A Novel Method of presenting Kinematic gait analysis data to Healthcare Professionals –

The ‘TRAFFIC LIGHTS SYSTEM’

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Abstract

Background: In recent years, the use of instrumented gait analysis has become an important addition to the clinical management of musculoskeletal and neurological conditions. However, its use remains limited by the inability of most healthcare professionals to interpret complex data outputs generated during testing.

Aim: The aim of this study was to design and validate a visual method of displaying gait analysis results, one based on the Traffic Lights System (TLS).

Methodology: Following the design of this new approach, the TLS was compared to the Traditional Graphical System (TGS) currently employed for the presentation of results in order to ascertain its validity, inter-rater and intra-rater reliability. Gait analysis data outputs from simulated gait patterns were converted from the Traditional Graphical System to the Traffic Lights System. An online form was created and disseminated to healthcare professionals for the comparison of data interpretation of gait analysis results, as portrayed by both the Traditional Graphical System and the newly proposed Traffic Lights System. To obtain validity results, the TLS results were statistically compared to a gold standard response of the Traditional Graphical System obtained via consensus by two experienced gait analysts. Intra-rater reliability of the TGS was obtained by comparing results from 2 raters who had prior training in this system, who interpreted the results twice, over a period of 1 month, whilst that of the TLS was established from the results of 1 rater who also responded twice. Inter-rater reliability for both the TLS and the TGS was established by statistically analysing the results of all the raters.

Results: Utilising Cronbach's Alpha, validity results for the TLS were 0.92, even when the rater was untrained. Intra-rater reliability of both systems were high, although that of the TLS was higher (TGS 0.733 to 1.00; TLS 0.867 to 1.00). When comparing results obtained between the interpretation of data output in the TGS vs the TLS, it was noted that the TLS obtained a higher Fleiss Multirater Kappa coefficient**,** demonstrating the higher inter-rater reliability of this new, proposed approach, even though 64% of individuals had some prior training in the TGS and none of the respondents had prior training in the TLS. The majority of healthcare professionals preferred the Traffic lights System due to its ease of operation and interpretation, when compared to the graphical system.

Conclusion: This new proposed system, utilising an untrained rater, has been shown to be valid and has equivalent intra-rater reliability to the TGS utilising trained raters. The TLS also has higher inter-rater reliability than the TGS. Although further studies need to be carried out for the optimisation of this method of displaying visual data, the TRAFFIC LIGHT SYSTEM for reporting of gait analysis data is noted to have a strong potential to become the preferred system of choice by healthcare workers, for the benefit of the patient.

Keywords: Gait analysis, data visualisation, Biomechanical modelling, gait cycle, pathological gait

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This accomplishment would not have been possible without the constant support from my parents, Alfred and Nathalie, who were by my side every step of the way. Thank you for cheering me up when I needed a boost, and for inspiring me to always become a better version of myself.

Finally, I would like to thank my boyfriend, Zak, for his continuous encouragement and for helping me believe in myself more. I wouldn’t be where I am today without him.

Dedication

I would like to dedicate this dissertation to my beloved parents, Alfred and Nathalie, as well as my Boyfriend, Zak, for their love and support throughout.

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Chapter 1

Introduction

1.1 Background

Instrumented gait analysis is a highly specialized procedure in which various body segments are modelled and analyzed utilizing various means of motion capture systems, such as optoelectronic motion capture systems, in order to record and produce objective data relating to movement of these segments during gait. Instrumented gait analysis is a useful clinical tool in the assessment and treatment of gait dysfunction and is not an experimental methodology (Moon and Esquenazi, 2016). These systems are employed primarily in order to inform surgeons prior to surgical interventions, such as in instances of cerebral palsy (Chang et al. 2006), or to inform clinicians about appropriate treatment in other musculoskeletal or neurological conditions before a specific treatment plan is carried out (Wren et al. 2020).

Instrumented gait analysis can be used to accurately assess the efficiency of a gait rehabilitation program and may be an important tool for designing personalized training (Carlea et al. 2015). Indeed, 3D gait analysis systems have the potential to change treatment plans, increase clinicians' confidence in their treatment decisions and to increase agreement among clinicians (Wren et al. 2020).

Currently these analyses are carried out in specialized laboratories in hospitals and universities, given the high costs of implementation and the specialized nature of the required analyses that necessitates highly trained professional gait analysts, who can produce and analyze the large amount of data that is generated by these systems (Moon and Esquenazi, 2016).

Given the ever-decreasing costs in equipment, instrumented gait analysis has the potential to benefit a higher number of patients than are presently being attended to. However, the interpretation of this data presents a significant problem to clinicians such as physiotherapists, podiatrists, neurologists and physicians in general, who are generally untrained in such interpretations within their normal training programmes. These clinicians represent the highest proportion of health care providers who, ultimately, could still benefit from interpreting these gait analyses results in order to better manage and treat their patients complaining from neurological and/or neuromuscular conditions.

Data generated by instrumented gait analyses systems typically include various graphical outputs representing movement of the various body segments in the 3 body planes, i.e. 3 graphs for every joint of that part of the body, typically from the pelvis down to the foot, that is being analyzed. This may include kinematic data, i.e. analysis of motion, without including external or internal forces that are producing it (Moon and Esquenazi, 2016), or kinetic data, i.e. analysis that include the measurement of forces.

Figure 1.1 denotes some examples of data generated through a complete gait analysis. As may be seen, these are displayed in the form of graphs that are normalised to the gait cycle.

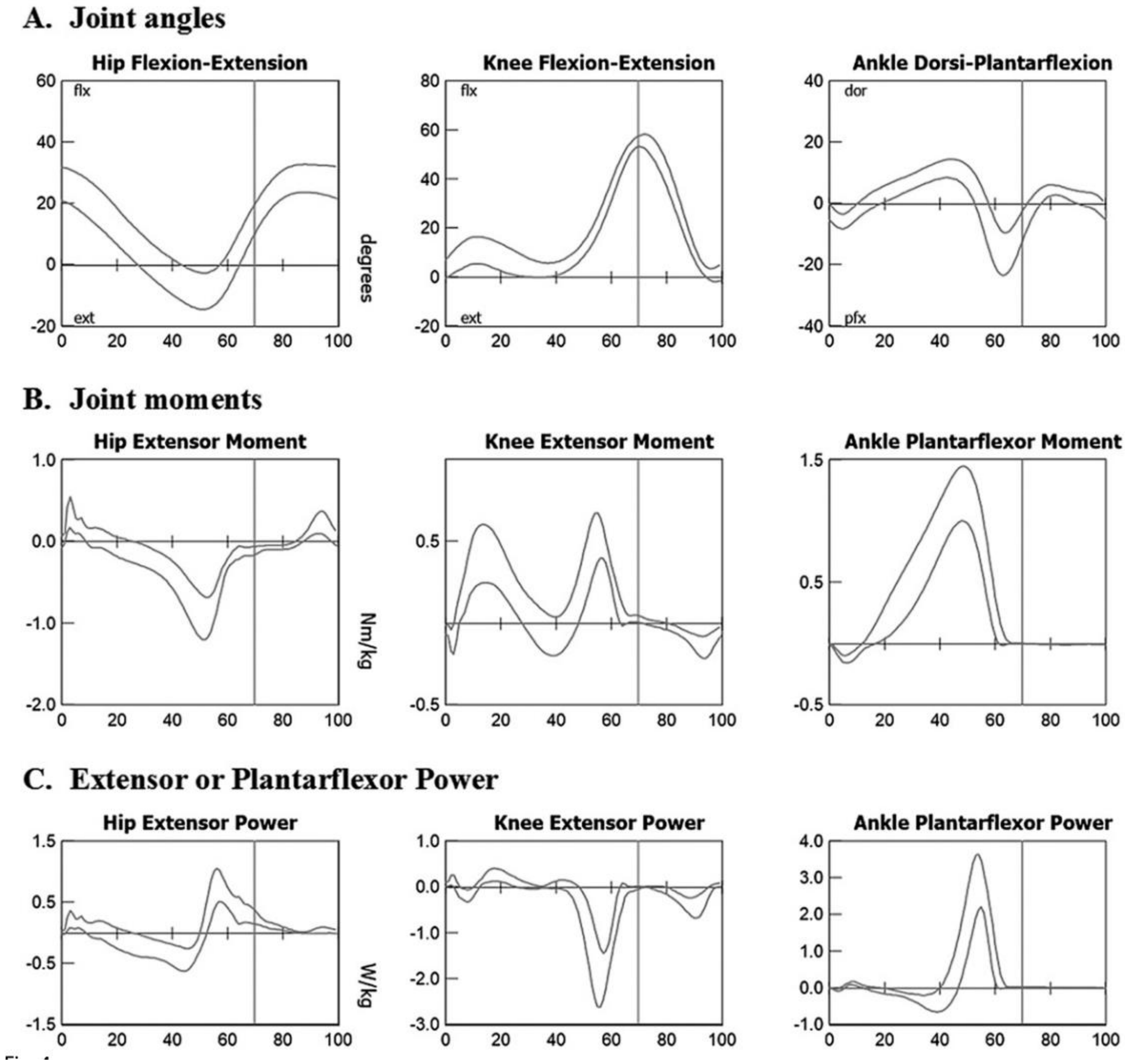


Figure 1.1 Typical analysis test results showing kinematics (A) and kinetics (B, C) (from Moon and Esquenazi, 2016)

In this figure, the hip, knee and ankle are only shown in the sagittal plane, i.e. flexion and extension. All body segments produce movement in 3 body planes, thus the outputs from these tests tend to be rather complex as there are 3 graphs per joint being displayed.

Although the importance of 3d gait analysis (3DGA) can be immediately apparent, this is not often used as much as it may be desired. Mukaino et al (2018) confirm that instrumented gait analysis are not commonly used in clinics because of lengthy evaluation and lack of understanding of the results, which are often presented using numerous graphs. These authors attempted to present a clinician-friendly 3DGA method developed to facilitate the clinical use of 3DGA. Their method consisted of simplified preparation and measurement processes that can be performed in a short time period in clinical settings and intuitive results presentation to facilitate clinicians' understanding of results (Mukaino et al. 2018).

Spinelli et al (2015) used angle-angle, coupling angle-movement cycle, and phase-plane graphs to provide information about the amount and timing of segmental motion, which can be used by clinicians to assess movements. This method, however, produces even more graphs which might make it quite difficult for the general health professional to understand and thus utilise in their clinical practice.

There is a surprising lack of evidence relating to the actual *interpretation* of gait analysis data. Whilst there are validity and reliability studies on gait analysis systems themselves (Laroche et al. 2010), the reliability of actual *interpretations* of the results, especially when relating to non-trained health professionals, are probably non-existent in literature, as this researcher could not find any such studies in literature at all. Only Mukaino et al (2018) and Itoh et al (2012) have pointed out that the main reason for this lack of utilisation of gait analysis may be due to the large number of graphs presented to the practitioner, thus limiting their use clinically.

1.2 Justification for the study

It is evident that this complex data generated by instrumented gait analysis systems may be hard to understand by non-engineers. The researcher, as a medically-trained physician, had absolutely **no** prior training in these systems, even though, with a high interest in paediatric orthopaedics, it is expected that future patients would include children with neurological conditions requiring gait analysis. Throughout his/her career, the medical physician, together with other health professionals, is expected to treat a large number of musculoskeletal conditions, yet is untrained to understand the results of these 3DGA systems. This is clearly a lacuna that needs to be addressed since gait patterns would clearly have a significant effect on several musculoskeletal lower limb conditions. Thus, as the physician is expected to understand the results of laboratory testing, 3DGA testing results are also important for this category of patients. The barrier that precludes this is clearly the complexity of the results presented by 3DGA systems (Mukaino et al. 2018; Itoh et al. 2012), that at present may be understood only by highly trained gait analysts.

For this study, it is being postulated that a system that is easier to understand by health professionals who are untrained in gait analysis can be formulated through the use of a more visual approach to represent the same data, without changing the nature of this data in the first place. This would enable the treating physician to instantly understand the location of abnormal movement, thus making the understanding of the underlying pathology easier to understand.

This complexity issue may be solved through the use of infographics. An infographic is a visual representation of information or data, such as a chart or diagram (Oxford dictionary, 2020). Infographics are illustrations containing information. Basically, infographics are purely visual, used to showcase facts and data and work to present complex information quickly and clearly. This data may be statistical, informational, geographical and hierarchical, amongst others (Smiciklas, 2012). Infographics are intended to present complex data in a visual manner in a way that this data can be understood more easily and can improve cognition by utilizing graphics to enhance the human visual system’s ability to see patterns and trends. Since infographics are designed for mass communication, they are designed with fewer assumptions about the readers' knowledge base than other types of visualizations (Zaman, 2019). Thus a key point is that viewers should be able to easily understand the information that is presented to them through an infographic.

The ability to produce a system whereby, without changing the nature of the data that is presented utilizing a more visual approach, would possibly allow the clinician without prior gait analysis training to better understand gait patterns and visualise, in a more comprehensible manner, the movement occurring at each joint, thus easily detecting in which joint there is any aberrant movement. This would enable these clinicians to understand their patients' movement strategies, thus effectively allowing them to provide treatment that is more targeted at their presenting complaint.

Additionally, with a greater client base, gait analysis laboratories could also consequently be able to provide more analyses for the benefit of the patient. Thus from such a system, beneficiaries would be:

- the patients themselves, as they would be getting a more targeted treatment
- the physicians and health care professionals, as they can understand patterns of any abnormal movement occurring in the joints, thus allowing them to target their treatment to specific joints
- the biomechanical laboratories, as their potential client base would consequently increase

Simplified methods could facilitate implementation of 3DGA in clinical settings and further encourage development of measurement strategies from the clinician's point of view (Mukaino et al. 2018).

1.3 Research Question

Does a new method of visual representation of lower limb kinematic gait analysis data provide a reliable and valid method of interpretation of biomechanical data for healthcare professionals?

1.4 Aim

The aim of this project was to produce and validate a more visual approach of presenting gait analysis results, which will be called ‘The TRAFFIC LIGHT system of Gait Data Representation’, than the Traditional Graphical System being presently utilised. This Traffic Lights System should be readily understood and interpreted by qualified health care professionals who are not trained in gait analysis.

1.5 Objectives

- To develop a method of presenting lower limb gait analysis data in a colourful and visual approach to make it easier to interpret by clinicians with little or no training in such interpretations.
- To convert a sample of gait analysis data into a more visual representative mode for presentation to participating clinicians.
- To compare results from the Traffic Lights System to the Traditional Graphical System, thus establishing how this new proposed system would compare to the Traditional Graphical System.
- To establish validity and inter-rater and intra-rater reliability of the Traffic Lights system for visual representation of kinematic lower limb data by healthcare professionals.

1.6 Hypotheses:

1.6.1 Alternative Hypothesis H1:

There are significant differences between the responses of the participants relating to the outputs of the new proposed Traffic Lights System when compared with the same outputs of the Traditional Graphical System of reporting gait analysis joint movement data.

1.6.2 Null Hypothesis H_0:

There are no significant differences between the responses of the participants relating to the outputs of the new proposed Traffic Lights System when compared with the same outputs of the Traditional Graphical System of reporting gait analysis joint movement data.

1.6.3 Alternative Hypothesis H_2:

There are significant differences in validity and inter-rater reliability of the new proposed Traffic Lights System of data visualization when compared with the Traditional Graphical System of reporting gait analysis joint movement data.

1.6.4 Null Hypothesis H_0:

There are no significant differences in validity and inter-rater reliability of the new proposed Traffic Lights System of data visualization when compared with the Traditional Graphical System of reporting gait analysis joint movement data.

1.7 Layout of this dissertation

Chapter 1: In the introduction chapter, the subject matter will be introduced, providing background information on instrumented gait analysis systems, the complexity of the nature of interpreting the graphical output, together with presentation of the Research Question, Aims and Objectives and Alternative and Null Hypotheses.

Chapter 2: This chapter will explore all the necessary background evidence relating to the subject matter; initially by formulating the correct search criteria and then to critically analyze all the information presented.

Chapter 3: The chapter on methodology will provide the methodological approached used to arrive at answering the research question. This will include the details on how the new system of reporting gait analysis data has been developed, the philosophical approach to the research methodology used, the study design adopted, recruitment of participants, the actual method of presenting the data and analysis of the data obtained.

Chapter 4: The results chapter will present the results of the various analyses, both from a statistical view and from a descriptive nature.

Chapter 5: This chapter will discuss the results in relation to any published articles, discuss the results comparing the validity of the Traffic Lights System and explore ways in which the system can be further improved.

Chapter 6: This chapter will discuss Implications for Clinical Practice together with Limitations of the study

Conclusion: The conclusions of the study will be presented in this final chapter.

Appendices: All support material will be included in the various appendices.

Chapter 2

Literature Review

2.1 Search Strategy

2.1.1 Electronic Search

Given the vast literature available on the subject at hand, a thorough electronic literature search was carried out on the topic being researched. This included the use of eLibrary provided by the University of Malta; Hydi, as well as PubMed, Science direct/Elsevier. Keywords used included, but were not limited to: Gait analysis, data visualisation, Biomechanical modelling, gait cycle, conventional gait models, Helen-Hayes model, motion capture, validity and reliability.

2.1.2 Journals

A number of biomechanically-related journals were also consulted. These included, amongst others:

Gait and Posture
Journal of Clinical Biomechanics
Journal of Biomechanics
Clinical Biomechanics
Journal of Applied Biomechanics
Journal of Electromyography & Kinesiology

This manual search involved the search of any possibly related articles by going through each issue of each journal, reading the abstract of any articles that appeared related to the topic under investigation and, if found appropriate, downloading and reading the full text article.

2.1.3 Non-electronic search

A number of books were also consulted and these included

- An introduction to Gait Analysis (Levine et al. 2012)
- GAIT ANALYSIS. Normal and Pathological Function (Perry & Burnfield, 2010)
- Research Methods in Biomechanics (Robertson G et al. 2014)

2.2 Gait Analysis

Wallmann (2009) defines Gait Analysis as “the functional evaluation of a person’s walking or running style”. This is achieved by the documentation of an individual’s gait with the objective of interpreting biomechanical parameters to aid decision-taking (Baker et al. 2016). It is an important tool that guides podiatrists, physiotherapists and even orthopaedic surgeons, to recognize and hence, propose a solution to a patient’s pathology. The objective of gait is to reach a desired distance as efficiently as possible, whilst adapting to several obstacles that one might come across along the way. This provides independence in activities of daily living and allows the individual to partake in physical activity ensuring a better quality of life (Wallmann, 2009).

2.2.1 Gait Cycle

Before delving into the different types of gait analysis, it is important that one understands the fundamentals of gait. Although taken for granted by many, walking entails an elaborate synergy between multiple muscle groups in the upper and lower body. It makes use of a person’s momentum so as to allow for better energy utilisation (Moore et al. 2017). This in turn, means that there are more components that could be injured, resulting in a pathological gait; i.e. a walking style that could lead to musculoskeletal problems. The only way to be able to locate the troublesome muscle group/joint, is to visualise the subject’s walking pattern. This can be explained by using three main approaches; the reciprocal floor contact pattern, the timing and distance of cycle, and functionality of gait phases (Perry, 1992).

The Reciprocal Floor Contact Pattern is the simplest method to explain the gait cycle effectively. It is based on the concept that, as one limb supports the weight of the individual, the other limb progresses in a forward motion to eventually become the supporting limb. Both limbs work in a reciprocal manner to alternate their roles until the individual has reached the desired target. A single series of events of one leg, i.e from supporting to advancing forward in the air until it reaches supporting phase again, is known as the *gait cycle*.

The gait cycle, also referred to as “Stride”, is divided into two main stages; the stance phase and the swing phase. The stance phase represents the length of time when the foot is in contact with the ground. Most people start their gait by placing their heel on the floor. This is then followed by the midfoot and eventually, the forefoot, ending up as the only part of the foot still in contact with the ground. The stance phase is further subdivided into three intervals, as depicted in figure 2.1.

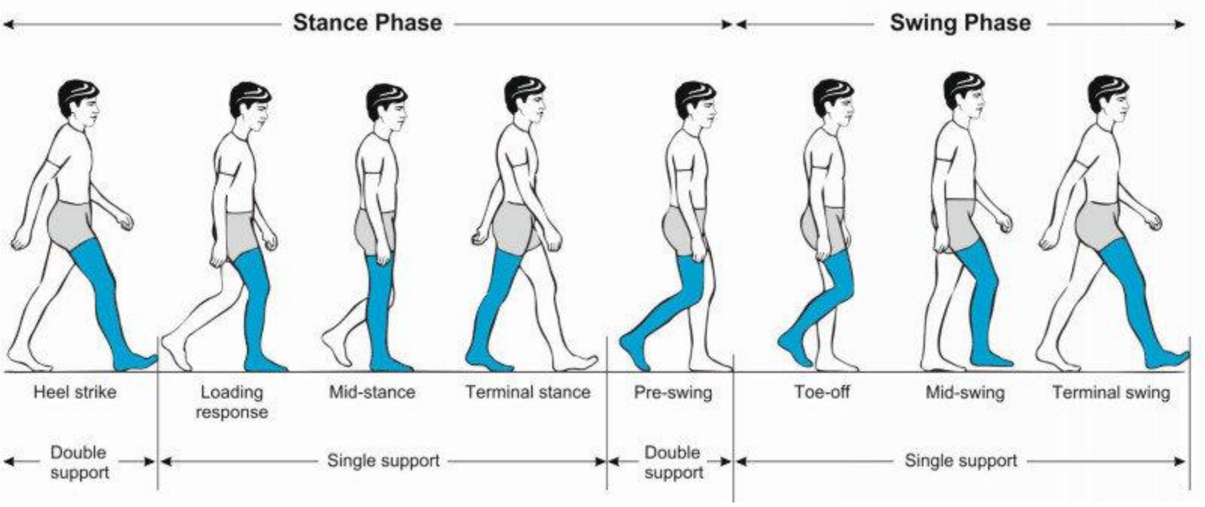


Figure 2.1 The Gait Cycle (from Katzenschlager and Pirker, 2016)

Initial double stance starts off the gait cycle. It occurs when both feet are on the ground, still at initial contact. So if the heel of the left leg is noted to be on the floor, the forefoot of the right leg is still touching and has not yet started its swing phase. This is the only period where the stance phase of one leg corresponds to the stance phase of the opposite leg (Wallmann, 2009). The ipsilateral leg will then advance to *single leg support*, where only one foot is grounded and supporting the individual, whilst the other has started swinging in the air. This is also referred to as the **full foot loading.** The duration of this phase depends on that limb's capacity to support the bodyweight. The final interval of the stance phase is the *terminal double stance,* where both feet are again on the floor. This starts with contralateral initial contact and ipsilateral toe-off, which corresponds to the commencement of the swing phase (Perry, 1992).

As the name implies, swing phase occurs when the other foot (contralateral to that in the stance phase), leaves the ground and ends when the heel strikes the floor. The initial segment is known as ‘toe-off’ where the forefoot pushes against the ground to initiate swinging. This is known as the “non weight bearing phase” and it is also subdivided into three phases (Pal Singh, n.d).

The first part of the swing phase is known as *Acceleration* and it occurs immediately after the termination of the stance phase. As previously mentioned, this would correspond to an ipsilateral toe off. As the forefoot leaves the floor, the foot immediately dorsiflexes and gains momentum as it approaches the contralateral leg, meaning that the leg that was behind the body, has now started to move towards the centre. At this point, both the knees and the hips are starting to flex, so as to reach the *midswing phase.* During this next part of the swing phase, one can observe a shortening of the leg, so that it doesn’t hit the floor as it is shifted forwards. The foot is no longer held in dorsiflexion, but rather in a neutral position, but the knee is completely flexed. This is in contrast to the final part of this phase, known as *deceleration*, where the knee fully extends so as to prepare for heel strike, and hence, commencement of the stance phase once again (Pal Singh, n.d).

As stated previously, the second approach to explain the gait cycle is that of timing of each phase in the gait. It is said that the stance phase occupies 60% of the gait cycle, with the remaining 40% occurring in the swing phase. The percentage for the stance phase is further subdivided into 10% for each double stance and 40% for the single leg support. Here, one can note that the duration of the single leg support of one leg is identical to the swing phase of the other as they are occurring simultaneously.

It is important to note that timing of the gait cycle is dependent on the individual’s walking velocity, and percentages will adapt accordingly. For instance, if a person walks slower than usual, the extent of time spent on one leg i.e. the single leg support, will decrease and double stance intervals will increase, and opposingly for fast paced gaits. *Cadence*, the total number of steps in a period time, has been shown to affect stride, with stride length decreasing with very high cadences (Egerton et al. 2011).

Cadence is usually calculated as steps per minute and not seconds as dictated by the international standards of measurement. Given that each gait cycle is made up of two steps, as previously explained, cadence is said to be a “measure of half-cycles” (Levine et al. 2012). Gender is noted to affect cadence, with a faster step rate noted in women (117 steps per minute), when compared to 113 steps per minute in men. Having said that, this is a compensatory mechanism to women’s shorter stride length i.e the distance between consecutive initial contact of the same foot (Perry, 1992).

Once stride length and cadence are known, one can determine the individual’s *walking velocity or speed*. This is calculated in metres per minute, and refers to the distance covered by the patient during a given time. This time, the whole body is affected and it does not apply only for the lower limbs.

Other important terms regularly described in gait analysis include *joint moments* and *joint powers*. Joint moments essentially refer to the structures in the vicinity of the joint under examination that are becoming taut. Here, the extent of tension can also be quantified. On the other hand, joint powers distinguish between shortening and lengthening of muscles, also referred to as concentric vs eccentric muscle contracture, as well as the “passive tension in soft tissues” (Levine et al. 2012). Electromyography contributes to these by identifying which muscles are demonstrating electrical impulses and hence, developing tension. Finally, *joint angles* are required to provide information on the direction of movement of the examined joint.

2.2.2 Criteria for Gait Analysis

Clinical Gait Analysis is a very feasible option for the interpretation of musculoskeletal, neurological and pathological gaits. However, as with any other investigation, certain criteria for eligibility need to be met. Most of these relate to the ability of the subject to cooperate fully with the equipment required.

The duration of the assessment usually depends on the physical constraints of the individual. Analysis will clearly take longer if orthotics or walking aids also need to be tested. Fundamentally, the participant must be capable of understanding and performing the cues instructed. They must be ambulatory and most importantly, must be cooperative with arrangement of the markers and electrodes (Feng et al. 2016). Although there is no specified age minimum, it is noted that it is usually difficult to obtain results in children under the age of five, in view of lack of cooperation to the investigations (Levine et al. 2012).

In 1981, Brand and Crowninshield issued a number of criteria for the appropriate selection of biomechanical measuring tools. This has since been updated by Brand himself in 1987. Amongst these criteria, Brand raises the importance of reliability and validity of any biomechanical measure for the sake of stability, reproducibility and efficiency. Another noteworthy criterion mentioned is the ability for the selected test to provide additional data that is not apparent to the clinician. This will effectively aid in the diagnosis of a condition, rather than waste the patient’s time with investigations that will only confirm what is already known. This should be done without the assessment tool interfering with the patient’s functionality, and results should not be altered by the individual’s mood or pain at the time of investigation. Moreover, Brand stresses that any adequate investigation should primarily discern the pathological from the ordinary, in a cost-effective manner so as to make sure it is a feasible option for all. Lastly, the final criterion published deals with the reporting of results in a manner that is comparable to previously available notions, without the need to propose new ones (Brand & Crowninshield, 1981; Brand, 1987; Baker, 2006).

2.2.3 Types of Gait Analysis

Gait Analysis can be broadly divided into two types: Observational and Instrumental. The purpose of both these approaches is to be able to properly assess patients with pathological gaits, and treat them as necessary.

2.2.3.1 Observational gait analysis

Observational gait analysis (OGA) is a process by which clinicians are able to identify anomalies in the gait cycle by visualising the patient's gait (McGingley et al. 2009). It is surely the most readily available between the two, but requires a trained eye to accurately assess for deviations from the normal gait. In observational gait analysis, the researcher will watch the individual walk several times up and down a walkway between eight and twelve metres long, from the sides, the back and the front (Chow et al. 2006). This will ensure optimal direction of observation for the most common gait abnormalities, such as abnormal foot rotation, rhythmic disturbances and abnormal walking base, amongst others. The type of data yielded by observational gait analysis is *qualitative*, since descriptive terms are used, in contrast to numerical values.

OGA is obviously, not without its limitations. Whittle (2012) explains that observational gait analysis is subjective to the observer's capacity to recognise aberrations from normal gaits, owing to the high-speed at which events are occurring. Although the human eye is able to perceive variations and anomalies in the individual's movement, it is unable to accurately determine compensatory mechanisms (Baker et al. 2016). During visualisation, the researcher is only able to comment on the movements being carried out by the individual, and can not comment on the forces being applied hence, excluding kinetic data from data collection. Finally, no permanent record can be provided since no video recordings are used.

On the other hand, Observational gait analysis is easy, quick and straightforward to use. It is the most convenient method between the two, especially when it comes to time utilisation (Levine et al. 2012).

2.2.3.2 Instrumental gait analysis

As the name implies, in instrumental gait analysis, the researcher has at his or her disposal, instruments and equipment that facilitate data collection. In contrast to observational gait analysis, the use of instruments allows for the collection and evaluation of *quantitative* and objective data. There are several forms of equipment that can be used, and the aim of the instruments is to capture movement and forces in order to assess the kinetics and kinematics of the individual's gait patterns (Levine et al. 2012)

Components of Instrumental Gait Analysis

Gait Video

The first step in instrumented gait analysis, is to record the individual's gait. This gives the researcher a first impression of the possible pathologies and enables them to replay the recording as many times as needed. Advancing technologies have also contributed greatly, with the help of slow motion and ability to zoom in and closely locate anomalies. The use of video also offers a permanent record for future studies. In video gait analysis, the individual's walks are captured on video in order to enable the practitioner to visualise and then analyse the patient's walking pattern as many times as necessary without tiring the patient.

Clinical Examination

Although instrumental gait analysis relied on the use of equipment and labs, one must not overlook the important information that can be noted with musculoskeletal examinations. Here, one can appreciate power, tone, range of motion and asymmetry, all within a few minutes and with minimal intervention. Thus, it is normal practice for a detailed clinical examination to be performed prior to any instrumented or video gait analysis. This is important because the results of the analysis can then be put in context with the results of the clinical examination.

Kinematics

An important type of data that is obtained by instrumental gait analysis is Kinematic data. It refers to the assessment of movement by the calculation of joint angles of the distal segment in relation to the proximal one (Baker et al. 2017). It does this irrespective of the forces that are causing it. Kinematic data is generated with the use of retro-reflective skin markers and biomechanical models to obtain three-dimensional values (Feng et al. 2016). Kinematic data is able to provide information regarding aberrant movements but is not able to identify the involved muscles (Levine et al. 2012).

Kinematic output includes spatiotemporal gait parameters which have previously been mentioned, including step length and stride.

