A STUDY ON POSTURAL CONTROL AND LOWER LIMB MUSCLE ACTIVATION AMONG INDIVIDUALS WITH AND WITHOUT ANKLE SPRAIN

NUREEN SHAHIRAH BINTI AHMAD ZAGHLUL

FACULTY OF ENGINEERING
UNIVERSITI MALAYA
KUALA LUMPUR

2023

A STUDY ON POSTURAL CONTROL AND LOWER LIMB MUSCLE ACTIVATION AMONG INDIVIDUALS WITH AND WITHOUT ANKLE SPRAIN

NUREEN SHAHIRAH BINTI AHMAD ZAGHLUL

DISSERTATION SUBMITTED IN FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE OF MASTER
OF ENGINEERING SCIENCE

FACULTY OF ENGINEERING
UNIVERSITI MALAYA
KUALA LUMPUR

2023

UNIVERSITI MALAYA
ORIGINAL LITERARY WORK DECLARATION

Name of Candidate: Nureen Shahirah binti Ahmad Zaghlul

Matric No: S2000762

Name of Degree: Master of Engineering Science

Title of Project Paper/Research Report/Dissertation/Thesis ("this Work"):

A Study on Postural Control and Lower Limb Muscle Activation among Individuals with and without Ankle Sprain

Field of Study: Biomechanics

I do solemnly and sincerely declare that:

(1) I am the sole author/writer of this Work;
(2) This Work is original;
(3) Any use of any work in which copyright exists was done by way of fair dealing and for permitted purposes and any excerpt or extract from, or reference to or reproduction of any copyright work has been disclosed expressly and sufficiently and the title of the Work and its authorship have been acknowledged in this Work;
(4) I do not have any actual knowledge nor do I ought reasonably to know that the making of this work constitutes an infringement of any copyright work;
(5) I hereby assign all and every rights in the copyright to this Work to the University of Malaya ("UM"), who henceforth shall be owner of the copyright in this Work and that any reproduction or use in any form or by any means whatsoever is prohibited without the written consent of UM having been first had and obtained;
(6) I am fully aware that if in the course of making this Work I have infringed any copyright whether intentionally or otherwise, I may be subject to legal action or any other action as may be determined by UM.

Candidate's Signature Date: 19/8/2022

Subscribed and solemnly declared before,

Witness's Signature Date: 19/8/2022

Name:

Designation:

A STUDY ON POSTURAL CONTROL AND LOWER LIMB MUSCLE ACTIVATION AMONG INDIVIDUALS WITH AND WITHOUT ANKLE SPRAIN

ABSTRACT

Damaged joint mechanoreceptors may necessitate the individuals with ankle sprain to develop coping strategies to maintain balance. This study investigated whether visual input contributes significantly to the balancing ability of individuals who had unilateral ankle sprains (AI). The specific objectives were to i) compare the time in balance (TIB) and Peroneus Longus (PL) activity with eyes-open (EO) and eyes-closed (EC) when performing balancing tasks, ii) compare the changes observed in AI with healthy individuals (HI), and iii) investigate whether the correlation between the Foot and Ankle Ability Measure (FAAM), a self-reported balance measure, with the observed performance (i.e. TIB and PL activity) is the same between AI and HI. Participants performed single leg (SL) and double leg (DL) tasks on a Lafayette stability platform. As this platform is frequently used for DL tasks, a reliability study for the SL stance on the Lafayette stability platform was first conducted with 36 healthy volunteers. After which, another 48 individuals (AI: n=24; age=23.5 ± 2.3 years; HI: n=24; age=23.5 ± 1.7 years) were recruited for the assessment. The participants performed three 20s trials of DL and SL stance in EO and EC conditions. The order of testing was randomized between conditions (i.e. EO, EC) and tasks (i.e. DL, SL). Bilateral activity of PL was recorded only during DL stance and was normalized to the peak maximum voluntary contraction (MVC). It was expressed as the side-to-side comparison, in percentage difference (%MVC). The duration the participants maintained the platform within ±1° deviation was considered as TIB. The TIB, PL activity, and FAAM scores were compared between groups and conditions. The relationship between FAAM scores and TIB and PL activity was analyzed using Spearman's correlation coefficient (ρ). The results obtained suggest

SL stance is reliable on the Lafayette stability platform. The TIB was statistically longer during EO in AI (DL_EO: 19.69 ± 0.80s; DL_EC: 18.12 ± 3.69s, $p < 0.05$; SL_EO: 18.59 ± 3.59s; SL_EC; 17.39 ± 2.66s, $p < 0.05$) and in HI (DL_EO: 19.68 ± 1.28s; DL_EC: 18.08 ± 3.60s, $p< 0.05$; SL_EO: 18.44 ± 2.59s; SL_EC: 17.01 ± 3.02s, $p < 0.05$). During DL stance, AI individuals showed a consistently lower side-to-side comparison PL activity in both EO (AI: 25.17 ± 12.53%MVC; HI: 29.82 ± 18.85%MVC, $p = 0.163$) and EC (AI: 24.48 ± 11.40%MVC; HI: 30.47 ± 19.03%MVC, $p = 0.060$) compared to HI. However, no significant difference in the TIB and side-to-side comparison PL activity was observed between groups. Additionally, a significant positive correlation was observed between FAAM and TIB during EO in AI (DL: $\rho = 0.43$, $p = 0.04$; SL: $\rho = 0.59$, $p = 0.00$), but not in HI (DL: $\rho = -0.06$, $p = 0.77$; SL: $\rho = -0.11$, $p = 0.62$). PL activity on the other hand had no significant correlation with FAAM scores in both groups irrespective of EO or EC. Overall, findings in this study suggested that AI does not rely on visual input entirely compared to HI in maintaining postural control.

Keywords: Peroneus Longus, Reliability, Stability Performance, Unilateral Ankle Sprain, Vision.

KAJIAN KAWALAN POSTUR DAN PENGAKTIFAN OTOT BAHAGIAN BAWAH DALAM KALANGAN INDIVIDU YANG TERSELIUH BUKU LALI DAN INDIVIDU SIHAT

ABSTRAK

Kerosakan mekanoreseptor sendi boleh menyebabkan individu yang terseliuh di pergelangan kaki mengadaptasi strategi penyesuaian untuk mengekalkan keseimbangan. Kajian ini menyiasat sama ada input visual menyumbang dengan signifikasi kepada keupayaan keseimbangan individu yang mengalami terseliuh pergelangan kaki unilateral (AI). Objektif kajian khususnya ialah i) membandingkan masa dalam keseimbangan (TIB) dan aktiviti Peroneus Longus (PL) dengan mata terbuka (EO) dan mata tertutup (EC) semasa melaksanakan aktiviti keseimbangan, ii) membandingkan perubahan yang diperhatikan dalam AI dengan individu sihat (HI), dan iii) menyiasat sama ada korelasi antara Ukuran Keupayaan Kaki dan Pergelangan Kaki (FAAM), iaitu soal selidik ukuran keseimbangan yang dilaporkan sendiri, dengan prestasi yang diperhatikan (iaitu TIB dan aktiviti PL) adalah sama di antara AI dan HI. Peserta menjalankan tugas kaki tunggal (SL) dan kaki berganda (DL) pada platform kestabilan Lafayette. Oleh kerana platform ini sering digunakan untuk tugas DL, kajian awal untuk menentukan kebolehpercayaan ujian pendirian SL pada platform kestabilan Lafayette telah dijalankan dengan 36 sukarelawan sihat. Kemudian, 48 individu lain (AI: n = 24; umur = 23.5 ± 2.3 tahun; HI: n=24; umur = 23.5 ± 1.7 tahun) direkrut untuk penilaian keseimbangan. Peserta melakukan tiga percubaan 20s DL dan SL dalam keadaan EO dan EC. Susunan ujian adalah rawak antara keadaan (iaitu EO, EC) dan tugas (iaitu DL, SL). Aktiviti bilateral PL direkodkan hanya semasa DL dan dinormalisasi kepada kekuatan maksimum sukarela puncak (MVC). Ia dinyatakan sebagai perbandingan sisi-ke-sisi, dalam peratus perbezaan (%MVC). Tempoh peserta mengekalkan platform dalam ± 1° sisihan dianggap sebagai TIB. Data TIB, aktiviti PL, dan skor FAAM dibandingkan antara kumpulan dan keadaan.

Hubungan antara skor FAAM dan TIB dan aktiviti PL dianalisis menggunakan pekali korelasi Spearman (ρ). Hasil kajian menunjukkan SL boleh dipercayai pada platform kestabilan Lafayette. Durasi TIB adalah lebih panjang secara statistik dalam kumpulan AI (DL_EO: 19.69 ± 0.80s; DL_EC: 18.12 ± 3.69s, $p < 0.05$; SL_EO: 18.59 ± 3.59s; SL_EC; 17.39 ± 2.66s, $p < 0.05$) dan HI (DL_EO: 19.68 ± 1.28s; DL_EC: 18.08 ± 3.60s, $p < 0.05$; SL_EO: 18.44 ± 2.59s; SL_EC: 17.01 ± 3.02s, $p < 0.05$) semasa EO. Ketika tugas DL, individu AI menunjukkan perbandingan sisi aktiviti PL yang lebih rendah dalam kedua-dua keadaan EO (AI: 25.17 ± 12.53%MVC; HI: 29.82 ± 18.85%MVC, $p = 0.163$) dan EC (AI: 24.48 ± 11.40%MVC; HI: 30.47 ± 19.03%MVC, $p = 0.060$) secara konsisten berbanding dengan individu HI. Walau bagaimanapun, tiada perbezaan yang signifikan dalam TIB dan perbandingan sisi aktiviti PL diperhatikan antara kedua-dua kumpulan. Selain itu, korelasi antara skor FAAM dengan TIB semasa EO adalah positif dan signifikan dalam AI (DL: $\rho = 0.43$, $p = 0.04$; SL: $\rho = 0.59$, $p = 0.00$), tetapi tidak dalam HI (DL: $\rho = -0.06$, $p = 0.77$; SL: $\rho = -0.11$, $p = 0.62$). Sebaliknya, tiada korelasi yang signifikan antara aktiviti PL dengan skor FAAM dalam kedua-dua kumpulan, sama ada dalam EO atau EC. Keseluruhannya, dapatan kajian ini menunjukkan bahawa individu AI tidak bergantung sepenuhnya pada input visual untuk mengekalkan keseimbangan jika dibandingkan dengan HI.

Keywords: Peroneus Longus, Penglihatan, Kebolehpercayaan, Prestasi Kestabilan,
Terseliuh Pergelangan Kaki Unilateral.

ACKNOWLEDGEMENTS

First and foremost, praises and thanks to the Almighty God, for His showers of blessings throughout my research work to complete the study successfully.

I would like to express my sincere gratitude to my supervisors; Dr Chan Chow Khuen (Dept of Biomedical Engineering), Assoc. Prof Dr Goh Siew Li (Sports Medicine Unit), and Dr Rizal Razman (Centre for Sport & Exercise Sciences) for the continuous support throughout my master study and research, for their patience, motivation, enthusiasm, and immense knowledge. Their guidance and advice carried me through all the stages of writing and completing this master project and study.

I am extremely grateful to my parents and siblings for their love, prayers, caring, and sacrifices while undertaking my research. Their prayers for me were what sustained me this far. I would also like to give my warmest thanks to my lab mates; Husna and Athirah for their emotional support, input on various issues, and for always being there for me throughout this tough journey.

My sincere thanks also go to Prof Richard, Dr Graham, Dr Mahmoud, and Dr Anisah for the opportunity of working together on a few manuscripts. I would also like to thank the laboratory staff and technicians for their assistance especially Pn Liyana, En Rahman, Pn Hafidzatulnur, and En Adhli. Finally, I would like to thank all my participants (whom I could not list all of their names here) who participated in this project. Without their cooperation, this study might not succeed.

TABLE OF CONTENTS

Abstract iii

Abstrak v

Acknowledgements viii

List of Figures xi

List of Tables xii

List of Symbols and Abbreviations xiii

List of Appendices xv

CHAPTER 1: INTRODUCTION 1

1.1 Research Background 1

1.1.1 Introduction 1

1.1.2 Research Objective 2

1.1.3 Research Questions 3

1.1.4 Hypothesis 3

CHAPTER 2: LITERATURE REVIEW 4

2.1 Postural Control 4

2.1.1 Double leg vs single leg tasks 5

2.1.2 Static vs dynamic tasks 7

2.2 Ankle Sprains 8

2.2.1 Grades, terminologies, and symptoms associated with ankle sprains 10

2.2.2 Mechanism of ankle sprains 11

2.3 Electromyography (EMG) 12

2.3.1 Background of EMG 12

2.3.2 Peroneus longus (PL) muscle 14

2.4 Relationship between postural control and ankle sprains……………………….16

2.5 Balance performance with EMG………………………………………………..16

2.6 Relationship between ankle sprain and EMG…………………………………..17

2.7 Visual input in ankle sprain studies……………………..…………………...18

CHAPTER 3: METHODOLOGY..19

3.1 Instrument: Lafayette stability platform……………………………………….. 21

3.2 Evaluation of the test-retest reliability of the SL stance on the Lafayette stability platform ………………………………………………………………..……….22

3.2.1 Sample size…………………………………………………………..22

3.2.2 Experimental procedure….…………………………………………..23

3.2.2.1 Recruitment of subjects…..…………………………………...23

3.2.2.2 Testing procedure…..…………………………………………...23

3.2.3 Statistical analysis……………………………………………………24

3.3 The assessment of postural control in individuals with and without unilateral ankle sprains...………………………………………………………………………...25

3.3.1 Sample size……………………………………………………….. 25

3.3.2 Experimental protocol...……….……………………………………..26

3.3.2.1 Recruitment of participants……………………………………..26

3.3.2.2 Testing protocol..……………………………………………......27

3.3.3 Electromyography…………………………………………………... 28

3.3.4 Foot and Ankle Ability Measure (FAAM) questionnaire………………29

3.3.5 Statistical analysis……………………………………………………29

CHAPTER 4: RESULTS..31

4.1 Evaluation of the test-retest reliability of the single leg stance on the Lafayette stability platform …………………………………………...……………..31

4.2 The assessment of postural control in individuals with and without unilateral ankle sprains…… 33

4.2.1 Time in balance……34

4.2.2 The side-to-side comparison PL activity……35

4.2.3 Foot and Ankle Ability Measure (FAAM) scores……35

4.2.4 Spearman's correlation coefficient……36

4.2.4.1 Correlation between FAAM and TIB……36

4.2.4.2 Correlation between FAAM and side-to-side comparison PL activity…… 37

CHAPTER 5: DISCUSSION……39

5.1 Evaluation of the test-retest reliability of the single leg stance on the Lafayette stability platform ……39

5.2 The assessment of postural control in individuals with and without unilateral ankle sprains ……41

CHAPTER 6: CONCLUSION……45

6.1 Recommendation for future studies……45

6.2 Clinical implications of the study……46

References……48

List of Publications and Papers Presented……62

Appendix……63

LIST OF FIGURES

Figure 2.1: Example of instruments used in assessing postural control 7

Figure 2.2: The ankle joint…………………………………………………………….…9

Figure 2.3: Timeline of the development of EMG………………………………………13

Figure 2.4: Peroneus Longus (PL) muscle………………………………………………15

Figure 3.1: Flowchart of the study………………………………………………………20

Figure 3.2: A participant performed double leg stance on the Lafayette stability platform ………………………………………………………………………………………….22

Figure 4.1: Bland-Altman plot for the time in balance of the single leg stance in eyes-open condition……………………………………………………………………………..32

Figure 4.2: Bland-Altman plot for the time in balance of the single leg stance in eyes-closed condition…………………………………………………………………………...32

