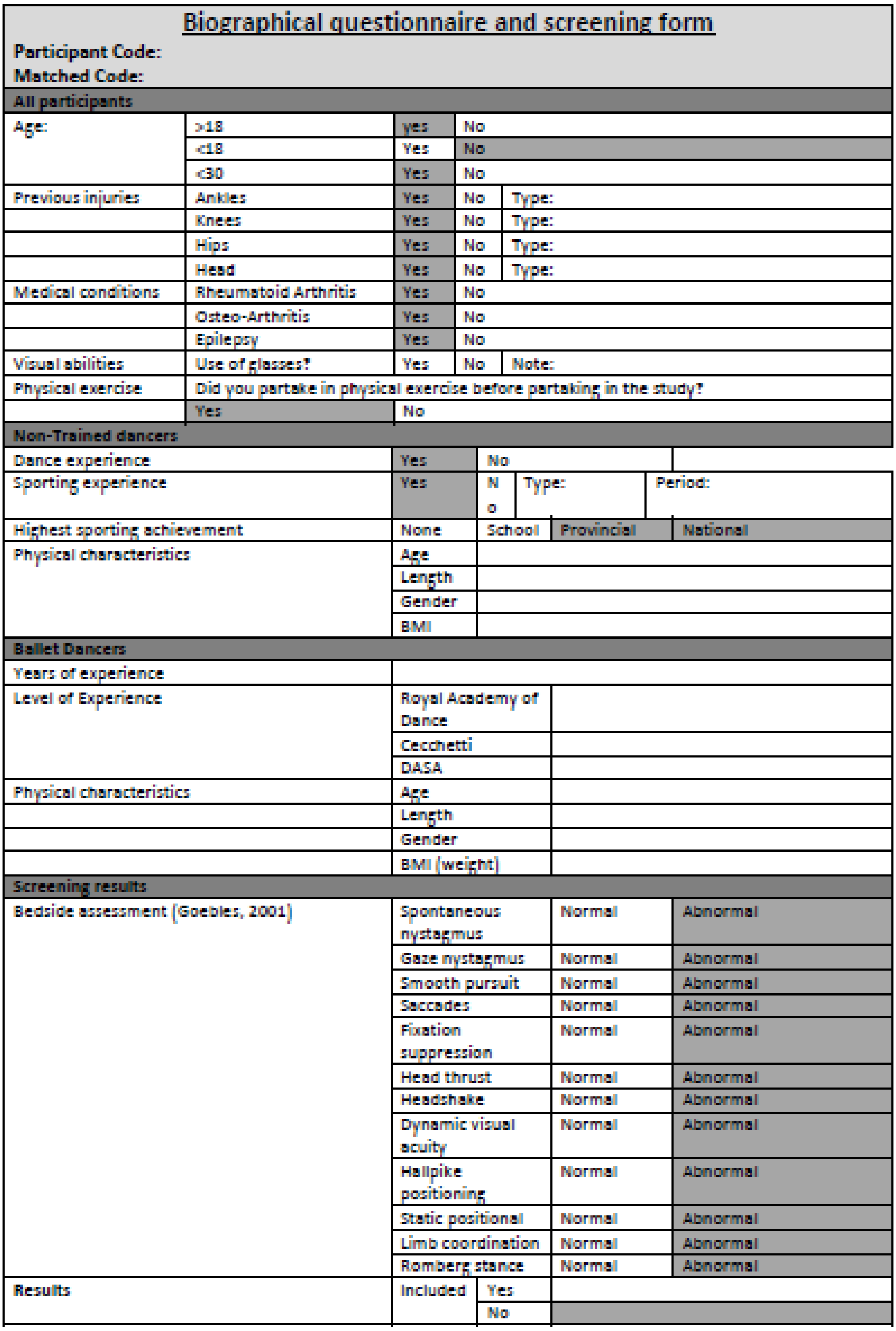
| | |
|---|---|
| **Ms Marike Venter**<br>Student | **Prof Bart Vinck**<br>Supervisor |
| **Dr Leen Maes**<br>Co-Supervisor | **Dr Barbara Heinze**<br>Co-supervisor |

Written consent

I, ____________________ agree to take part in this study as a research participant. By my signature, I affirm that I have read this document and I know what is expected of me. I also know the procedures and what my rights are.

| | |
|---|---|
| ____________________<br>Signature of participant | ____________________<br>Date |
| ____________________<br>Witness | ____________________<br>Date |

Appendix C- Biographical questionnaire and screening form



## Biographical questionnaire and screening form

**Participant Code:**
**Matched Code:**

**All participants**

| | | | | |
|---|---|---|---|---|
| Age: | >18 | yes | No | |
| | <18 | Yes | No | |
| | <30 | Yes | No | |
| Previous injuries | Ankles | Yes | No | Type: |
| | Knees | Yes | No | Type: |
| | Hips | Yes | No | Type: |
| | Head | Yes | No | Type: |
| Medical conditions | Rheumatoid Arthritis | Yes | No | |
| | Osteo-Arthritis | Yes | No | |
| | Epilepsy | Yes | No | |
| Visual abilities | Use of glasses? | Yes | No | Note: |
| Physical exercise | Did you partake in physical exercise before partaking in the study? | | | |
| | Yes | No | | |

**Non-Trained dancers**

| | | | | |
|---|---|---|---|---|
| Dance experience | Yes | No | | |
| Sporting experience | Yes | No | Type: | Period: |
| Highest sporting achievement | None | School | Provincial | National |
| Physical characteristics | Age | | | |
| | Length | | | |
| | Gender | | | |
| | BMI | | | |

**Ballet Dancers**

| | | |
|---|---|---|
| Years of experience | | |
| Level of Experience | Royal Academy of Dance | |
| | Cecchetti | |
| | DASA | |
| Physical characteristics | Age | |
| | Length | |
| | Gender | |
| | BMI (weight) | |

**Screening results**

| | | | |
|---|---|---|---|
| Bedside assessment (Goebles, 2001) | Spontaneous nystagmus | Normal | Abnormal |
| | Gaze nystagmus | Normal | Abnormal |
| | Smooth pursuit | Normal | Abnormal |
| | Saccades | Normal | Abnormal |
| | Fixation suppression | Normal | Abnormal |
| | Head thrust | Normal | Abnormal |
| | Headshake | Normal | Abnormal |
| | Dynamic visual acuity | Normal | Abnormal |
| | Hallpike positioning | Normal | Abnormal |
| | Static positional | Normal | Abnormal |
| | Limb coordination | Normal | Abnormal |
| | Romberg stance | Normal | Abnormal |
| Results | Included | Yes | |
| | | No | |