In a typical motion capture lab, some method of capturing movement is usually employed. The most common systems include optoelectronic systems, which are specially-designed cameras with infra-red emitters and fitted with filters that block off the visible light spectrum. Many of these cameras have onboard image processing electronics, hence the term ‘opto-electronic’ (optical/electronic). The infrared light is reflected off retro-reflective markers that are placed on anatomical landmarks or aligned with joint axes. Since light waves in the visible spectrum are filtered, only the infra-red reflections of the markers will be visible in the camera. Multiple cameras are normally used, as the process of triangulation requires the same marker to be visible to two cameras. Additionally, movement will sometimes block the view of a marker from a certain camera, such as that caused by the swinging arms during walking. Thus having as many cameras as possible would ensure that all markers are seen by at least two cameras at all times during the gait cycle, thus minimizing the possibility of gaps in the data. Although these gaps can be later filled using spline functions in the software, ideally real data should be preferred to gap-filled data. It is not unusual for some motion laboratories to have a large number of cameras; indeed the Biomechanics Laboratory at the Faculty of Health Sciences is equipped with sixteen such cameras to ensure that the captured data is as clean as possible (Baker, 2006; Feng et al. 2016; Molina-Rueda et al. 2021).

Thus kinematics allow the clinicians to quantify movement occurring at each joint using repeatable methods. Each joint produces movement in the 3 body planes, which need to be described individually.

Flexion

- This refers to movement occurring in the sagittal plane. Two segments close towards each other with the angle between the two becoming smaller. This can be noted when the leg is swung forward, resulting in a smaller angle between the pelvis and the femur, or when the knee is bent with the femur becoming closer to the tibia as seen in figures 2.2 and 2.3. (Levine et al. 2012).

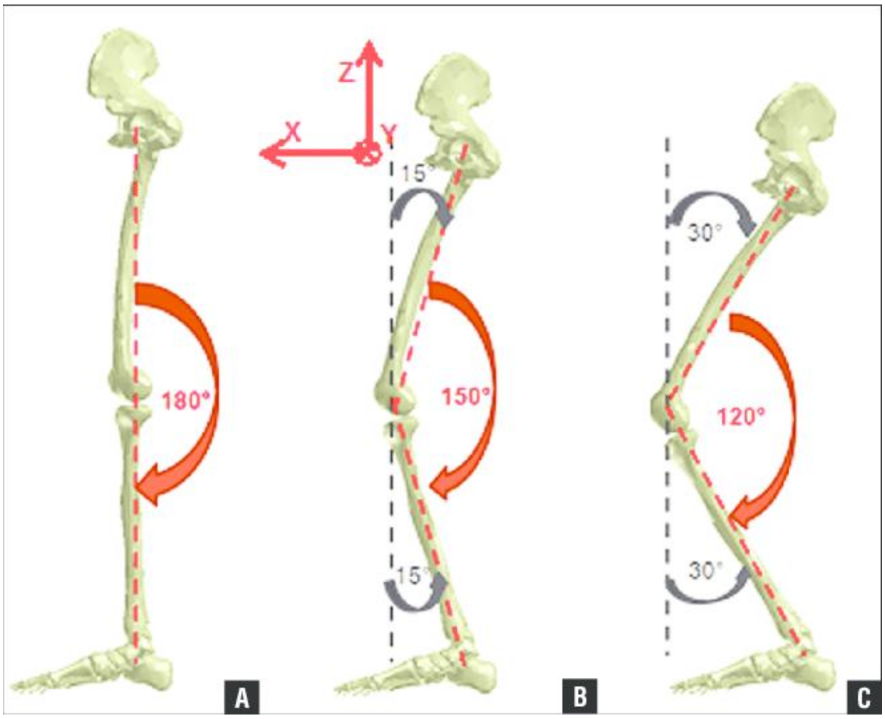


Figure 2.2 showing knee flexion (from Hinckel et al. 2016)

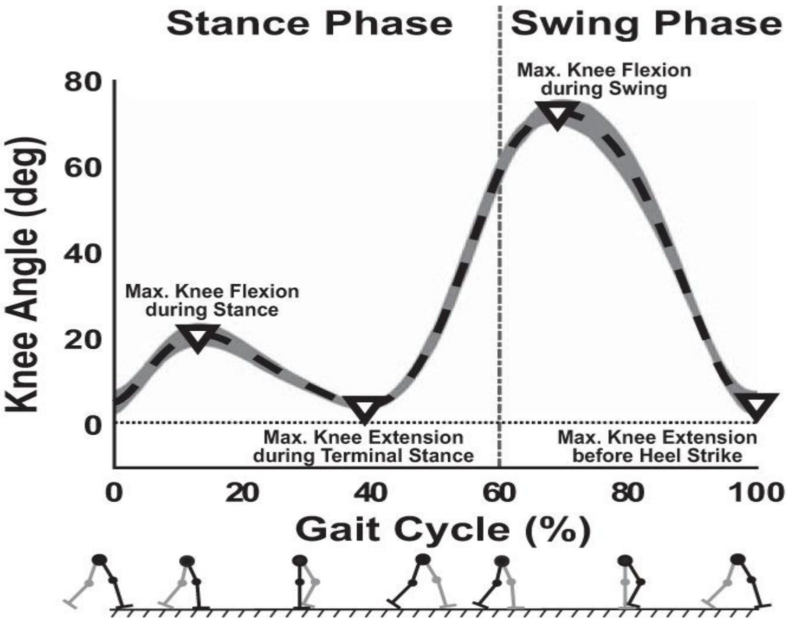


Figure 2.3 Knee flexion during the gait cycle (from Ochoa, Sternad, Hogan (2017)

Extension

- On the other hand, the angle between the two segments in extension becomes larger as one body part is directed away from the other. In keeping with the above example, the femur and tibia are pushed away from each other when the knee is straightened (Figure 2.4), (Levine et al. 2012).

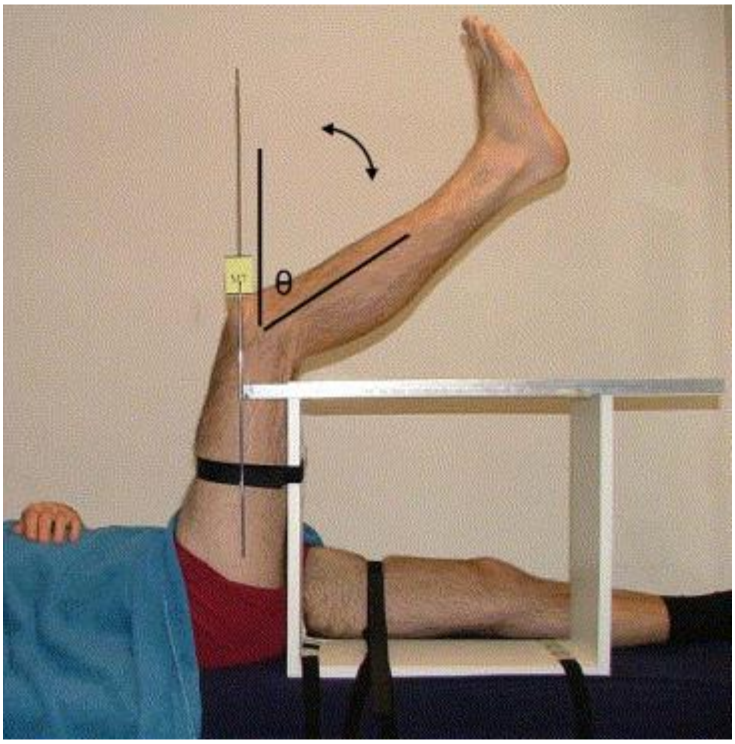


Figure 2.4 Knee extension test (from Kuilart et al. 2007)

Abduction

- Abduction indicates movement of a body segment away from the centre of the body. This would include shoulder abduction with the arm being raised away from the torso, or the leg being elevated laterally as in figure 2.5. However, when referring to abduction of the fingers or the toes, movement is correlated to the middle of the pertaining segments, so abduction of the toes would be with respect to the foot (Levine et al. 2012).

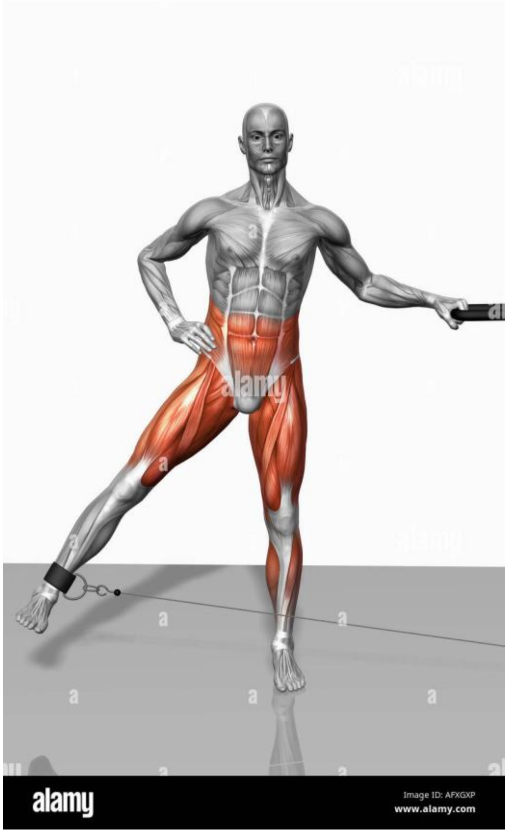


Figure 2.5: Abduction of the leg (www.alamy.com)

Adduction

- Contrary to the above, adduction refers to the movement of the affected segment towards the body and in shoulder adduction, this would be observed as the arm is brought down towards the torso. As in abduction, adduction of the fingers and the toes is also taken with regards to the hand and foot, respectively (Levine et al. 2012)

Inversion and Eversion

- Inversion and eversion are movements that are exclusive to the ankle joint, and it refers to the act of rotating the foot along its axis. In inversion, the sole is noted to be turned to face medially, whilst in eversion the sole is rotated to face laterally.

Dorsiflexion and plantarflexion

- Another two terms which are most frequently used to describe motions of the ankle include dorsiflexion and plantarflexion. In the former, the angle between the distal tibia and talus, i.e ankle joint, is decreased as the dorsal aspect of the foot is brought towards the tibia. On the contrary, the latter movement refers to the extension of the ankle joint as the dorsum of the foot is moved away from the tibia.

The movements of the ankle are clearly depicted in figure 2.6 below.

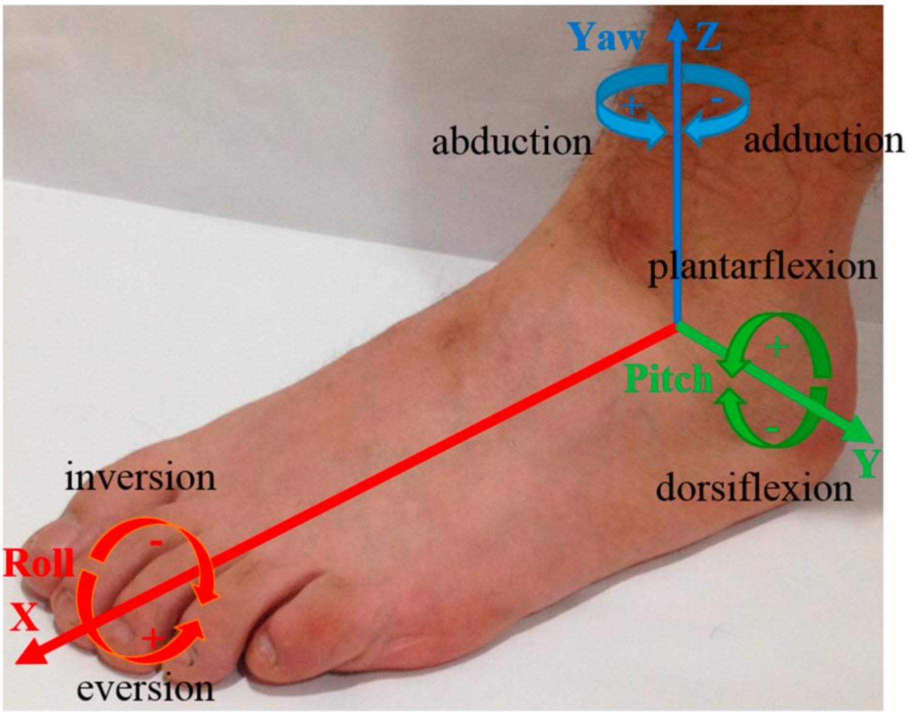


Figure 2.6: axes of rotation of the foot, denoting abduction/adduction, inversion/eversion and dorsiflexion/plantarflexion (Gómez-Espinosa, Espinosa-Castillo & Valdés-Aguirre, 2018)

There are four main segments in lower extremities of note when discussing gait analysis: The pelvis, Hips, Knees and Ankles. Each of these have a specialised set of movements which need to be properly explained prior to understanding any results obtained by gait analysis.

Pelvis

The pelvis is formed by the sacrum posteriorly and the fusion of the ilium, ischium and pubis that together form the innominate bone on either side. The pelvis in itself is a rigid structure and not much movement is noted, apart from a small degree at the sacroiliac joints. Movements of the pelvis are noted to occur in three main cardinal axes (Cappozzo et al. 2005).

Anterior and posterior pelvic tilt, occur along the sagittal plane along the mediolateral axis. These are noticeable in mid-stance and double stance, respectively. In anterior tilt, the Anterior superior iliac spine (ASIS) are noted to move anteriorly and down, on both sides whilst the posterior superior iliac spines (PSIS) bilatelly move up. The reverse occurs in posterior tilt with the ASIS moving posteriorly and up, and PSIS directed down bilaterally (Levangie and Norkin, 2011). A neutral pelvis is one where the ASIS and PSIS are noted to be on the same plane when an imaginary line is drawn between the two, and palpation of each can give an indication of pathologies prior to gait analysis (Lewis et al. 2017).

During gait analysis, the presence or absence of pelvic obliquity is also recorded. This refers to the lateral displacement of the pelvis, along the frontal plane occurring in the anteroposterior axis. In this case, the Iliac crest on one side is noted to be higher than on the other side (Lewis et al., 2017). There are several causes of pelvic obliquity which can be broadly characterised as suprapelvic, infrapelvic and intrapelvic, and some of the causes include the presence of leg length discrepancy, cerebral palsy, as well as contractures of the muscles and tendons located below the pelvis. Pelvic Obliquity can be either left or right, depending on which side of the misaligned pelvis is noted to be higher (Zhang et al. 2015), (Yen et al. 2021). It is most often detected in the single support stage of the gait cycle, with the motion being described in accordance with that of the contralateral hip (Neumann, 2010a). For instance, left pelvic obliquity refers to the drop of the left iliac crest, as the subject under investigation weight-bears on the right leg. On the other hand, if a patient is standing on the right leg and the left hip is noted to be higher, this is referred to as pelvic hike, or list (Lewis et al. 2017). These movements are mainly under the control of hip abductor muscles and weakness in this will cause pathologies and observable clinical signs such as Trendelenburg Sign (Neumann, 2010b).

The final movements observed during biomechanical testing of the pelvis concern the degree of pelvic rotation, with this being indicated by the anterior superior iliac spine of one side being more forward than that of the other side. This motion mainly occurs along the vertical axis in the horizontal plane (Lewis et al. 2017). Pelvic rotation can be either forward or backwards, but nomenclature differs between researchers, with them also being referred to as external or internal rotation, respectively. Naming is once again established with respect to the movement of the opposite pelvis, with forward rotation of the left pelvis being observed when the left ASIS moves forward (clockwise), when compared to the right. Conversely is noted for backward rotation, with the left ASIS this time being moved posteriorly i.e. anti-clockwise (Figure 2.7) (Neumann, 2010a), (Lewis et al. 2017).

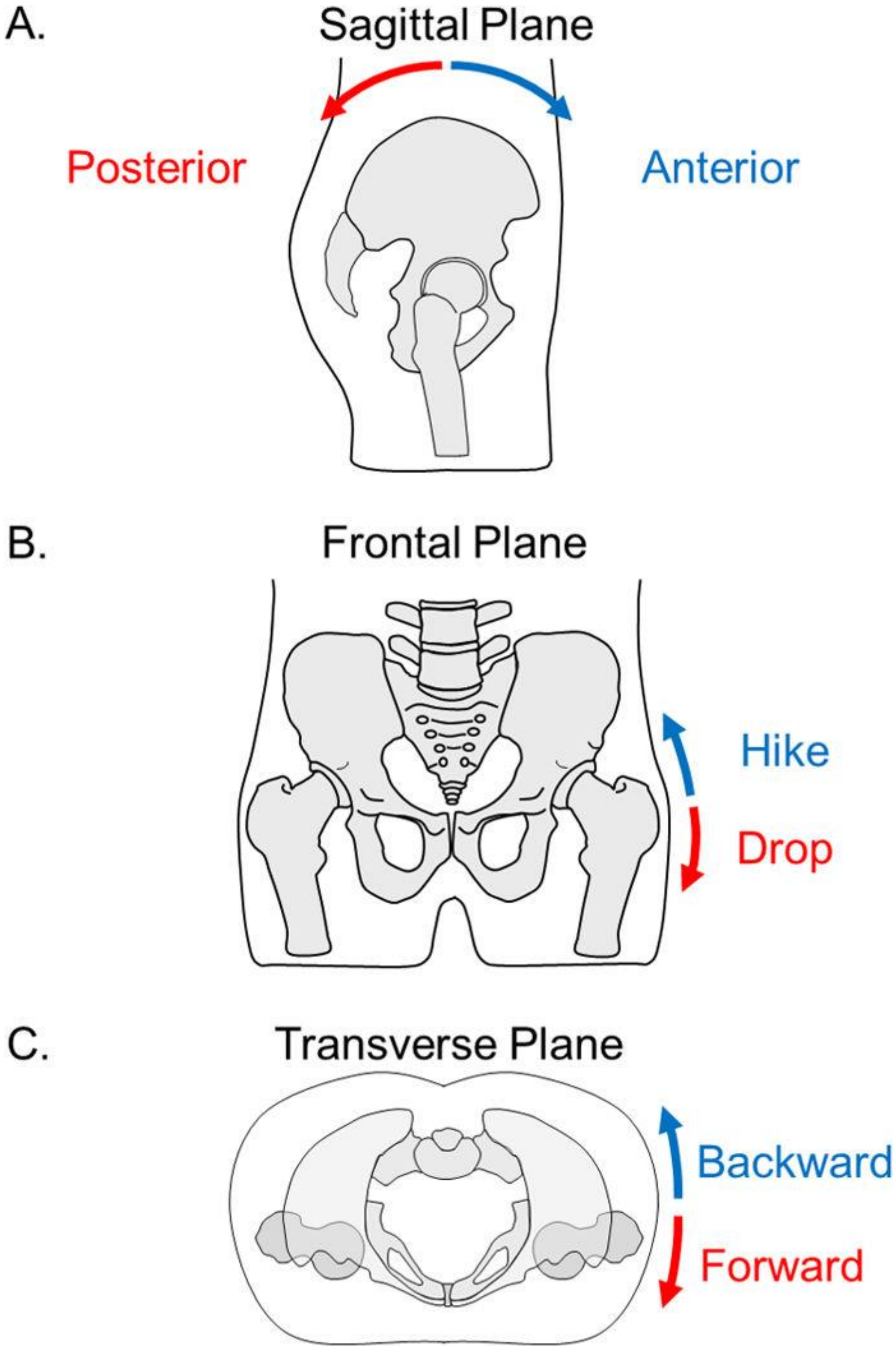


Figure 2.7: describing the movements of the pelvis. A. Anterior or Posterior pelvic tilt. B. Pelvic Obliquity, also referred to as Pelvic drop or pelvic hike. C. Forward (external) and Backward (internal) rotation of the pelvis (Lewis et al. 2017).

Hips

The Hip joint is a typical example of a ball-and-socket joint, noted to be as such in view of the articulation between the head of the femur and the pelvic acetabulum (Speirs et al. 2012). This feature allows for movement in multiple axes. Motions noted at the hip joint include Hip flexion and extension along the sagittal plane, Hip abduction and adduction along the frontal plane and internal and external rotation along the transverse plane (Moore et al. 2017). When referring to the latter, rotation can be described as being clockwise or anti-clockwise, as though observed from a superior perspective (Lewis et al.,2017). Therefore, internal rotation would show the head of the femur to turn counter-clockwise, whilst the opposite is true for external rotation. Hip flexion and extension are especially important during gait and can be individually identified upon careful observation (Speirs et al. 2012).

Flexion of the hip is noted to commence at the terminal double stance stage of the gait cycle, and progressively increases as the swing phase progresses. Maximal flexion is reached at mid-swing, with angle being around 30 degrees. On the other hand, hip extension starts around the time of loading response and is noted to peak at contralateral initial contact (Moore et al. 2017; Levine et al. 2012).

As previously stated, the hip abductors are important muscles that are especially important during the single support stage to prevent pelvic obliquity. The hip is allowed to drop slightly towards the side of the swinging limb; however, activation of the gluteus medius and tensor fascia lata, primarily, prevent extreme pelvic dips for a smoother, more efficient gait (Levine et al. 2012).

Knees

Contrary to the hip joint, the knee is a hinge joint and hence, allows for minimal lateral movements. It is a relatively weak joint and is subject to several sports injuries, especially with footballers and physical activities requiring fast changes in direction. Its stability depends greatly on surrounding musculature and tendons, mainly the inferior fibres of quadriceps muscle and strengthening of these muscles can prevent a great deal of pain. The most prominent movements noted at the knees include flexion and extension. There are 3 main articulations that can be observed at this joint, two femorotibial articulations, one medial and one lateral, as well as articulation present between the femur and the patella (Moore et al. 2017).

During initial contact, the knee is noted to be in extension with maximal extension achieved at heel rise. Flexion of the knee commences at pre-swing and maximal angle of 60-70 degrees is noted during mid-stance (Levine et al. 2012).

Ankles

Similarly to the knee joint, the ankles are another type of hinge joint with main movements occurring along the sagittal plane (Moore et al. 2017). There are three main articulations which are crucial for motions required in the foot during gait. The subtalar joint is formed by the talus and the anterior aspect of the calcaneus. This joint is mainly supported by the interosseous talocalcaneal ligament, and also by two weaker lateral and anterior talocalcaneal ligaments. The tendons of the flexors and peroneal muscles also contribute to stabilisation of the subtalar joint. Foot inversion and eversion are the main movements identified at this joint (Brockett and Chapman, 2016)

.

The tibiotalar joint is more proximal than the previously mentioned joint, and it is formed by the distal tibia and fibula, which articulate with superior aspect of the talus. The connection between the tibia and the talus is what provides the load bearing aspect of the tibiotalar joint, and the lateral and medial malleoli act to stabilise the talus, resulting in a hinge movement. Here, the main movements are dorsiflexion and plantarflexion of the ankle (Brockett and Chapman, 2016). Having a wider shape at the anterior aspect of the talus, results in the joint being most stable in dorsiflexion, leaving it susceptible to injury when plantarflexed, as the tapered end of the trochlea now sits unstable between the malleoli (Moore et al. 2017), (Brockett and Chapman, 2016). The tibiotalar ligament is highly stabilised by the tibiofibular syndesmosis, which comprises the anterior and posterior tibiofibular ligament, as well as the interosseous tibiofibular ligament. The medial and lateral collateral ligaments prevent excessive valgus and varus stresses, respectively (Brockett and Chapman, 2016).

Finally, the transverse tarsal joint is made up of the articulation between the anterior talus and posterior navicular bone, together with the calcaneocuboid joint. Motions in this joint are of the same axis as the subtalar joint and aid in dorsiflexion and plantarflexion, whilst also allowing for inversion and eversion of the foot as in figure 2.8. (Brockett and Chapman, 2016).

The ankle is also able to perform minimal degree of abduction and adduction, mainly occurring at the subtalar joint. Given the calcaneal articulation surface with the talus above, adduction is usually accompanied by inversion and abduction by eversion (Mansfield et al. 2014).

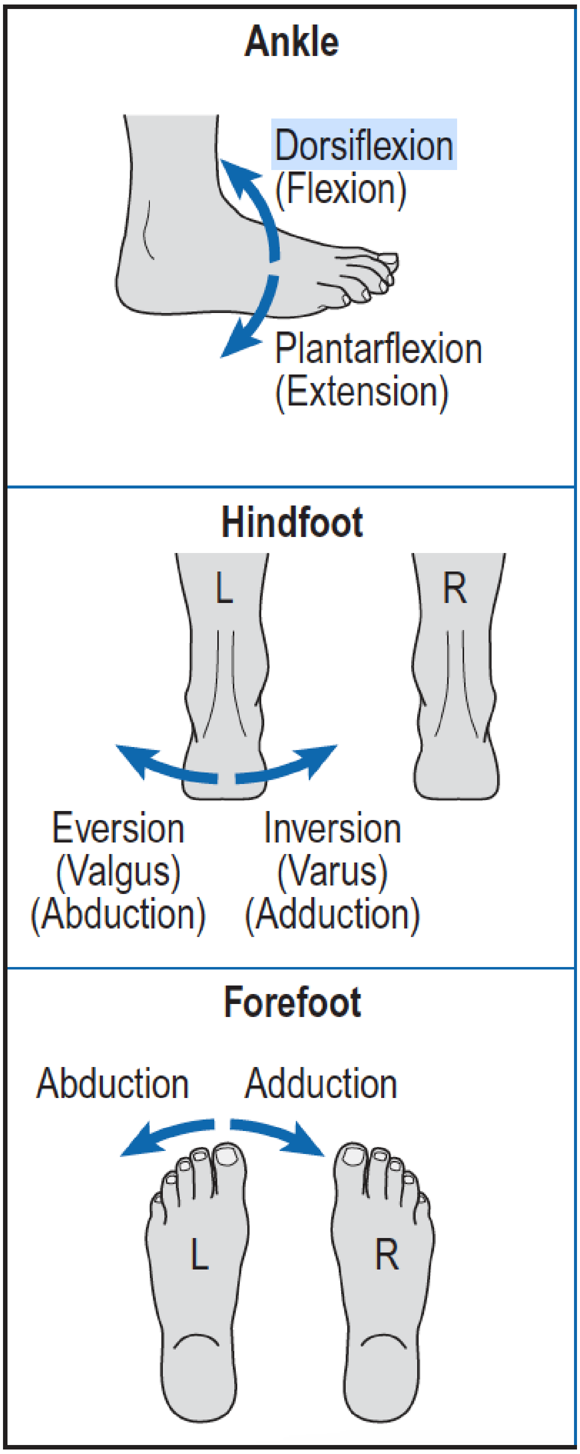


Figure 2.8: Movements of the ankle (Levine et al. 2012)

Kinetics

The second important data gathered with this type of analysis is kinetic data. "*It is the study of forces, moments, masses and accelerations, but without any detailed knowledge of the position* *or orientation of the objects involved*” (Levine et al. 2012). Kinematic data is added to ground reaction forces generated during the gait cycle with the use of force platforms. Kinetic outputs include joint powers and joint moments. (Feng, J et al. 2016). This will give an indication of the force being exerted by muscles and soft tissues for successful movement at the joints. The integration of optoelectronic systems and force plates to give kinematic and kinetic output will ultimately provide a complete and thorough evaluation of the participant’s physiological dynamics and both are hence, required for a definite assessment (Baker et al. 2016).

EMG

Electromyography refers to the evaluation of electrical activity of skeletal muscles. Muscle fibres contract and relax through a sequence of events known as the “excitation-contraction-relaxation cycle” i.e the Muscle action potential. An influx of sodium ions and subsequent efflux of potassium ions causes a variation in the charge of the membrane from a negative to a positive one and vice-versa, which is ultimately picked up with the use of surface or fine-wire electrodes. Surface EMG is preferred for gait analysis in view of the dynamic aspect of the investigation. This can provide useful information on the timing and intensity of muscular contraction for possible surgical purposes (Brand, 1987). Needle- or static-EMG on the other hand, is more appropriate for the diagnosis of neurological conditions such as Myasthenia gravis and Guillain-Barre Syndrome. Electromyography is an integral part of instrumental gait analysis as it provides joint movement and joint powers, which can be especially useful in hemiparetic patients (Levine et al. 2012).

Foot Pressure data

Pressures generated by the foot when walking can be measured by using pressure mats or pressure sensors, such as pressure insoles inserted in the individual’s shoes. Force dissemination over the plantar aspect of the foot is calculated to create a pattern of weight distribution and loading during gait (Feng et al. 2016). This will help researchers and therapists determine biomechanical issues more thoroughly. An example of this is the difference in pressures and centres of gravity in patients with normal gaits vs pes planus. The weakening of the medial longitudinal arch in patients with flat feet is such that the weight of the individual is shifted medially towards the second and third metatarsals. This causes an increase in the contact area of the medial foot during stance phase when compared to individuals with normal foot placement (Kim, 2015).

Energy Consumption

The final component of instrumental gait analysis is the measurement of energy consumption, together with heart rate and production of carbon dioxide. One can anticipate the relationship between energy consumption and efficiency of walking by personal experience. It is noted that as energy consumption is increased, walking efficiency will decrease at an inverse relationship (Feng et al. 2016)

Biomechanical Models

The most commonly used biomechanical model is known as the Conventional gait model. This delineates a group of models which all employ similar criteria and assumptions, to yield similar results and conclusions. All models rely on retro-reflective skin markers that are placed on standardised bony landmarks , which will be detected by optical systems to create a three dimensional depiction of the subject's gait. This is possible as long as the marker is "picked up" by two or more cameras. (Baker, 2006; Feng et al. 2016). The Conventional gait model was initially proposed in the 1970s, when the above mentioned skin markings were computerised from two dimensional stills, to represent anatomical loci, such as the anterior superior iliac spine and malleoli. This then brought forward the possibility to evaluate and calculate joint angles, even more so when euler angles were integrated to propose a true 3-D orientation (Shoemaker, 1978; Chao, 1980; Baker, 2017).

Many modifications to the initial model have been made along the years, two of the most noteworthy alterations were those done at the Newington Hospital, Connecticut by Gage in 1991 and at the Helen Hayes Hospital by Kadaba, 1990. The former model went on to be circulated to several American Hospitals, and together with the model developed at Newington Hospital, a new version was created by Oxford Metrics, nowadays known as Vicon. This was sold as a software and hardware bundle known as the Vicon Clinical manager and the Plug-in Gait (PiG) Model was later established, and these can be seen in figures 2.9 and 2.10 below (Baker, 2017).

Conventional gait models mainly take into consideration the lower limbs, dividing them into seven divisions; The left foot, left tibia, left femur, pelvis, right femur, right tibia and the right foot. The knees and the hips are shaped as hinge joints with two degrees of freedom and as ball-and-socket joints with three degrees of freedom, respectively (Feng et al. 2016).