LIST OF TABLES

Table 3.1: Participants demographic data 26

Table 4.1: The evaluation of the test-retest reliability of the single leg stance on a Lafayette stability platform……………………………………………………………..31

Table 4.2: Foot and Ankle Ability Measure (FAAM) questionnaire…………………..34

Table 4.3: Time in balance during double leg and single leg stances on the Lafayette stability platform……………………………………………………………………… 35

Table 4.4: The side-to-side comparison of Peroneus Longus activity during double leg stance…………………………………………………………………………………...36

Table 4.5: Spearman's correlation coefficient between individuals with and without ankle sprains…………………………………………………………………………………..38

LIST OF SYMBOLS AND ABBREVIATIONS

BMI : Body mass index

Hz : Hertz

kg : kilogram

kg/m^2 : kilogram/meter^2

m : meter

min : minute

p : p-value

s : second

ADL : activity of daily living

AI : ankle sprains group

CI : confidence interval

CV : coefficient of variation

DL : double leg

EC : eyes-closed

EMG : electromyography

EO : eyes-open

HI : healthy group

LoA : Limit of agreement

ICC : Intraclass correlation coefficient

MVC : maximum voluntary contraction

PL : Peroneus longus

SD : standard deviation

SEM : standard error of measurement

SL : single leg

TIB : time in balance

W1 : week 1

W2 : week 2

LIST OF APPENDICES

Appendix A: Sample of the participants' enrollment and analysis………………. 63

Appendix B: A sample of PL amplitude before and after normalization process... 64

Appendix C: Foot and Ankle Ability Measure (FAAM) questionnaire………….. 65

Appendix D: Volunteer Recruitment Criteria……………………………………. 68

Appendix E: Participant's Consent Form……………………………………... 69

Appendix F: Ethics Approval…………………………………………………. 70

Appendix G: Gantt Chart……………………………………………………… 71

CHAPTER 1: INTRODUCTION

1.1 Research Background

1.1.1 Introduction

Ankle sprain is among one of the most common injuries sustained within physically active populations and is one of the most frequent sports-related injuries (Ahn et al., 2020). Sprain itself is defined as an injury to the ligament. The degree of severity can range from the involvement of one or more ligaments to injury of surrounding tendons, bones, and other tissues (Lampell, 2007). Approximately 14% of all sports-related orthopedic emergency visits were diagnosed as lateral ankle sprain (LAS) (McGovern & Martin, 2016). As ankle sprain is associated with physical activity, athletes are highly prone to ankle sprains (Gan et al., 2020).

Individuals with LAS generally complained of restricted movement functions during sports post-injury (Miklovic et al., 2017), decreased strength (Kobayashi et al., 2017), and long-lasting subjective feelings of the ankle 'giving way' (Simpson et al., 2020). The most common mechanism of ankle sprain involves sudden ankle inversion and plantarflexion, leading to injuries and tears of the stabilizing ligaments, with the majority (up to 85%) of cases involving the anterior talofibular ligament (ATFL) (Kobayashi and Gamada, 2014). A high proportion (as much as 70%) of these injured individuals experienced repetitive LAS, and in worst case scenario, it may lead to longstanding ankle dysfunction; chronic ankle instability (CAI) (Terada et al., 2020). This reoccurrence has been associated with the damaged mechanoreceptors in the injured ankle ligament following sprains (Rosen et al., 2019; Kwon, 2018), with disorganized collagen formation in the healing ligament. Other than that, the weakness of the peroneal muscle after immobilization of the muscle or due to overstretching of the peroneal nerves at the time of inversion trauma might contribute to recurrent injuries (Louwerens et al., 1995).

Sports performance post-injury may differ for each individual. Some reported being able to return to pre-injury status without residual symptoms (i.e. coper) while others sustained recurrent injuries, and developed CAI (Pozzi et al., 2015; Kwon, 2018; Jaber et al., 2018). These variations in data proposed that not all injured individuals develop long-term sequelae. In this sense, coping strategies may be adopted to compensate for the deterioration of postural control after injury among these individuals. Generally, good postural control relies on the integrity of the somatosensory and neuromotor systems, which include visual, vestibular, and proprioceptive signals. Injury to any one of these neural signal pathways will impair postural control, such as that found in individuals with ankle sprains (Kazemi et al., 2017; Gan et al., 2020).

A recent study reported visual adaptation among individuals with chronic ankle instability (CAI) and anterior cruciate ligaments (ACL) impairment (Kim, 2020). However, it remains unclear whether individuals with LAS, who had seemingly restored their ankle function, used a similar adaptation in the balance after ankle sprains. Only a small number of studies had directly compared both eyes-open (EO) and eyes-closed (EC) conditions (Deun et al., 2007; Deun et al., 2011; Feger et al., 2014; Kwon, 2018) and the finding of these studies is inconsistent.

Therefore, the purpose of this study is to investigate whether visual input has significant contribution in restoring postural control in individuals with unilateral ankle sprains. This knowledge could be useful to design effective rehabilitation programs. The research objectives were:

1.1.2 Research objectives

i. To investigate the time in balance (TIB) between unilateral ankle sprains individuals (AI) and healthy (HI) during eyes-open (EO) and eyes-closed (EC).

ii. To compare the side-to-side comparison Peroneus Longus (PL) activity between groups (AI vs HI) and conditions (EO vs EC).

iii. To correlate the Foot and Ankle Ability Measure (FAAM) questionnaire with TIB and side-to-side comparison PL activity.

Concurrently, a few research questions were highlighted throughout the study period to ensure the direction of the study was always clear. The research questions and hypotheses of the study were:

1.1.3 Research Questions

The research questions of this study:

i. Was there any difference in the balancing ability between people with and without ankle sprain?

ii. Did the participant with ankle sprain adapt coping strategy after the sprain during balancing task?

iii. Did the perceptions on postural control tally with the objective lab-based stability tests?

We hypothesized the following in our study.

1.1.4 Hypothesis

i. The TIB during EC is significantly shorter compared to EO in AI individuals.

ii. The AI group will display a significantly greater side-to-side comparison PL activity during EC compared to EO.

iii. FAAM scores will have a positive relationship with TIB and side-to-side comparison PL activity.

CHAPTER 2: LITERATURE REVIEW

Postural control and lower limb muscle activity is interrelated (Lyytinen et al., 2010). Wolburg et al. (2016) highlighted that postural control strategies are characterized primarily by muscle activation pattern and body kinematics. Perturbation-based balance training is purposely to produce body sway and trigger a reactive motor response, which may improve postural control and muscle activity of the ankle (Thais et al., 2021).

2.1 Postural control

Postural control plays a crucial role in maintaining daily functions as well as in sports (Ku et al., 2014). Chaari et al. (2021) defined postural control as the process of maintaining the body's gravity centre position vertically over the base of support. With the integration of sensory inputs (visual, vestibular, and somatosensory information), muscle activations, and cognitive function, proper postural control enables safe functional activities (Hung & Miller, 2016).

Besides the elements aforementioned, several researchers determined proprioception, particularly ankle proprioception contributes a part in the postural control (Ku et al., 2014; Han et al., 2015). Generally, proprioception is one's ability to integrate the sensory signals from various mechanoreceptors to thereby determine body position and movements in space (Han et al., 2015). The proprioception is demanded in a quiet standing task, complemented with the integration of visuals and vestibular (Ku et al., 2014).

Feletti et al. (2019) reported athletes often rely on their vestibular system and sensory integration to excel in a game. Furthermore, concept of greater postural control may lead to a better performance has been acknowledged (Feletti et al., 2019). Andreeva et al. (2021) added that an effective postural control reduces the risk of sport injuries, which is a critical issue to be addressed among the sports athletes.

2.1.1 Double leg vs single leg tasks

Various protocols were used in assessing postural control between healthy and individuals with AI, which include gait (Low et al., 2023) the double leg (DL) (Mora et al., 2003; Deun et al., 2007; Deun et al., 2011) and single leg (SL) (Feger et al., 2014; Pozzi et al., 2015; Kwon, 2018) tasks. SL tasks were commonly used in determining the physical function status compared to DL, nonetheless, both tasks were essential (Song et al., 2018). Additionally, SL stance is common in reliability study (Choi et al., 2014; Ponce-Gonzalez et al., 2014; Arifin et al., 2014; Laessoe et al., 2019).

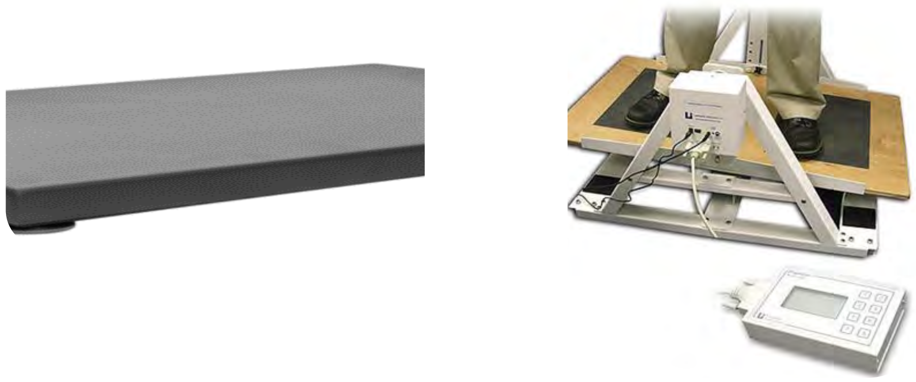
Several DL tasks documented in literature were DL stance using force plates (Mora et al., 2003; Groters et al., 2013), transition of DL to SL stance (Deun et al., 2007; Deun et al., 2011), multiple hop test (Groters et al., 2013), and DL stop-jump (Ma et al., 2022). Whereas common SL tasks were SL stance on floor (Kwon, 2018; Mineta et al., 2017), Star Excursion Balance Test (SEBT) (Pozzi et al., 2015; Jaber et al., 2018), SL jump landing (Simpson et al., 2020), and SL hops (Mineta et al., 2017).

One of the common devices used to examine both static and dynamic postural control is the Biodex Balance System (Hung & Miller, 2018). Most studies evaluated center of pressure (CoP) using force plate technology (Schelldorfer et al., 2015) whereas some studies measured postural control using computerized dynamic posturography (CDP) (Feletti et al., 2019) (Kolarova et al., 2021). A few examples of stability devices were presented in Figure 2.1. In terms of data collection, Biodex Balance System computed the anterior posterior stability index (APSI), medial-lateral stability index (MLSI), and overall stability index (OSI). Several researchers used Biodex Balance

System in balance training and intervention programs in assessing the improvement of balance post-training (Clark & Burden, 2005; Akhbari et al. 2007).

Apart from that, the Lafayette stability platform is one of the stability devices that has been utilized widely for balance training, particularly in the double leg (DL) stance investigation. Zech et al. (2018) investigated the effect of barefooted or in shod whereas Schedler et al. (2020) studied the influence of dynamic training between genders. Additionally, Vagaja and Bizovska (2019) performed balancing assessment on the saccadic eye movements on postural stability on unstable platform. All these research protocols implemented DL stance exclusively.

Balance performance on the Lafayette stability platform is usually measured as time in balance (TIB), which defined as the duration during which the platform is stabilized before it eventually deviates beyond a pre-determined degree. The majority of the researchers used root-mean-square error (RMSE) with the cutoff of ±3° (3° above or below the horizontal plane) to indicate the participants as 'in balance' (Kiss et al., 2018, Brueckner et al., 2019; Schedler et al., 2020). A decreased RMSE was observed from measurements of two acquisition days and during the testing day, indicating there was an improvement in the dynamic balance in primary school-aged children (Schedler et al., 2020).



Force plate (Adapted from Force Plates: Bertec, 2022)

Lafayette stability platform (Adapted from NexGen Medical Systems, 2022 (nexgenergo.com))

Computerized Dynamic Posturography (Adapted from ENT Care, Rockville, MD - Siegel, Bosworth and Sorensen Division, 2022 (ent-md.com))

Biodex Balance System (Adapted from Balance System™ SD - Balance - Physical Medicine | Biodex, 2022)

Figure 2.1: Example of instruments used in assessing postural control

2.1.2 Static vs dynamic tasks

Human's static and dynamic postural control are used to understand the equilibrium conditions of human body (Rajasekaran et al., 2015). Thais et al. (2021) stated that static and dynamic elements are main components of postural control. Kasahara and Saito (2021) added both static and dynamic elements have to function instantaneously to control the equilibrium, whether in real time or in response to the changes to the body and environment (homeostasis).

Various tasks were performed in both conditions, whether static, dynamic or the combination of both. Some researchers argued static postural control serves as an indicator of dynamic postural control (Ku et al., 2014) whereas some of them contended that dynamic balance is more relevant aspects to be assessed (Groters et al., 2013). Liu et al. (2013) demonstrated that dynamic measures have been used extensively to classify ankle instability status. Bansbach et al. (2017) added dynamic measures are preferred for military and athletic groups as they are more challenging than static tasks and may better differentiate between risk factors in healthy, physically active individuals compared to people with deformities.

If a single balance measure is being assessed, dynamic tests might be advantageous, as they are more sport specific and seem to be more sensitive in detecting persisting sensorimotor deficits in an athletic population (Steib et al., 2013). SL landing task has been identified as the most representative mechanism for an ankle sprain because it replicates sports activity and the requirement of strength, proprioception, and neuromuscular control in this task (Brown et al., 2010) leading the researchers to frequently applied this protocol to measure dynamic postural stability (Liu et al., 2013).

2.2 Ankle sprains

Ankle joint (Figure 2.2) is the most commonly injured part of the body during sports (Nozu et al., 2021). Approximately 23 000 ankle sprains occur daily in the United States (McKeon & Hoch, 2019), particularly those involving the lateral ligament complex, are one of the most prevalent injuries occurring during sports and physical activities (Abassi et al., 2019). Nearly 3000 emergency department visits per year in the

United States involve dancers with ankle sprains (Miller et al., 2018). Some estimate with an approximate cost of $1000 per injury (Rosen et al., 2017). Chen et al. (2019) stated that ankle sprains are common injuries sustained in both general and athletic populations, but it is more prevalent in military personnel (Kazemi et al., 2017).

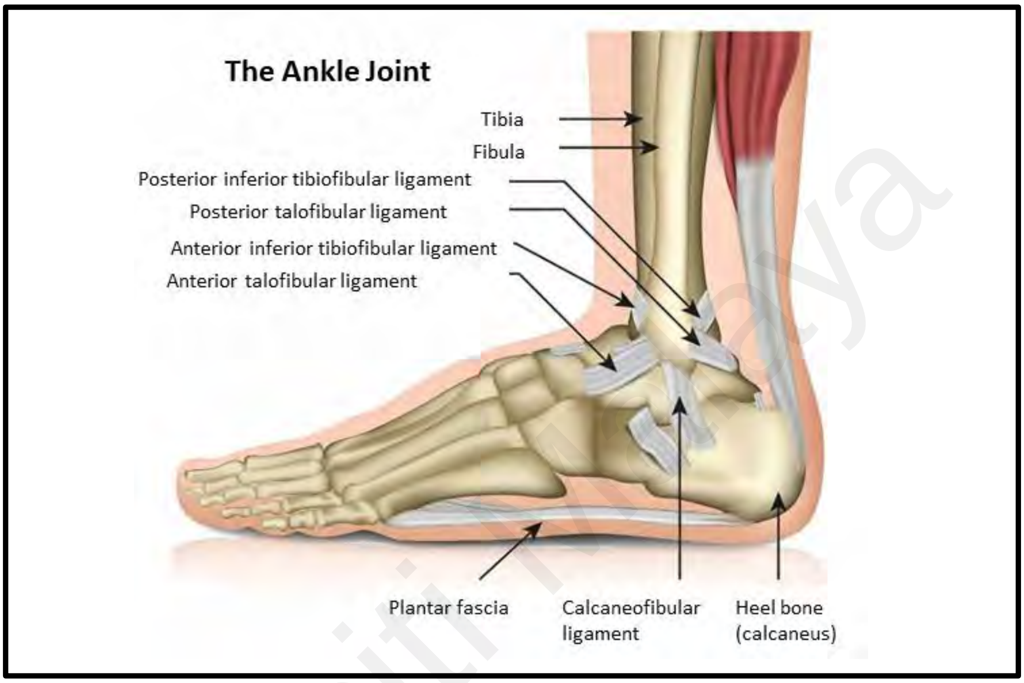


Figure 2.2: The ankle joint (Adapted from Lateral ankle ligament sprain - Ultrasound Guided Injections (ultrasound-guided-injections.co.uk), 2022)

Foot inversion is the common case where ankle ligaments are susceptible to injury, which involves the anterior talofibular ligaments (ATFL) primarily or the only ligament to sustain injury, with 66% of cases reported (Golanó et al., 2010), followed with calcaneofibular ligament (CFL), and lastly posterior talofibular ligament (PTFL) (Golanó et al., 2010). ATFL contributes mainly in limiting anterior displacement of the talus and plantar flexion of the ankle (Golanó et al., 2010) whereas CFL restricts excessive supination of both the talocrural and subtalar joints. The PTFL provides restraint to both inversion and internal rotation of the loaded talocrural joint, which requires extra force or strength in order to cause it to be sprained. This is probably the reason it is the lateral ankle ligaments that is least commonly sprained (Hertel, 2002).

2.2.1 Grades, terminologies, and symptoms associated in individuals with ankle sprains

The severity classification of ankle sprains was published by Chen at al. (2019). Generally, three grades were established; Grade 1: mild injury defined as stretching of the lateral ligament, without tear, Grade 2: partial tearing of one or more ligaments, Grade 3: the most severe sprain injuries with complete disruption of all ligaments of the lateral ligamentous complex.

Several terminologies of ankle sprains were documented in literature, a few of them that were commonly reported were chronic ankle instability (CAI), which is defined as a condition in which the recurrent sprains occurred with lasting residual symptoms at the ankle joint, such as pain or weakness (Kobayashi et al., 2017) (De Jong et al., 2020). Individuals with CAI also associated with decreased self-reported function, feelings of instability or episodes of “giving way”, decreased physical activity, and higher risk of earlier onset of ankle osteoarthritis (De Jong et al., 2020). Another terminology of sprains is lateral ankle sprains (LAS), which is often viewed to be innocuous injuries. Inappropriate management of it after the initial injury may lead to recurrent sprains (De Jong et al., 2020).

Several researchers used the term functional ankle instability (FAI) in defining the ankle sprains of their participants’ cohort (Shih et al., 2018; Huang et al., 2021). Rahnama et al. (2010) described FAI as repeated ankle sprains and “giving way” feelings that occur in some individuals after the first sprains. Lin et al. (2015), on the other hand, defined FAI as the self-reported subjective perception of symptoms and instability. It is reported as a common lower extremity dysfunction following LAS (Shih et al., 2018).

Another term for ankle sprains is mechanical ankle instability (MAI) (Kobayashi & Gamada, 2014), although this term is rarely reported in the literature. MAI is described as insufficiencies in ankle tissues and structures, such as pathologic laxity, impaired arthrokinematics, synovial, and degenerative changes (Lin et al., 2015). MAI is more related to a deficit in ligament laxity (Kobayashi & Gamada, 2014). Cho et al. (2019) reported that many authors agreed CAI is a multifaceted condition caused by a combination of MAI and FAI. The findings should be interpreted with caution as the grades and terminologies of ankle sprain being used are vary.

2.2.2 Mechanism of ankle sprains

In ankle sprain, injury to the stabilizing ligaments around the ankle joint often lead to mechanical instability while damage to proprioceptive fibres (that are responsible for transmitting and regulating neuromuscular signals) then lead to functional instability (Bonnel et al., 2010). The mechanical and functional instability resultant from the injury is predisposing factors for recurrence or chronic instability, impairing physical function and predisposing the joint to osteoarthritis. Rate of recurrence varies but may occur in as high as one third of the people after the first injury (van Rijn et al., 2008).

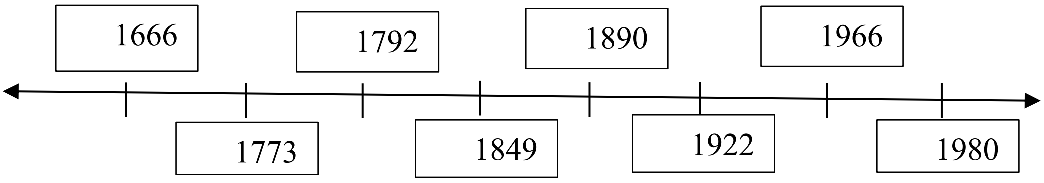
Despite the presence of ligament laxity, it is possible for some patients to remain asymptomatic and recover sufficiently well to achieve functional level equivalent to non-injured individuals (Croy et al., 2012). The findings from Croy et al. are consistent with the lab-based assessment by Wikstrom et al. (2010) that mechanical stability did not differ between injured individuals who eventually cope (copers) and those who continue to experience instability (non-copers). The difference in functional outcome is instead attributed to better dynamic postural control in the copers. As such, it may be inferred that restoration of functional stability, in lieu of the mechanical stability, plays more important role in rehabilitation for ankle sprains.

Ankle sprains often occur as the result of trauma (e.g., landing on uneven surface from a jump), compromising the physical structural and functional integrity of the tissues surrounding the joint (Hung & Miller, 2016). As mentioned in the above section, LAS is the common injury. Recent injury surveillance data from the National Collegiate Athletic Association (NCAA) demonstrated LAS to be the most common type of ankle sprain (Chen et al., 2019). Researchers agreed that LAS are usually caused by excessive plantar flexion and inversion (Herb & Hertel, 2014; Kobayashi et al., 2017; Chen et al., 2019). Other than that, Kobayashi et al. (2017) added that this injury might integrate with excessive ankle supination. In another study, LAS involved the talocrural plantarflexion and subtalar inversion (Chen et al., 2019). Nevertheless, the mechanism of LAS is still unclear.

2.3 Electromyography (EMG)

2.3.1 Background of EMG

Biosignal means a collective electrical signal acquired from any organ that represents a physical variable of interest. This signal is normally a function of time and is describable from the aspect of amplitude, frequency and phase. The electromyography (EMG) signal is a biomedical signal that measures electrical currents generated in muscles during its contraction, which representing neuromuscular activities (Reaz et al., 2006). It is the study of muscle electrical signals. EMG is sometimes referred to as myoelectric activity. Surface EMG is a method of recording the information present in these muscle action potentials (Reaz et al., 2006). The development of EMG based on Reaz et al. (2006) were illustrated in Figure 2.3.



- 1666: Francesco Redi demonstrated highly specialized muscle of the electric ray fish generates electricity
- 1773: Walsh proved eel fish's muscle tissue could generate a spark of electricity
- 1792: Galvani proposed that electricity could initiate muscle contraction
- 1849: Dubios-Raymond discovered muscle activity during voluntary contraction could be recorded
- 1890: Marey introduced the term electromyography
- 1922: Gasser and Erlanger used an oscilloscope to show electrical signals from muscles
- 1930-1950: The capability of detecting EMG signals steadily improved
- 1966: Hardyck and his researchers were the first practitioners who used the EMG
- 1980: Cram and Steger introduced a clinical method for scanning a variety of muscles using an EMG sensing device

Figure 2.3: Timeline of the development of EMG (summarized from Reaz et al., 2006).

Surface electromyography (surface EMG: sEMG) is a common research tool used to observe muscle physiology during human movements. Recently, technology of sEMG is used in understanding the neuromuscular system behaviours (Vigotsky et al., 2018). In addition, sEMG is able to interpret the intensity of muscle recruitment and describe muscle characteristics (Thais et al., 2021). The study of biomechanics on ankle sprain can be explored via the process of recording electric activities of muscles, which is also known as EMG. The signal generated from the contraction of muscle fibres produce a small electric current, called electromyogram (Amrutha and Arul, 2017). In addition, electromyogram is the summation of the motor unit action potentials (MUAP) during contraction, which is measured at a given electrode location. EMG can be further categorized into two; non-invasive and invasive. Surface EMG (sEMG) is a non-invasive technique to measure the muscle activity by placing the surface electrodes on the skin (Drost et al., 2006). Intramuscular EMG is an invasive technique which requires the needle electrodes being directly inserted into muscle tissue to evaluate muscle activity when at rest and when contracted (Morrison, 2018).

Previous study demonstrated that the magnitude of muscle activity depends on the stability of the device (Ridder et al., 2014). Approximately twice of the muscle activity would be required to control standing posture on an unstable platform compared to the stable platform (Hirono et al., 2020). Additionally, maximally stimulating muscle activity level is expected to accelerate the re-habilitation process to pre-injury functional level (Wolburg et al., 2016).

2.3.2 Peroneus longus (PL) muscle

Peroneus longus (PL) is one of the ankle’s stabilizers muscles (Slevin et al., 2020). It plays an essential role in preventing ankle inversion (Delahunt et al., 2007). Bavdek et al. (2018) reported that PL is active during dynamic movement, particularly during walking. The PL contributes to ankle stability, particularly to frontal plane ankle stability during SL tasks, by preventing the ankle from inverting excessively (Mineta et al., 2017). It has been reported that individuals with AI demonstrated PL impairment after sprain

(Mineta et al., 2017; Fereydounnia et al., 2018). The PL has been the most assessed muscle in individuals with ankle instability.

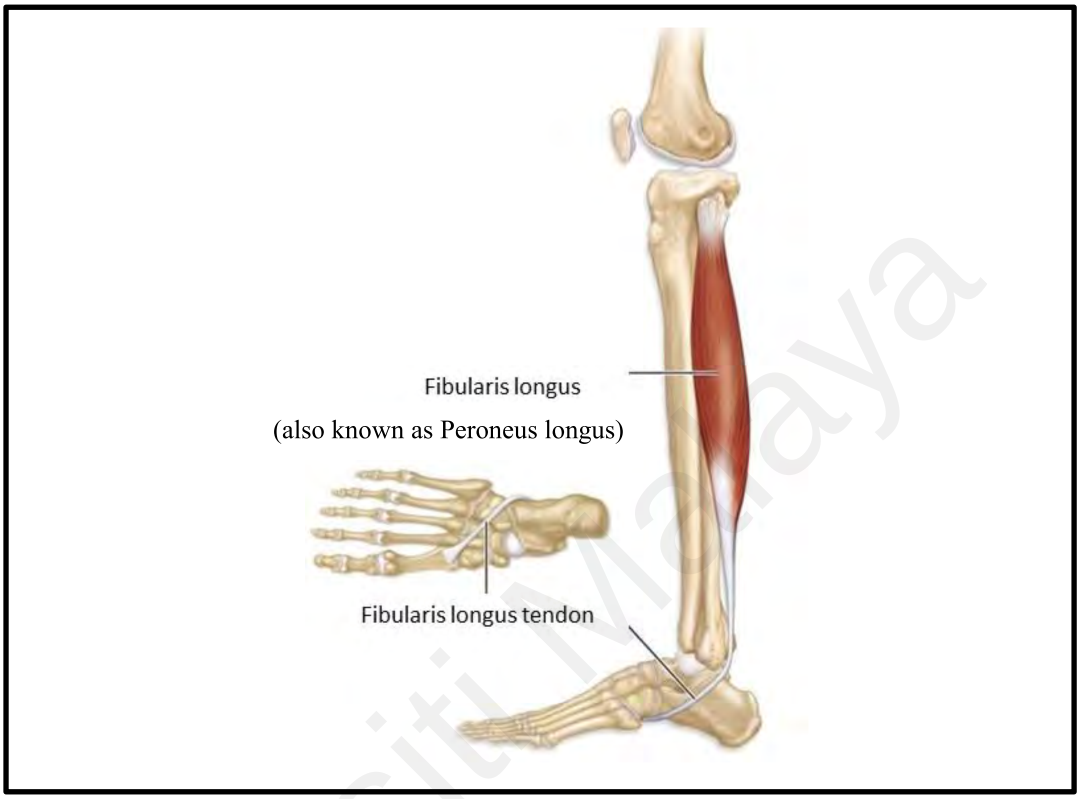


Figure 2.4: Peroneus Longus (PL) muscle

(Adapted from McGrawHill textbook, Muscles Part 9 flashcards - Easy Notecards, 2022)

Huang et al. (2021) reported that PL activates first followed by tibialis anterior (TA) and lateral gastrocnemius in healthy individuals during a landing task. Moreover, it was reported that individuals with FAI demonstrated a longer time to stabilization compared to healthy ankle when performing a jump with SL standing (Huang et al., 2021). According to Slevin et al. (2020), in a normal reaction to a sudden ankle inversion, the PL reacts first followed by the TA. However, it was demonstrated that in those with LAS, the sequence is lost, with the TA contracting almost instantaneously with the PL (Slevin et al., 2020). It was reported that basketball players with FAI displayed reduced postural control and longer reaction time of the PL compared to basketball players without FAI and to healthy controls (Lubetzky et al., 2016). Since function of PL is very important and already being reported to be impaired after sprain, there is a need to target PL during rehabilitation.

2.4 Relationship between postural control and ankle sprains

Ankle sprain may modify the physiology and structure of the ankle, which might cause ankle instability. As a result, individual afflicted with ankle sprain might display altered postural control. This has been demonstrated in individuals with MAI, which were associated with the degenerative changes in joint laxity (Lin et al., 2015). Therefore, it is crucial to understand the relationship between postural control and ankle instability.

2.5 Balance performance with Electromyography (EMG)

Literature showed that the fundamental of balance in biomechanics tasks had been intensively studied when the stability was being assessed alone (Wikstrom et al., 2010; Doherty et al., 2016). Recently, EMG was used exclusively in combination with the balance performance particularly in interpreting the muscle activation during the tasks performed (Fereydounnia et al., 2018; Feger et al., 2018). For instance, Bavdek et al. (2018) determined muscle activity during walking gait. The main objective was to determine the greatest EMG record for Peroneus Longus (PL) on different walking platform. The greatest evertor strength was the best strategy in preventing sudden imbalance that causes sprained ankle. This is in line with the fact that PL plays an important role in stability during walking (Che et al., 2015). Other than that, Chen et al. (2015) proposed that PL strength, muscle activation and proprioception should be improved in enabling PL to evert when sudden inversion occurs. Incorporating EMG in creating or modifying rehabilitation strategy might be beneficial for primary healthcare and clinicians. In this regard, a study on the balance performance of healthy individuals using wavelet-based time-frequency analysis extracted from the EMG signal was reported using Lafayette stability platform (Figure 3.2) (Brueckner et al., 2019). The reduction in integrated EMG (iEMG) and EMG intensity demonstrated improvement in balance performance on the stability platform.

2.6 Relationship between ankle sprains and EMG

Literature demonstrated poor postural control in people with ankle instability compared to the healthy population with no history of ankle injury. Laessoe et al. (2019) determined lower performance during unilateral stance stabilization on wobble board in injured individuals. Findings revealed that higher variations of tilt angle recorded from the wobble board indicates less stabilization ability among the injured individuals. Nevertheless, the pain, residual symptoms and aftereffect following ankle sprain might be different for different individual. Concerning the aforementioned problems, balance training was provided to reduce and prevent the ankle sprain risks. Jung et al. (2017) agreed that sensorimotor function and stability of ankle joints can be improved through rehabilitation. Better understanding of the relationship between muscle activity and balance tasks would aid the primary healthcare and clinicians to justify a specific rehabilitation strategy. The latest review on rehabilitation recovery demonstrated one year recovery post injury (Bleakley et al., 2019). Early management by joining rehabilitation sessions is able to improve recovery by a week faster. It can be said that functional treatment is able to reduce the reinjury rate and promote earlier return to normal ankle function.