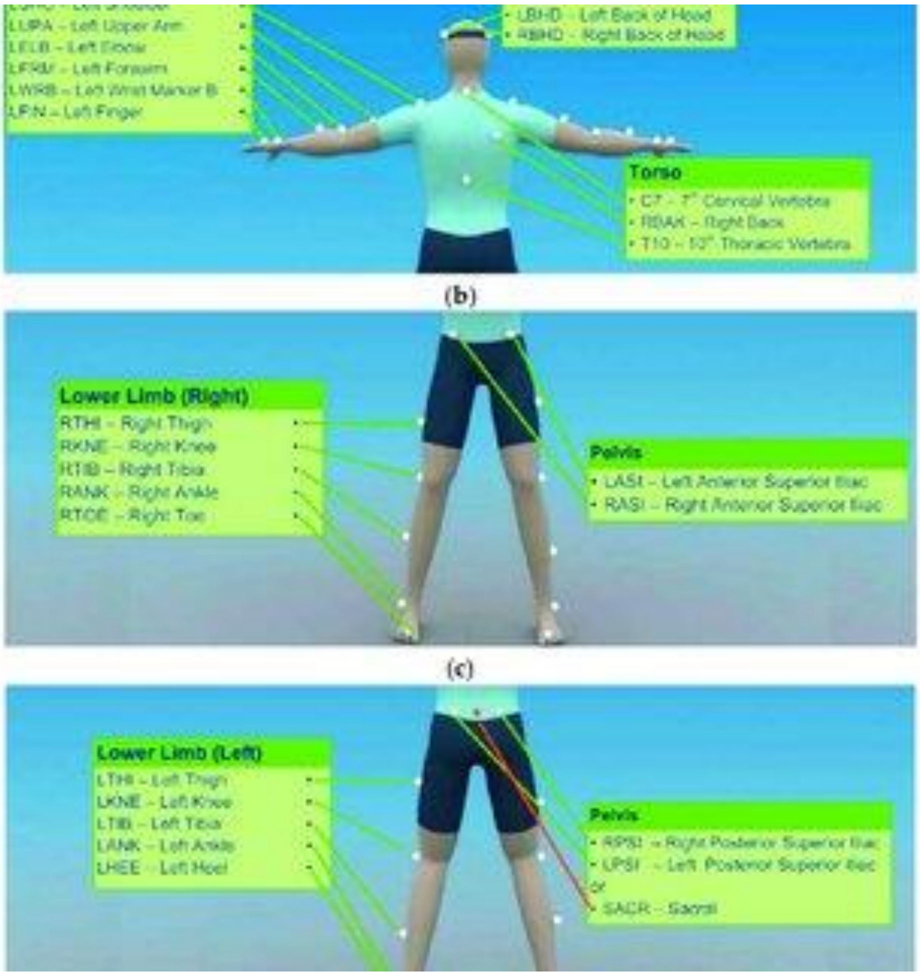


Figure 2.9: PlugIn Gait Model (Vicon) marker placement

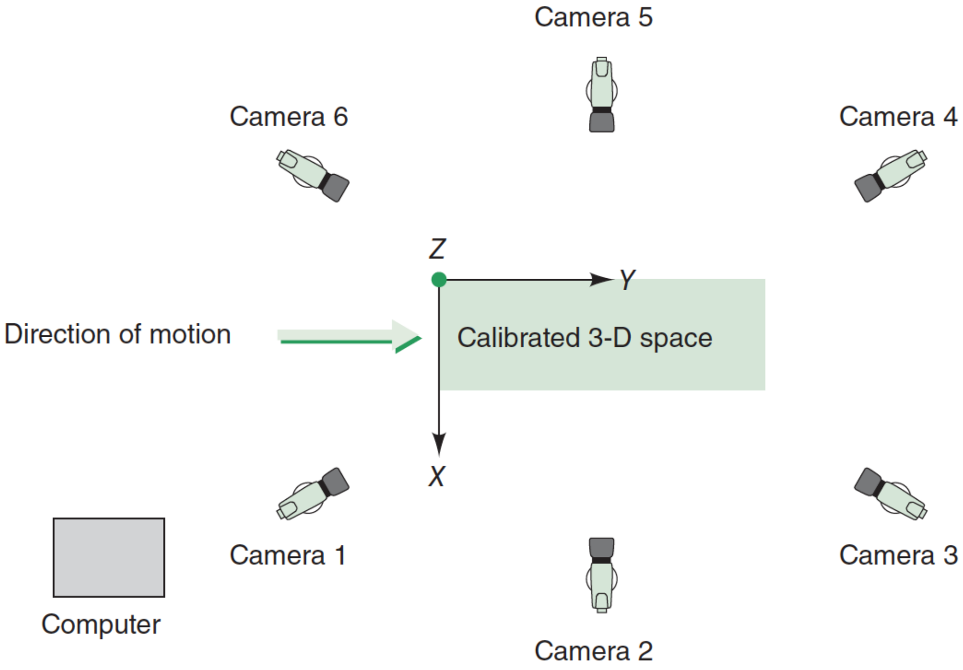


Figure 2.10 describes the positioning of cameras whilst the subject is walking on a walkway

2.3 Presentation of Gait Analysis data to the practitioner

Gait analysis has been proven to add significant information on gait pathologies and has become an integral part of the decision making process. However, interpretation of results obtained by 3D gait models is noted to be a very specialised field and requires the help of gait specialists to adequately decipher the information collected. Once gait analysts gather the large amount of data obtained from 3DGA, a process of data reduction must commence so as to extract the most significant data and provide relevant results. In order for the gait analysis results to be understood by the clinical biomechanist or the clinicians, the test results are normally presented in a graphical format that represents the type of motion plotted against the gait cycle, as depicted in figure 2.11 (Baker et al. 2017).

Thus for each segment, 3 graphs are presented, representing movement in:

A. The sagittal plane - flexion/extension, dorsiflexion//plantarflexion

B. The coronal plane - inversion/eversion

C. The transverse plane - adduction/abduction

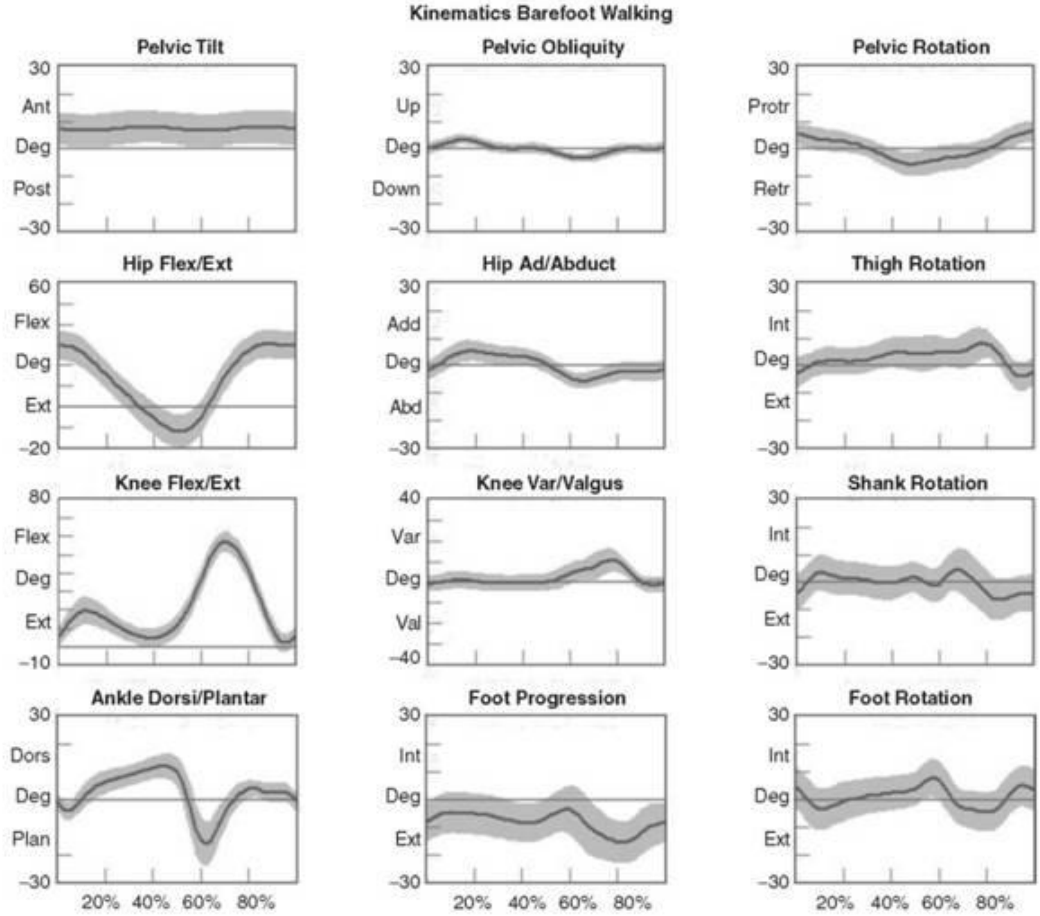


Figure 2.11 : 3 body plane movement representation for each segment (Baker et al. 2017)

A gait graph represents one gait cycle, taken to commence from initial contact of one foot, till the occurrence of ipsilateral initial contact. The degree of the force or movement being assessed, be it knee flexion or hip extension, is usually plotted on the Y-axis, whilst the percentage of gait cycle or time is listed on the X-axis. Here, one can note a great degree of variability as the gait cycle progresses (Baker, 2017), (Tekscan, n.d)

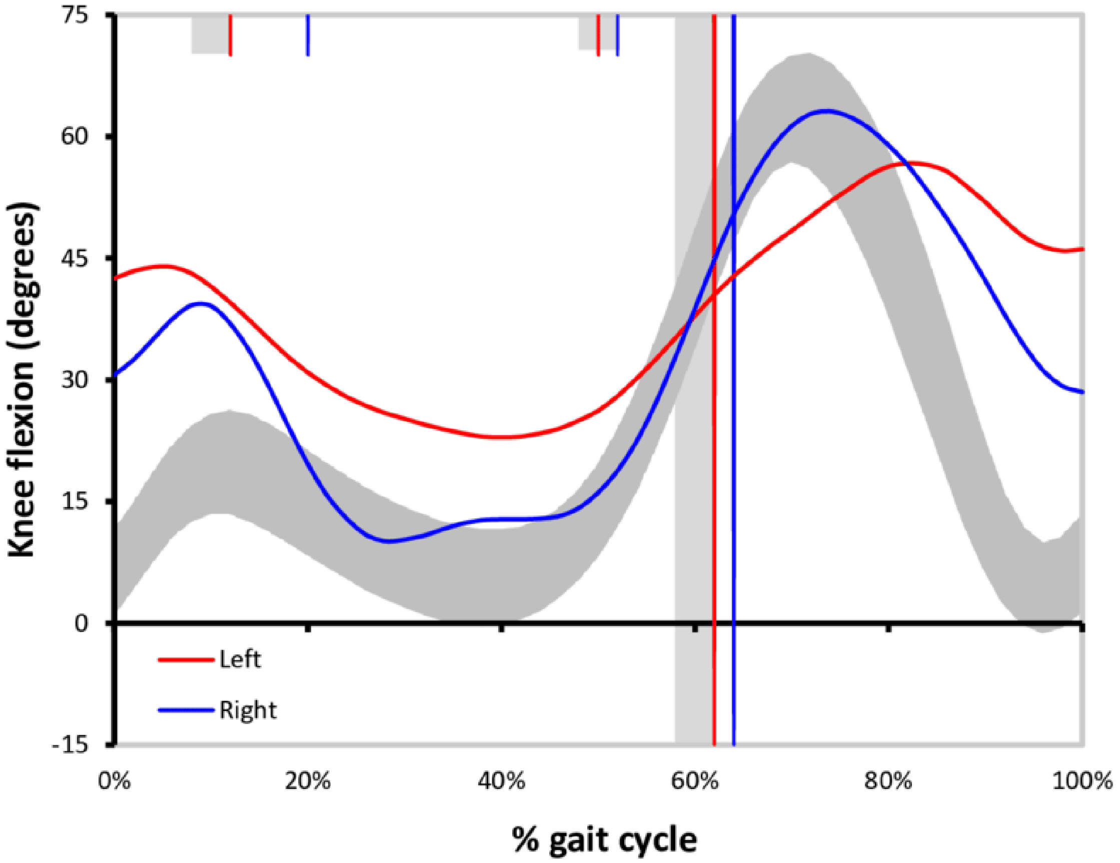


Figure 2.12: Graph denoting knee flexion and extension for the knee joint (from Baker et al. 2017)

In the graph in Figure 2.12, the grey band represents normative data that the laboratory would have gathered from a number of pathology-free participants to represent 'normal gait', against which the left (red) and right (blue) traces of the patient's gait can be compared. The gait cycle (100%), the stance phase (0 to 60%) and swing phase (60% to 100%) are represented in this graph.

As seen in figure 2.11 (Baker et al. 2017), representation of movement at each joint is represented in the 3 body planes; i.e. sagittal, frontal (coronal) and transverse planes. Thus movement in each joint is normally presented by 3 separate graphs, making a total of 12 such graphs to present movement of the joints of the lower extremity. Also as may be seen in figure 2.12, the two contralateral limbs are represented on the same graph, with an additional band that denotes normative data (the grey band), that equates to 1 standard deviation. It is thus understandable why these graphs may be difficult to interpret by the busy physician, who might also have a multitude of other laboratory tests (blood results, imaging results such as xrays and MRI) to refer to.

One final information presented in these graphs is the relation of movement to the gait cycle. Whilst the normal gait cycle involves 60% stance phase and 40% swing phase, these do not necessarily apply to all patients and may vary, e.g. in neurological patients with ataxic gait patterns. As seen in section 2.2.1, the gait cycle is also sub-divided into sub-phases that include Initial Contact (IC), Loading Response (LR), Midstance (MS) and a Propulsion Phase. All this invaluable information is not presented in these graphs, thus giving the clinician an incomplete picture of the patient’s gait.

Other types of gait graphs frequently encountered in gait analysis are those indicating kinetic outputs and vertical ground forces. When taking the ankle as an example, one can note two observable peaks in the gait curve, the heel peak and the forefoot peak. These represent vertical ground reaction forces as the heel and forefoot, respectively, are placed on the ground. The two mentioned peaks are separated by a central dip, which correlates to the instance the heel contact moves to become the midfoot. Figure 2.13 shows these variations in gait cycle as V-P1 (heel peek), V-P2 (Midfoot) and V-P3 (forefoot peak) (Lauzière et al. 2014).

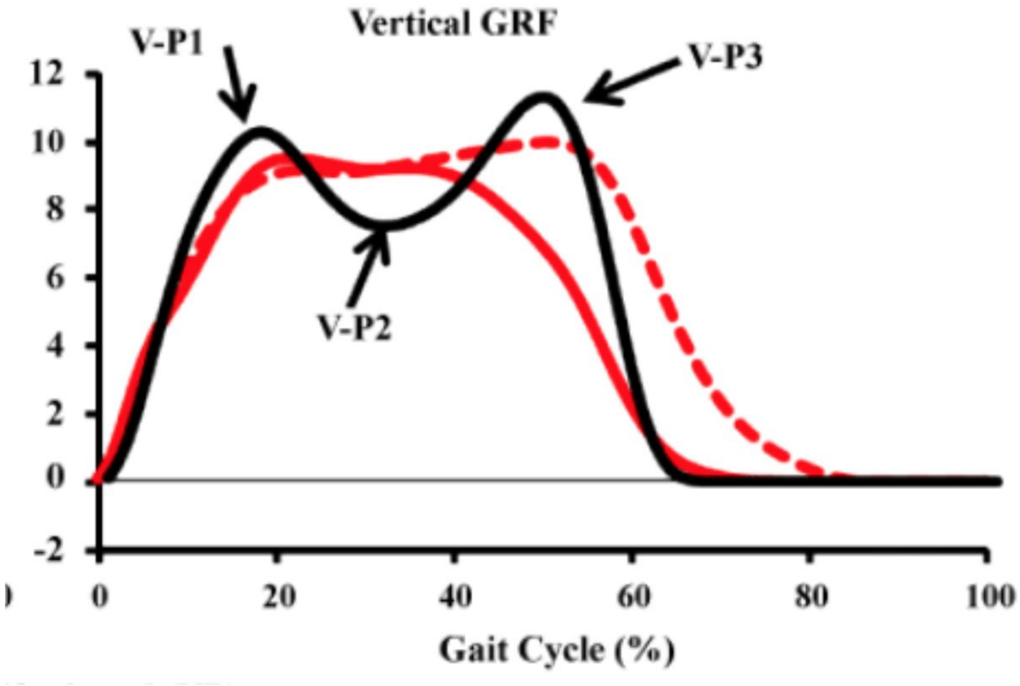


Figure 2.13: Vertical Ground reaction forces during gait cycle in normal healthy individual in black vs patients with cerebrovascular accident in red (Lauzière et al. 2014).

This graph can be adapted and formulated for each movement at any given joint. When taking into consideration the knee joint, a similar curve can be expected for a healthy individual. In figure 2.14, the progression of the knee angle along the gait cycle is noted. An increase in the angle of the knee correlates to increasing knee extension, with maximal angle of 60-70% achieved at midstance, as previously described (Levine et al. 2012).

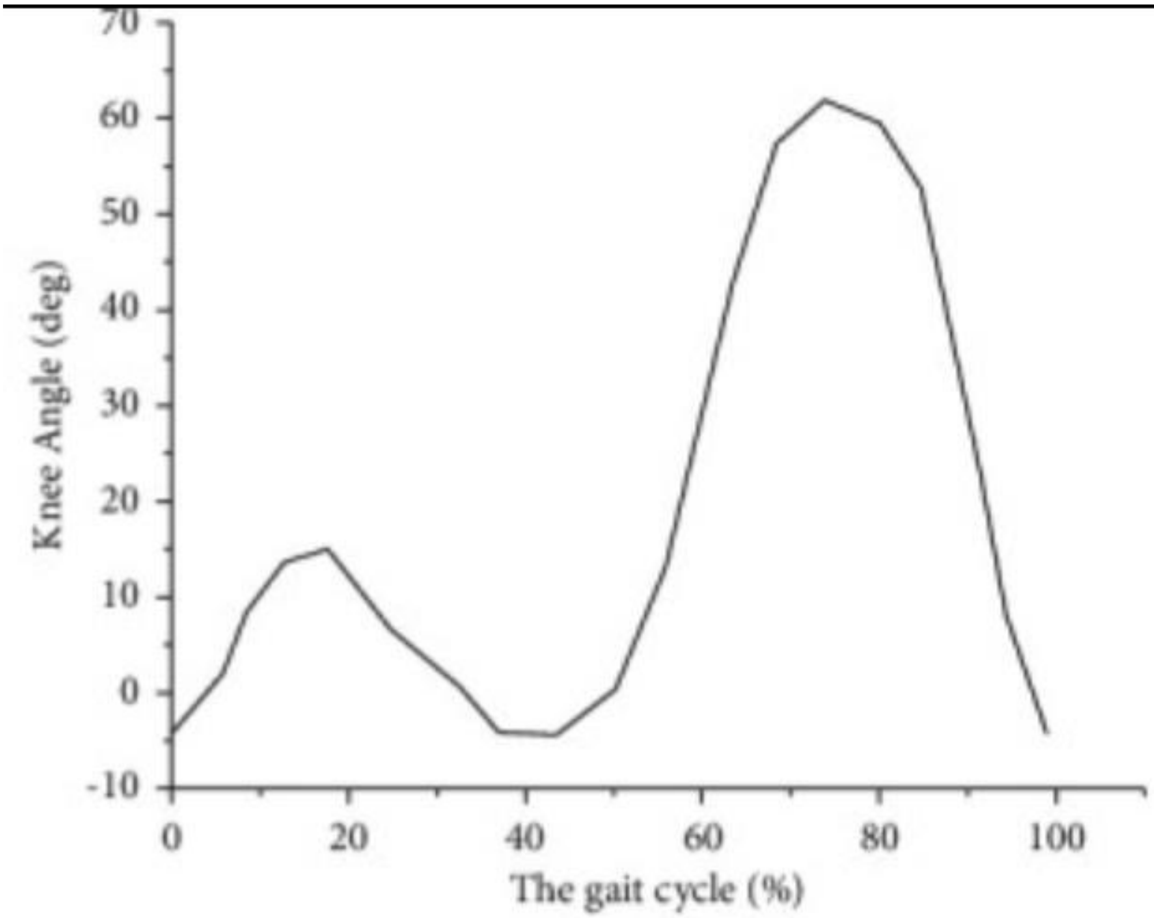


Figure 2.14 depicts the angle of knee as the gait cycle progresses (Wang, S. 2022)

Needless to say, the analysis of the data collected and the ultimate formulation of a gait graph for every joint movement is an elaborate and time consuming process, which depends greatly on experienced gait specialists.

Mukaino et al (2018) confirm that the use of 3DGA in actual clinics remains uncommon, because it is difficult to understand these measurement results as they are presented with a large number of graphs. This limits the use of these gait analysis result graphs in a clinical setting (Itoh et al. 2012).

2.4 Current use of Gait analysis

Gait analysis is an assessment tool which is mostly utilised by healthcare workers whose work is related to the musculoskeletal field. It is able to provide a more comprehensive look into the core of a patient's problem, and aids the professional in the decision making process. At present, gait assessment i.e. the observation of a person's gait, provides an informal perception of the way the individual walks, but it is only with the use of gait analysis that a clinician can indisputably identify and document a patient's condition (Levine et al. 2012). This will in turn formulate proposals for treatment planning, which may include physiotherapy or even a more invasive surgical option (Feng et al. 2016). The most common indication for gait assessment in patients requiring surgical inervention is for spastic conditions, which could be congenital, such as cerebral palsy or even acquired later on in life, and this would include cerebrovascular accidents, Tumours and Traumatic Brain Injuries (Davis, 1997).

In 1987, Richard Brand published four motives as to why any clinical test is executed. The first and possibly, most important consideration discussed by Brand was that assessment tools could be used so as to aid to confirm a condition amongst differential diagnoses. Once this has been achieved and a diagnosis obtained, the impairment resulting from the syndrome can be assessed. This will ultimately, then assist in the selection of an appropriate intervention and finally, a prognosis can be formulated (Brand and Crowninshield 1981), (Brand, 1987), (Baker, 2006).

These four principles have been modified to reflect the use of gait analysis in the clinical field. The main differences noted in this approach with regards to the initial set published by Brand, is the integration of assessment with respect to an intervention. Here, one can note that clinical gait analysis can be used both as a tool to monitor the disease evolution when a procedure is carried out or omitted, as well as to anticipate the outcome, or its absence, when an intervention is done (Baker, 2006; Baker et al. 2016).

In spite of the fact that this above mentioned approach does imply that clinical gait analysis can be utilised for the attainment of a diagnosis, it is most beneficial for the evaluation of gait to be applied on an individual with a confirmed condition before a procedure is planned (Baker et al. 2016).

Before a clinician is able to make a decision as to which treatment plan is best suitable for his or her patient, there are certain steps to be taken. In any medical profession, a thorough history taking will shed a light on what the causative agent or diagnosis may be. This includes an extensive past medical, as well as a surgical history and family history, together with the list of any medications that are taken on a daily basis. However, a good history will not single-handedly suffice to confirm any theories brewing at this point, and it should always be accompanied by a complete physical examination with the addition of special investigations. Here, is where a formal gait evaluation comes into play.

Once gait analysis is performed and results obtained, a hypothesis is formulated and the multidisciplinary team is called to consult and review the data. Occasionally, when the diagnosis is still not clear at this point, testing of the hypothesis is required by either choosing another evaluation approach, or by trying to alter the patient’s gait with the use of orthotics or more invasive surgical interventions (Levine et al. 2012; Rose, 1983; Gage, 1983) noted that identification of causation may sometimes prove arduous due to the individual's ability to compensate for the deficit, resulting in an ambiguous gait pattern.

2.4.1 Cerebral Palsy

Cerebral palsy is "a persistent but not unchanging disorder of movement and posture due to a non-progressive disorder of the immature brain" Hinchcliffe et al (2007). It is most often linked to prematurity and insults on the developing foetal brain. This condition is linked to several movement patterns which have been thoroughly analysed by the use of instrumental gait analysis for several years. These include spastic hemiplegia, spastic diplegia, and occasionally, spastic quadriplegia (Levine et al. 2012). The resulting pathological gait is affected by the position of the brain lesion and will ultimately produce instability and spasticity.

Given the complex aetiology of the condition, clinical presentation can be widely variable and will ultimately give different patterns of gait which continue to develop over time. Gait Analysis is hence the most appropriate tool to continuously assess this dynamic presentation for the purpose of providing insight on the adequate management plan.

The role of gait analysis in patients with cerebral palsy is not to confirm the diagnosis, since patients who are referred for gait analysis in this population would already have characterised neurological diagnosis. In this case, gait interpretation is especially useful to pinpoint the motor deficits and functional pathological features to aid in the clinical decision making process.

Apart from being a valuable preoperative assessment tool, gait analysis also plays an important role in the follow up of individuals with cerebral palsy who have undergone specific treatment regimes. An example of this would be the interpretation of gait analysis after botulinum injections, when compared to cerebral palsy patients having had no intervention at all (Molenaers et al.2006). Evaluation of these patients' gait following the procedure can be utilised for statistical purposes, as well as to guide future treatment options (Baker, et al. 2016). With the results gathered, the clinicians are able to carry out a critical review of the diagnosis, and the choices made to confirm if they were appropriate (Levine et al. 2012).

2.4.2 Adult acquired Hemiparetic Gait

The most common gait deviation quoted in literature when describing acquired pathologies is spastic gait, which can be both hemiparetic or paraparetic. As the name implies, hemiparetic gaits are those caused by a unilateral lesion, such as a stroke or a neoplasm, which compress upper motor neurons resulting in contralateral muscle spasticity and hyperreflexia. However a broader paraparetic pattern can also be observed with conditions such as multiple sclerosis and lesions affecting the spinal cord.

A closer look at the biomechanical components of a patient with a hemiplastic gait, reveals an overall asymmetry with a prolonged stance phase of the unaffected side. One may also note a reduction or absence of reciprocal arm movement of the affected upper limb, as opposed to what is normally observed in non-pathological gaits. Instead, the arm in a hemiparetic gait is usually kept in close proximity to the patient and in a flexed position. Moreover, ipsilateral limb clearance is affected in view of stiffening and extension of the afflicted lower limb. This results in the implementation of compensatory movements (lateral sway, hip hiking, etc), for adaptation and protection of stability in gait cycle (Baker et al. 2016).

2.4.3 Gait Analysis as a Research Tool

The purpose of gait analysis is not only limited to clinical use, but is also the subject of extensive research in academia.

Gait research can be divided into two: *Clinical research vs Fundamental Research*. In the former, the research focuses on diseases and their respective treatment options. On the other hand, in fundamental research one will study the ways in which data can be collected more efficiently, the methods used and ways to improve on biomechanical and physiological knowledge (Levine et al. 2012). Gait Analysis has been an important addition to the world of medical research such that conditions affecting groups of individuals can be discovered, so as to be able to propose new and innovative methods to both assess and treat these conditions (Baker, 2006)

2.5 Data

As described by the Cambridge dictionary, data refers to any information, be it words or numbers, gathered for the purpose of evaluation and assessment to aid in the decision-making process, or electronic data that is stored in a computer. Most scientific research follows a concept of evidence-based investigations, the basis of which relies on the information collected during the first stages of research. It is more often regarded as raw material which has not been given meaning as of yet (Li, 2020)**.** Agarwal (2013) goes on to identify two types of data - primary and secondary data. Primary data is one that is obtained directly from the researcher to answer a scientific question. On the other hand, secondary data is one which has been obtained from previously available data and statistically analysed to provide further information to another researcher or for another research question.

As with any scientific study, the initial step towards achieving a researcher's desired result is to formulate a hypothesis and collect the data to support or disprove a theory. This information is gathered via definite methods, which require to be described thoroughly to ensure a transparent and reproducible study. This could include data collected from a laboratory or in the field (Petrie & Sabin, 2019).

There are three main types of data representation: textual, tabular and diagrammatic. In the former, the researcher is expected to present data by writing down the results in a paragraph. This is the simplest way out of the three, but it is clearly the most time consuming for the reader. With tabular representation, data is written down in rows and columns, so as to provide a shorter and a more straightforward way to understand the information. Finally, the diagrammatic approach is one that attracts the eye and uses colour visualisation to display the findings (Pupovac & Petrovecki, 2011), (Petrie & Sabin, 2019).

The method chosen by a researcher to represent data depends largely on two factors. Firstly, the nature of the data and secondly, on the type of questions that are of interest.

When it comes to data interpretation, one may come across several issues that might hinder successful analysis. The most important thing to keep in mind is that, even though most data is analysed by software and computers, it is initially inputted manually by an individual. This might lead to typographical errors or entry of wrong numbers or wrong fields. Data might be duplicate or ambiguous and one may also be incomplete. Brown et al (2018) systematically detail a number of issues with bad data and communication, mainly data acquired poorly due to “low-quality collection methods”, inadequate study designs and sampling techniques, as well as selective reporting resulting in pertinent information being left out (Brown et al. 2018).

2.6 The use of colour to visualise data

The use of graphical representation of data has been noted to become more widely used in scientific papers and journals. It provides a simple and straightforward method with which to present data sets, without the need of numerical data alone. Graphical representation of data allows the readers to understand the results being presented to them in a more efficient manner and aids them to formulate theories in a more structured way. Visual learning has been found to be a powerful tool for data interpretation and visualisation of results (Midway, 2020).

As already mentioned previously, the choice of data representation relies greatly on the type of data that is going to be presented, be it quantitative or qualitative. It also depends on what the intended objective of the charts being displayed is (Li, 2020).

According to Kirk (2012), data visualisation refers to “the representation and presentation of data that exploits our visual perception abilities in order to amplify cognition”. It relies on the graphical depiction of patterns for the reader to effectively get a grasp on the information being displayed. There are many advantages to the use of visual representation of data, the first being the ability to depict a large quantity of data in an illustration. This being said, one is also capable to recognise and intuitively locate patterns within the data set and pinpoint problems which may emerge (Li, 2020).

The use of colour for data visualisation has also been linked to increased attention and memory recollection. In a study carried out by Pan (2012), it was demonstrated that after being shown different shapes and asked to recall the exact shape and colour of the illustration, most participants were only able to effectively remember the colour used. This goes to show how the brain is able to more effectively process colour when compared to geometrical shapes and numerical figures.

2.7 Infographics

Infographics are graphical visual representations of information, data, or knowledge intended to present information quickly and clearly (Smiciklas, 2012). Patterns and trends may be easier to detect for the human eye than rows of numbers or words (Card, 2009). Infographics provide visualization of information and/or data, as infographics are primarily aimed at mass communication, the designer of the infographic does not assume any specific skills or knowledge (Zaman, 2019).

As an example of a well known infographic, gait cycle representation may be considered as an infographic because it represents the gait cycle and uses snippets of information together with colour to deliver a message (Figure 2.15)

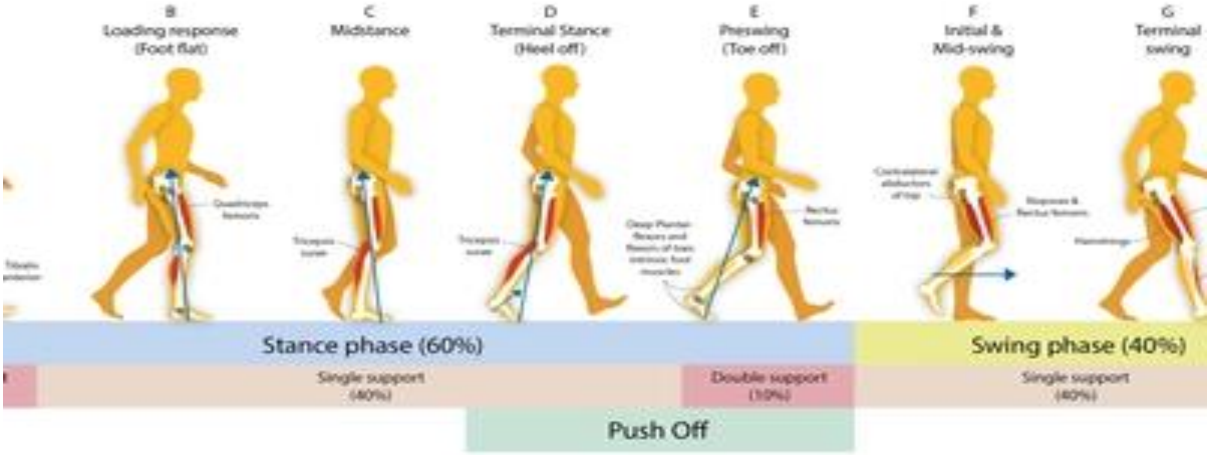
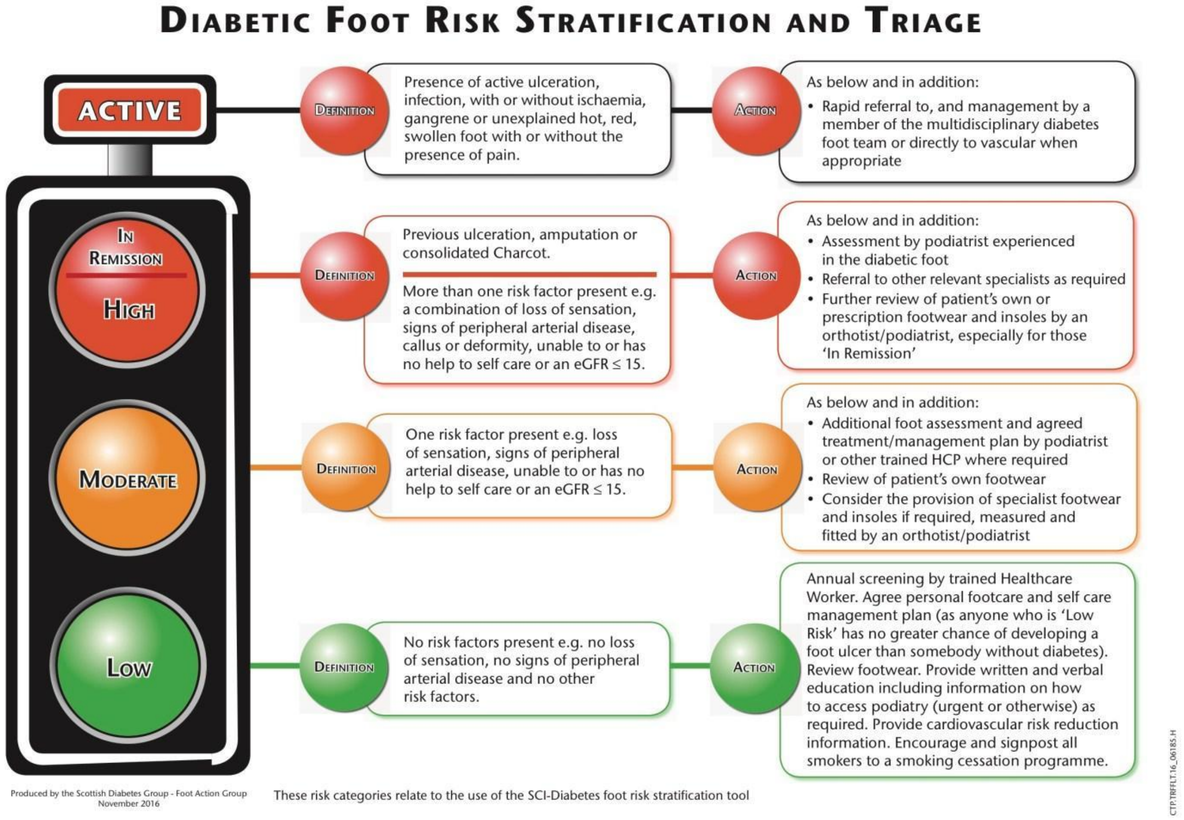


Figure 2.15: Gait cycle infographic. Note use of colours to make it more understandable (https://dribbble.com/shots/15099311-The-gait-cycle-01-copy)

2.8 Use of Traffic Light Systems in Health

Traffic light systems are being currently used in various aspects of medicine. This is because they are relatively easy to interpret and can be readily interpreted by the reader. One such example is the foot risk stratification system adopted by the Scottish Health System (Crawford F, Cezard G, Chappell FM, et al, 2015). As may be seen in figure 2.16, low, medium and high risk are easily identifiable by their yellow, green and red colour respectively.



Active – Definition: Presence of active ulceration, infection, with or without ischaemia, gangrene or unexplained hot, red, swollen foot with or without the presence of pain.

Active – Action: As below and in addition:

- Rapid referral to, and management by a member of the multidisciplinary diabetes foot team or directly to vascular when appropriate

In Remission / High – Definition: Previous ulceration, amputation or consolidated Charcot.

More than one risk factor present e.g. a combination of loss of sensation, signs of peripheral arterial disease, callus or deformity, unable to or has no help to self care or an eGFR ≤ 15.

In Remission / High – Action: As below and in addition:

- Assessment by podiatrist experienced in the diabetic foot
- Referral to other relevant specialists as required
- Further review of patient's own or prescription footwear and insoles by an orthotist/podiatrist, especially for those 'In Remission'

Moderate – Definition: One risk factor present e.g. loss of sensation, signs of peripheral arterial disease, unable to or has no help to self care or an eGFR ≤ 15.

Moderate – Action: As below and in addition:

- Additional foot assessment and agreed treatment/management plan by podiatrist or other trained HCP where required
- Review of patient's own footwear
- Consider the provision of specialist footwear and insoles if required, measured and fitted by an orthotist/podiatrist

Low – Definition: No risk factors present e.g. no loss of sensation, no signs of peripheral arterial disease and no other risk factors.

Low – Action: Annual screening by trained Healthcare Worker. Agree personal footcare and self care management plan (as anyone who is 'Low Risk' has no greater chance of developing a foot ulcer than somebody without diabetes). Review footwear. Provide written and verbal education including information on how to access podiatry (urgent or otherwise) as required. Provide cardiovascular risk reduction information. Encourage and signpost all smokers to a smoking cessation programme.

Produced by the Scottish Diabetes Group - Foot Action Group
November 2016

These risk categories relate to the use of the SCI-Diabetes foot risk stratification tool

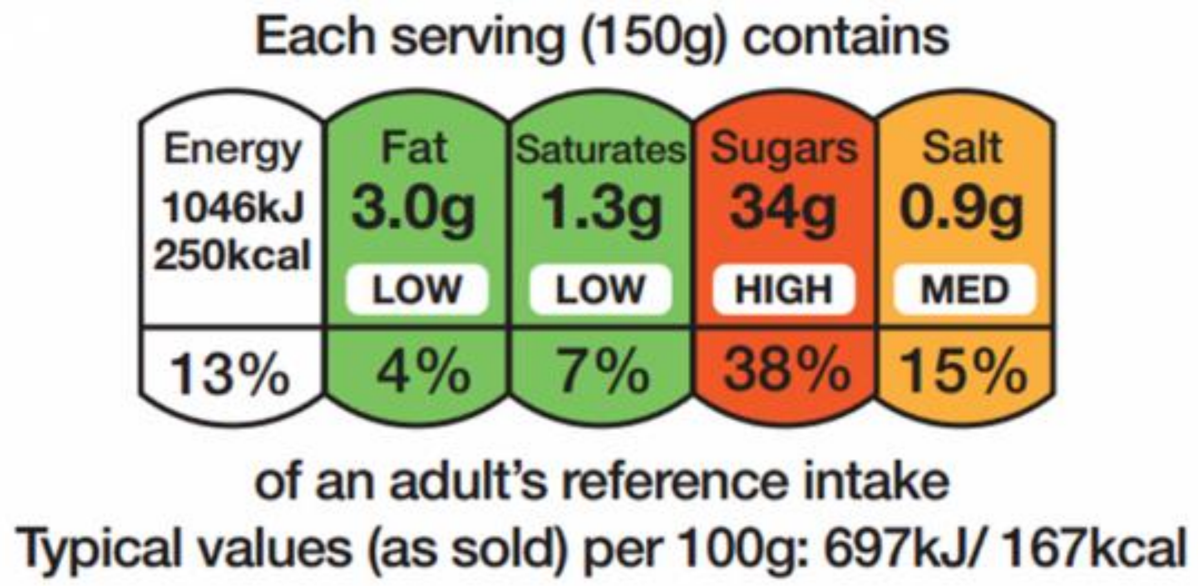
CTP.TRFFLT.16_06185.H

Figure 2.16: Diabetic foot risk stratification and triage (from Crawford F, Cezard G, Chappell FM, et al, 2015)

Another example of a Traffic Light System is that adopted by the Government of Victoria in Australia. Their Healthy Choices guidelines uses a 'trafflic light system' to categorise foods and drinks into three groups.

- Foods and drinks in the **GREEN** category are the healthiest choices.
- **AMBER** foods and drinks should be selected carefully and should only be eaten in moderation.
- Foods and drinks in the **RED** category are not essential. If they are consumed too often, or in large amounts, they can lead to weight gain and chronic diseases.

  (Health Eating Advisory Service. https://heas.health.vic.gov.au/healthy-choices/guidelines/traffic-light-system)



Each serving (150g) contains

Energy	Fat	Saturates	Sugars	Salt
1046kJ 250kcal	3.0g	1.3g	34g	0.9g
	LOW	LOW	HIGH	MED
13%	4%	7%	38%	15%

of an adult's reference intake
Typical values (as sold) per 100g: 697kJ/ 167kcal

Figure 2.17. Colour used in the Traffic Light System of the Victorian Australian Government

Another example is shown in Figure 2.18. Wilkes proposes a Traffic Lights system to signal the best clinical outcomes for National Health Service Patients in the United Kingdom.

Figure 2.18: Stop! Traffic Lights signal the best clinical outcomes (from Wilkes, 2018)

2.9 Big Data in Biomechanics

After the introduction of social media in 2008, the generation and classification of big data was noted to play a large part in research and academia. The term “Big Data” essentially refers to datasets which are too large for conventional analytical tools to adequately process in an appropriate time range required (Phinyomark et al. 2017; Herland et al. 2014; Demchenko et al. 2012).

Big Data can be produced by three distinct manners; by humans, by machines, or by an organised mixture of the two. The largest contribution to big data sets are generated by machines, and in biomechanical analysis, this would include the data collected by infrared cameras and retroreflective markers to formulate kinematic outputs and eventually, 3D characteristic patterns of pathological gaits. With regards to the data sets generated by humans in biomechanics, here we can discuss the information obtained by physical examination prior to any biomechanical testing (Ghotkar et al. 2016).

Several key qualities have been noted to be included in the definition of big data along the years, with the intent to provide a more thorough explanation of what it entails and these include Volume, Variety, Velocity, Veracity and Value (Phinyomark et al. 2017; Demchenko et al. 2012; Ghotkar et al. 2016).

2.9.1 Volume

The first attribute described in big data is the concept of volume. This refers to the quantity of data that is generated from any given investigation. Whilst biomechanical analysis used to involve a small number of participants with little variables, modernisation of collecting systems and upgrades in the overall process has yielded an increase in the amount of data obtained per subject. In fact, one can note a rise in variables per individual to approximately "50-150 variables, hundred to thousands variables for joint angle data and another thousand to hundred thousand variables for data related to marker placement". Despite the fact that biomechanical studies still involve only a small number of participants at a time, it is advised to broaden this cohort so as to be able to elicit data on reproducibility and generalisability of test results for contrasting populations (Tsai et al. 2015; Phinyomark et al. 2017; Ghotkar et al. 2016).

2.9.2 Variety

In contrast to structured data that was previously obtained, the large variety of information that is collected nowadays with the advancement of technology, gives rise to unstructured data and it comprises 90% of the material generated. This can be attributed to the vast parameters and outputs formulated in biomechanical testing, together with ample sources available for its collection (Ghotkar et al. 2016). Apart from the use of computerised systems for the compilation of data, we must also remember the data obtained by the clinical physician and subjective features described by the patient themselves, including pain and functionality. This broad information will hence, require intricate statistical tools for evaluation (Phinyomark et al. 2017).

2.9.3 Velocity

When discussing velocity in the context of big data, one is referring to the speed at which new information can be gathered and evaluated. In the context of biomechanical studies, most patients with pathological gaits, be it due to musculoskeletal injuries or because of neurological conditions, will require multiple testing over weeks to months, initially to determine a baseline and thereafter, to document and appreciate any deterioration in the condition (Phinyomark et al. 2017.

2.9.4 Veracity

Another important factor in big data is the quality of the data collected, and in biomechanical analysis, there may be the possibility of obtaining inaccurate or incomplete information especially due to issues with marker positioning and artifacts due to soft tissues (Tsai et al.. 2015). The advancement of big data softwares has, however, allowed for this phenomenon and are able to compensate for the missing data with modalities such as the “k-nearest neighbours” (Phinyomark et al. 2017). Having said this, data collected from gait analysis laboratories are usually of good quality.

2.9.5 Value

Although the information obtained through big data analytics has the ability to provide great value, not much research is available with regards to big data analytics in biomechanics and further techniques may need to be tested.

2.10 Reliability and validity of Gait analysis Data

2.10.1 Validity

According to 1999 *Standards for Education and Psychological Testing*, initially published in 1985 and revised several times thereafter, validity is described as “the degree to which evidence and theory support the interpretations of test scores for proposed uses of tests”. It implies a high grade of certainty and accuracy, with regards to the statements and findings obtained with the assessment tool being used (Sullivan, 2011; Last, 2001; Mahapatra et al. 2020).

There are many types of validity evidence that have been discussed in detail over the years. These can be largely grouped into two domains namely, internal and external validity. Internal Validity refers to the degree to which results obtained from the study are accurate and representative of the population being investigated (Patino et al. 2018; Kember et al. 2008). Once internal validity is obtained, the researcher can progress to test for external validity i.e. whether or not findings can be generalised (Last, 2001). Most frequently, when the researcher places too many constraints to try to achieve internal validity, problems with generalizability may arise. This is why it is important to choose which type of validity is more pertinent to the research question.

In 2000, K. George explained the importance of validity in clinical research and described each one further (Figure 2.19).

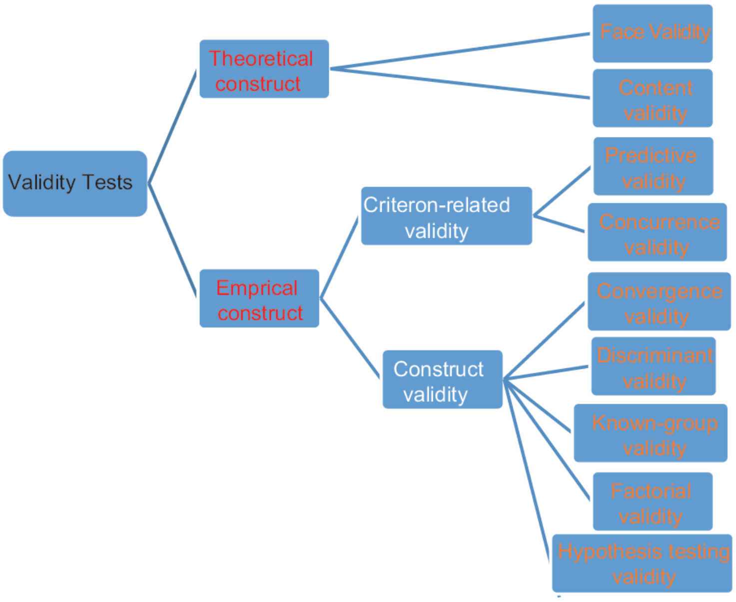


Figure 2.19: Graphical representation of the subtypes of various forms of validity tests (from Bolarinwa, 2015)

Face Validity

When most people think about Validity, their instinct is to innately remember the definition that has been imprinted over and over again - is it measuring what it needs to be measuring? Face validity is achieved with the help of an expert in the field, who after reviewing the tool used, be it a questionnaire or a software, amongst others, believes that the questions and the format is adequate to test for the trait of interest (Bolarinwa, 2015). This brings about a high level of subjectivity and may cause problems with reproducibility in the future. It is generally considered "casual" and is at the centre of many debates as to whether it is an appropriate tool for measuring validity (Last, 2001).

Content Validity

According to the American Psychological Association, content validity refers to "the extent to which a test measures a representative sample of the subject matter or behaviour under investigation". Said tool is evaluated by a group of experts, who will make sure that the questions being asked are pertinent to the construct being investigated (American Psychological Association, 2015). They will review for “readability, clarity and comprehensiveness”, so as to present a finalised version of the assessment tool. This is mainly done by different rating systems, including the Flesch-Kincaid readability formula and the Fog Index (Bolarinwa, 2015). As with face validity, content validity has also been deemed to have a high level of subjectivity (Last, 2001).

Both Face and content validity form part of what is known as a theoretical construct, where an analytical approach of the assessment tool is established with the help of professionals (Bolarinwa, 2015).

Criterion-Related Validity

As the name implies, Criterion-related validity is assessed when the researcher wants to compare findings to an already-existing instrument. It is a measure of how appropriate his/her assessment tool is in correlation to other predictors in the field (Bolarinwa, 2015), (Last, 2001). There are two subtypes when speaking about criterion-related validity; Concurrent and predictive. In concurrent validity, the tool at hand is compared to the “gold standard” test currently being used, whilst predictive validity is used so as to be able to anticipate future conclusions (Last, 2001). This, together with construct validity tests, form part of an empirical construct, which measure results relating to external criteria.

Construct Validity

The American Psychological Association defines construct validity as “the degree to which a test or instrument is capable of measuring a concept, trait, or other theoretical entity”. It does not use an existing construct but rather, a speculative idea based on observations as to whether the assessment tool will adequately formulate the expected results (Last, 2001). Here we speak about convergent vs discriminant validity, where two opposing views are tested to correlate relatability. In convergent validity, two or more tests that are used to yield similar results, are evaluated to confirm that they are, in fact, analogous. On the other hand, divergent validity proposes that two measures which should not be reciprocal, are in fact, extraneous.

Another subtype of construct validity is Known-group Validity, where a tool is assessed for the ability to discern between a group of people with a known feature or pathology, and another group without (Rodrigues et al. 2019).

The final subtype of construct validity is Hypothesis-testing validity, where a known notion or theory is evaluated against already existing theories, results of which are used to support a hypothesis (Last, 2001)..

2.10.2 Reliability

Another important aspect of any scientific study is reliability. Several definitions can be noted when researching reliability, but broadly speaking, it refers to the degree of reproducibility of the assessment tool being investigated. The term reliability has been utilised so as to imply a sense of coherence of findings across repeated testing (Standards for education and testing, 1999), (Last, 2001), (Lachin, 2004), (Bartlett & Frost, 2008).

There are three main forms of reliability testing; test-retest reliability, alternate-form reliability and internal consistency reliability.

Test-retest Reliability

This form of reliability testing is mainly an indication of stability of the instrument over time. It is said that a high level of stability or reliability, is elicited when comparable results are collected from the same participants over a period of time (Mahapatra et al. 2020). This means that, if a questionnaire is supplied to a number of individuals, results obtained initially should be analogous to the results collected again once the same questionnaire is distributed to the same group of individuals after some time (Bolarinwa, 2015).

However, for results to be considered to be reliable, two assumptions need to be made. The first assumption tackles what is known as the ‘testing effect’, by claiming that the characteristic being investigated should remain the same over the period of time between tests. Secondly, the time frame allocated between each test should be adequately spaced, so that the participants do not memorise the questions, but not too long that external factors influence responses (Fink, 2010). This phenomenon is referred to as the ‘memory effect’. Correlation coefficient results of more than 0.7 yield adequate test-retest reliability (Bolarinwa, 2015).

This is the commonest form of reliability testing in surveys, especially when questionnaires are involved (Bolarinwa, 2015), (Mahapatra et al. 2020).

Alternate-form Reliability

Alternate-form reliability refers to the extent of conformity between two or more assessment tools, which are tested at the same point in time. Instruments are tested out in parallel to either the same group of individuals or to a separate group, and both instruments should be measuring the same construct. Equivalence is said to be adequate when a “high degree of correlation” is noted between the instruments (Mahapatra et al. 2020). Again, this type of reliability testing is utilised primarily with questionnaires, but it can also be enforced when “subjective judgements” are to be made by more than one person (Bolarinwa, 2015).

Internal Consistency Reliability

As the previous dealt with reliability between different tools, internal consistency reliability ensures that questions on the instrument being used are actually testing for the same thing. This was initially done with the use of formulas such as the split-half reliability index and the coefficient alpha index (Mahapatra et al. 2020). Nowadays, statistical analysis softwares have been created so as to be able to test for internal consistency. Results higher than 0.70 are said to have a high homogeneity and researchers should strive to achieve this (Bolarinwa, 2015).

Rater Reliability

When assessing a measurement tool for reliability and thus, reproducibility, for the purpose of aiding in decision making, rater reliability is very important. There are two types of rater reliability, intra-rater and inter-rater reliability (Schlager et al. 2018). In the former, data collected by one researcher is evaluated against data collected by the same researcher during numerous trials in close vicinity to each other. On the other hand, inter-rater reliability refers to the coherence between data collected by more than two researchers amongst themselves, with regards to the same trial and same patients. High inter-rater reliability indicates that the tool at hand is clear and will ultimately prove to have a high degree of validity (Scheel et al. 2018).

Statistical methods of analysing two sets of data for correlation, such as, for example, when comparing rating responses to a Gold Standard response, include three main types of testing:

Intraclass Correlation Coefficient (ICC), is an adequate descriptive statistical test used to assess the degree of inter-rater reliability. Values between 0.95 and 1.0 indicate excellent inter-rater reliability scores with poor ones being less than 0.50. Anything in between would be considered as moderate (Scheel et al. 2018), (Mahapatra et al. 2020; Schlager et al. 2018). This can, however, be used only when data is of a continuous format.

Cronbach's Alpha is often utilized when multiple-item measures of a concept or construct are employed, it is easier to use in comparison to other (Cohen and Swerdlick, 2010) as it is only necessary to perform one test (Tavakol and Dennick, 2011). This test can be used to test correlations between two raters.

Fleiss Multirater Kappa can be utilized to assess correlations between multiple testers, as measured in a categorical scale of -1 to +1, with +1 being an perfect positive correlation between raters whilst -1 denotes a negative correlation i.e. as one ranking increases, the other decreases. Interpretation of the Fless Multirater Kappa analysis can be found in Table 4.9.

2.10.3 Accreditation

So as to offer appropriate and standardised procedures, gait analysis laboratories go through an accreditation process by Motion Laboratory Accreditation Test (MLAT) if in the USA, or by Clinical Movement Analysis Society (CMAS) if in the UK (Holder et al. 2013). This will ultimately ensure the highest quality of examinations and will aid in the consistency and reliability of data obtained (Baker, 2017).

2.11 Conclusion

Even though the act of gait analysis testing has been subject to many debates to increase standardisation of testing, interpretation of gait analysis is said to be mostly a subjective process which requires a profound expertise of biomechanical concepts (Baker et al. 2016). A detailed literature search about the reliability of interpretation of graphs used to denote movement failed to produce any results. This thus demonstrates the need to conduct research in this area, to establish if raters can reliably interpret these graphs and what level of training is required to interpret these graphs.

The aim of the "Traffic Lights System" is to try to convert this subjectivity into an objective tool, so as to increase validity and reliability and make it feasible for healthcare workers to easily interpret results more efficiently.

Chapter 3

Methodology

3.1 Introduction

This chapter details the methodological approach adapted to perform this study.

It aims to :

1. Illustrate the process by which the Traffic Lights System (TLS) was developed
2. How the Traditional Graphical System (TGS) graphs were converted into the TLS
3. The research design process
4. The workflow adopted to validate this new tool
5. To determine its reliability, both at intra- and inter-rater levels.

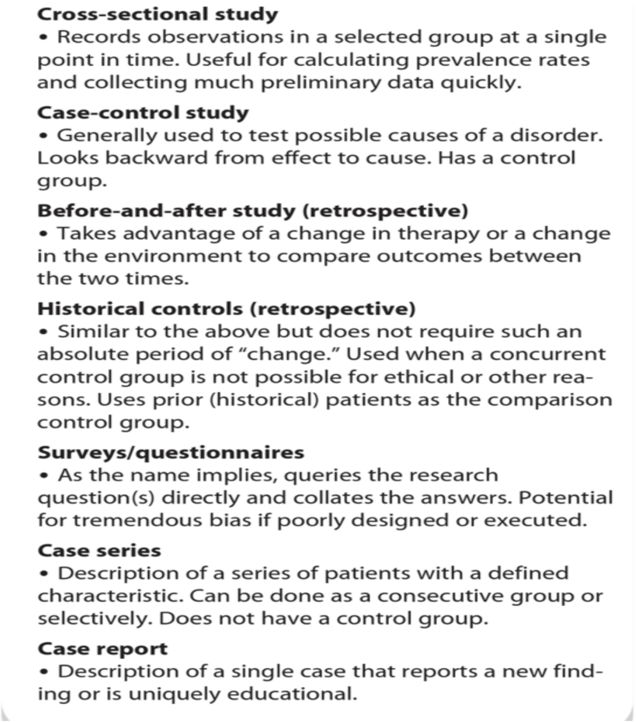
3.2 Study Design

This is a blinded, prospective, non-experimental design. The study design was selected in order to produce the most appropriate results pertaining to the aims and objectives that had been determined beforehand (Chapter 1). The term 'study design' refers to a framework, or the set of methods and procedures used to collect and analyze data on variables specified in a particular research problem (Ranganathan and Aggarwal, 2018).

Blinded design: A blinded design ensures that all participants, both subjects and researcher, cannot influence the outcome of the research being conducted. This refers to, for example, the concealment of group allocation from one or more individuals involved in a clinical research study (Karanicolas et al. 2010). However, blinding also involves hiding the results from participants so that they cannot be influenced by previous outcomes. In this study, although both Traditional Graphics and Traffic Lights results related to the same datasets, the responders were not aware of this so that their responses would not be influenced.

A **prospective study design** is one in which the documentation of the presence or absence of an exposure of interest is documented at a time period preceding the onset of the condition being studied. Most importantly, the occurrence/nonoccurrence of the condition is then assessed over a time period following recruitment (Salkind, 2010).

Non-experimental study designs are purely observational and the results intended to be purely descriptive (Bagley Thompson and Panacek, 2007). Observational studies can be either descriptive (non-analytical) or analytical (inferential) (Ranganathan and Aggarwal, 2018). The types of non-experimental designs are listed in Figure 3.1 (adapted from Bagley Thompson and Panacek, 2007).



Cross-sectional study
- Records observations in a selected group at a single point in time. Useful for calculating prevalence rates and collecting much preliminary data quickly.

Case-control study
- Generally used to test possible causes of a disorder. Looks backward from effect to cause. Has a control group.

Before-and-after study (retrospective)
- Takes advantage of a change in therapy or a change in the environment to compare outcomes between the two times.

Historical controls (retrospective)
- Similar to the above but does not require such an absolute period of "change." Used when a concurrent control group is not possible for ethical or other reasons. Uses prior (historical) patients as the comparison control group.

Surveys/questionnaires
- As the name implies, queries the research question(s) directly and collates the answers. Potential for tremendous bias if poorly designed or executed.

Case series
- Description of a series of patients with a defined characteristic. Can be done as a consecutive group or selectively. Does not have a control group.

Case report
- Description of a single case that reports a new finding or is uniquely educational.

Figure 3.1: Types of non-experimental design types, (from Bagley Thompson and Panacek, 2007)

In non-experimental designs, there are no interventions, thus no dependent and independent variables that can be statistically evaluated, e.g as in a pre-post intervention design.

It should be noted from Figure 3.2 that surveys and questionnaires have a "potential for tremendous bias if not designed and executed correctly" (Bagley Thompson and Panacek, 2007); thus in this research various steps were taken to ensure as minimal a bias as possible. The most important is blinding, in order not to influence the respondents in any particular way.

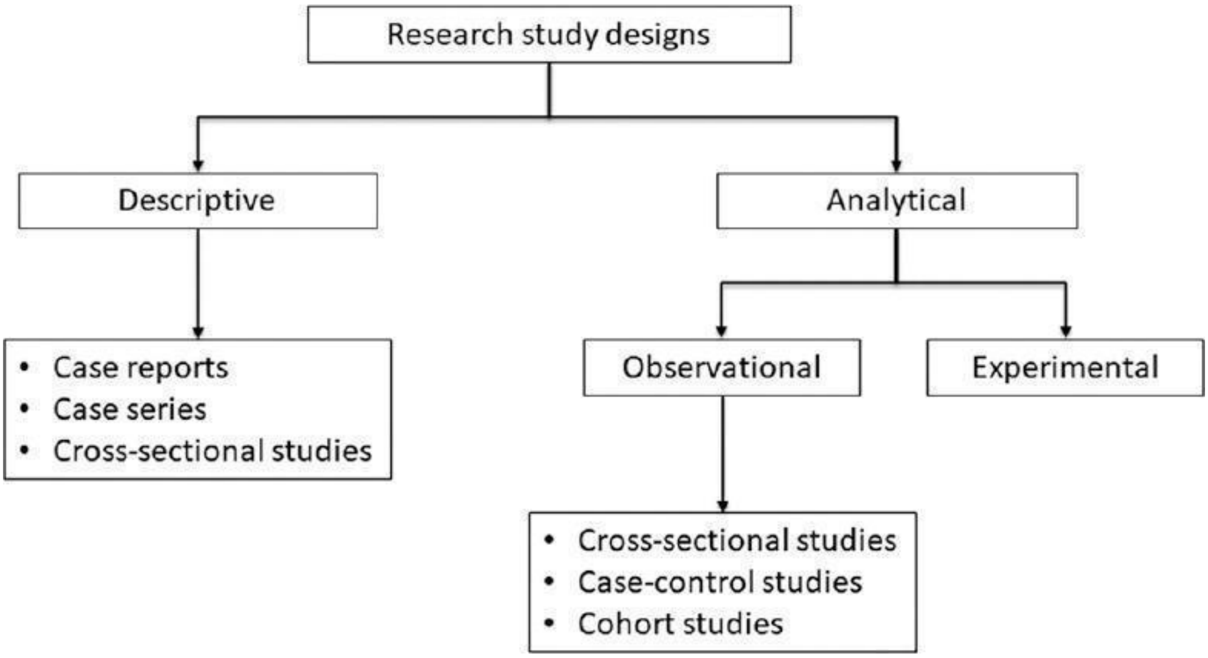


Figure 3.2: classification of research study designs (from Ranganathan and Aggarwal, 2018).