From the perspective of EMG, lower muscle activity was identified from majority of the past studies. Ridder et al. (2015) assessed single leg balance task with eyes open on different surfaces and concluded that people with ankle injury demonstrated low amplitude during balancing comparing to healthy participants without injury.

2.7 Visual input in ankle sprain study

The central nervous system (CNS) integrates visual, vestibular, and proprioceptive information to control balance (Han et al., 2015). Previously, balance assessment using eyes-open (EO) was widely performed among individuals with ankle sprains in most studies. These included SL test (Ridder et al., 2015), Star Excursion Balance Test (SEBT) (Ahn et al., 2011; Feger et al., 2014; Pozzi et al., 2015; Jaber et al., 2018), forward lunges (Feger et al., 2014), and lateral hops (Delahunt et al., 2007; Feger et al., 2014). The deprivation of visual information increases the difficulty of the task (Muelas et al., 2014). Higher visual reliance, demonstrated by greater than normal disruption of balance when visual input was removed, may be an adaptive postural control mechanism to compensate for sensorimotor deficits of injured ankle (Kim, 2020).

Sensorimotor deficit has been associated with CAI, which was referred to damage to the afferent receptors (carry information from sensory receptors of the skin to the CNS) within injured ligaments and joint capsule (Hertel, 2008). In general, sensorimotor is a combination of senses and motor movements, which includes the works of afferent neurons, efferent neurons (carry motor information away from CNS to the muscle and glands of body), and interneurons (connect the afferent and efferent neurons) (Akinrodoye and Lui, 2022). Damage to receptors due to ankle sprain may justify the delayed reaction of PL during SL test (Ahn et al., 2011; Deun et al., 2011) and the inconsistencies of PL amplitudes (Labanca et al., 2021). On top of that, due to the limited studies that compare both visual presence (EO) and absence of the visual aspect (EC), it is difficult to deduce whether the individuals with ankle sprains could adapt the visual strategy to compromise with the ankle deficit due to post injury.

CHAPTER 3: METHODOLOGY

Postural control can be assessed by using the double leg (DL) and single leg (SL) stances. Majority of the studies used both tasks in the postural control assessment. However, based on our knowledge, no SL task has been executed and no known reliability study pertaining to the SL stance has been investigated using the Lafayette stability platform (Zaghlul et al., 2023). Thus, a pilot study on the reliability of the SL stance among healthy individuals was conducted prior to the assessment of postural control of the participants with and without history of unilateral ankle sprains. As such, the methodology section in this study is divided into two parts; 1) the evaluation of test-retest reliability of the SL stance on the Lafayette stability platform and 2) the postural control assessment in individuals with and without unilateral ankle sprains. The flow of the study is illustrated in Figure 3.1.

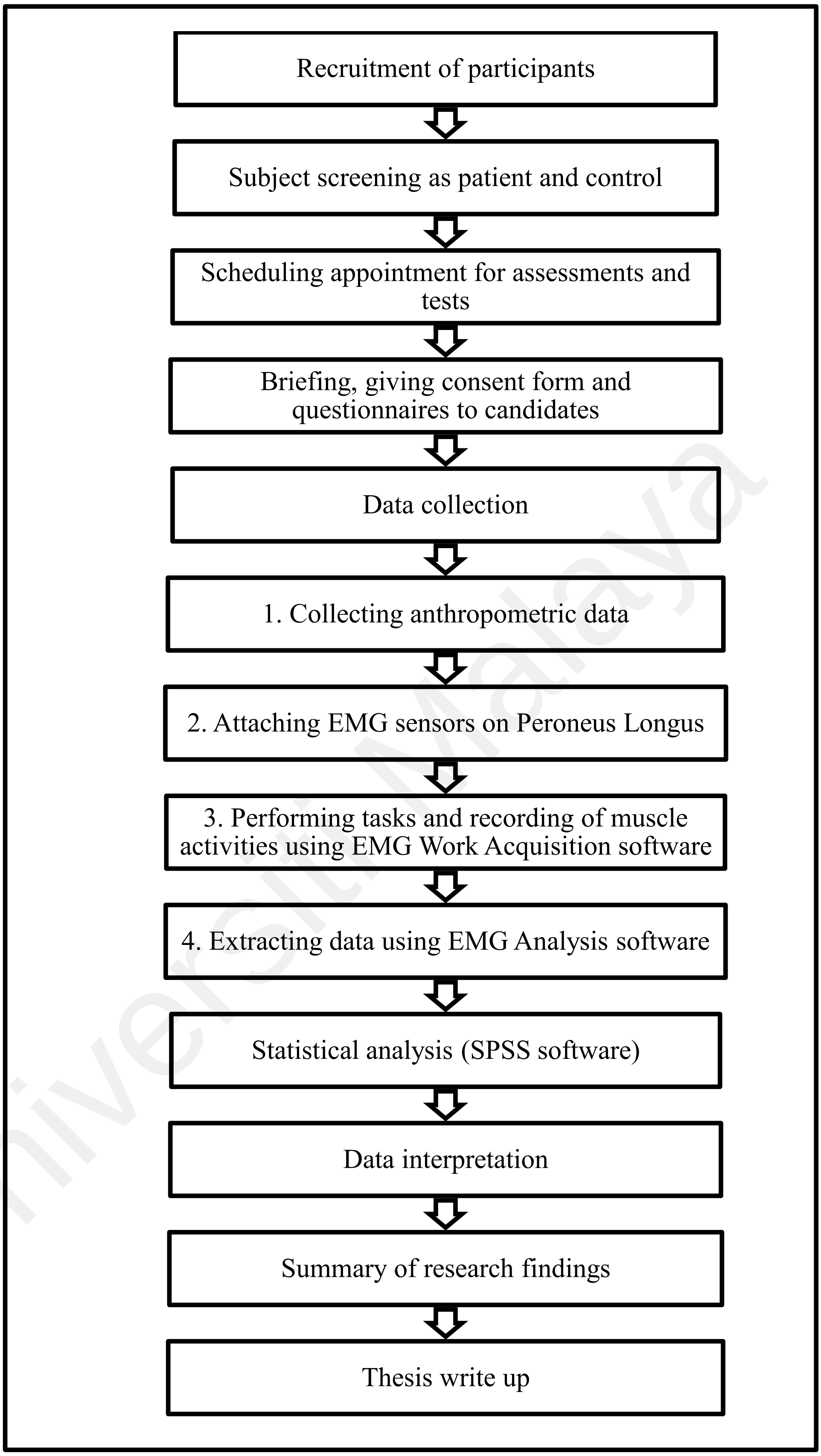


Figure 3.1. Flowchart of the study

3.1 Instrument: Lafayette stability platform

A Lafayette stability platform Model 16030 (Lafayette Instrument, Indiana, USA; see Figure 3.2) was used to assess the participants' postural control. The platform provides tilt angle which represents the participant's error score, reflecting deviation (medio-lateral) from the target horizontal platform position (0°). The stability platform consisted of a 65 x 107 cm wooden platform, allowing a maximum deviation of 15° from the horizontal to either side of the platform. A safety rail was mounted on the stability platform to prevent participants from falling if losing stability (Muelas et al., 2014). Using Psymlab software, the time in balance (TIB) (in second) was measured, the duration over which the participants maintained the platform within the permitted range of deviation (cutoff).

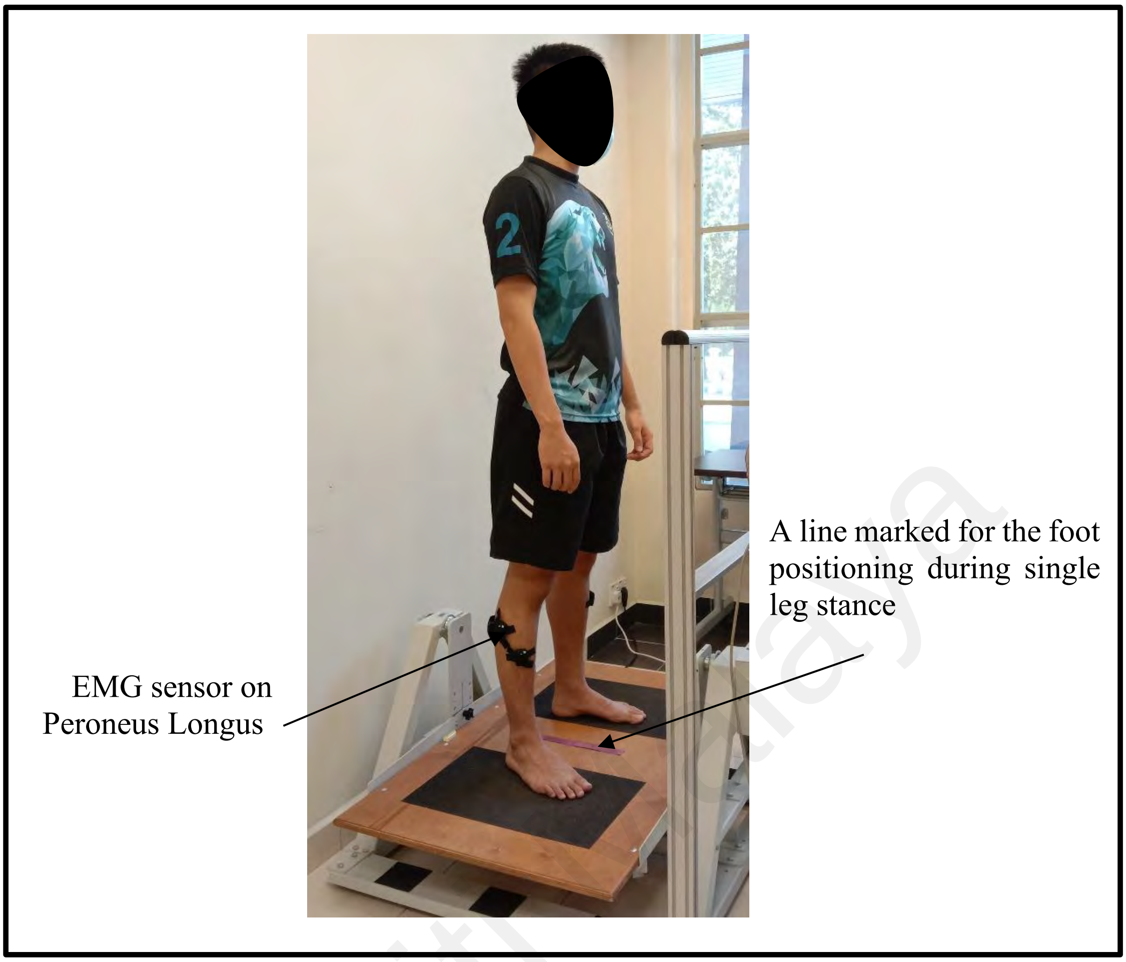


Figure 3.2: A participant performed double leg stance on the Lafayette stability platform

3.2 Evaluation of the test-retest reliability of the SL stance on the Lafayette stability platform

3.2.1 Sample size

An a priori sample size calculation was performed using G*Power statistical software, whereby a minimum of 19 participants were required to achieve an effect size of 0.80 and power of 90%. Thereafter, thirty-six (36) healthy and physically active university students (17 males, 19 females; age 23.2 ± 3.2 years; height 1.7 ± 0.1 m; weight 59.8 ± 11 kg; BMI 21.1 ± 3.1 kg/m^2) were recruited.

3.2.2 Experimental Procedure

3.2.2.1 Recruitment of subjects

The participants were recruited via flyers shared in the students' community email and using words of mouth. Inclusion criteria were both male and female aged between 18 and 25 years old, physically active with no musculoskeletal pain that may affect the testing. Physically active was defined as having regular exercises of at least 30 min per day or at least 3 days a week (Zech et al., 2018). To avoid bias, participants with prior experience with the stability platform were excluded from the study. In addition, participants with any lower extremity injury (acute or overuse) that has prevented them from participating in sports activities for at least one day in the previous 6 months were also exempted (Zech et al., 2018). This study was approved by the Medical Research Ethics Committee (MREC) of University of Malaya Medical Centre (201984-7710). All subjects signed a consent form prior to testing.

3.2.2.2 Testing procedures

Participants were requested to position their dominant leg on the line marker in the middle of the platform (Ridder et al., 2014). Participants were required to do simple stretches and plyometrics of the lower limb (Patel, 2014) to prepare the muscles and avoid muscle cramps due to sudden movements, which include 10 seconds (s) of standing quadriceps and hamstring stretch, ankle plantar and dorsiflexion active stretches, ankle eversion, and inversion movements and ending with 20 double leg hops. Participants were tested only with their dominant leg with no assessment on the non-dominant leg. The dominant leg was defined as the leg used to kick a ball (Dingenen et. al, 2016). The participants stood barefooted on their dominant leg while the contralateral leg was lifted up approximately 10 cm above the platform. The arms were allowed to hang at the side

(Arifin et al., 2014). The participants were required to balance under two testing conditions, eyes-open (EO) and eyes-closed (EC), at random order. Participants were allowed to make multiple attempts until they achieved three successful trials. The successful trials were considered if they are able to keep their balance for minimum 20s (Becker & Hung, 2020). In a balance assessment, protocol comprising of three trials for at least 20s is considered sufficient as the participants were not tested for an improvement (by familiarizing the task). This was to negate the potential of learning effect and avoid fatigue (Arifin et al., 2014). The trials were repeated if the non-dominant leg touched the platform or the participants fell off the platform before the time limit of 20s was reached. Similar protocol was applied a week later. Participants were advised to refrain from intense physical activity and to report any injuries during the week of experimental trials.

Using the Psymlab software (Lafayette Instrument, Indiana, USA), time in balance (TIB) in the two testing sessions were recorded. TIB (in seconds) was defined as the duration in which the platform was maintained within the range of 0° from horizontal plane. Longer TIB indicated better achievement of the postural control.

3.2.3 Statistical analysis

Comparison of the data from thirty-six participants between two different time points (Week 1, W1 and Week 2, W2) and between trials for each testing conditions (EO and EC) were computed using MedCalc statistical software version 20.009 (Medcalc Software Ltd, Ostend, Belgium). Along with 95% limits of agreement (LoA), Bland-Altman analysis was performed to assess the agreement between data sets obtained at W1 and W2. A scatterplot was constructed, whereby the differences between two measurements (W1-W2) was plotted against the mean of two measurements ((W1+W2)/2). The 95% LoA is defined as ±1.96 standard deviation (SD) (Giavarina, 2014). 95% of data that lie within the LoA indicated there was acceptable agreement between both measurements (Ionan et al., 2014). No significant difference between the measurements was reflected if the line of equality were within the interval (Barbado et al., 2020). Subsequently, intraclass correlation coefficient (ICC) for a two-way model, average measures and absolute agreement were computed to quantify the reliability of the measurement. To interpret the ICC values, ICC classification of Barbado et al. (2020) (less than 0.5, low; between 0.5 and 0.69, moderate; between 0.70 and 0.89, high; between 0.9 and 1.00, excellent) was applied. Level of significance was set at 0.05. Absolute reliability was calculated using the following formula, in which the precision of the instrument, the standard error of measurement (SEM) and SD is the mean SD of W1 and W2 (Arifin et al., 2014).

$$\boldsymbol{SEM} = \mathbf{SD}\sqrt{\mathbf{1} - \boldsymbol{ICC}} \qquad \text{(eq. 3.1)}$$

Additionally, the reproducibility of the SL stance was determined using coefficient of variation (CV); between (interCV) and within (intraCV) trials (Fauth et al., 2010).