3.3 Philosophical Frameworks

Research philosophy is associated with assumption, knowledge and nature of a study because it deals with the specific way of developing knowledge. This is important because researchers may have different assumptions about the nature of truth and knowledge; thus philosophy helps us to understand their assumptions (Dudovskiy, 2022).

Dudovskiy highlights the importance of discussing research philosophy at a master's level dissertation, which should include the need to specify the research philosophy of the study.

Research assumptions are all essentially philosophical in nature and encompass the common elements, including:

- axiology—beliefs about the role of values and morals in research
- ontology—assumptions about the nature of reality
- epistemology—assumptions about how we know the world, how we gain knowledge, the relationship between the knower and the known
- methodology—shared understanding of best means for gaining knowledge about the world
- rhetoric—shared understanding of the language of research

(Cresswell, 2009)

The research philosophy can be :

Pragmatism recognizes that there are many different ways of undertaking research and consequent interpretation and that no single point of view can ever give the entire picture and that there may be multiple realities" (Saunders, Lewis & Thornhill, 2012). These philosophical assumptions constitute a basic set of beliefs that guide the actions and define the worldview of the researcher (Lincoln et al. 2011).

Positivism: This is based on the idea science is the only way to learn about the truth. Indeed positivism adheres positivists to base their philosophy that only "factual" knowledge gained through observation and measurement, is trustworthy. Positivist research relies on quantifiable measurements that can be analysed statistically (Collins, 2010). This paradigm is often associated with quantitative methods and highly formal rhetoric which focuses on precision, generalizability, reliability, and replicability (Kaushik and Walsh, 2019). Positivist research is based on an approach centred on objectivity, standardization, deductive reasoning, and control within the research process (Creswell, 2013)

Realism is a research philosophy that relies on the idea of independence of reality from the human mind. This philosophy is based on the assumption of a scientific approach to the development of knowledge and can be divided into two groups: direct and critical.

Direct realism portrays the world through personal human senses (Saunders, Lewis & Thornhill, 2012), whilst ***critical** realism* argues that whilst humans experience the sensations and images of the real world, sensations and images of the real world can be deceptive and they do not always depict the real world (Novikov & Novikov, 2013)

Interpretivism, also known as the anti-positivism paradigm, is based on the concept that individuals, in their reasoning, do not have access to the real world, suggesting that their knowledge of the perceived world is meaningful in its own terms and can be understood through careful use of interpretivist procedures. As may be deduced, the phenomenological and ethnomethodological methodologies relating to this concept, which is purely qualitative in nature, does not represent an adequate philosophical concept for this research being conducted in this thesis.

	Research approach	**Ontology**	**Axiology**	**Research strategy**
Positivism	Deductive	Objective	Value-free	Quantitative
Interpretivism	Inductive	Subjective	Biased	Qualitative
Pragmatism	Deductive/Inductive	Objective or subjective	Value-free/biased	Qualitative and/or quantitative

Table 3.1: Positivism, interpretivism and epistemologies (from Wilson, 2010)

3.4 Research Framework adopted for this study

This research study adopts a post-positivist framework. This type of framework differs from positivism in that, whilst the latter emphasizes independence between the researcher and research, post-positivism recognizes that certain aspects of the researcher such as values, theories and background knowledge, could possibly influence what is being observed (Robson, 2022), and recognize the possibility of bias (Miller, 2007).

This researcher recognizes the fact that past influences on her behalf could possibly create some imbalances and possibly biases, which cannot always be identified even after a thorough analysis of the methodology employed throughout this study. For instance, since the researcher was the developer of this Traffic Light System, it could happen that responses or results that are put forth could be unwittingly placed in such a manner as to prefer this system, thus creating a bias. The knowledge related to this effect is important because it enables the researcher to make allowances for this possible imbalance and cater for it by being impartial throughout the whole research process. Thus it is the researcher’s opinion that a post-positivist approach would best reflect the optimal theoretical framework for this research study, enabling the researcher to turn a limitation into an advantage by putting a significant effort to eliminate this possible bias by every possible means.

3.5 Ethics

Research ethics direct the principles of conduct for scientific researchers. Ethical principles are important in order to protect the dignity, rights and welfare of research participants. All research involving human beings should be reviewed by an ethics committee to ensure that the appropriate ethical standards are being upheld (WHO, n.d).

All research must be conducted to high ethical standards. The identification and management of ethical issues (such as appropriate protection and respect for participants) are important steps that must be maintained throughout the research process.

The World Medical Associated produced an important document entitled The Declaration of Helsinsi (WMA, 2013). This states that "*It is the duty of the physician to promote and safeguard the health, well-being and rights of patients, including those who are involved in medical research. The physician's knowledge and conscience are dedicated to the fulfilment of this duty*."

According to Resnick (2015), some principles covered by ethical codes include:

- Honesty and integrity
- Objectivity
- Carefulness
- Openness
- Respect for intellectual property
- Confidentiality
- Legality
- Animal Care
- Human subject protection

One of the fundamental principles in ethics regards ‘informed consent’. The American Medical Association highlights that patients have the right to receive information and ask questions so that they can make well-considered decisions about care. Successful communication in the patient-physician relationship fosters trust and supports shared decision making (AMA, nd).

Informed consent arises from the basic concepts of patient autonomy (Beauchamp and Childress, 2001) and basic human rights (Madhava Menon, 2000). Patients have all the freedom to decide what information should be gathered. No one else has the right to coerce the patient to act in a particular way (Satyanarayana Rao, 2008).

The University of Malta has a Code of Practice to “ensure that the highest standards of integrity and professionalism are observed in the conduct of research at the University”. This document was derived from the European Commission Ethics for Researchers (2013). This was produced in order to observe and comply with all legal, regulatory and ethical requirements in Malta and in countries where research is conducted or participants are from, relevant to the field of study and any funding bodies or collaborative partner organizations (UM, 2019). Among the 13 points mentioned in this document, some important aims are to:

- respect the integrity and dignity of participants
- follow the ‘no harm’ principle’
- Recognise the rights of individuals to privacy and personal data protection
- Honour the requirement of informed consent and continuous dialogue with research participants.

Naturally, as relates to human participation, all points are of great importance and should be strictly adhered to, which they were in this study.

3.5.1 Ethical issues related to the project

As with any research project, any existing ethical issues must be identified so that the ethics review board be made aware of these issues. In this present studies, after careful consideration, 3 main issues that needed to be addressed were found.

Informed Consent: This first principle that must be included in all research project was addressed by including a declaration that had to be ticked before the participant could continue filling in the Google Form. This was preceded by information about the Form, what it entailed and the participant's right not to take part if s/he deemed it thus. Being an online Form, it was not possible to request the participant to sign the form, however it was made clear that 'ticking the box' would imply the participant's agreement to participate in the study.

Vulnerability: Vulnerable participants are a special group of people who require special care when included in a research project. Persons are vulnerable in research either because they have difficulty providing voluntary, informed consent arising from limitations in decision making capacity, situational circumstances or because they are at risk for exploitation (NBAC,2001).

However, since this study aimed to recruit healthcare professionals, they clearly do not fit in this category of participants, it was thus deemed as not being an issue at all as it relates to the ethics approval.

Anonymity: anonymity and confidentiality are key considerations in ethical research practice that dictate professional research guidelines for researchers. Participants need to be made aware what will happen to the data, how they will be reported, whether it will be possible for them to be identified from these data and what the implications of that might be for them (Wiles, 2013).

3.5.2 Ethics approval

Ethical approval was obtained by following the procedures adopted by the University of Malta UREC (University Research Ethics Committee) guidelines (https://www.um.edu.mt/media/um/docs/research/urec/ResearchCodeofPractice.pdf).

According to University of Malta UREC guidelines, there are two methods of applying for ethical approval; an application '*for Review*' and '*for Records*' (Figure 3.3).

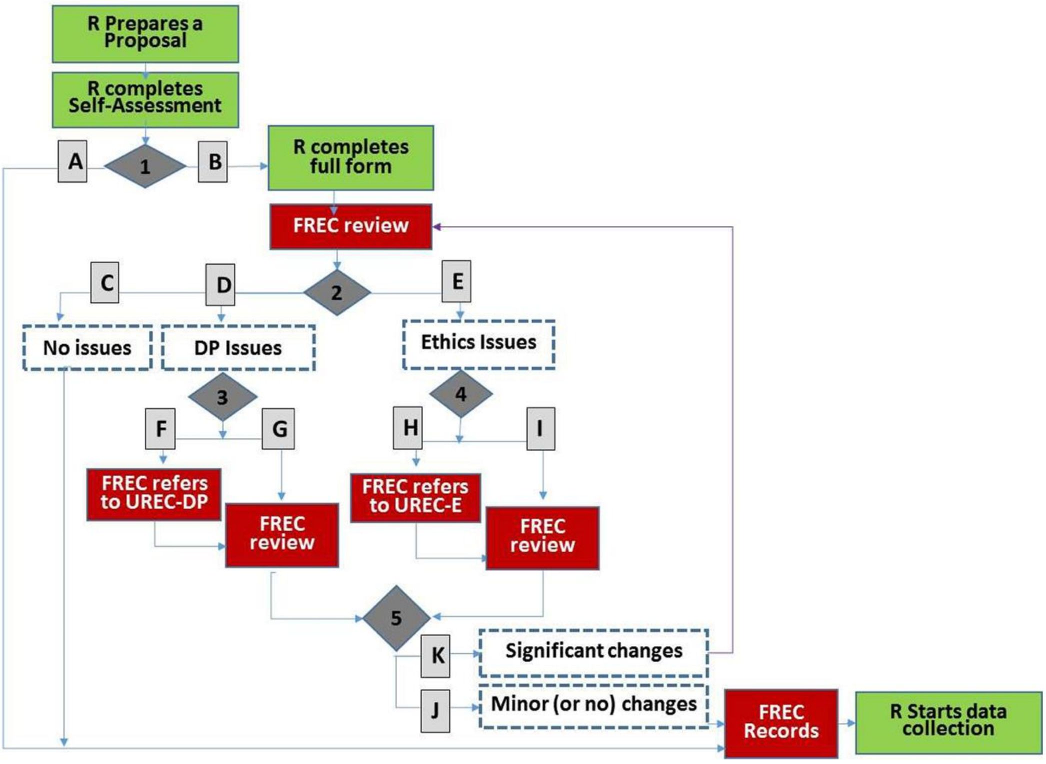


Figure 3.3: Research Ethics Review Procedure (from the UM Ethics Code of Practice)

The outcome of whether the application is referred *for review* or *for records* depends on an assessment that the applicant makes. In the case when ethical issues, such as anonymity, and recruitment of vulnerable persons, the application must be forwarded for review.

When no ethical issues are envisaged, *for records* application can be applied for:

> “the research project has no further Ethical and Data Protection review requirements. In this case, the Researcher sends the completed form to the appropriate FREC for record and audit purposes and the research may commence“ (UREC Code of Practice).

In this application there were no ethical issues identified since the respondents were all qualified and experienced health practitioners. Furthermore, the gait analysis data presented

was fictitional and did not involve any actual patients, thus there were no identifiable means as relates to any actual patients, since it was the presentation of the result that were of interest to this study. Additionally, there were no vulnerable applicants and no issues with anonymity since the Form was an online instrument. Hence this application was sent *for records* and approval was received on 08/05/2020.
(Ethics application may be found in Appendix 1)

3.6. Design process of 'The TRAFFIC LIGHT system of Gait Data Representation'

This process involved various stages through which various iterations were developed and discussed with experts in the field, i.e. experienced gait analysts.

Product development is defined as a series of steps from concept, design, and development to the marketing, production, and management of a new product (Ledbury, 2018).

According to Ledbury (2018), this design process can be divided in 4 distinct phases (Figure 3.4):

1. Discover: seek inspiration, gathering information on what is new and exciting through market intelligence, user inquiry, mind mapping, and design research collectives.
2. Define: identify and establish which are the most important priorities and in what order they are addressed. Definition thus determines the design brief and presents the challenges to the design/development team.
3. Develop: when prototypes are developed, tested, revisited, and refined;

4. Deliver: feedback is gathered, prototypes are selected and approved, and products are finalized and launched

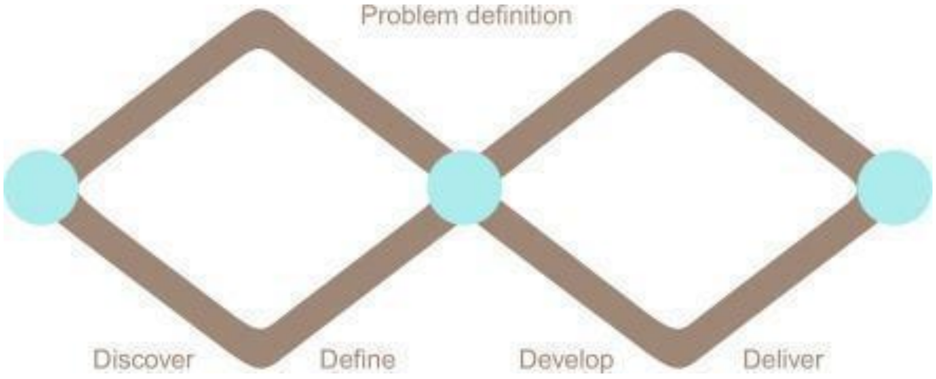


Figure 3.4: from Ledbury, 2018

Thus the design process adopted was as listed above. This helped to streamline the process and to keep the researcher focused on identifying and solving the process of product development, with the product being defined as “An easy to understand, visual system for interpreting gait analysis data.” This research focused on the lower limbs, from the pelvis down to the ankle, in order to facilitate the design and proof of concept of the finished system.

1. **Discover**

Initial thoughts on the possibility of developing a somewhat easier system to understand occurred to the researcher when trying to understand the various outputs given by the optoelectronic motion capture system at the Faculty of Health Sciences, University of Malta. This system consists of 16 infra-red cameras that track the motion of retroreflective markers in order to model the various segments of the lower limbs, i.e. the pelvis, thigh, shin and foot.

This system uses standard procedures and ‘models’, such as the Plugin Gait and the Oxford Foot Model, as used in most gait analysis laboratories abroad. Indeed, this system is used by Mater Dei hospital staff in order to analyze gait of cerebral palsy children prior to the visit of a UK surgeon who would interpret the outputs, together with the help of a team of specialists, in order to plan treatment, including surgery.

One important limitation, from this researcher’s view, is that the various outputs are provided in an engineering format, i.e. 3 graphs per segment denoting movement at each body plane. Whilst these are true representations of the data, there may be various problems associated with the way they are presented. As they are produced from an engineering point of view, they may not be very understandable to persons outside of the engineering professions, which included the majority of clinicians. Additionally, they provide information related to a whole gait cycle, typically from heel strike to the next heel strike (including stance and swing phases), but do not adequately display these phases from a temporal point of view and often it is taken as being 60% stance phase and 40% swing phase, without denoting exactly when the transition happens. It is well known that the normal heel-toe pattern may be altered in pathological gait, such as initial forefoot contact in steppage gait (Baker, 2017), yet this information is not provided in these graphs. Additionally, it is also well known that the stance phase of gait is divided further in smaller phases, with *Initial Contact, Midstance and Propulsion,* being the main sub-phases (Perry, date).

2. **Define**: identify and establish which are the most important priorities and in what order they are addressed. Definition thus determines the design brief and presents the challenges to the design/development team.

Once an issue or a research area, or a product requirement is **discovered**, **definition** of the important priorities is the natural next step. It is very important to be able to come up with the necessary parameters and 'design brief' in order to guide the developer towards a more cohesive design process.

As regards the Traffic Lights System, the important design considerations were identified as being:

- To develop an infographic that would unambiguously convey the nature of the gait analysis results in a manner that could be understood by health professionals
- To simplify the outputs and possibly provide the most important data - it was reasoned that it was better that the interpreter (i.e. the health professional) would be able to understand the most important data than being presented with a daunting amount of graphs that, whilst providing most, if not all, of the gait data relevant to the patient, would cause the interpreter to become confused and consequently not understand anything at all. This would be a case where too much data would be confusing for the health professional-interpreter.
- To present data in an attractive manner that could be understood with little or no prior training. Hence the use of colour and the Traffic Lights System, with which everyone is familiar in other situations.
- To present the data for the most important aspects of the gait cycle; these are undoubtedly Initial Loading (most of the time Heel Strike), Midstance and Propulsion.

These main design specifications, which were defined in an appropriate way, enabled the next step, i.e. the development of the product.

3. **Develop**: when prototypes are developed, tested, revisited, and refined;

This was a crucial part of the whole process; from design concept to development of the ‘product’ was extremely important since a final product is necessary in order to implement the concept of this research project. A detailed overview of the various iterations attempted before reaching the final product are presented in the next section.

4. **Deliver**: feedback is gathered, prototypes are selected and approved, and products are finalized and launched

The final part of the project involved the actual research project presented in this thesis. Before any product, in this case the Traffic Lights System, could be applied for use with actual patients, a rigorous testing phase was required, as described further on in this thesis. This testing phase required that users, both experienced and inexperienced, provide feedback in order to determine the validity and reliability of this system. The determination of validity and reliability, together with relevant feedback, would enable the product to be finalized and launched as explained by Ledbury (2018).

Various iterations of the TRAFFIC LIGHTS SYSTEM OF VISUAL REPORTING

The main concept behind this system was to produce a method that can be more readily understood by those health professionals who, although they manage lower limb musculoskeletal conditions on a regular basis, are not properly trained to interpret traditional movement graphs as output by instrumented gait analysis systems. It is a known fact that the majority of these professionals do not get proper gait analysis training, yet at the same time they treat these lower limb musculoskeletal conditions on a regular basis. To attest to this, the researcher, who is a medical physician, never received any training regarding the matter throughout her medical training. It stands to reason that if a health professional is treating a knee problem, for example, it would be very beneficial for this professional to be able to understand what is occurring during gait, especially during the stance phase of gait when the knee is bearing the weight of the whole body. Such an understanding would permit these professionals to produce better management plans that directly address such knee movement alterations. Thus the importance of such a system becomes evident and will open new opportunities even for gait analysis laboratories to expand their activities and also to diversify their work areas.

As traditionally presented, 3D Gait analysis results are:

- Not easy to understand

  It is difficult for a person without a mathematical or engineering background to piece together 3 graphs that illustrate 3 different movements in 3 body planes. Traditionally, many biomechanists do come from an engineering background, so it is understandable that these graphs are easier to understand and interpret. However, as regards health professionals, these may not have the necessary solid foundations to fully understand these graphs, thus an easier method is required.

- Non-intuitive

  Again, graphs may not be as intuitive, or easy to understand, for those persons with a physiology or health background. Indeed, other systems do include colour charts or topographical maps to further illustrate the results. For example, foot pressure mapping systems almost invariably include both a graphical and a colour topographical chart to illustrate the pressure map, with various shades from blue to red to denote higher pressures (Figures 3.5 and 3.6). This not only makes these charts easier to understand and allows the assessor to instantly identify those areas of high pressure, but they are also so simple that it allows the clinician to explain the results to patients, ensuring better compliance than if just providing graphs.

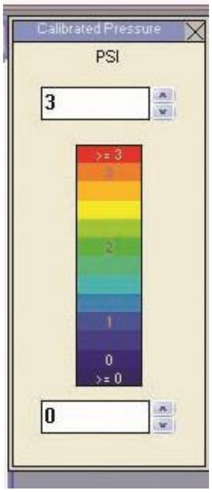
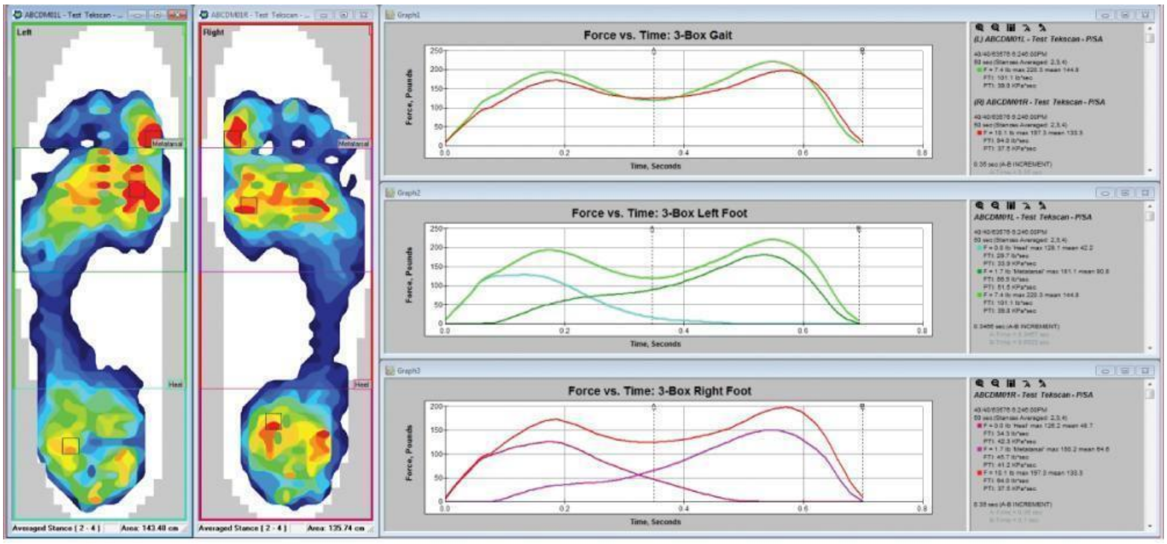


Figure 3.5: Colour scheme denoting extent of Pressure in Tekscan Software



F-Scan 3-Box Analysis segments the foot into three key regions.

Figure 3.6: 2D pressure map, clearly demonstrating the areas where highest pressure is located

Some software systems allow the pressure to be displayed in '3D format", which allows the 'peaks' to illustrate the magnitude of the pressure, allowing for easier visualization of the peak pressure areas, as depicted in figure 3.7.

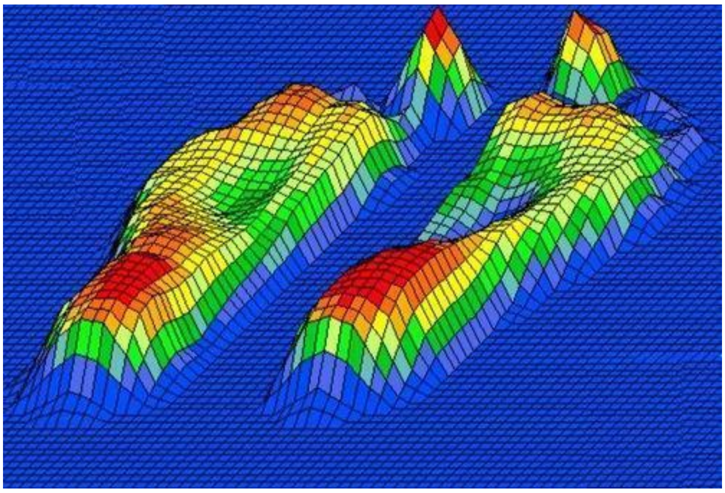


Figure 3.7: 3D pressure maps, with the extent of the peaks, together with the colour, denoting the extent of the pressure

Thus the prolific use of colours and graphics are just a different representation of the data, which they do not change, however which make the output more intuitive to understand.

- Require great expertise to understand
- Lose a lot of temporal data

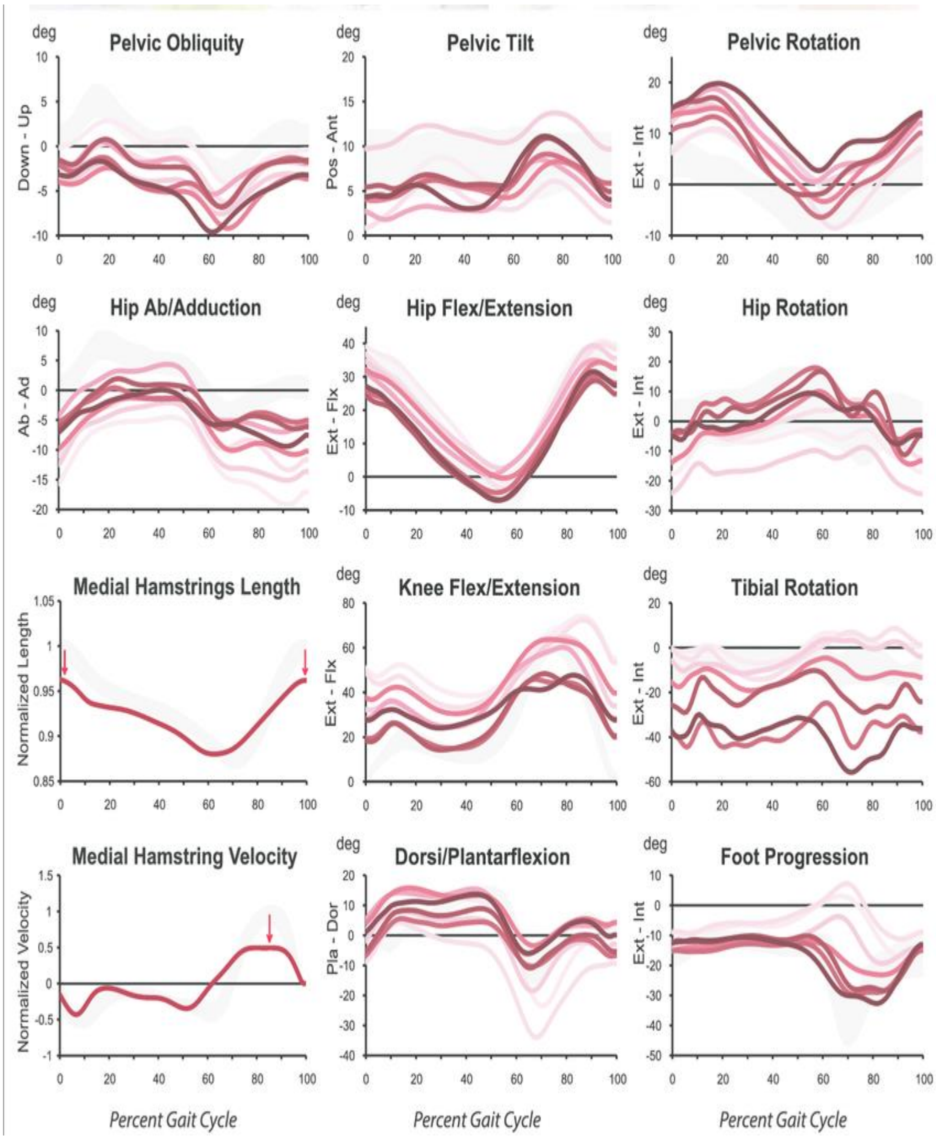


Figure 3.8: The gait cycle as represented by the Traditional Graphical System

The Gait cycle is not just composed of a stance phase and a swing phase, as traditionally presented in gait analysis results (Figures 3.8 and 3.9). These phases are mainly composed of various sub- phases, i.e:

Stance Phase:

- Initial Contact
- Loading Response
- Midstance
- Terminal Stance
- Preswing

Swing Phase

- Initial Swing
- Mid-Swing
- Terminal Swing

(Chapter 2, section 2.2.1)

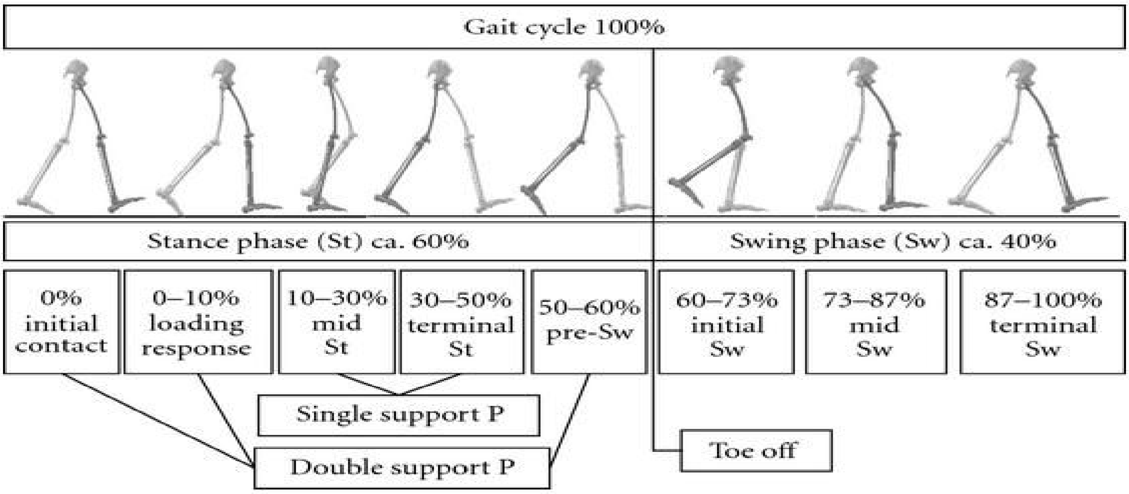


Figure 3.9: Gait cycle phases

These temporal sub-phases could be important when interpreting gait analysis results and these are lost when presenting gait data in the traditional format, as may be seen in Figure 3.10, for ankle joint sagittal plane movement.

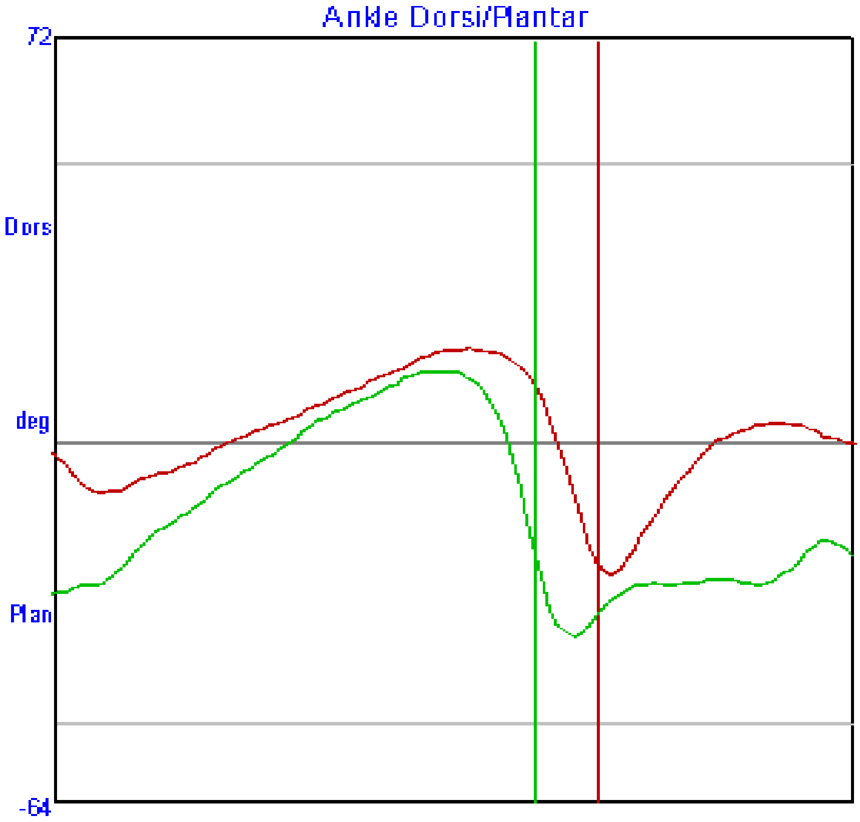


Figure 3.10: Sagittal plane movement of the ankle as presented in the traditional graphing method. Here only a distinction between stance and swing phases may be seen.