3.3 The postural control assessment in individuals with and without unilateral ankle sprains

3.3.1 Sample size

A priori sample size was calculated using G*Power version 3.1.9.7. With 0.80 effect size and 81% power, a total of 48 participants were recruited to fulfill the minimum requirement of 21 participants per group. Table 3.1 presents the participants' demographic data.

Table 3.1: Participants demographic data

		AI	HI
No of participants, n		24	24
Gender, n	Male	15	12
	Female	9	12
Age, year		23.5 ± 2.3	23.5 ± 1.7
Height, m		1.68 ± 0.07	1.64 ± 0.09
Weight, kg		60.9 ± 7.3	58.1 ± 10.2
BMI, kg/ m^2		21.7 ± 1.9	21.5 ± 4.2
Time of last injury, year		2 ± 2.4	-

Results were presented as mean ± SD

AI: ankle sprains group; HI: healthy individual group

3.3.2 Experimental Protocol

3.3.2.1 Recruitment of participants

The recruitment of participants was performed through the advertisements and flyers shared among students' community via student mails and words of mouth. The participants were grouped into two; individuals with unilateral ankle sprains (AI) and healthy individuals (HI). General inclusion criteria for both groups were physically active, with regularly exercises of at least three times in a week (Zech et al., 2018). The participants in the AI group consist of individuals who had at least one unilateral ankle sprain previously and had returned to normal daily activities within 3 months without the use of assistive devices. Additional criteria for the participants in AI group were no concurrent joint or neuromuscular disorders, pain, injuries or deformities in the lower limb that could pose as confounding factors to the biomechanical analysis outcomes, and able to perform activities without significant difficulties. Participants with surgery or fracture in the lower limb were excluded to avoid any excessive variation in results. Meanwhile, the individuals in the HI group had to be physically active and no history of ankle sprain.

3.3.2.2 Testing protocol

Participants were briefed about the protocol and the flow of the experiment, and a written consent was obtained prior to testing. A self-reported questionnaire reporting the symptoms and functional status of the ankle (see 3.3.4) was collected and physical examination (anthropometric data such as height and weight) was performed on each participant.

The participants stood barefooted on the Lafayette stability platform, using double leg (DL) and single leg (SL) stances in eyes-open (EO) and eyes-closed (EC) conditions, with their hands on the side (Arifin et al., 2014; Laessoe et al., 2019). The width of the leg during DL stance was based on their shoulder width. This was to avoid the effect of size of the base. During SL stance, the participants positioned their leg in the middle of the line marked on the platform (see Figure 3.2). Both legs were tested for the SL stance and the order of testing of DL and SL was randomly selected among participants.

During EO condition, the participants looked ahead at a target placed on the wall about 2.5 m away whereas during EC condition, the participants closed both of their eyes. The participants were not allowed to speak, and there was no distracting noise or conversation throughout the testing session. Additionally, the participants kept their contralateral hip and knee slightly flexed with the foot approximately at least 10 cm above the platform in the SL stance (Silva et al., 2016).

The participants were allowed to have only one practice trial on the platform, to familiarize themselves with the protocol but not for the learning effect. Three successful trials of the 20s each were recorded for both the DL and SL stances in each condition. The trials were repeated if the participants fell off of the platform, touch the rail or the contralateral leg (during SL) touch the platform. The duration of TIB, which the participants maintained on the platform within ±1° were considered as 'in balance'. TIB data were collected during both DL and SL stances. To avoid limb dominance effect in the SL stance, the left and right TIB values were averaged for each condition.

3.3.3 Electromyography (EMG)

A 16-channel of Delsys Trigno wireless EMG system (Delsys, MA, USA) was used to record muscle activity in both left and right Peroneus Longus (PL) of the participants only during DL stance. The skin was cleaned with isopropyl alcohol to diminish the resistance (Jung et al., 2017). The PL electrode was placed on the line between the head of the fibula and the lateral malleolus, approximately 4 cm distal to the fibular head (Jaber et al., 2018). The PL electrodes were further secured with adhesive tapes to prevent slippage during testing and to minimize movement artifacts (Jaber et al., 2018). Prior to testing, participants were required to record maximum voluntary contraction (MVC) of the muscle. According to Surface Electromyography for Non-Invasive Assessment of Muscles (SENIAM) guidelines, eversion was performed for three trials of five seconds to record the peak amplitude (Merletti et al., 2001).

Data processing: EMG signals were recorded at a sampling rate of 2000 Hz. All EMG data were digitized, stored and analyzed using EMG Works Acquisition and Analysis software. EMG signals were filtered using a second order Butterworth filter, with a low pass filter at 350 Hz. The mean PL activity was normalized to the peak MVC and expressed as the percentage of MVC (%MVC) (Jung et al., 2017).

Again, to avoid the effect of limb dominance, the activity of PL was expressed as the side-to-side comparison by calculating the absolute values of the subtracted left and right PL in the DL stance.

3.3.4 Foot and Ankle Ability Measure (FAAM) Questionnaire

Foot and Ankle Ability Measure (FAAM) questionnaire was used to evaluate the perception of individual's ability balance (Martin et al., 2005). Two sections were assessed; activity of daily living (ADL) with 21 questions and sports subscale with 8 questions. The highest score of both sections (ADL: 84 marks; sports: 32 marks), which reflects 4 marks for each question carry the score of the stability perceptions. The total score of the items was divided by the highest potential score and then multiplied with 100 to get the percentage. A higher score represents a higher level of physical function. The FAAM scores were assessed simultaneously with the TIB and side-to-side comparison PL activity to determine the relationship between those two. The complete FAAM questionnaire adopted for this study can be seen in Appendix C.

3.3.5 Statistical analysis

The statistical analyses were conducted with Statistical Package for the Social Sciences (SPSS) version 23 (SPSS Inc., Chicago, IL., USA). The mean of TIB data (s), side-to-side comparison PL activity (%MVC), and FAAM scores were established in the SPSS. The normal distribution of the data of TIB, %MVC, and FAAM was checked using Shapiro-Wilk test. Due to the non-normally distributed data, the Kruskal-Wallis H test was performed to compare the TIB and MVC between groups (AI and HI) and conditions (EO and EC). Further, using Mann-Whitney U test, the self-reported FAAM scores were compared between groups.

Furthermore, the degree of association between self-reported FAAM scores and TIB measurement and MVC was determined using Spearman’s correlation coefficient (ρ). The analysis results were interpreted according to the degree of association as strong (0.5-1.0), moderate (0.3-0.5), and weak (0-0.3) (Kim et al., 2016). The significance level was set at $p \leq 0.05$.

CHAPTER 4: RESULTS

4.1 The evaluation of the test-retest reliability of the SL stance on a Lafayette stability platform

Data of the test-retest reliability of the Lafayette stability platform using SL stance collected from healthy and physically active university students, was determined over two different sessions one week apart. The mean TIB calculated from three 20s-trials each during EO and EC were summarized in Table 4.1.

Table 4.1: The evaluation of the test-retest reliability of the single leg stance on a Lafayette stability platform

	Mean time in balance, s			
Task conditions	**W1**	**W2**	**SEM**	**ICC**
Eyes-open	17.02 ± 1.04	17.32 ± 1.03	0.53	0.74
Eyes-closed	11.55 ± 1.73	13.08 ± 1.82	0.87	0.76

ICC: intraclass correlation coefficient; s: second; SEM: standard error of measurement; W1: Week 1; W2: Week 2

The differences between trials and LoA for two testing conditions (i.e EO and EC) were illustrated in Figure 4.1 and 4.2. The mean difference (bias) between EO_{W1} and EO_{W2} was -0.30s (95% confidence interval (CI) -0.211 to 1.51). Upper and lower LoA for EO were 10.19s (95% CI 7.07 to 13.31) and -10.79s (95% CI -2.73 to -1.72). On the other hand, the EC_{W1} and EC_{W2} had a mean difference of -1.53s (95% CI -3.09 to 0.02). Upper and lower LoA for EC were 7.48s (95% CI 4.81 to 10.16) and -10.54s (95% CI -13.22 to -7.86).

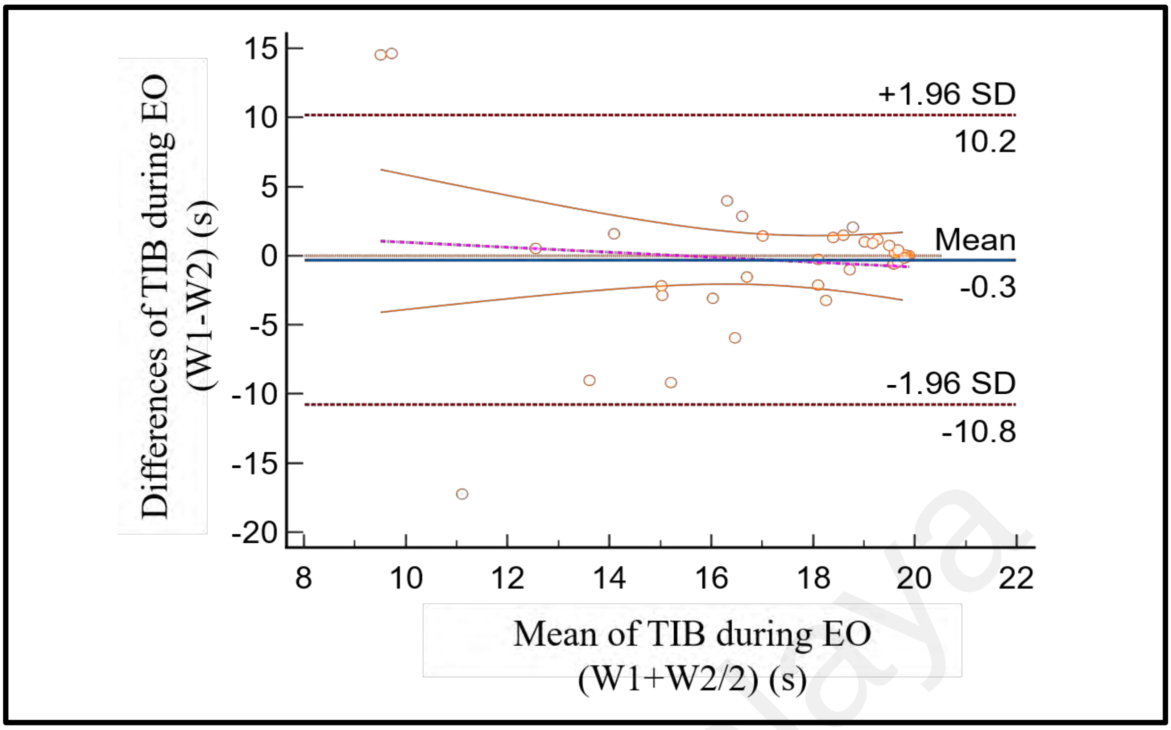


Figure 4.1: Bland-Altman plot for the time in balance of the single leg stance task in eyes-open condition. W1: Week 1, W2: Week 2. The differences between W1 and W2 were plotted against the mean of W1 and W2. The blue line indicated the mean difference (bias). The interval between upper and lower limits represented 95% Limit of Agreement.

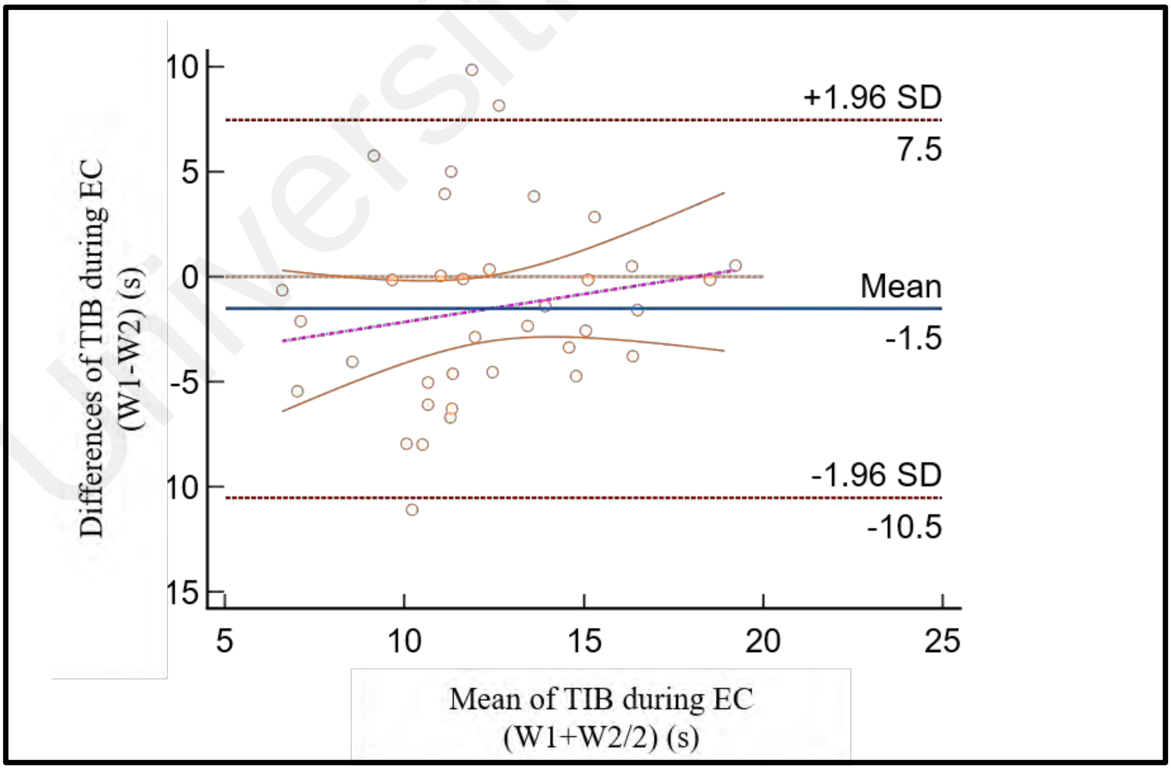


Figure 4.2: Bland-Altman plot for the time in balance of the single leg stance task in eyes-closed condition. W1: Week 1, W2: Week 2. The differences between W1 and W2 were plotted against the mean of W1 and W2. The blue line indicated the mean difference (bias). The interval between upper and lower limits represented 95% Limit of Agreement.

Based on the Bland-Altman plot, the scatterplot graph showed most of the points were evenly distributed within the interval in both EO and EC. There were few outliers detected beyond the interval, however, majority of the points were within LoA. Furthermore, the lines of equality for both EO and EC were within the LoA and close to the mean difference. This showed that no trend existed between the two measurements, which indicated the absence of systematic bias. The *p*-value reported from the Bland-Altman analysis indicated no significant difference between the two data sets (W1 vs W2) in both conditions (EO, $p = 0.736$; EC, $p = 0.054$).

The computed ICC between weeks demonstrated "high" ICC values during EO (ICC = 0.74, 95% CI = from 0.58 to 0.85) and EC (ICC = 0.76, 95% CI = from 0.61 to 0.86). Moreover, the calculated ICC for three consecutive trials in each condition over the two sessions revealed "high" ICC values for all the trials (EO_{W1}, ICC = 0.79; EO_{W2}, ICC = 0.86; EC_{W1}, ICC = 0.71; EC_{W2}, ICC = 0.71).

As indicated in Table 4.1, lower SEM during EO condition indicated more precise score compared during EC condition. Intersubject CVs were calculated to determine between-subject variability and ranged from 0% to 26.89% during EO and 1.21% to 28.49% during EC. Intrasubject CVs were calculated to assess within-subjects variability between repeated tests, and values ranged from 0% to 26.61% during EO_{W1} and 0% to 27.17% during EO_{W2}, whereas 1.05% to 27.78% during EC_{W1} and 1.37% to 29.2% during EC_{W2}.

4.2 Postural control assessment in individuals with and without unilateral ankle sprains

Data for forty-eight participants with and without unilateral ankle sprains using the DL and SL stance were computed via SPSS version 23.0. The time in balance (TIB) and side-to-side comparison PL activity (MVC) were analyzed to determine the postural control and muscle activity generated on the Lafayette stability platform.

4.2.1 Time in balance

A significantly shorter TIB during EC as compared to EO was recorded for both AI (EC: 18.12 ± 3.69s; EO: 19.69 ± 0.80s, $p < 0.05$) and HI (EC: 18.08 ± 3.60s; EO: 19.68 ± 1.28s, $p < 0.05$) individuals during DL stance. However, there is no difference in the TIB of the DL stance between groups.

Similar finding was observed during the SL stance. Both AI and HI groups demonstrated a statistically shorter TIB during EC (AI: 17.39 ± 2.66s; HI: 17.01 ± 3.02s, $p = 0.94$) compared to EO (AI: 18.59 ± 3.59s; HI: 18.44 ± 2.59s, $p = 0.22$). However, no significant difference was observed between the two groups. The results of TIB were tabulated in Table 4.2.

Table 4.2: Time in Balance during double leg and single leg stances on the Lafayette stability platform

	Double leg stance		**Single leg stance**	
Groups/Conditions	**EO**	**EC**	**EO**	**EC**
AI	19.69 ± 0.80	18.12 ± 3.69	18.59 ± 3.59	17.39 ± 2.66
HI	19.68 ± 1.28	18.08 ± 3.60	18.44 ± 2.59	17.01 ± 3.02
p-value (between groups)	0.61	0.42	0.22	0.94

Results were presented as mean ± SD.

AI: ankle sprains group; EC: eyes-closed; EO: eyes-open; HI: healthy individual group; s: second; SD: standard deviation

4.2.2 The side-to-side comparison PL activity

AI individuals had a lower side-to-side comparison PL activity compared to HI in both EO (AI: 25.17 ± 12.53%; HI: 29.82 ± 18.85%, p = 0.16) and EC (AI: 24.48 ± 11.40%; HI: 30.47 ± 19.03%, p = 0.06) conditions. No significant difference between EO and EC was observed between AI (p = 0.98) and HI (p = 0.74) groups. The results were summarized in Table 4.3.

Table 4.3: The side-to-side comparison Peroneus Longus (PL) activity during double leg stance

Side-to-side comparisons of PL activity (%MVC)		
Groups/conditions	**EO**	**EC**
AI	25.17 ± 12.53	24.48 ± 11.40
HI	29.82 ± 18.85	30.47 ± 19.03
p-value	0.16	0.06

Results were presented as mean ± SD. AI: ankle sprains group; EC: eyes-closed; EO: eyes-open; HI: healthy individual group; SD: standard deviation

4.2.3 Foot and Ankle Ability Measure (FAAM) scores

AI group had a significantly lower sports score compared to HI (AI: 92.99 ± 9.86%; HI: 99.87 ± 0.64%; p = 0.001). No difference in the ADL scores (AI: 97.42 ± 4.57%; HI: 99.26 ± 1.98%, p = 0.077) between the groups. Table 4.4 summarizes the FAAM scores.

Table 4.4: Foot and Ankle Ability Measure (FAAM) scores

Groups	AI	HI	p-value
ADL (%)	97.42 ± 4.57	99.26 ± 1.98	0.077
Sports (%)	92.99 ± 9.86	99.87 ± 0.64	0.001

Results were presented as mean ± SD. ADL: activity of daily living scores; AI: ankle sprains group; HI: healthy individual group; SD: standard deviation

4.2.4 Spearman's correlation coefficient

Overall, a significant correlation was observed between FAAM scores and TIB, but not in the correlation between FAAM scores and the side-to-side comparison PL activity.

4.2.4.1 Correlation between FAAM and TIB

A significant moderate to strong correlation between sports scores and DL (ρ = 0.43; p = 0.04) and SL (ρ = 0.59; p = 0.003) during EO was demonstrated in AI group. Whereas in HI group, a consistent negative correlation between sports scores and TIB was observed during EO (DL: -0.06, p = 0.77; SL: -0.11, p = 0.62) compared to EC (DL: -0.17, p = 0.43; SL: ρ = 0.19, p = 0.34).

In the correlation between ADL scores and TIB, a positive association were observed in the DL and SL stances during EO (DL: ρ = 0.13, p = 0.53; SL: ρ = 0.27, p = 0.20) and EC (DL: 0.07, p = 0.76; SL: ρ = 0.05, p = 0.83) conditions in AI group. In contrast, HI group showed a moderate correlation between ADL scores and TIB in SL during EO (EO: ρ = -0.32, p = 0.13; EC: ρ = 0.20, p = 0.34) but not with the DL (EO: ρ = 0.18, p = 0.41; EC: ρ = -0.14, p = 0.50).

4.2.4.2 Correlation between FAAM and side-to-side comparison PL activity

Based on Table 4.5, the correlation between sports scores and side-to-side comparison PL activity was stronger in the EO for both AI (ρ = -0.13; p = 0.56) and HI (ρ = -0.19; p = 0.34) groups.

In contrast, weak correlations were observed between ADL scores and side-to-side comparison PL activity in both EO (AI: ρ = 0.03, p = 0.88; HI: ρ = -0.002, p = 0.99) and EC (AI: ρ = -0.02, p = 0.93; HI: ρ = 0.09, p = 0.68) in both groups.

The summary of the correlation between FAAM scores and TIB and the side-to-side comparison PL activity were tabulated in Table 4.5.

Table 4.5: Spearman's correlation coefficient between individuals with and without ankle sprains.

Group	**FAAM**	**Outcome measures**	**Spearman's correlation (ρ)**	**p-value**
With ankle sprain	ADL	%MVC_EO	0.03	0.88
		%MVC_EC	-0.02	0.93
		TIB_DL_EO	0.13	0.53
		TIB_DL_EC	0.07	0.76
		TIB_SL_EO	0.27	0.20
		TIB_SL_EC	0.05	0.83
	Sports	%MVC_EO	-0.13	0.56
		%MVC_EC	-0.12	0.57
		TIB_DL_EO	**0.43***	**0.04**
		TIB_DL_EC	0.26	0.23
		TIB_SL_EO	**0.59****	**0.003**
		TIB_SL_EC	0.37	0.08
Without ankle sprain	ADL	%MVC_EO	-0.00	0.99
		%MVC_EC	0.09	0.68
		TIB_DL_EO	0.18	0.41
		TIB_DL_EC	-0.14	0.50
		TIB_SL_EO	-0.32	0.13
		TIB_SL_EC	0.20	0.34
	Sports	%MVC_EO	-0.19	0.34
		%MVC_EC	-0.05	0.83
		TIB_DL_EO	-0.06	0.77
		TIB_DL_EC	-0.17	0.43
		TIB_SL_EO	-0.11	0.62
		TIB_SL_EC	0.19	0.34

*indicate significant at $p < 0.05$; **indicate significant at $p < 0.01$

ADL: activity of daily living subscale; DL: double leg stance; EC: eyes-closed; EO: eyes-open, FAAM: foot and ankle ability measure questionnaire; %MVC: side-to-side comparison PL activity; SL: single leg stance; TIB: time in balance

CHAPTER 5: DISCUSSION

5.1 The evaluation of the test-retest reliability of the SL stance on a Lafayette stability platform

SL testing has been widely assessed on force plates and Biodex stability system, but usually not assessed using the Lafayette stability platform. Considering that SL testing is sensitive and able to distinguish postural impairment between injured and healthy individuals, thus, this study performed the test-retest reliability of the SL stance on a Lafayette stability platform among physically active university students. Results obtained from this group of participants showed low SEM values, high ICC values, and lower subject variability, which suggest acceptable degree of reliability.

The reliability of the SL stance on a Lafayette stability platform was analyzed using a combination of reliability measures, unlike previous studies. According to a systematic review of the evaluation of the test-retest reliability studies, Park et al. (2018) found that majority of the studies used only two types of statistical analyses in quantifying the instruments' reliability, which included ICC and SEM (Choi et al., 2014; Arifin et al., 2014; Barbado et al., 2020), Bland-Altman and ICC (Ponce-González et al., 2014), and ICC with correlation coefficient (Howell et al., 2019). Hänninen et al. (2021) applied an additional Wilcoxon ranked test to assess the mean difference between testing sessions. On the other hand, a more rigorous method was adopted in this study by using a combination of analyses (i.e. ICC, CV, SEM) including a graphical analysis of the Bland-Altman plot to enhance the confidence in deducing the conclusion.

High ICC values in both conditions portrayed a reliable SL stance on the platform. No clear consensus has been reported on the applicable standard values for acceptable reliability using ICC. In an earlier study, Fleiss (1986) classified ICC generally as ≥0.75

to be excellent, however, the findings should be interpreted with caution in regard to the study's field. Conversely, the ICC cutoff (i.e. threshold) adopted in this study was more relevant and had been used in previous reliability studies that assessed force platform's postural sway measures (Meshkati et al., 2011) and gait using tri-axial accelerometer (Fujiwara et al., 2020). When compared with ICC values in the previous test-retest reliability studies of SL stance, Laessoe et al. (2019) reported an ICC value of 0.87 on an instrumented wobble board, whereby a study of a dynamic SL stance using Biodex stability system elicited to an ICC value of 0.65 (Arifin et al., 2014) during EO condition. With an ICC of 0.74, finding in this study supported that the Lafayette stability platform is considered a reliable tool for SL stance.

Lower SEM values in both conditions indicated higher precision of the TIB measurements between the trials (Arifin et al., 2014; Laessoe et al., 2019), which implies the platform is able to produce consistent output at different time points. The reliability assessment of the SL stance on a Lafayette stability platform was further strengthened with the coefficient of variation (CV). Findings in this study showed a CV of <30%, in inter-and intrasubject variabilities in both conditions, which were in the acceptable range for the field experiments. A similar CV threshold was reported in previous reliability studies, including the validation of devices (Squara et al., 2009; Nagymaté et al., 2019) to the fitness measurements (Lubans et al., 2011), suggesting CV ranges of <30% were common in reliability studies. Hence, CV values in this study may be considered acceptable. Lower subject variability during EO suggested a homogeneity in the TIB measurements between weeks and repeated trials. These findings were common in the assessment with one type of population (Fauth et al., 2010), in which this study engaged only physically active university students. Referring to Park et al. (2018) and Atkinson and Nevill (1998), the statistical analyses performed in this study were considered to be comprehensive and exhaustive.

5.2 Postural control assessment in individuals with and without unilateral ankle sprains

This study aimed to investigate the contribution of visual input in the restoration of postural control among individuals with unilateral ankle sprains while balancing on the Lafayette stability platform. The Lafayette stability platform showed good reliability in evaluating TIB and PL activity in both EO and EC conditions. Both groups demonstrated a significantly shorter TIB during EC in the DL and SL stances. AI individuals had a consistently lower side-to-side comparison PL activity compared to the healthy ones. However, no significant difference in the TIB and the side-to-side comparison PL activity was demonstrated between the groups. Furthermore, a significant correlation was observed between sports scores and TIB in AI group during EO. Overall, the injured and healthy individuals demonstrated approximately equal TIB and the side-to-side comparison PL activity during postural control assessment on the Lafayette stability platform. This indicates that the injured individuals may return to their normal ankle pre-injury function, suggesting two years of recovery of postural control seems to be sufficient.

During postural control assessment, both AI and HI groups demonstrated significantly shorter TIB in EC than in EO. Lower TIB during the DL and SL stances may have resulted when the vision is blocked. The availability of visual input during EO complements the functionality of the vestibular and ankle proprioception. As previously reported in the literature, the absence of visual information may cause postural control disruption (Kim, 2020). Findings in this study were consistent with Kim et al. (2019), whereby a large difference in postural control was observed during EC between acute LAS and healthy individuals. As such, when one of the elements of the postural control is suppressed (i.e. visual input), the central nervous system may possibly utilize the reweighting strategy (Kwon et al., 2021), shifting the visuals approach to the ankle proprioception strategy to maintain postural control, when the ankle-foot complex is contacted directly with the ground (Han et al., 2015). Consequently, side-to-side comparison PL activity during EC is greater than EO in this study. This finding may answer the second research question, which is to determine whether the participants with AI adopt a visual coping strategy after sprain. As there is no significant difference between groups, there is no profound evidence to claim that these injured individuals adopt visual coping strategy entirely during balancing. By adopting side-to-side comparison calculation, this study was able to minimize bias relating to limb dominance and between injured and non-injured limbs. This method had been commonly adopted in a few studies that investigated the joint position sense, peroneal strength, postural control ability (Cho and Park, 2019), isokinetic strength (Cho et al., 2019), and ankle kinematics during gait (Drewes et al., 2008).

No significant difference in the observed performance (i.e. TIB, side-to-side comparison PL activity) between AI and HI groups in this study may suggest that individuals with unilateral ankle sprains and healthy had approximately equal postural control performance and side-to-side comparison PL activity during DL and SL stances on the Lafayette stability platform. This finding answered the first research question regarding the differences in the balancing ability between injured and non-injured groups. This finding indicated that individuals with unilateral ankle sprains may not fully rely on visual input to maintain postural control. Other alternative mechanisms might be adopted in this circumstance, which warrants further investigations. Additionally, with the average injury onset of more than two years, these individuals were assumed to have successfully returned to their pre-injury status with the likelihood of the postural control being restored after two years. A systematic review discovered that a significant improvement of stability would likely occur at the earliest 6 weeks to 3 months for the ligament to heal (Hubbard & Hicks-Little, 2009). Dubin et al. (2011) narrated the phases of the healing process of a completely ruptured ligament; inflammatory (initial response: lasting from 24-72 hours), reparative (granulation of connective tissue: approximately 3-5 days post-injury), remodeling (newly formed collagen fibers: 15-28 days post-injury). Despite this evidence, the exact amount of time needed for the ligament to heal may vary among individuals. The severity of the ankle sprain may influence the process, such that mild ankle ligament injury might take a shorter time to heal compared to severe injury. Nevertheless, extensive experimental trials are needed to evidence the possible factors that have been mentioned previously.

Furthermore, this study investigated the correlation between subjective measures (FAAM scores) and observed performance. A significant moderate to strong association between sports scores and TIB during EO was observed in AI group. This can be interpreted as a higher confidence level in sports performance will exhibit a better ability to balance, especially during visible presence. The sports subscale assesses the difficulty of performing a specific task during sports, thus, the significant association between sports scores and TIB among the AI individuals was anticipated. Compared to the ADL scores that evaluate the ankle function during normal daily tasks, which may not require a specific skill and technique, no significant correlation was observed between the ADL scores and observed performance in both groups. Lower sports score did not reflect the poor balancing ability in the injured group. This shows that their perception did not tally with the biomechanics test, which indirectly answered the third research question. Finding in this study may offer insight and meaningful understanding for the clinician, who needs to consider a comprehensive understanding, initiating from the injury cause till the ability of the patient to recover. By considering the patient’s perception of their ankle function, the rehabilitation technique can be strategized to ensure a suitable treatment and may speed up the recovery phase. Previous ankle sprain studies used subjective measures such as Ankle Instability Instrument (AII), FAAM (Jung et al., 2017), and Functional Ankle Instability Index (FADI) (Pozzi et al., 2015) only to measure the scores in categorizing the participants into groups of healthy and ankle sprain without correlating them with the outcomes. Therefore, by providing significant correlation outcomes, this study suggests incorporating both the subjective and objective measures in the postural control assessment in ankle sprains studies.