If temporal data is inserted in the above graph, with each section denoting the various phases of the gait cycle, more information can be presented to the clinician (Figure 3.11).

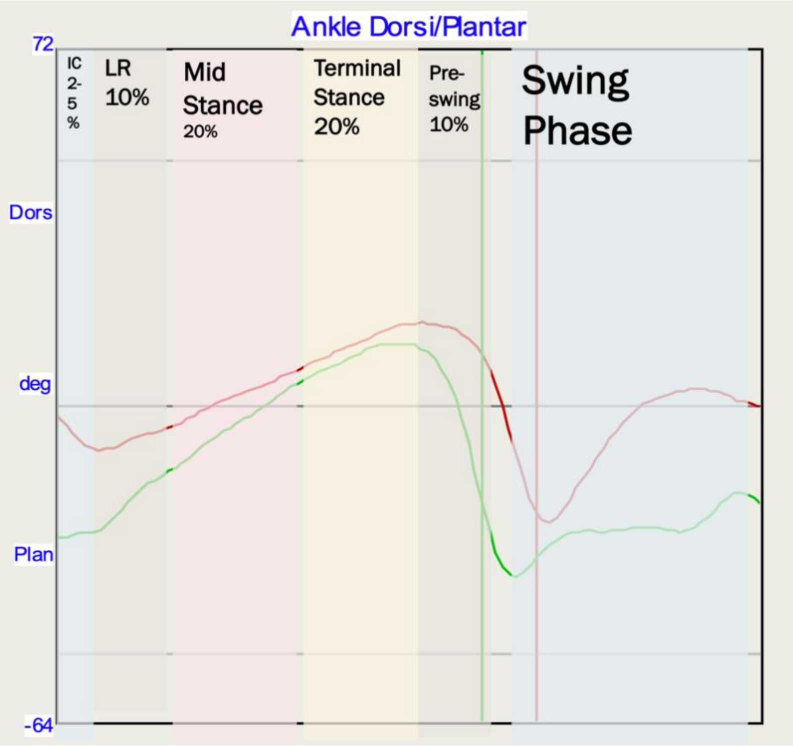


Figure 3.11: Stance phase sub-phases added to the original output of Figure 3.10

These sub-phases may be determined utilizing the output of the Vicon Polygon software, whereby the timing of each phase was manually determined by checking the movement of the lower limbs against the timing of the gait cycle.

The various phases were defined, according to literature (Perry, 1994) as :

Initial contact (IC):

Loading Response (LR):

Midstance (MS):

Terminal Stance (TS):

Thus it becomes evident that new ways of looking at data, utilizing a simpler but perhaps more informative method, for clinical purposes are required. Gait data should be in the realm of the clinician, who does not necessarily find graphs easy to understand.

Requirements for this visual system must clearly be:

- Easy to understand by clinicians
- Represent data for the various phases of the gait cycle
- Be intuitive to use and understand
- Represent both magnitude of motion and temporal data

First iteration:

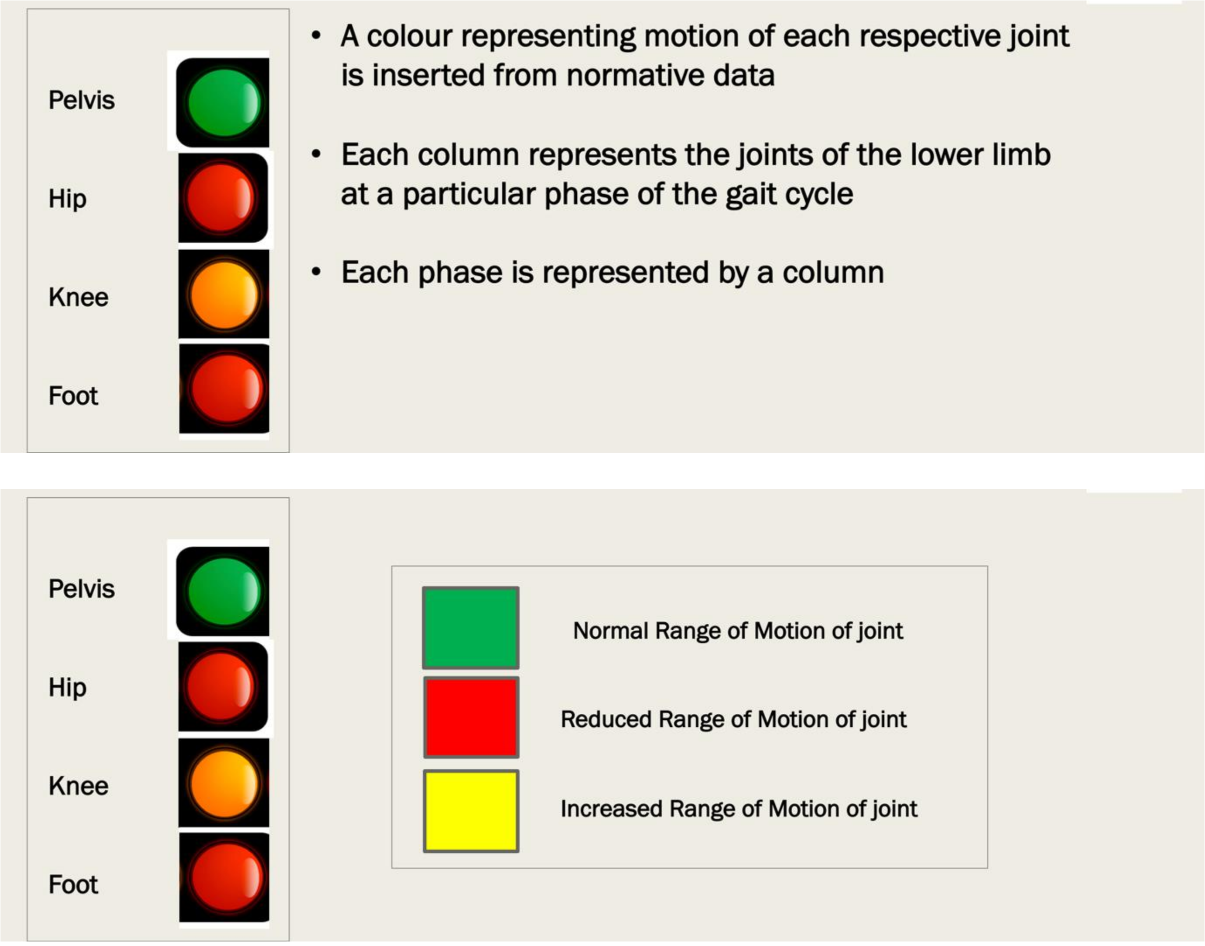
The first iteration of this design (figure 3.12), termed the Traffic Lights System of Visual Reporting of Gait Analysis data, was based on the principle of the said traffic lights, with the 3 colour representing the amount of movement.

In this iteration, the colours represent movements as:

GREEN denoting a normal range of movement

YELLOW denoting increased range of movement

RED denoting reduced range of movement



- A colour representing motion of each respective joint is inserted from normative data
- Each column represents the joints of the lower limb at a particular phase of the gait cycle
- Each phase is represented by a column

🟩	Normal Range of Motion of joint
🟥	Reduced Range of Motion of joint
🟨	Increased Range of Motion of joint

Figure 3.12: First iteration based on actual Traffic Lights

From the above figures, it becomes clear that in the pelvis, there is normal movement, whilst in the hip and foot there is reduced movement and increased movement in the knee (totally hypothetical situation).

For the ankle movement in Figure 3.13, the system represents movement as:

GREEN region: within normative range

YELLOW region: above normative range

RED region: below normative range. (Figure 3.13)

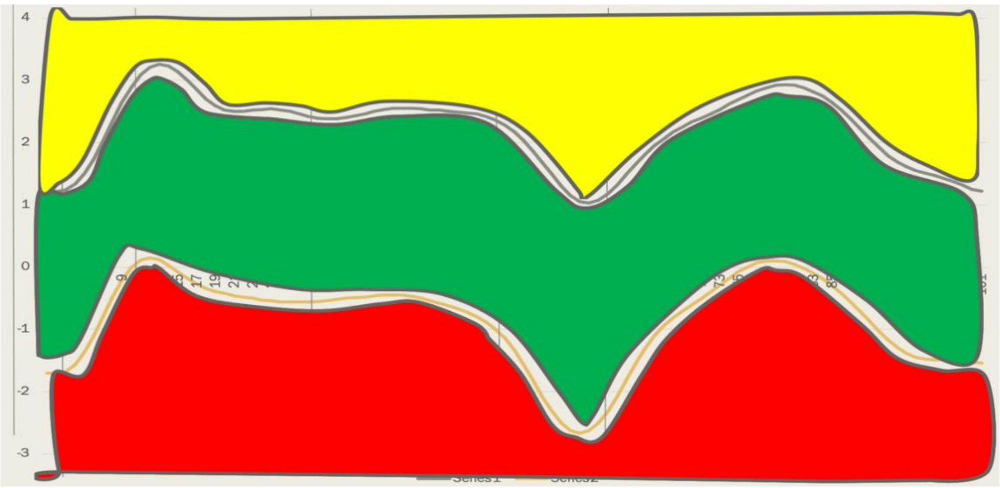
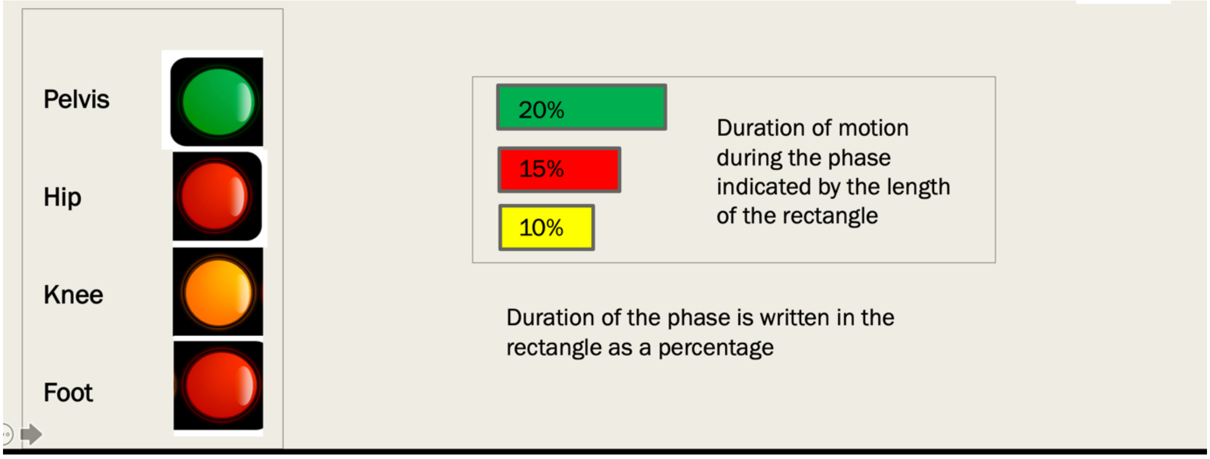


Figure 3.13: Ankle sagittal plane movement demonstrating the 3 regions regions

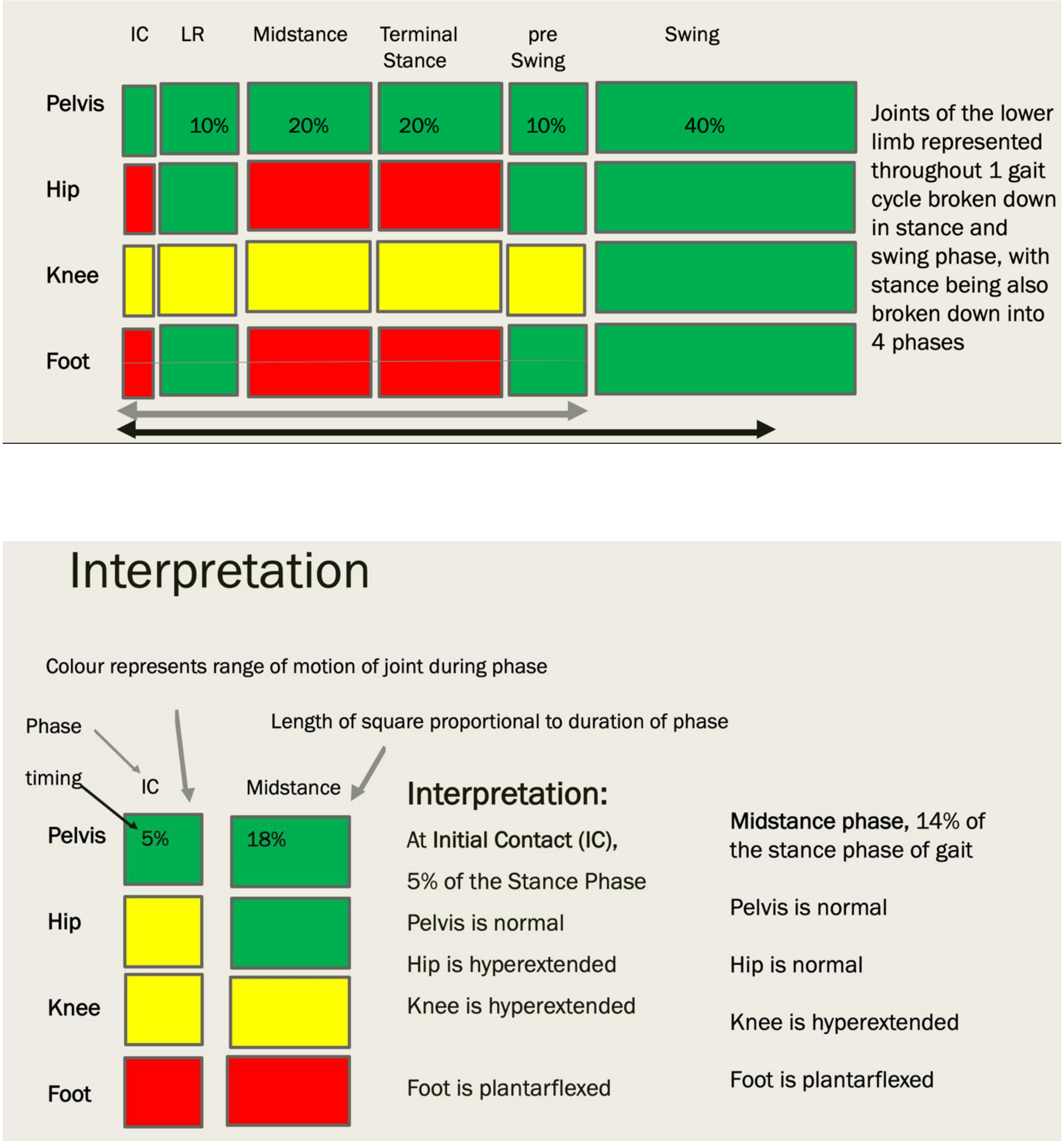
This however, lacks real temporal data. This data could be further added to the system (figure 3.14).



Duration of motion during the phase indicated by the length of the rectangle

Duration of the phase is written in the rectangle as a percentage

Figure 3.14: Adding some temporal data



Joints of the lower limb represented throughout 1 gait cycle broken down in stance and swing phase, with stance being also broken down into 4 phases

Interpretation

Colour represents range of motion of joint during phase

Length of square proportional to duration of phase

Interpretation:

At Initial Contact (IC),
5% of the Stance Phase
Pelvis is normal
Hip is hyperextended
Knee is hyperextended
Foot is plantarflexed

Midstance phase, 14% of the stance phase of gait
Pelvis is normal
Hip is normal
Knee is hyperextended
Foot is plantarflexed

Figure 3.15 a and b: Final envisaged system for the first iteration

Other iterations of the Traffic Lights System

An infographic (**info**rmation **graphic**al) may be defined as a graphic that visually represents information such as data or knowledge in a quick and clear format (Haynes and Newsom, 2004; Smiciklas, 2012).

Since the term ‘clear’ and ‘quick’ are important aspects of infographics, it was decided to design a more ‘organic’ format in the final system. Thus it would be easier to represent a joint as a circle than a box since joint movement is normally in an arc and circles would be easir to associate with lower limb joints of the hips, knees and ankles.

It was also decided to use widely-recognized biomechanical terms to describe the movement in these joints; i.e:

Flexion/extension
Internal/External Rotation
Adduction/Abduction
Plantarflexion/Dorsiflexion

These terms are more widely understood by clinicians.

The colours utilised are quite standard, pertaining to the traditional Traffic Lights System. Thus

Red represents a ‘severe’ condition
Yellow represents a ‘mild‘ condition
Green represents a ‘normal’ condition

The important consideration is at what amount of movement does one draw the line? Between mild and severe, normal and mild?

Although joint ranges of motion vary greatly amongst the general population (Rombaut et al. 2011), literature suggests that joint range of motion above two standard deviations (2SD) from the average may be considered to be hypermobile (Remvig, Jensen and Ward, 2007). An increased joint range of motion may be defined as Generalized Joint Hypermobility, usually associated with chronic muscoluskeletal conditions (Engelbert et al. 2017). This clearly shows that increased range of motion above 2SD may be pathological and thus 2SD was considered as the ideal cut-off between mild and severe conditions.

Normal gait variations include motions up to 1SD. Thus up to 1SD is considered as **normal**, *green*, between 1 and 2SD as **mild**, *yellow*, and >2SD as **severe**, *red* (figure 3.16).

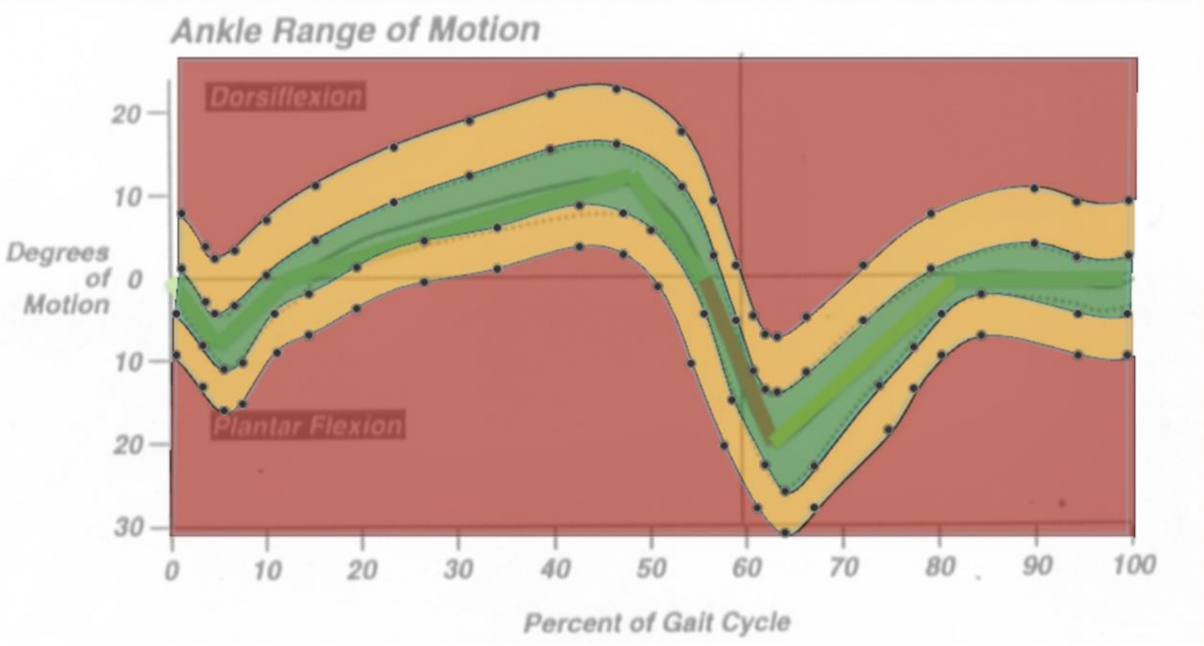


Figure 3.16: Representation of colours in an ankle sagittal plane graph, as represented by the TLS. Green represents normative range +/- 1 SD; Yellow represents +/1 2SD; RED represents movement more than 2SD

Figures 3.17 to 3.22 represent other iterations designed:

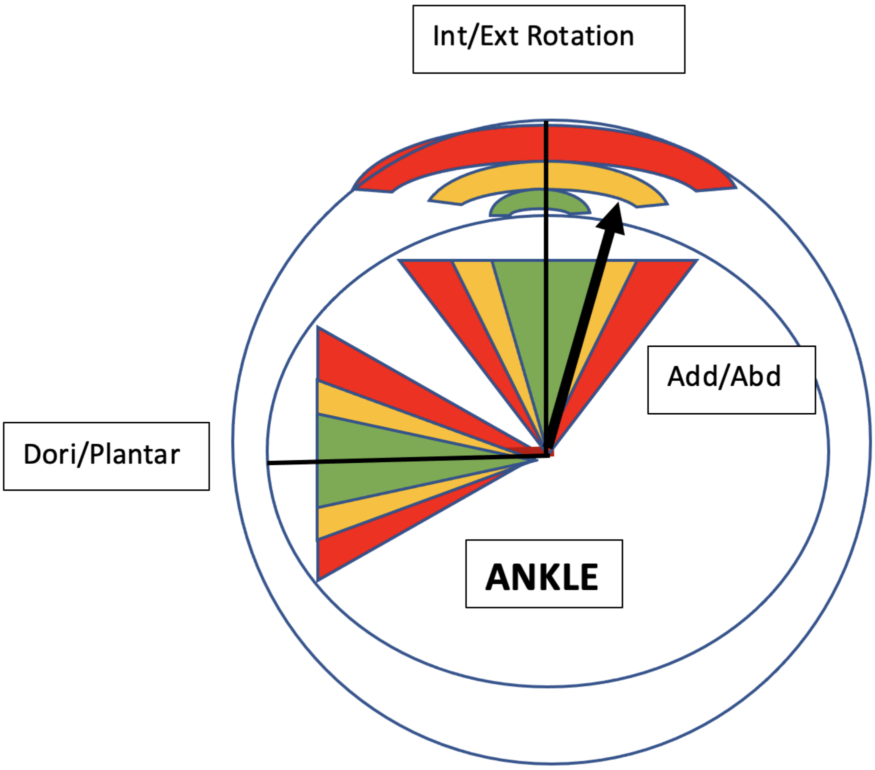


Figure 3.17: A 'watchface' representation

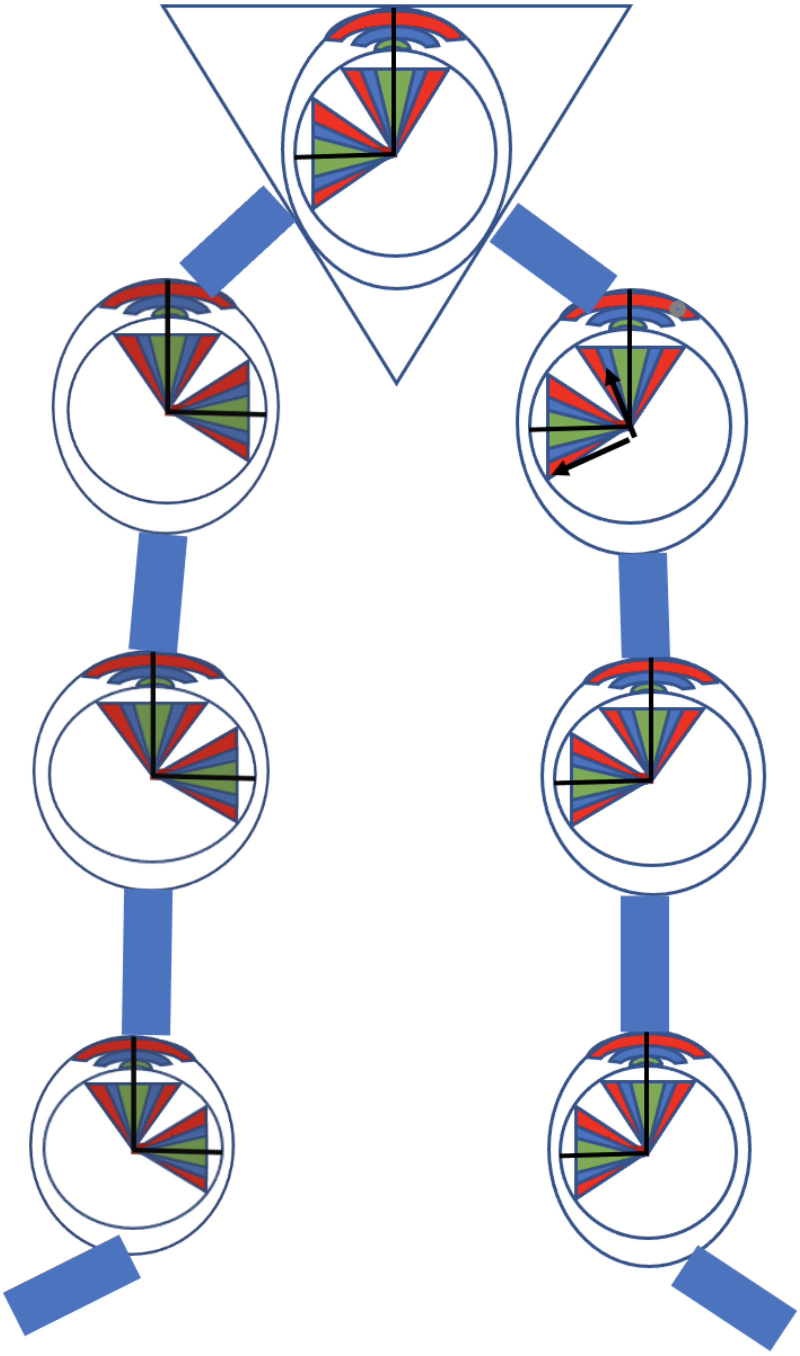


Figure 3.18: The watchface representation as a lower limb kinetic chain representing the pelvis, hips, knees and ankles.