Increased sample size would be advantageous in this study. As this study only investigated the postural control between individuals with unilateral ankle sprains and healthy, the outcomes might be different for chronic ankle sprain individuals. Implementing FAAM with biomechanics tests able to provide a better understanding of the functional performance among individuals with unilateral ankle sprains. Therefore, it is recommended to integrate both qualitative and quantitative measures in ankle sprain research for the advancement of rehabilitation.

CHAPTER 6: CONCLUSION

Lafayette stability platform is reliable for use in testing the double leg and single leg stances. Individuals with unilateral ankle sprains and healthy individuals demonstrated approximately equal postural control and Peroneus Longus activity during postural control assessment on the Lafayette stability platform, which can be reflected as no difference in the balancing activity between individuals with and without ankle sprains. Findings in this study also demonstrated that individuals with ankle sprain did not adopt visual coping strategy after the sprain during balancing tasks. The individuals' perceptions towards their sports performance, particularly injured individuals are not tally with the balancing tests; the participants performed better compared to their self-scoring of FAAM. It can be deduced that individuals with unilateral ankle sprains successfully resume normal ankle pre-injury function, suggesting two years of recovery of postural control seems to be sufficient.

6.1 Recommendation for future studies

From the reliable data of SL and DL in this study, it is suggested to incorporate the Lafayette stability platform widely in ankle sprain studies in the future. TIB data and the side-to-side calculation PL activity in this study may be considered to measure balance performance. Since this study only evaluates postural control between injured and healthy participant cohorts, research exploring strategies between genders might present interesting findings. Generally, males and females have different strength criteria and the ability to concentrate during balancing (Schedler et al., 2020). Additionally, the effect of footwear during balance training among individuals with unilateral ankle sprains on the platform may provide valuable insights in the rehabilitation treatment. It is also recommended to investigate the effect of fatigue on postural control assessment using the Lafayette stability platform.

6.2 Clinical implications of the study

As this study incorporated both subjective (self-reported questionnaire) and objective (TIB, PL activity) measures in interpreting the results, a meaningful understanding of the status and functionality of the ankle can be discovered. This might benefit the clinician and therapists to strategize the rehabilitation treatment follows the individuals' condition, capability, and their limit. Exploring the athletes' perception particularly in the rehabilitation may assist in speeding up the return to play time. By constantly measuring their perception (pre and post balance training) and made them aware of this, it might boost their confidence level by lessening the effect of trauma of the pain and injury. Thus, improving the sports performance.

Other than that, findings in this study revealed that various methods can be adopted to analyze biomechanics data. Whilst previous studies frequently adopt kinetic and kinematics parameters, emphasizing the center of mass, and center of gravity in ankle sprain research, findings of TIB and the side-to-side comparison PL activity in this study may show that it is noteworthy to consider various measurements in interpreting balance performance. Furthermore, the side-to-side comparison calculation, which should be further implemented in future analysis, allows the minimization of bias and may provide clarity to the findings (by reducing the effect of limb dominance and between the injured and non-injured limbs).

Moreover, data from this study may support the idea of rehabilitating both injured and non-injured limbs involving individuals with unilateral ankle sprains. This may also offer additional data in the rehabilitation studies; in the development of a model to mimic the capability of the non-injured limbs among individuals with lower limb comorbidity (e.g. stroke patients). Incorporating artificial intelligence technology by using algorithms and programming features may allow a comprehensive data analysis of PL activity to be performed, not only in extracting the data in time domain or frequency domain individually, but also in time-frequency domain. This will provide meaningful findings for the advancement of rehabilitation.

REFERENCES

Abassi, M., Bleakley, C., & Whiteley, R. (2019). Athletes at latestage rehabilitation have persisting deficits in plantar- and dorsiflexion, and inversion (but not eversion) after ankle sprain. *Physical Therapy in Sport*, 38, 30–35.

Ahn, S. H., Hwang, U. J., Gwak, G. T., Yoo, H. I., & Kwon, O. Y. (2020). Comparison of the strength and electromyography of the evertor muscles with and without toe flexion in patients with chronic ankle instability. *Foot and Ankle International*, 41(4), 479–485.

Akhbari, B., & Ebrahimi, I. (2007). A 4-week biodex stability exercise program improved ankle musculature onset, peak latency and balance measures in functionally unstable ankles. *Physical Therapy in Sport*, 8, 117–129.

Akinrodoye MA, Lui F. Neuroanatomy, Somatic Nervous System. 2022 Nov 7. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2022 Jan–. PMID: 32310487.

Amrutha, N., & Arul, V. H. (2017). A review on noises in EMG signal and its removal. *International Journal of Scientific and Research Publications*, 7(5), 23. Retrieved from www.ijsrp.orgf

Andreeva, A., Melnikov, A., Skvortsov, D., Akhmerova, K., Vavaev, A., Golov, A., Zemková, E. (2021). Postural stability in athletes: The role of sport direction. *Gait and Posture*, 89(April), 120–125.

Arifin, N., Azuan, N., Osman, A., Abu, W., & Wan, B. (2014). Intrarater test-retest reliability of static and dynamic stability indexes measurement using the Biodex Stability System during unilateral stance. *Journal of Applied Biomechanics,* 20, 300–304.

Bansbach, H. M., Lovalekar, M. T., Abt, J. P., Rafferty, D., Yount, D., & Sell, T. C. (2017). Military personnel with self-reported ankle injuries do not demonstrate deficits in dynamic postural stability or landing kinematics. *Clinical Biomechanics*, 47(June 2016), 27–32.

Barbado, D., Gomez-Illan, R., Moreno-Navarro, P., Valero-Conesa, G., Reina, R., & Vera-Garcia, F. J. (2020). Postural control quantification in minimally and moderately impaired persons with multiple sclerosis: The reliability of a posturographic test and its relationships with functional ability. *Journal of Sport and Health Science*, 9(6), 677–684.

Bavdek, R., Strojnik, V., & Dolenec, A. (2018). Peroneal muscle activity during different types of walking. *Journal of Foot and Ankle Research*, 1–9.

Becker, K. A., & Hung, C. (2020). Attentional focus influences sample entropy in a balancing task. *Human Movement Science*, 72, 1–7.

Bleakley, C. M., Taylor, J. B., Dischiavi, S. L., Doherty, C., & Delahunt, E. (2019). Rehabilitation exercises reduce reinjury post ankle sprain, but the content and parameters of an optimal exercise program have yet to be established: A Systematic Review and Meta-analysis. *Archives of Physical Medicine and Rehabilitation*, 100(7), 1367–1375.

Bonnel FT, Toullec E, Mabit C, Tourné Y. (2010). Chronic ankle instability: biomechanics and pathomechanics of ligaments injury and associated lesions. Orthopaedics & traumatology: *Surgery & research*, 96(4), 424-32.

Brown, C. N., Bowser, B., & Orellana, A. (2010). Dynamic postural stability in females with chronic ankle instability. *Medicine & Science in Sports & Exercise*. 2258–2263.

Brueckner, D., Göpfert, B., Kiss, R., & Muehlbauer, T. (2019). Effects of motor practice on learning a dynamic balance task in healthy young adults: A wavelet-based time-frequency analysis. *Gait & Posture*, 70, 264–269.

Chaari, F., Rebai, H., Boyas, S., Rahmani, A., Fendri, T., Harrabi, M. A., & Sahli, S. (2021). Postural balance impairment in Tunisian second division soccer players with groin pain: A case-control study. *Physical Therapy in Sport*, 51, 85–91.

Che, S., Gregory, Y., Ying, M. G., Wang, C., & Murphy, P. (2015). Alteration of ankle kinematics and muscle activity during heel contact when walking with external loading. *European Journal of Applied Physiology*.

Chen, J., Jack, R., Appelle, J., Bushuk, M., & Smith, C. (2015). Surface electromyographic study of peroneus longus activation during ankle eversion and heel lift. *Open Journal of Therapy and Rehabilitation*, 3, 101–108.

Chen, E. T., McInnis, K. C., & Borg-Stein, J. (2019). Ankle sprains: evaluation, rehabilitation, and prevention. *Current Sports Medicine Reports*, 18(6), 217–223.

Cho, B. K., & Park, J. K. (2019). Correlation between joint-position sense, peroneal strength, postural control, and functional performance ability in patients with chronic lateral ankle instability. *Foot and Ankle International*, 40(8), 961–968.

Cho, B., Park, J., Choi, S., Kang, S., & Soohoo, N. F. (2019). The peroneal strength deficits in patients with chronic ankle instability compared to ankle sprain copers and normal individuals. *Foot and Ankle Surgery*, 25(2), 231–236.

Choi Y. M., Dobson F., Martin J., Bennell K. L., & Hinman R. S. (2014). Interrater and intrarater reliability of common clinical standing balance tests for people with hip osteoarthritis. *Physical Therapy*, 94(5), 696-704.

Clark, V. M., & Burden, A. M. (2005). A 4-week wobble board exercise programme improved muscle onset latency and perceived stability in individuals with a functionally unstable ankle. *Physical Therapy in Sport*, 6, 181–187.

Croy T., Saliba S., Saliba E., Anderson M.W., Hertel J. (2012). Differences in lateral ankle laxity measured via stress ultrasonography in individuals with chronic ankle instability, ankle sprain copers, and healthy individuals. *Journal of Orthopaedic & Sports Physical Therapy*, 42(7), 593-600.

De Jong, A. F., Koldenhoven, R. M., & Hertel, J. A. Y. (2020). Proximal adaptations in chronic ankle instability: systematic review and meta-analysis. *Medicine and Science in Sports and Exercise*, 52(7), 1563–1575.

Deun, S. Van, Staes, F. F., & Stappaerts, K. H. (2007). Relationship of chronic ankle instability to muscle activation patterns during the transition from double-leg to single-leg stance. *The American Journal of Sports Medicine*, 35(2). 274–281.

Deun, S. Van, Stappaerts, K., Levin, O., Janssens, L., & Staes, F. (2011). Stability of measurement outcomes for voluntary task performance in participants with chronic ankle instability and healthy participants. 46(4), 366–375.

Delahunt, E., Monaghan, K., & Caulfield, B. (2007). Ankle function during hopping in subjects with functional instability of the ankle joint. *Scand J Med Sci Sports,* 17, 641–648.

Dingenen, B., & Vereecken, S. (2016). Postural stability during single-leg stance: a preliminary evaluation of noncontact lower extremity injury risk. 46(8), 650–657.

Doherty C, Bleakley C, Hertel J, Caulfield B, Ryan J, Delahunt E. (2016). Recovery from a first-time lateral ankle sprain and the predictors of chronic ankle instability: a prospective cohort analysis. *The American Journal of Sports Medicine*. 44(4), 995-1003.

Drewes, Lindsay K. Lee, Sae Yong, McKeon, Patrick O., Paolini, Gabriele, Kerrigan, D. Casey, Hertel, Jay (2008). Side-to-side comparisons of ankle kinematics during gait among individuals with unilateral chronic ankle instability. *Medicine & Science in Sports & Exercise*, 40 (5), 18.

Drost, G., & Stegeman, D. F. (2006). Clinical applications of high-density surface EMG: A systematic review. *Journal of Electromyography and Kinesiology*, 16, 586–602.

Dubin, J. C., Comeau, D., McClelland, R. I., Dubin, R. A., & Ferrel, E. (2011). Lateral and syndesmotic ankle sprain injuries: A narrative literature review. *Journal of Chiropractic Medicine*, 10(3), 204–219.

Fauth, M. L., Petushek, E. J., Feldmann, C. R., Hsu, B. E., Garceau, L. R., Lutsch, B. N., & Ebben, W. P. (2010). Reliability of surface electromyography during maximal voluntary isometric contractions, jump landings, and cutting. *Journal of Strength and Conditioning Research*, 24(4), 1131–1137.

Feger, M. A., Donovan, L., Hart, J. M., & Hertel, J. (2014). Lower Extremity Muscle Activation During Functional Exercises in Patients With and Without Chronic Ankle Instability. *PM&R*, 1–10.

Feger, M. A., Hart, J. M., Saliba, S., Abel, M. F., & Hertel, J. (2018). Gait training for chronic ankle instability improves neuromechanics during walking. *Journal of Orthopaedic Research*, 515–524.

Feletti, F., Mucci, V., & Aliverti, A. (2019). Posture analysis in extreme sports. *In DHM and Posturography.*

Fereydounnia, S., Shadmehr, A., Talebian, S., & Olyaei, G. (2018). The comparison of dynamic postural control and muscle activity in time domain in athletes with and without chronic ankle instability. *Muscles, Ligaments and Tendons Journal*, 8(4), 552-559.

Fujiwara, S., Sato, S., Sugawara, A., Nishikawa, Y., Koji, T., Nishimura, Y., & Ogasawara, K. (2020). The coefficient of variation of step time can overestimate gait abnormality: Test-retest reliability of gait-related parameters obtained with a tri-axial accelerometer in healthy subjects. *Sensors* (Switzerland), 20(3).

Gan, Q. F., Leong, P. P., Cheong, S. K., & Foo, C. N. (2020). Regenerative medicine as a potential and future intervention for ankle sprain. *Malaysian Journal of Medicine and Health Sciences*, 16(2), 290–299.

Giavarina D. (2014). Lessons in biostatistics. past, present, and future of statistical science. *Biochemia Medica*, 25(2), 359–372.

Golanó, P., Vega, J., de Leeuw, P. A. J., Malagelada, F., Manzanares, M. C., Götzens, V., & van Dijk, C. N. (2010). Anatomy of the ankle ligaments: A pictorial essay. *Knee Surgery, Sports Traumatology, Arthroscopy*, 18(5), 557–569.

Groters, S., Groen, B. E., Cingel, R. Van, & Duysens, J. (2013). Double-leg stance and dynamic balance in individuals with functional ankle instability. *Gait & Posture*, 12–15.

Han, J., Anson, J., Waddington, G., Adams, R., & Liu, Y. (2015). The role of ankle proprioception for balance control in relation to sports performance and injury. *BioMed Research International.*

Hänninen, T., Parkkari, J., Howell, D. R., Palola, V., Seppänen, A., Tuominen, M., Luoto, T. M. (2021). Reliability of the Sport Concussion Assessment Tool 5 baseline testing: A 2-week test–retest study. *Journal of Science and Medicine in Sport*, 24(2), 129–134.

Herb, C. C., & Hertel, J. (2014). Current concepts on the pathophysiology and management of recurrent ankle sprains and chronic ankle instability. *Current Physical Medicine and Rehabilitation Reports*, 2(1), 25–34.

Hertel, J. (2002). Functional anatomy, pathomechanics, and pathophysiology of lateral ankle instability. *Journal of Athletic Training*, 37(4), 364–375.

Hirono, T., Ikezoe, T., Taniguchi, M., Yamagata, M., & Miyakoshi, K. (2020). Relationship between ankle plantar flexor force steadiness and postural stability on stable and unstable platforms. *European Journal of Applied Physiology*.

Howell, D. R., Brilliant, A. N., & Meehan, W. P. (2019). Tandem gait test-retest reliability among healthy child and adolescent athletes. *Journal of Athletic Training*, 54(12), 1254–1259.

Huang, P. Y., Jankaew, A., & Lin, C. F. (2021). Effects of plyometric and balance training on neuromuscular control of recreational athletes with functional ankle instability: A randomized controlled laboratory study. *International Journal of Environmental Research and Public Health*, 18(10).

Hubbard, T. J., & Hicks-Little, C. A. (2008). Ankle ligament healing after an acute ankle sprain: An evidence-based approach. *Journal of Athletic Training*, 43(5), 523–529.

Hung, Y., & Miller, J. (2016). Extrinsic visual feedback and additional cognitive/physical demands affect single-limb balance control in individuals with ankle instability. *World Journal of Orthopedics*, 7(12), 801–807.

Ionan, A. C., Polley, M. Y. C., McShane, L. M., & Dobbin, K. K. (2014). Comparison of confidence interval methods for an intra-class correlation coefficient (ICC). B*MC Medical Research Methodology*, 14(1), 1–11.