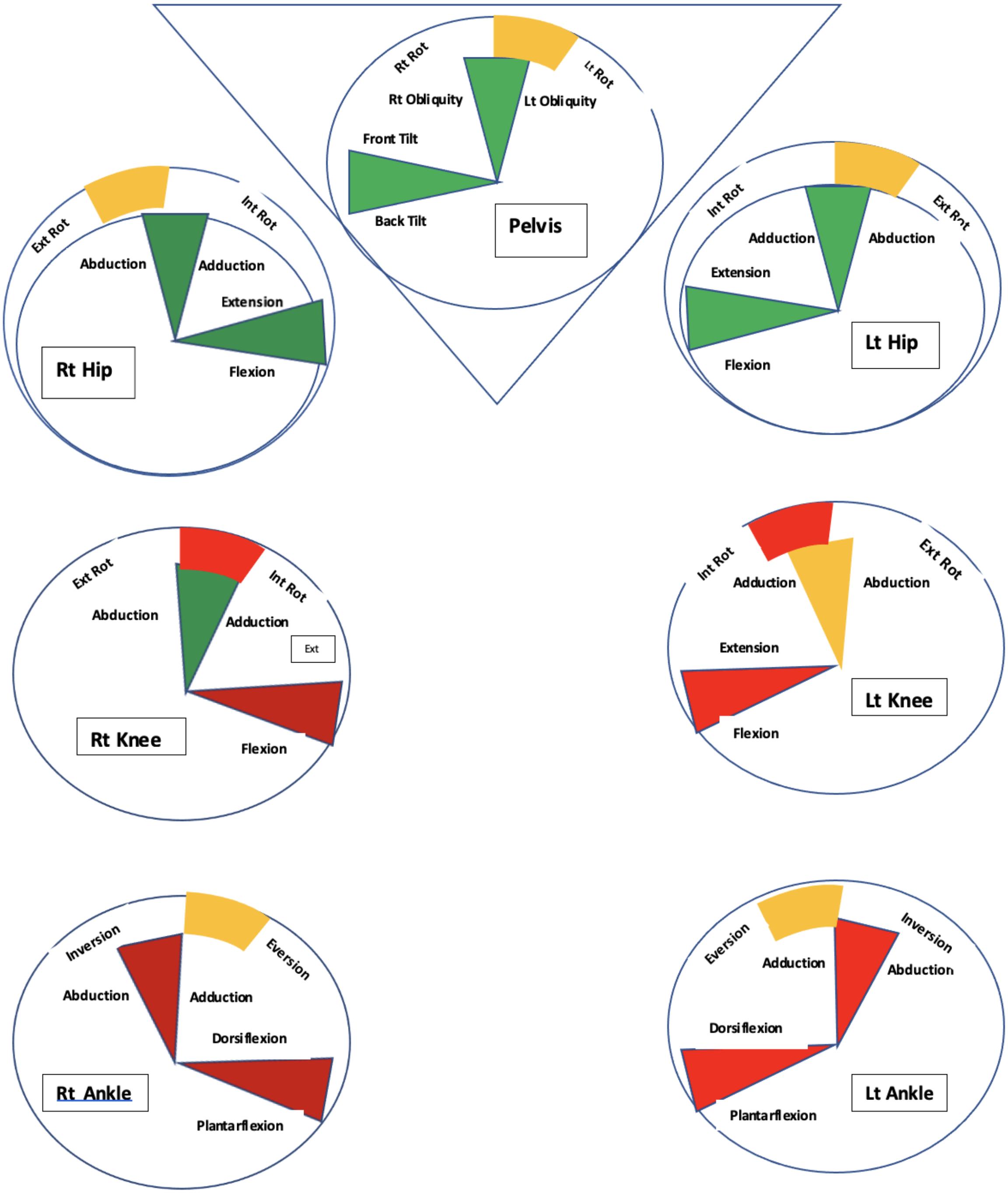


Figure 3.19: introducing the concept of a whole lower limb kinetic chain; pelvis, hips, knees and ankles

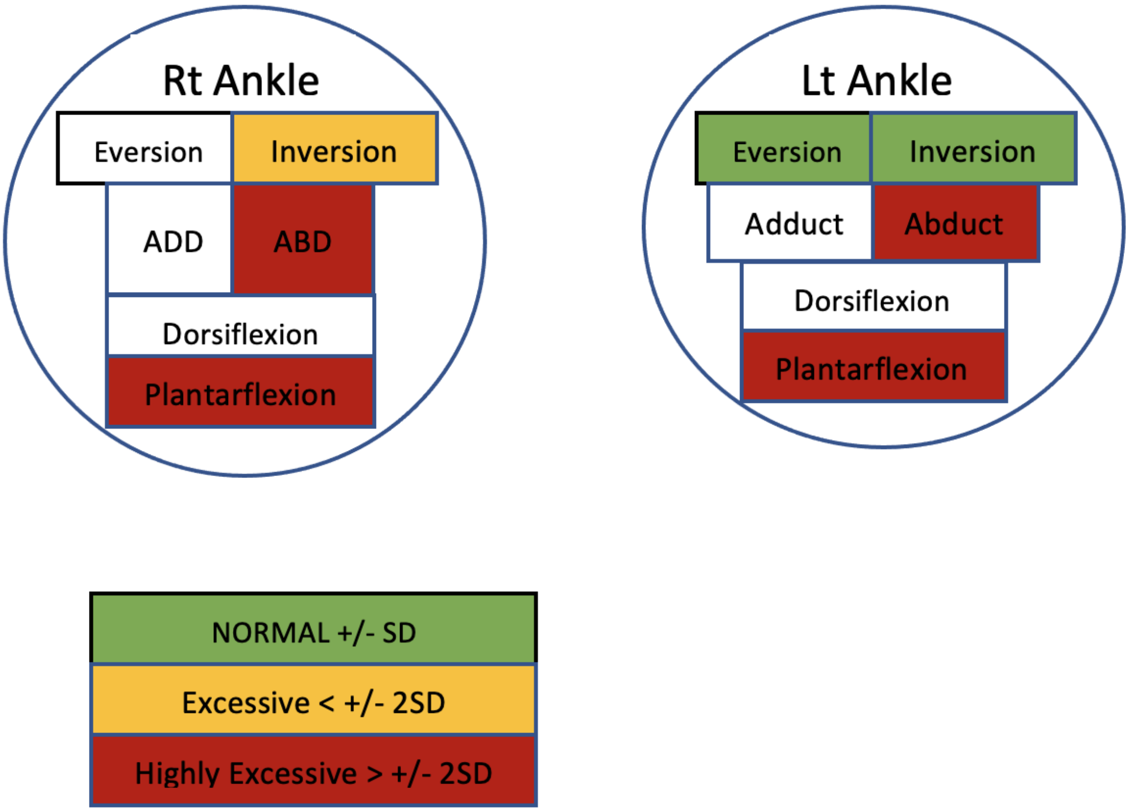


Figure 3.20: simple description of movement in a 'joint' circle, with amount of movement represented by colours

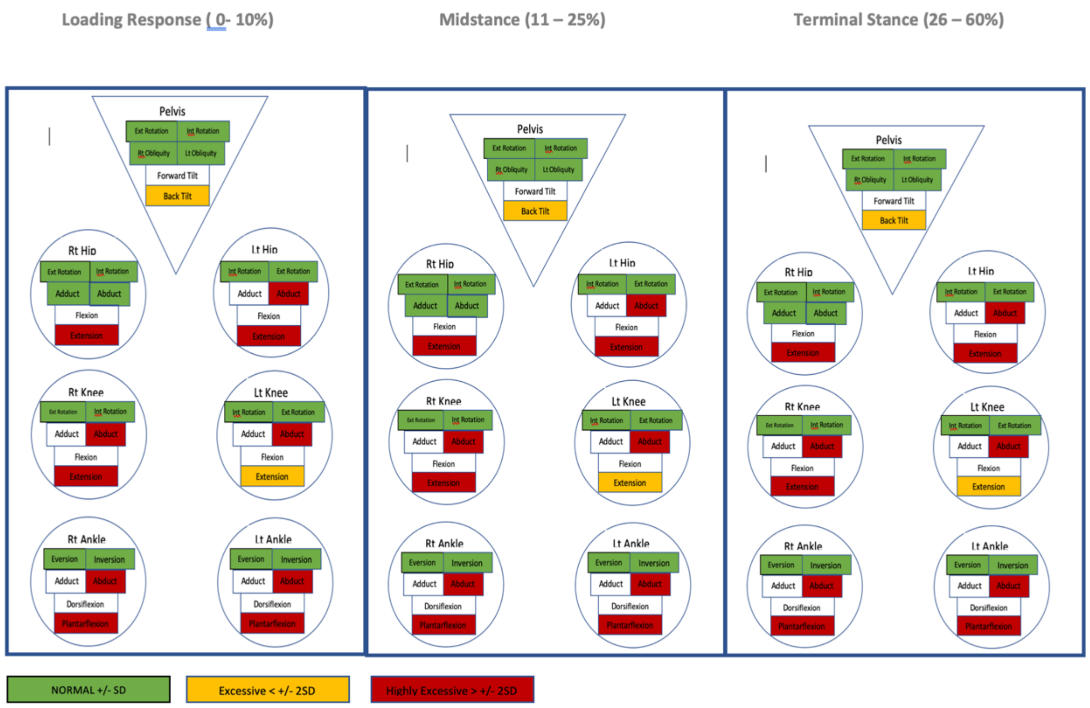


Figure 3.21: as previous figure, but also introducing the concept of dividing the stance phase of gait into 3 temporal phases; loading response, midstance and terminal stance

Another Possible Iteration of the TLS

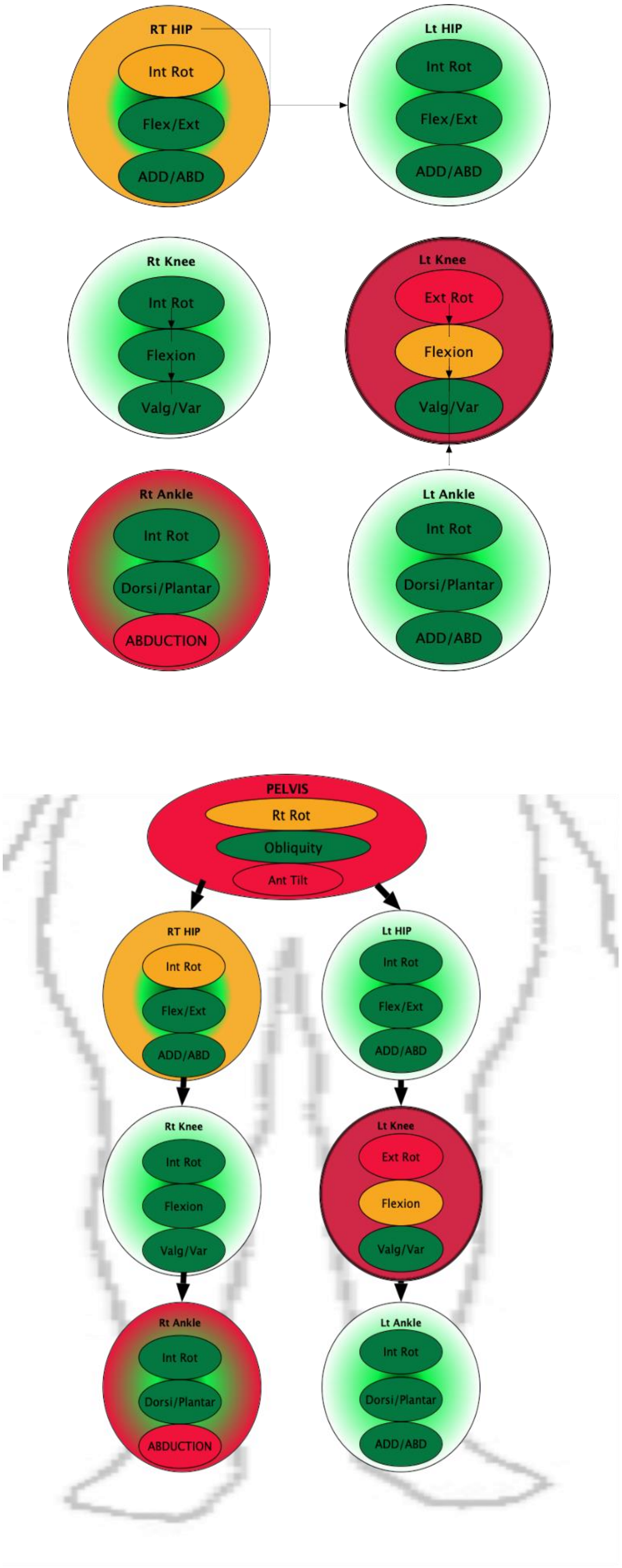


Figure 3.22 a, b: Another possible iteration of the TLS

Figure 3.23 represents the final version of the Traffic Lights System

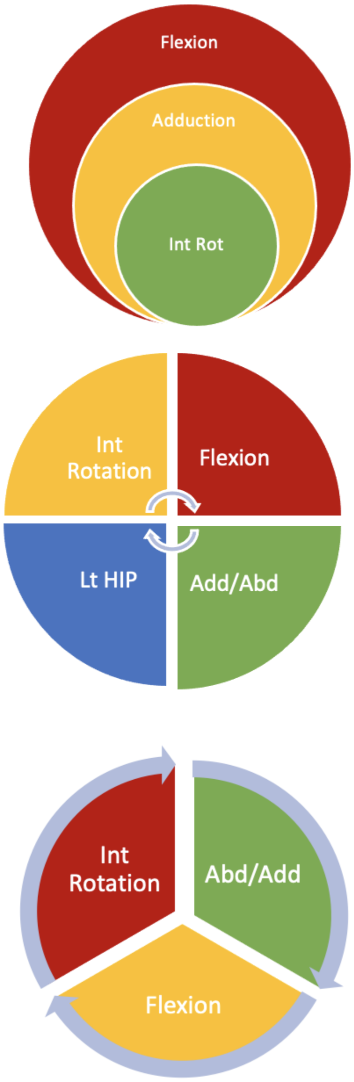


Figure 3.23: last iterations for the Traffic Lights System

The final chosen infographic to represent the amount and quality of motion in the joints was based on the lowest infographic in Figure 3.23. This was ultimately chosen for the main reason being that it is a shape readily available in Microsoft Word (figure 3.24).

In Word, Insert > Smartart> Cycle >

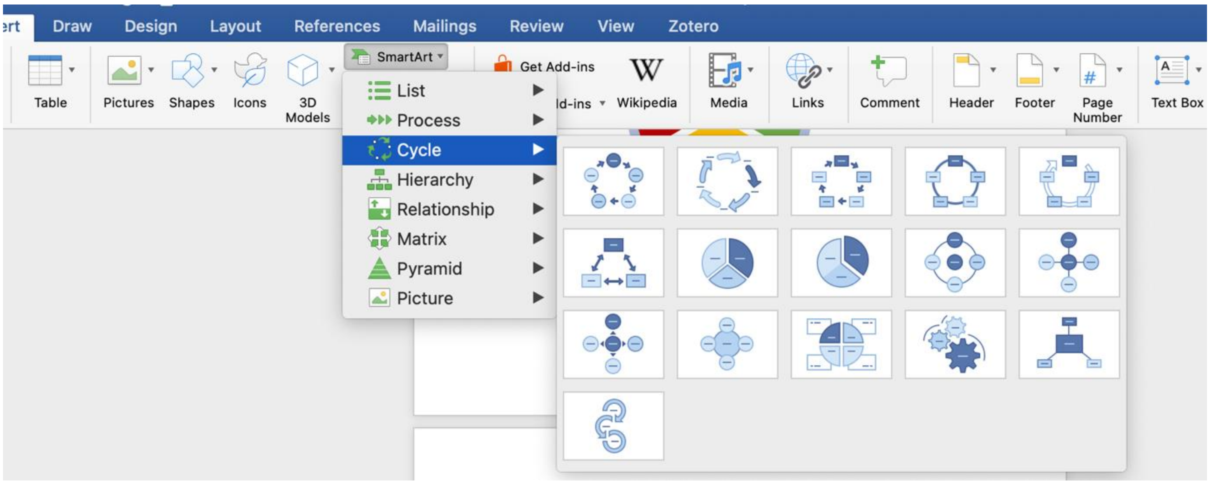


Figure 3.24 a and b: The infographic in Microsoft Word

Then the 3 regions’ colour was changed and the text was changed accordingly.

This ensures that this can easily be adapted by other researchers.

In order to make it attractive and provide graphical meaning, a background graphic was used to depict the location of the nodes; i.e. the pelvis, the hips, knees and ankles. This graphic was included 3 times to represent the *temporal* aspect of the stance phase of gait, taking ‘snapshots’ at Initial Loading, Midstance and Terminal Stance (figure 3.25).

For the purpose of this study, in order to avoid ‘overcrowding’, the diagrams were divided into one diagram for the Pelvis and hips and another diagram for the knees and ankles.

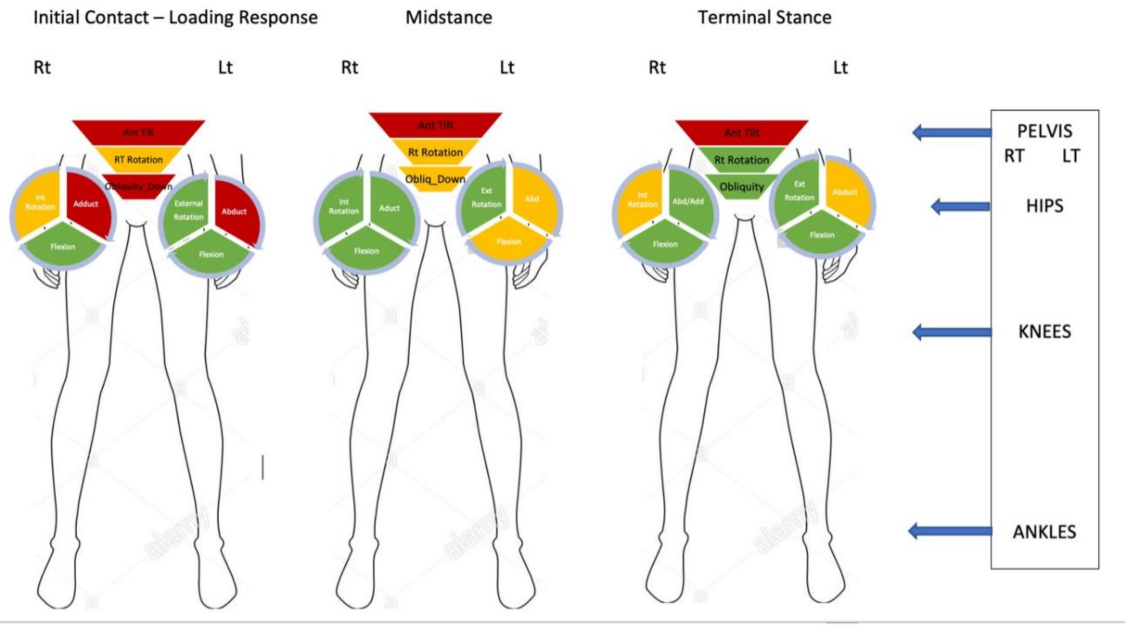


Figure 3.25: The TLS representing the Pelvis and Hips. The arrows on the left denote the level of the joint

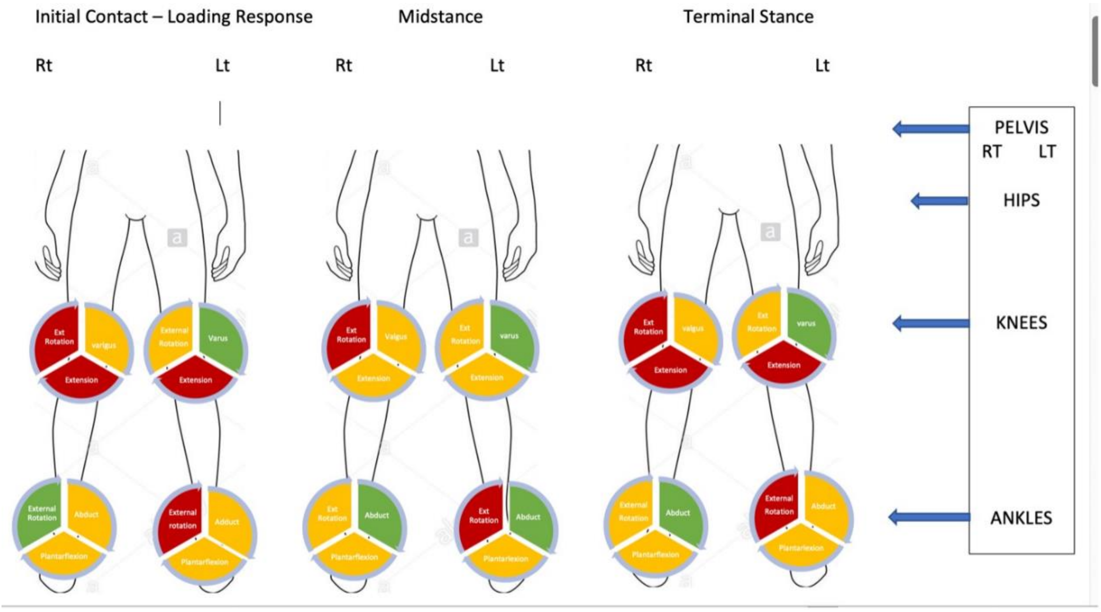


Figure 3.26: The TLS for the knees and ankles. The blue arrows denote the level of the joints

3.7 Methodology

In order to produce the data for analysis by both the Traditional Graphical Output (TGO) and the new proposed Traffic Lights System (TLS), an instrumented gait analysis needed to be performed., representing various types of gait patterns. Since the type of data itself was not deemed to be important, and for ethical reasons not to involve actual participants who would be required to walk and perform a lengthy gait analysis session not for their gain, it was decided to simulate the walking pattern by an experienced gait analyst. The type of data was not deemed important because the study centers on the *outputs* of the analysis (i.e. the graphical results), and whether these outputs could be reliably interpreted by the raters.

For this reason, a gait analysis session was scheduled at the Clinical Biomechanics Laboratory at the Faculty of Health Sciences, University of Malta. Two experienced gait analysts were involved in this session. Analyst A took on the role of the patient, whilst Analyst B performed the actual marker placement and directed the gait analysis session as what would happen in real scenarios. Analyst B was a highly-trained and experienced physiotherapist who regularly performed gait analysis sessions for the over 10 years at hospital level in the same laboratory, thus ensuring familiarity with both the surroundings and equipment used. His experience included regular gait analysis sessions mainly with children with neurological and/or musculoskeletal disorders, most often prior to orthopaedic surgery. His prior training included training at Oxford Gait Laboratory, which is part of Oxford University Hospitals in the United Kingdom and is a world leading centre in this area.

3.7.1 The Laboratory Setting

The gait analysis was performed at the Clinical Gait Analysis Laboratory at the Faculty of Health Sciences, University of Malta (figure 3.27). This 10 metre laboratory's main focal point was a 1.5m wide custom-built walkway that traversed the whole length of the lab.

The lab is equipped with 16 optoelectronic motion capture cameras running through a Vicon ethernet system. These 16 networked cameras are strategically placed around the perimeter of the laboratory, on a rail running just below the ceiling, in order to obtain a vantage view of the walkway, on which a calibrated volume would be constructed once the system was calibrated. All cameras are connected to a central vicon control unit, referred to as a Giganet in Vicon terminology, to control hardware connections of all cameras to the central processing computer (figure 3.28).

Figure 3.27: The Clinical Biomechanics Lab at FHS

Figure 3.28: Vicon Giganet rear view, showing all camera and network connections

The Lab is also equipped with two AMTI Optima forceplates set flush in the centre of the walkway. These forceplates were utilised to detect foot contact and foot-off to automatically define the stance and swing phases of gait, as used in standard practice (figure 3.29).

Figure 3.29: The AMTI Optima Forceplate

3.7.2 Motion Capture Cameras

A Vicon 16 camera optoelectronic motion capture system (Oxford Metrics, UK) was used as the system for capturing the simulated motion. This is the standard equipment used world wide for acquiring gait analysis data

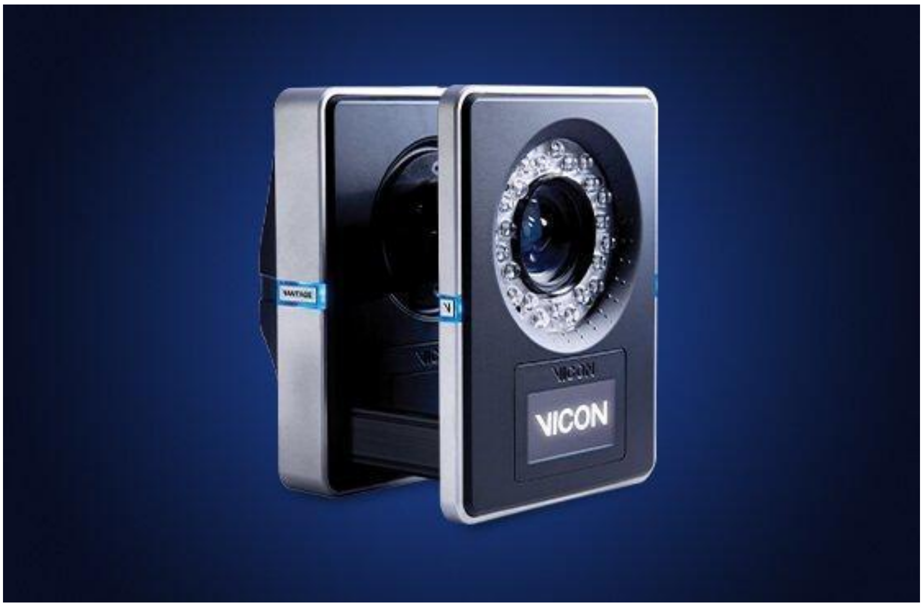


Figure 3.30: Vicon Vantage Camera

Six (6) Vicon Vantage V5 cameras are standard equipment in this lab. These are wide NIR Wide Optics Cameras with a custom 5 Megapixel sensor @ 420FPS at full frame. A wide FOV package with 8.5mm Lens and 70 degree secondary optics. High-powered NIR LED Strobe @ 780 nm.

Ten (10) Bonita cameras (figure 3.31) complete the full complement of capture cameras. These are smaller-resolution cameras; the important issue in gait labs is that there are enough cameras to enable each retro-reflective marker to be seen by at least two cameras during movement, as it may be hidden from view, such as the arm covering the pelvis marker. Although a gait lab would function with 8 or even 6 cameras, having a full complement of 16 cameras ensures that the good quality of data. For instance, at the world leading Oxford Lab, there are 12 cameras.

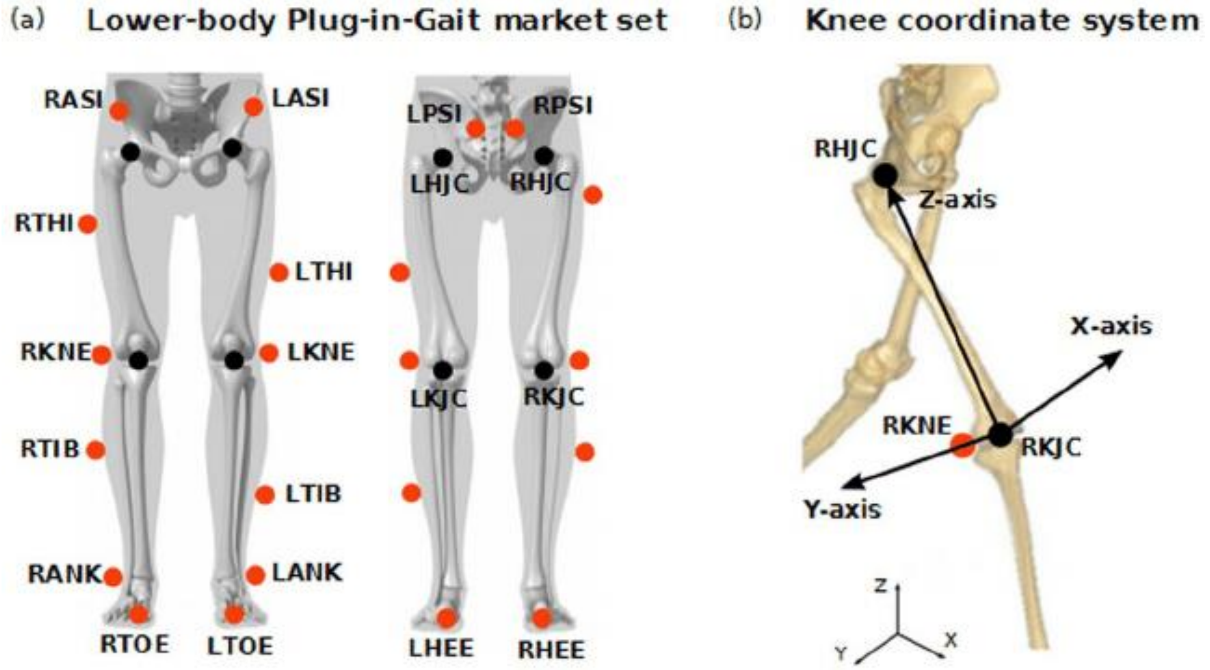
Figure 3.31: Vicon Bonita Camera

Specifications of Bonita Cameras

Frame Rate	250 fps (frames per second)
Resolution 1 megapixel	(1024 x 1024)
Lens Operating Range	Up to 13m
Angle of View Wide (4mm)	70.29° x 70.29°
Angle of View Narrow (12mm).	26.41° x 26.41°

3.7.3 Gait Model

The gait model used for capturing pelvis and lower limb kinematics was the Vicon Plugin Gait Model, which is the Vicon implementation of the traditional Helen Hayes model (Baker et al. 2017). This is widely used throughout the world as a standard model for this purpose. This model utilises 18 retro-reflective markers to model the lower limb and pelvis segments. Since 3 markers are required to mark a segment, with the assumption that these models are rigid, this model can thus model the pelvis, Left and Right Thigh, Left and Right Shank and Left and Right Foot (figure 3.32).


(a) Lower-body Plug-in-Gait market set

(b) Knee coordinate system

Figure 3.32: Plugin Gait marker placement (Vicon Documentation)

This highly validated marker set (Baker et al. 2017) can thus measure the inter-segmental movement of each rigid segment, as outlined in Figure 3.33 below.

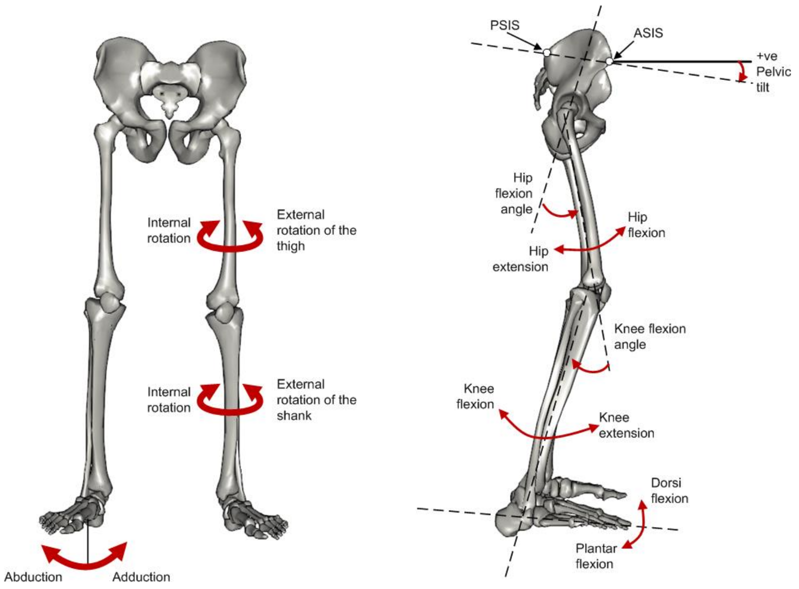


Figure 3.33: Movements at each segment that can be measured by Plugin Gait Model (Vicon Nexus Documentation)

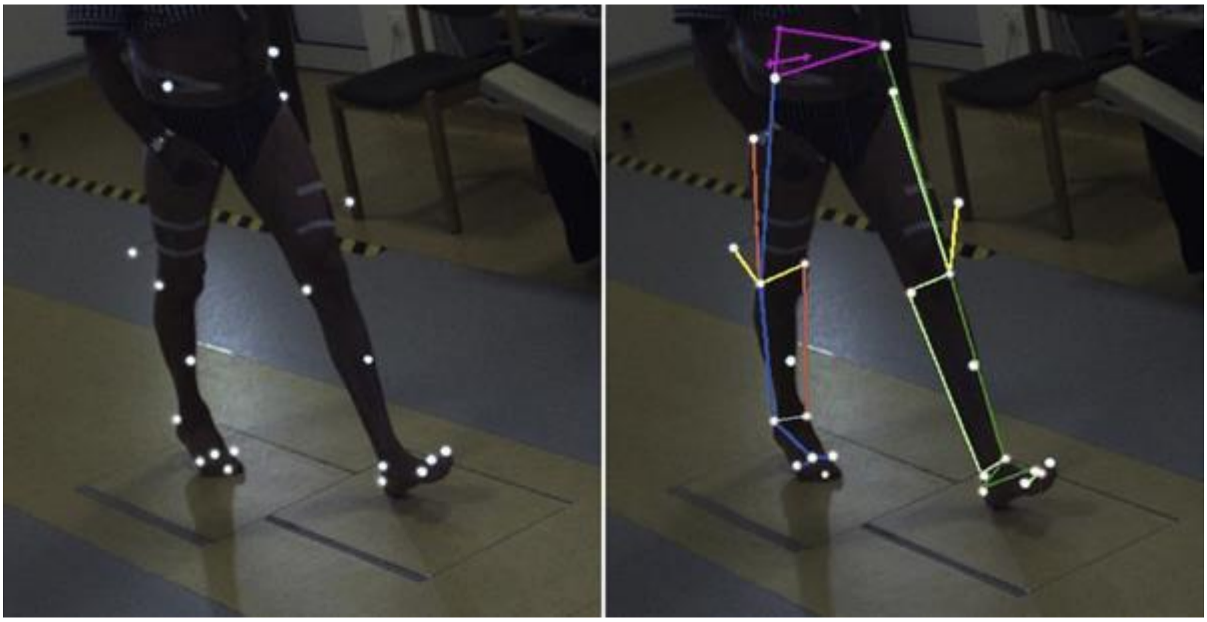


Figure 3.34: Markers during capture

3.7.3 Kinematic data collection method:

Calibration of the Vicon system was performed according to the manufacturer's instructions. This involved the use of a wand that is waved around in the expected capture volume so that each camera can 'learn' its position in relation to the other cameras and the forceplates.

The wand (Figure 3.35 below) has light emitting diodes that can be seen by the cameras. Once calibration was complete, the origin of the lab coordinate system was established by placing the wand on the right corner of the first AMTI forceplate, again as per standard practice required by the Vicon Nexus software that was then utilised to record and calculate each marker's position.

Figure 3.35 a and b: Calibration Screen and Calibration Wand

Anthropometric Measurements

The Plugin Gait model requires the anthropometric measurements of:

- Left Anterior Superio Iliac Spine (ASIS) to Right ASIS
- Leg Length, from ASIS to Lateral Malleolus
- Knee width
- Ankle width

Knee and ankle width were measured using a Lafayette anthropometer, whilst the other measurements were taken using a measuring tape.