Jaber, H., Lohman, E., Daher, N., Bains, G., Nagaraj, A., Mayekar, P., Alameri, M. (2018). Neuromuscular control of ankle and hip during performance of the star excursion balance test in subjects with and without chronic ankle instability. *PLoS ONE*, 1–16.

Jung, Y., Yi, C., Baek, Y., Son, J., & Lim, O. (2017). Comparison of functional exercises on lower limb and trunk muscle activation in people with chronic ankle instability. *International Journal of Therapy and Rehabilitation*, 24(10), 435–442.

Kasahara, S., & Saito, H. (2021). Mechanisms of postural control in older adults based on surface electromyography data. *Human Movement Science*.

Kazemi, K., Arab, A. M., Abdollahi, I., López-López, D., & Calvo-Lobo, C. (2017). Electromiography comparison of distal and proximal lower limb muscle activity patterns during external perturbation in subjects with and without functional ankle instability. *Human Movement Science*, 55(August), 211–220.

Kim, Y., Todd, T., Fujii, T., Lim, J.-C., Vrongistinos, K., & Jung, T. (2016). Effects of Taekwondo intervention on balance in children with autism spectrum disorder. *Journal of Exercise Rehabilitation*, 12(4), 314–319.

Kim, K. M., Kim, J. S., Oh, J., & Lee, S. Y. (2019). Time-to-boundary analysis of postural control following acute lateral ankle sprain. *Gait and Posture*, 67(May 2018), 151–153.

Kim, K. M. (2020). Higher visual reliance during single-leg balance bilaterally occurring following acute lateral ankle sprain: A potential central mechanism of bilateral sensorimotor deficits. *Gait and Posture*, 78(June 2019), 26–29.

Kiss R, Brueckner D, & Muehlbauer T. (2018). Effects of single compared to dual task practice on learning a dynamic balance task in young adults. *Frontiers in Psychology*, 9, 1–8.

Kobayashi, T., & Gamada, K. (2014). Lateral ankle sprain and chronic ankle instability. *Foot & Ankle Specialist*, 7(4), 298–326.

Kobayashi, T., Tanaka, M., & Shida, M. (2017). Intrinsic risk factors of lateral ankle sprain: A Systematic Review and Meta-analysis. *Sports Health*, 8(2), 190–193.

Kolářová, B., Janura, M., Svoboda, Z., Kolář, P., Tečová, D., & Elfmark, M. (2021). Postural control strategies and balance-related factors in individuals with traumatic transtibial amputations. *Sensors*, 21(21).

Ku, P., X., Azuan, N., Osman, A., Abu, W., & Wan, B. (2014). Balance control in lower extremity amputees during quiet standing: A systematic review. *Gait & Posture*, 39(2), 672–682.

Kwon, Y. U. (2018). Static postural stability in chronic ankle instability, an ankle sprain and healthy ankles. *Orthopedics & Biomechanics*.

Kwon, J. W., Nam, S. M., & Koo, D. K. (2021). Electromyographic analysis of ankle muscles in chronic ankle instability during sudden inversion according to visual information provision. *Sports Orthopaedics and Traumatology*, 37(3), 262–267.

Lafayette Instrument (2020). https://lafayetteevaluation.com/products/stability-platform-safety-rail

Lampell, M. S. (2007). Ankle Sprains. *Pediatric Clinical Advisor*, 34–36.

Laessoe, U., Weinreich, A., Norre, M., Rosenkrans, J., & Scharf, A. (2019). Evaluation of functional ankle instability assessed by an instrumented wobble board. *Physical Therapy in Sport*, 35, 133–138.

Lin, C. Y., Kang, J. H., Wang, C. L., & Shau, Y. W. (2015). Relationship between viscosity of the ankle joint complex and functional ankle instability for inversion ankle sprain patients. *Journal of Science and Medicine in Sport*, 18(2), 128–132.

Liu, K., Glutting, J., Wikstrom, E., Gustavsen, G., Royer, T., & Kaminski, T. W. (2013). Examining the diagnostic accuracy of dynamic postural stability measures in differentiating among ankle instability status. *Clinical Biomechanics*, 28, 211–217.

Louwerens, J. W. K., Linge, B. van, de Klerk, L. W. L., Mulder, P. G. H., & Snijders, C. J. (1995). Peroneus longus and tibialis anterior muscle activity in the stance phase: A quantified electromyographic study of 10 controls and 25 patients with chronic ankle instability. *Acta Orthopaedica*, 66(6), 517–523.

Low, W. S., Goh, K. Y., Goh, S. K., Yeow, C. H., Lai, K. W., Goh, S. L., Chuah, J. H., Chan, C. K. (2023). Lower extremity kinematics walking speed classification using long short-term memory neural frameworks. *Multimedia Tools and Applications*, (89), 9745-9760.

Lyytinen, T., Liikavainio, T., Bragge, T., Hakkarainen, M., Karjalainen, P. A., & Arokoski, J. P. A. (2010). Postural control and thigh muscle activity in men with knee osteoarthritis. *Journal of Electromyography and Kinesiology*, 20(6), 1066–1074.

Lubans, D. R., Morgan, P., Callister, R., Plotnikoff, R. C., Eather, N., Riley, N., & Smith, C. J. (2011). Test-retest reliability of a battery of field-based health-related fitness measures for adolescents. *Journal of Sports Sciences*, 29(7), 685–693.

Lubetzky, A. V, Price, R., & Mccoy, S. W. (2016). Effects of Achilles tendon vibration, surface and visual conditions on lower leg electromyography in young adults with and without recurrent ankle sprains. *Journal of Bodywork & Movement Therapies*, 20(3), 639–649.

Ma, W., Pan, C. Y., Diehl, L. H., Wittstein, J. R., Riboh, J. C., Toth, A. P., Sell, T. C. (2022). Altered lower extremity biomechanics following anterior cruciate ligament reconstruction during single-leg and double-leg stop-jump tasks: A bilateral total support moment analysis. *Clinical Biomechanics,* 91(January 2021), 105533.

Martin, R. R. L., Irrgang, J. J., Burdett, R. G., Conti, S. F., & Van Swearingen, J. M. (2005). Evidence of validity for the Foot and Ankle Ability Measure (FAAM). *Foot and Ankle International*, 26(11), 968–983.

McGovern, R., & Martin, R. (2016). Managing ankle ligament sprains and tears: current opinion. *Open Access Journal of Sports Medicine*, 33.

McKeon, J. M., & Hoch, M. C. (2019). The ankle-joint complex: A kinesiologic approach to lateral ankle sprains. *Journal of Athletic Training*, 54(6), 589–602.

Merletti, R., Rainoldi, A., & Farina, D. (2001). Surface electromyography for noninvasive characterization of muscle. *Exercise and Sport Sciences Reviews*, 29(1), 20–25.

Meshkati, Z., Namazizadeh, M., Salavati, M., & Mazaheri, M. (2011). Reliability of force-platform measures of postural sway and expertise-related differences. *Journal of Sport Rehabilitation*, 20(4), 442–456.

Miklovic, T. M., Donovan, L., Protzuk, O. A., Kang, M. S., & Feger, M. A. (2017). Acute lateral ankle sprain to chronic ankle instability: a pathway of dysfunction. *Physician and Sportsmedicine*, 46(1), 116–122.

Miller, H. N., Rice, P. E., Felpel, Z. J., Stirling, A. M., Bengtson, E. N., & Needle, A. R. (2018). Influence of mirror feedback and ankle joint laxity on dynamic balance in trained ballet dancers. *Journal of Dance Medicine & Science*, 22 (4), 184–191.

Mineta, S., Inami, T., Mariano, R., & Hirose, N. (2017). High lateral plantar pressure is related to an increased tibialis anterior / fibularis longus activity ratio in patients with recurrent lateral ankle sprain. *Journal of Sports Medicine*, 123–131.

Mora, I, Quinteiro-Blondin, S, & Chantal, P. (2003). Electromechanical assessment of ankle stability. *European Journal of Applied Physiology*, 88, 558–564.

Muelas R, Sabido R, Barbado D, & Javier F. (2014). Visual availability, balance performance and movement complexity in dancers. *Gait & Posture*, 40, 556–560.

Nagymáté, G., Orlovits, Z., & Kiss, R. M. (2019). Reliability analysis of a sensitive and independent stabilometry parameter set. *PLoS ONE*, 13(4), 1–14.

Nozu, S., Johnson, K. A., Takemura, M., & Shields, R. K. (2021). Disrupted somatosensory input alters postural control strategies during the Star Excursion Balance Test (SEBT) in healthy people. *Gait and Posture*, 90(August), 141–147.

Park, M. S., Kang, K. J., Jang, S. J., Lee, J. Y., & Chang, S. J. (2018). Evaluating test-retest reliability in patient-reported outcome measures for older people: A systematic review. *International Journal of Nursing Studies*, 79(November 2017), 58–69.

Patel, N. N. (2014). Plyometric Training: A Review Article. *International Journal of Current Research and Review*, 6(15), 33–37. Retrieved from http://www.scopemed.org/?mno=166116

Ponce-González, J. G., Sanchis-Moysi, J., González-Henrlquez, J. J., Arteaga-Ortiz, R., Calbet, J. A. L., & Dorado, C. (2014). A reliable unipedal stance test for the assessment of balance using a force platform. *Journal of Sports Medicine and Physical Fitness*, 54(1), 108–117.

Pozzi, F., Moffat, M., & Gutierrez, G. (2015). Neuromuscular control during performance of a dynamic balance task in subjects with and without ankle instability. *The International Journal of Sports Physical Therapy*, 10(4), 520–529.

Rahnama, L., & Akhbari, B. (2010). Attentional demands and postural control in athletes with and without functional ankle instability. *Journal of Orthopaedic & Sports Physical Therapy*, 40(3), 180-189.

Rajasekaran, V., Aranda, J., Casals, A., & Pons, J. L. (2015). An adaptive control strategy for postural stability using a wearable robot. *Robotics and Autonomous Systems*, 73, 16–23.

Reaz, M. B. I., Hussain, M. S., & Mohd-Yasin, F. (2006). Techniques of EMG signal analysis: Detection, processing, classification and applications. *Biological Procedures Online*, 8(1), 11–35.

Ridder, R. De, Willems, T., Mits, S. De, Vanrenterghem, J., & Roosen, P. (2014). Foot orientation affects muscle activation levels of ankle stabilizers in a single-legged balance board protocol. *Human Movement Science*, 33, 419–431.

Ridder, R. De, Willems, T., Vanrenterghem, J., & Roosen, P. (2015). Influence of balance surface on ankle stabilizing muscle activity in subjects with chronic ankle instability. *Journal of Rehabilitation Medicine,* 47, 632–638.

Rosen, A. B., Than, N. T., Smith, W. Z., Yentes, J. M., Mcgrath, M. L., Mukherjee, M., Maerlender, A. C. (2017). Attention is associated with postural control in those with chronic ankle instability. *Gait & Posture,* 54, 34–38.

Rosen, A. B., Yentes, J. M., McGrath, M. L., Maerlender, A. C., Myers, S. A., & Mukherjee, M. (2019). Alterations in cortical activation among individuals with chronic ankle instability during single-limb postural control. *Journal of Athletic Training*, 54(6), 718–726.

Schedler S, Brueckner D, Kiss R, & Muehlbauer T. (2020). Effect of practice on learning to maintain balance under dynamic conditions in children: are there sex differences? *BMC Sports Science, Medicine and Rehabilitation*, 1–7.

Schelldorfer, S., Ernst, M. J., Rast, F. M., Bauer, C. M., Meichtry, A., & Kool, J. (2015). Low back pain and postural control, effects of task difficulty on centre of pressure and spinal kinematics. *Gait and Posture*, 41(1), 112–118.

Shih, Y., Yu, H., Chen, W., Liao, K., & Lin, H. (2018). The effect of additional joint mobilization on neuromuscular performance in individuals with functional ankle instability. *Physical Therapy in Sport*, 30, 22–28.

Silva, P. de B., Oliveira, A. S., Mrachacz-Kersting, N., Laessoe, U., & Kersting, U. G. (2016). Strategies for equilibrium maintenance during single leg standing on a wobble board. *Gait and Posture*, 44, 149–154.

Simpson, J. D., Koldenhoven, R. M., Wilson, S. J., Stewart, E. M., Turner, A. J., Chander, H., & Knight, A. C. (2020). Ankle kinematics, center of pressure progression, and lower extremity muscle activity during a side-cutting task in participants with and without chronic ankle instability. *Journal of Electromyography and Kinesiology*, 54(July).

Slevin, Z. M., Arnold, G. P., Wang, W., Abboud, R. J., & Wang, W. (2020). Immediate effect of kinesiology tape on ankle stability. *BMJ Open Sport & Exercise Medicine*, 1–6.

Song, K., Rhodes, E., & Wikstrom, E. A. (2018). Balance training does not alter reliance on visual information during static stance in those with chronic ankle instability: A Systematic Review with Meta-Analysis. *Sports Medicine*, 48(4), 893–905.

Steib, S., Zech, A., Hentschke, C., & Pfeifer, K. (2013). Fatigue-induced alterations of static and dynamic postural control in athletes with a history of ankle sprain. *Journal of Athletic Training*,48(2), 203–208.

Squara, P., Cecconi, M., Rhodes, A., Singer, M., & Chiche, J. D. (2009). Tracking changes in cardiac output: Methodological considerations for the validation of monitoring devices. *Intensive Care Medicine*, 35(10), 1801–1808.

Terada, M., Kosik, K. B., McCann, R. S., Drinkard, C., & Gribble, P. A. (2020). Corticospinal activity during a single-leg stance in people with chronic ankle instability. *Journal of Sport and Health Science*, 2020, 1-9.

Thais F. DE. P., L. A. B., Barbosa, D., & Rossi, L. P. (2021). Analysis of the electromyographic activity of the ankle muscles on unstable proprioception devices with and without the use of shoes: A cross-sectional study. *Journal of Bodywork and Movement Therapies,* 26, 30–35.

Vagaja, M., & Bizovska, L. (2019). The influence of saccadic eye movements on postural stability during standing on an unstable platform. *Acta Gymnica*, 49(3), 138–143.

van Rijn RM, Van Os AG, Bernsen RM, Luijsterburg PA, Koes BW, Bierma-Zeinstra SM. (2008). What is the clinical course of acute ankle sprains? A systematic literature review. *The American journal of medicine*. 121(4), 324-31.

Vigotsky, A. D., Halperin, I., Lehman, G. J., Trajano, G. S., & Vieira, T. M. (2018). Interpreting signal amplitudes in surface electromyography studies in sport and rehabilitation sciences. *Frontiers in Physiology*, 8(985), 1-15.

Wikstrom E. A., Tillman M. D., Chmielewski T. L., Cauraugh J. H., Naugle K. E., Borsa P. A. (2010). Dynamic postural control but not mechanical stability differs among those with and without chronic ankle instability. *Scandinavian Journal of Medicine & Science in Sports.* 20(1), 137-44.

Wolburg, T., Rapp, W., Rieger, J., & Horstmann, T. (2016). Muscle activity of leg muscles during unipedal stance on therapy devices with different stability properties. *Physical Therapy in Sport*, 17, 58–62.

Zaghlul, N., Goh, S. L., Razman, R., Danaee, M., & Chan, C. K. (2023). Test-retest reliability of the single leg stance on a Lafayette stability platform. *PLoS ONE,* 18(1 January), 1–12.

Zech A., Meining S., Hötting K., Liebl D., Mattes K., Hollander K. (2018). Effects of barefoot and footwear conditions on learning of a dynamic balance task: a randomized controlled study. *European Journal of Applied Physiology*, 118(2).