Marker Placement

9mm Vicon retro-reflective markers were used to mark-up the subject as per Plugin Gait model shown in Figure 3.32. Extra care was taken for proper placement as this is an essential issue with gait analysis in order to ensure valid results (Tsushima et al. 2003)

The subject then walked along the walkway, imitating various gait styles that included styles of ‘bilateral equinus’, ‘bilateral arthrodesis’, ‘foot slap’ with the cameras recording the movement at 100Hz. 5 recordings were made of each gait style to ensure reproducibility.

Once recordings were acquired, the quality of the data was assessed – mainly if all the markers were captured throughout the recorded period and if there were any gaps in the traces. However, with the large number of cameras in place, there were no gaps that needed filling, thus confirming the quality of the data. All trials were then visually checked with each other to determine whether there were any captures that necessitated exclusion because of any quality issues.

Data were then processed in Vicon Polygon version 4.4.6 in order to produce the graphic outputs as would be normally done when producing gait analysis reports. An example is shown in Figure 3.36 below. This figure shows the data as it is produced by the Traditional Graphic System. Each row relates to the 3 motions in a particular segment, starting at Pelvis, then hips, knees and ankles. The green band represents the normative data that is available in the lab. This normative data, that takes the form of a .pcx file in the Vicon software, is the mean movement of each segment acquired from 50 adults with no history of any musculoskeletal conditions. The red line represents the left side of the body, and the green line represents the right side. Thus, for example, in the Knee joint, the motions of Flexion/Extension, Abduction/Adduction and Rotation of both the right and left knees are represented with reference to the normative data for comparison.

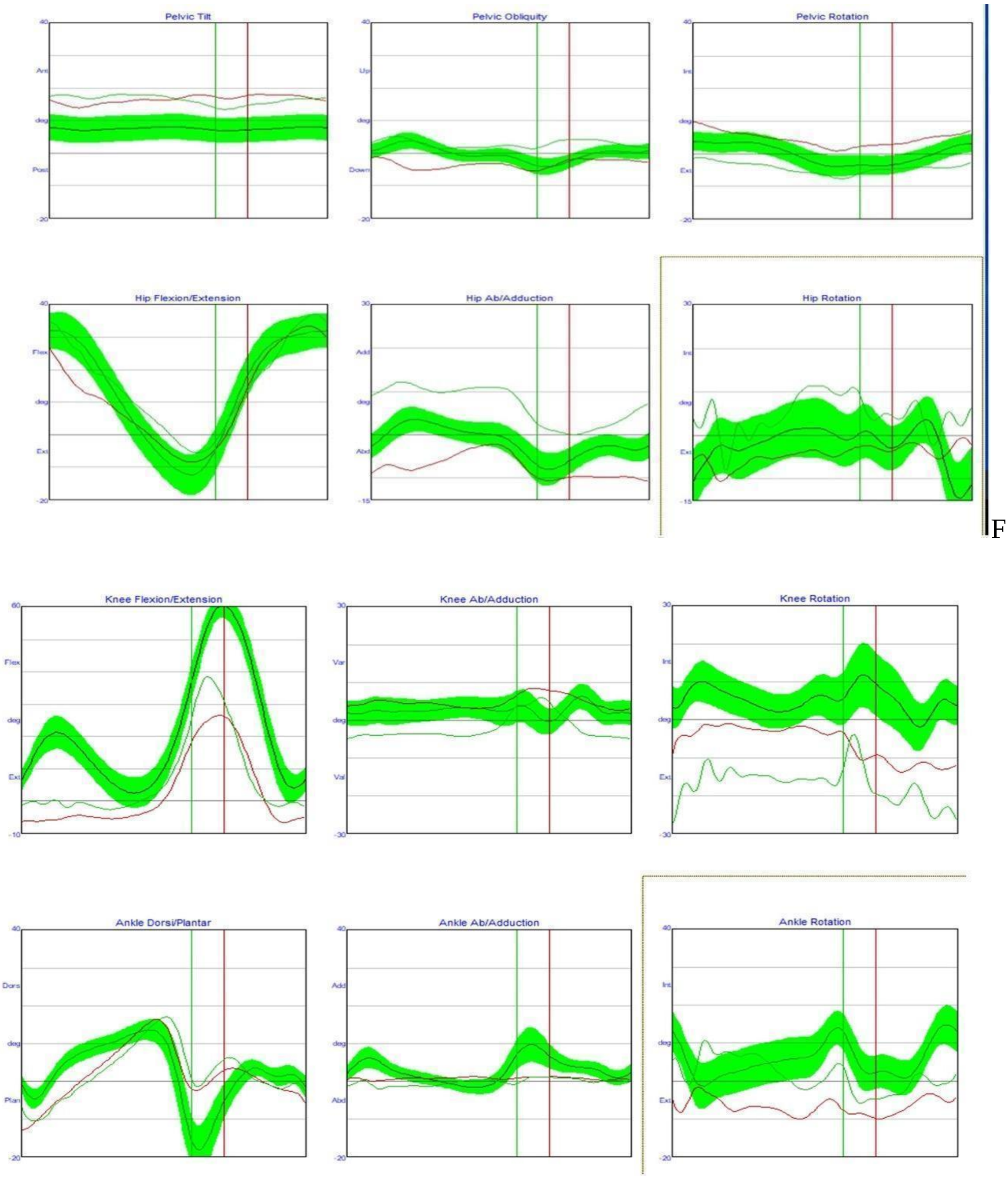


Figure 3.36: Graphical Output

Transfer of Gait data from the Traditional Graphs to the Traffic Light System

Normative Dataset

Before discussing how data was converted into the TLS, a note on normative data is warranted.

The availability of age-matched normative data is an essential component of clinical gait analyses. This is because a main objective of gait analysis is to identify deviations in a patient's gait from 'normal' movement patterns (Chester et al. 2007). Each gait analysis laboratory compiles a list of data for particular subject groups, such as male adults, female adults, hemiplegic gait, and so forth. This is very important because conditions may vary from one laboratory to another resulting in slight variations in data. Thus, although there is normative data for each joint, because even through physiology it is known how each joint functions, each patient’s gait analysis data needs to be compared for possible deviations. Thus, the Vicon system provides a .pcx file that would be the mean value of X number of participants that represent a normative population.

In this instance, the normative population consisted of 44 males with no known musculoskeletal conditions or health issues such as diabetes, neurological conditions and other conditions that could affect gait. This dataset contains 100 data points, outlining the mean value and another 100 data points as Standard Deviation values, as obtained from this population. This makes it possible to plot this .pcx file overlying a particular patient’s data, in order for the analyst to be able to determine whether the data falls within or outside of a normative band. This is shown in figure 3.36, with the green band representing the area within which movement would be considered as ‘normal’.

It was initially envisaged that in order to transfer the Graphical outputs to the Traffic Lights System, the design of an automated method would be investigated. This would have been possible because, once knowing each data point and the normative data, one can determine whether each data point falls within the green, yellow or red regions. Indeed, the researcher worked on two possibilities to perform this task; initially a Microsoft Excel spreadsheet, which calculated each data point relative to its equivalent data point in the normative data, then printed out a chart depending on its position. Figures 3.37 and 3.38 below illustrate the dashboard of this excel spreadsheet, which is updated from data in other tabs pertaining to the pelvis, hips, knees and ankles.

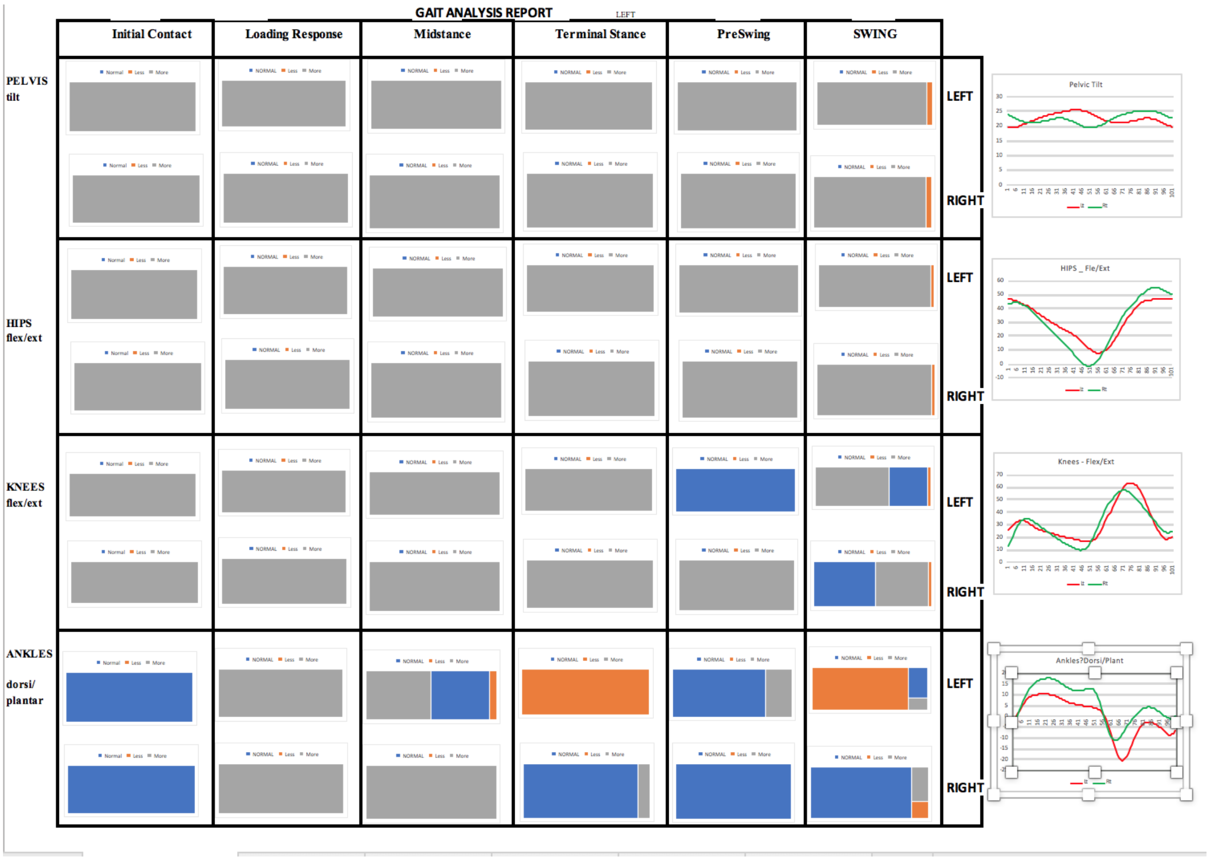


Figure 3.37: Microsoft Excel Dashboard

The figure below shows a typical calculation tab in Excel, giving the Left Knee flexion/extension as an example. As may be seen, normative data provides two values for each of the 100 data points (100 data points because the system was recording at 100 frames per second). These are the mean value, together with its standard deviation.

In the first column, it may be seen that the data derived from the Vicon Nexus software was divided into 3 main parts relating to Initial Contact (IC), Loading Response (LR) and Midstance (MS). These were collected individually for each trial since they can vary.

> IC was defined as the first point of contact at the start of the gait cycle
>
> LR was defined as that point in the gait cycle when the leading foot was in full contact with the ground
>
> MS was defined as the point when the body was supported by one leg
>
> (Loudon et al. 2008)

Column C provides the mean value of each data point

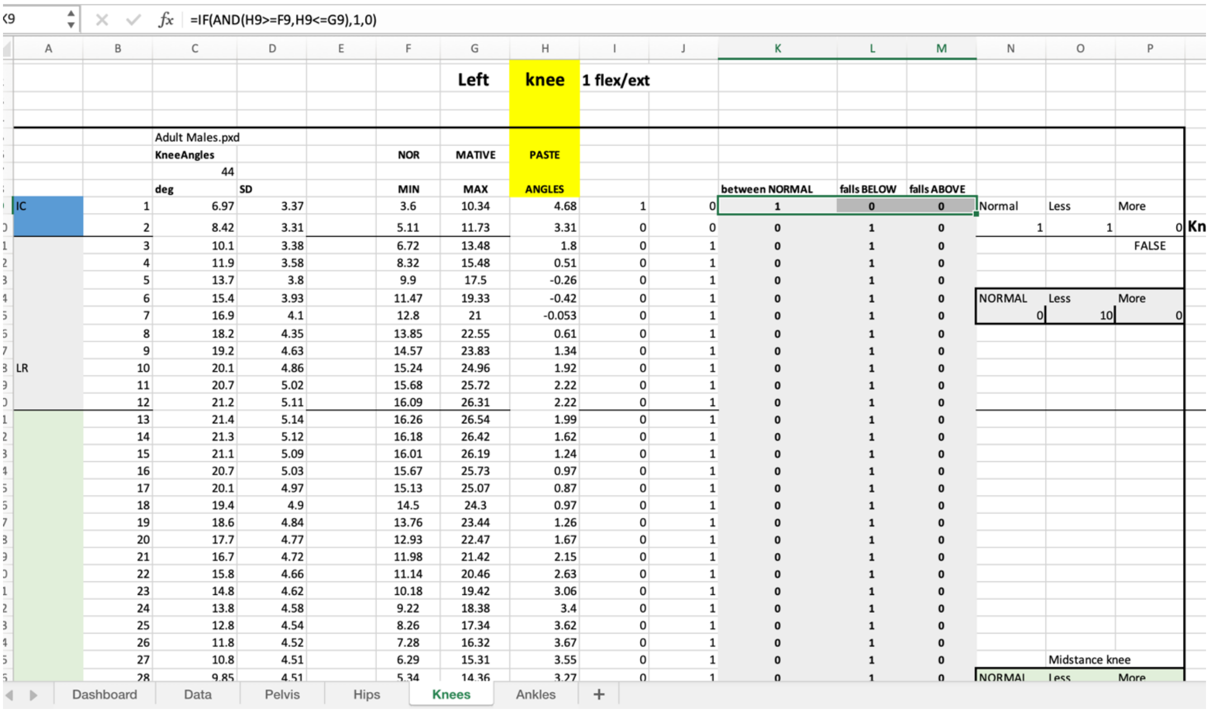
Colum D: Standard Deviation

Column F: Minimum Normative Angle (mean) for that data point

Column G Maximum Normative Angle (mean) for that data point

Colum H: Data points for the knee movement are pasted here to enable calculations to occur

Columns K, L,M provide calculations to determine if that data point was within normal (between MIN and MAX angles); BELOW normal (<MIN Angle) or ABOVE NORMAL (>MAX).



K9 =IF(AND(H9>=F9,H9<=G9),1,0)

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	
						Left	knee	1 flex/ext								
		Adult Males.pxd														
		KneeAngles			NOR	MATIVE	PASTE									
		44														
		deg	SD		MIN	MAX	ANGLES			between NORMAL	falls BELOW	falls ABOVE				
IC	1	6.97	3.37		3.6	10.34	4.68	1	0	1	0	0	Normal	Less	More	
	2	8.42	3.31		5.11	11.73	3.31	0	0	0	1	0	1	1	0	Kn
	3	10.1	3.38		6.72	13.48	1.8	0	1	0	1	0			FALSE	
	4	11.9	3.58		8.32	15.48	0.51	0	1	0	1	0				
	5	13.7	3.8		9.9	17.5	-0.26	0	1	0	1	0				
	6	15.4	3.93		11.47	19.33	-0.42	0	1	0	1	0	NORMAL	Less	More	
	7	16.9	4.1		12.8	21	-0.053	0	1	0	1	0	0	10	0	
	8	18.2	4.35		13.85	22.55	0.61	0	1	0	1	0				
	9	19.2	4.63		14.57	23.83	1.34	0	1	0	1	0				
LR	10	20.1	4.86		15.24	24.96	1.92	0	1	0	1	0				
	11	20.7	5.02		15.68	25.72	2.22	0	1	0	1	0				
	12	21.2	5.11		16.09	26.31	2.22	0	1	0	1	0				
	13	21.4	5.14		16.26	26.54	1.99	0	1	0	1	0				
	14	21.3	5.12		16.18	26.42	1.62	0	1	0	1	0				
	15	21.1	5.09		16.01	26.19	1.24	0	1	0	1	0				
	16	20.7	5.03		15.67	25.73	0.97	0	1	0	1	0				
	17	20.1	4.97		15.13	25.07	0.87	0	1	0	1	0				
	18	19.4	4.9		14.5	24.3	0.97	0	1	0	1	0				
	19	18.6	4.84		13.76	23.44	1.26	0	1	0	1	0				
	20	17.7	4.77		12.93	22.47	1.67	0	1	0	1	0				
	21	16.7	4.72		11.98	21.42	2.15	0	1	0	1	0				
	22	15.8	4.66		11.14	20.46	2.63	0	1	0	1	0				
	23	14.8	4.62		10.18	19.42	3.06	0	1	0	1	0				
	24	13.8	4.58		9.22	18.38	3.4	0	1	0	1	0				
	25	12.8	4.54		8.26	17.34	3.62	0	1	0	1	0				
	26	11.8	4.52		7.28	16.32	3.67	0	1	0	1	0				
	27	10.8	4.51		6.29	15.31	3.55	0	1	0	1	0		Midstance knee		
	28	9.85	4.51		5.34	14.36	3.27	0	1	0	1	0	NORMAL	Less	More	

Figure 3.38: Microsoft Excel calculation for the knee

As may be seen, this is just a simple calculation for one movement; here the ‘yellow’ zone had not been included at the time because this spreadsheet was a proof of concept. Unfortunately, with time limitations, this method was proving to be too complicated for the researcher, so it was decided to choose another method due to time constraints.

The design of a suitable computer program was also considered. Again, this is entirely possible however, with the researcher being a physician and not from an engineering or computing background, it was considered to be beyond the capabilities of the researcher and finding a suitable person with enough time to write this software proved difficult.

It was finally decided to transfer this data into the Traffic Lights System using a manual method in Microsoft Word. The researcher and an experienced gait analyst discussed the method with which data would be transformed into the required info graphical format, utilizing the same principle of checking out all data points in each of the 3 phases and deciding whether these data points fell into the 'normal', 'mild' or 'severe' categories, as defined elsewhere.

A typical output is shown in Figure 3.39

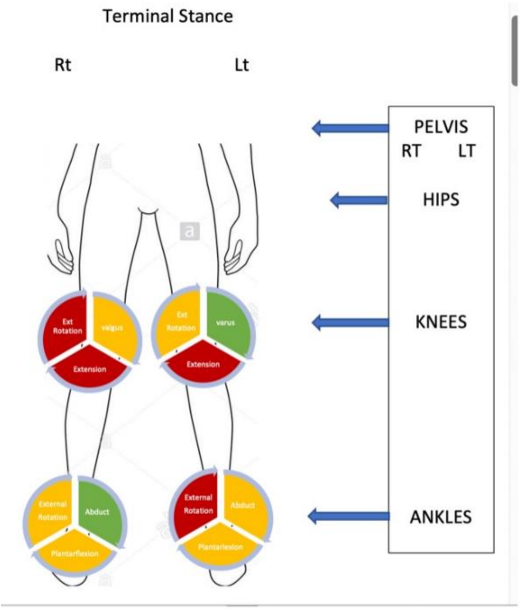


Figure 3.39: a typical output for Terminal Stance in Microsoft Word

The data for each phase was analysed from the graphical output and a consensus was reached what movement that particular dataset was referring to; e.g. External rotation at the Right knee in Figure 3.39; then whether that movement fell within the normal, slightly increased or outside of normative range, and the appropriate colour applied to that portion of the node. In the said figure 3.39. External Rotation was given the colour red to denote external rotation for that particular joint at that particular phase of the gait cycle. This method was repeated for the two other movements occurring at that joint, then repeated again for all the joints and for all 3 phases denoted by the particular node.

3.8 Method

3.8.1 Google Form Layout

Following the transfer of data into the TLS, a Google Form was designed and created. This was initially tried out by both the researcher and gait analyst, in order to determine whether it was feasible to be filled in by the participants.

The form was divided into 6 studies, with 3 studies utilizing the Traditional Graphical System and 3 studies utilizing the Traffic Light System. In reality, each study was represented by both systems, with the form for each study placed in a random order.

Following this, the Form was uploaded at

https://docs.google.com/forms/d/e/1FAIpQLSfLmuTCiMGmgr2YB8xVLDWdvfonJvA_I8xkenn2o5aTDMZDgQ/viewform

A copy of the form may be found in Appendix 2

3.8.2 Sampling

The study was aimed at all interested health professionals who regularly manage patients with pelvic or lower limb musculoskeletal conditions. It has been deemed important because information on the function of a particular joint should be of interest to these clinicians. For example, knee movement in Osgood Schlatter disease or patellofemoral pain syndrome, or hip movement in greater trochanteric bursitis; the amount of foot plantarflexion movement in a patient with metatarsalgia are just a few instances where gait analysis results would help the clinician determine the actual function of the involved joint or segment in order to come up with the relevant treatment plan.

Such health professionals would potentially include orthopaedic surgeons, medical physicians of various specialties (such as sports, pediatrics and rheumatology), physical therapists and podiatrists.

As explained in the Ethics section, an email was sent to the 3 associations representing these professionals; the Medical Association of Malta (MAM), the Malta Association of Physiotherapists (MAP) and the Association of Podiatrists of Malta (APM) in order to act as intermediaries and distribute the Google Form link to any interested members. Unfortunately, only one association replied, the APM, who agreed to distribute the link to its members. Thus, to prevent the responders being only podiatrists, the APM agreed to also disseminate the link to other health care professionals who were also acquainted with the association.

Initial response to the Google Form was initially quite poor, with only a few health professionals responding by filling out the form. This was initially thought to be due to the lengthy process required to fill in the form, which took about an hour to fill in.

Various reminders were sent after 1 month, then after 2 months. Two responders filled out the questionnaire twice, to enable intra-tester reliability testing. Another responder filled out the TLS part of the Form, as s/he quoted no training in gait analysis interpretation. This resulted in 3 responses for the TLS and 2 responses for the TGS for intra-rater assessment purposes.

The response from another rater, an experienced Gait Analyst, was utilised as a Gold Standard reply. This Gold Standard reply was important for validation purposes, so that it formed a datum against which responses could be compared. The utilization of Gold Standard responses is highly used in literature for validation purposes (Streiner et al. 1995), as this method of establishing validity has been claimed to be the most powerful type (Zaki, 2017).

By the time it was decided to stop collecting responses from healthcare professionals due to time constraints, a total of 25 + 1 gold standard responses had been input into the form. Although ideally a larger sample size was desired, 26 responses had to suffice for data analysis purposes.

3.8.3 Analysis of Data

Data was transferred into a Microsoft Excel Spreadsheet automatically by the Google Form. Data was then divided by different studies, into different spreadsheets to enable analysis. Data were then ranked into 4 possible categories:

1 Severe (i.e. excessive movement +/- >2SD)
2 Mild (movement between +/- 1 SD and 2SD)
3 Normal (between +/- 1 SD)
4 Don’t know

Analysis of validity, intra- and inter-rater (test-retest) reliability was performed for both the Traditional Graphic System and the Traffic Lights System, so that the results from each system could then be compared. Analysis of the data was performed using SPSS software, version 28.0.0.0.

Perhaps one of the most commonly known statistical test for measuring reliability is the Intraclass Correlation Coefficient (ICC). However, although the ICC is used to assess agreement when there are two or more independent raters, the outcome is measured at a continuous level. This makes this test unsuitable for this analysis, since the data returned by the participants was in a categorical scale.

Cronbach's alpha, α (or coefficient alpha), developed by Lee Cronbach in 1951, measures reliability, or internal consistency. "Reliability" is another name for consistency. Cronbach's alpha tests to see if multiple-question Likert scale surveys are reliable (Glen, n.d).

Calculating alpha has become common practice in medical research when multiple-item measures of a concept or construct are employed. This is because it is easier to use in comparison to other estimates (e.g. test-retest reliability estimates) (Cohen and Swerdlick, 2010) as it is only necessary to perform one test (Tavakol and Dennick, 2011). Reliability estimates show the amount of measurement error in a test. The interpretation of reliability is the correlation of the test with itself. To produce the index of measurement error, the correlation is squared and subtracted from 1.00 (Tavakol and Dennick, 2011). Cronbach's Alpha is expressed as a number between 0 and 1; the closer α is to 1, the higher the correlation, and vice versa. As in all research, the p-value is set to <0.05. This denotes the level of significance above which the Null hypothesis would be accepted.

3.8.4 Analysis of Validity

Validity refers to whether a construct is measuring what it is actually meant to measure (van der Vleuten and Schuwirth, 2005). Validity is the degree to which evidence and theory support the interpretations of test scores for the proposed uses of tests. Without evidence of validity, assessments in the medical field have little or no intrinsic meaning (Downing, 2003).

For validity purposes, a Gold Standard response was obtained for both the TGS and TLS. This was a consensus document between the experienced gait analyst and researcher, in order to arrive at an ‘ideal’ response for each system to which other responses could be compared. A gold standard study may refer to an experimental model that has been thoroughly tested and has a reputation in the field as a reliable method (Cardoso et al. 2014).

It was assumed that the gait analyst, who regularly analyzed children’s gait at the state hospital, had over 15 years’ experience in this field would be in a position to provide the best possible response to the gait analysis questions put forth in the Google Form. Additionally, when teaming up with the researcher who worked out the TLS, the consensus responses were also considered to be the Gold Standard in this field.

Statistical analysis for both systems was performed utilizing Cronbach’s Alpha in SPSS.

3.8.5 Analysis of Intra-Rater Reliability

Intra-rater reliability refers to the ability of a rater to the degree of agreement among repeated administrations of a test performed by a single rater. Intra-rater reliability and inter-rater reliability are also aspects of test validity (Scheel et al. 2018).

The reliability of an instrument is closely associated with its validity; it cannot be valid unless it is reliable. However, the reliability of an instrument does not depend on its validity (Nunnally and Berstein, 1994).

Cronbach’s Alpha was utilised in SPSS to explore the correlations between the responses of 2 raters who filled in the responses for the TGS and 3 raters who provided responses for the TLS. All responses were provided more than 1 month apart in order to ensure that previous responses were not remembered by the raters.

3.8.6 Analysis of Inter-Rater Reliability

Inter-rater reliability refers to the consistency of data recorded by two or more raters, measuring the same subjects over a single trial (Scheel et al. 2018).

Inter-rater reliability for both systems was explored utilizing the Multirater Fleiss Kappa statistical test, for all 3 studies utilizing the TGS and 3 studies utilizing the TLS. In this scenario, this is a better approach to using Cronbach’s Alpha since, whilst the latter can be used to test correlations between two raters, Fleiss Kappa can be utilised to assess correlations between multiple testers, as is the case in the 3 TGS and 3 TLS studies.

Chapter 4

Results

This chapter will present the results of the analyses performed on the responses by the 25 respondents who filled in the form. In total, over 250 health professionals were contacted via email, however unfortunately only 25 replied (just 10% of all health professionals contacted via email). This could perhaps be due to two main reasons: a lack of awareness and/or lack of training in this modality (as, at undergraduate levels, gait analysis training is not provided) or due to the rather, admittedly, complex nature of the subject matter itself.

These results focus on 3 main areas:

Demographics

Statistical Analysis

A qualitative analysis of comments provided by the respondents

4.1 Demographics

The majority of respondents (17) were podiatrists since this form was distributed by the Association of Podiatrists. Although over 100 other health professionals were contacted via email, besides podiatrists, only 4 physicians and 4 physiotherapists filled in the form (figure 4.1). Thus 68% of respondents were podiatrists, 16% medical physicians and 16% physiotherapists. An additional response from a gait analyst was used as a Gold Standard response for purposes of comparison.

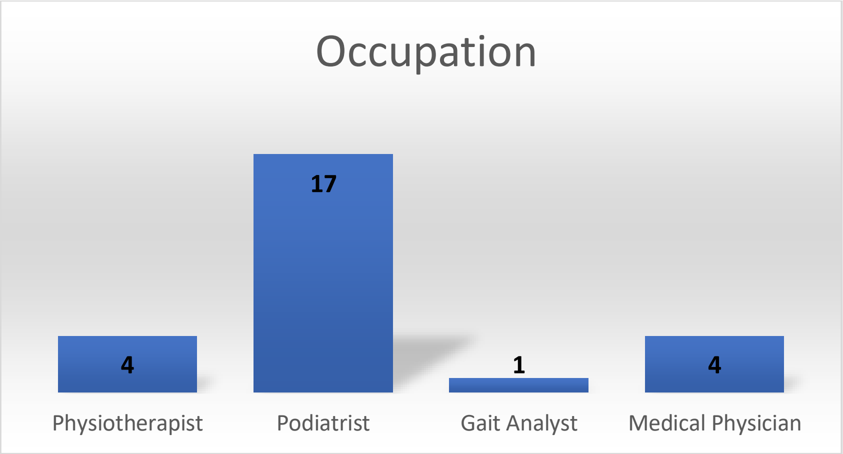


Figure 4.1: Breakdown of occupation of respondents

8 (32%) had prior training in gait analysis, 8 (32%) had some form of prior training whilst 9 (36%) respondents had no prior training at all, as noted in figure 4.2.

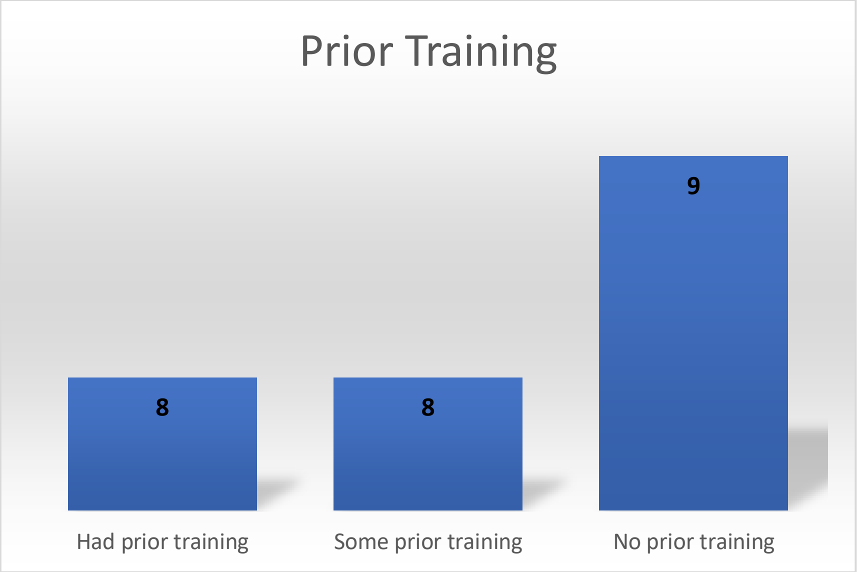


Figure 4.2: Prior training of respondents

Respondents with Prior Training in instrumented gait analysis: ease of understanding and interpretation

Amongst those respondents who had prior training, in reply to the question "Which format did you find easier to understand?" all 8 respondents found the Traffic Lights System easier to understand (figure 4.3).

Amongst those respondents who had prior training, in reply to the question "Which format did you find easier to interpret?", 7 respondents found the Traffic Lights System easier to interpret, whilst 1 respondent found the Traditional Graphical System easier to interpret (figure 4.4).

Amongst those respondents who had prior training, in reply to the question "In which format would you prefer this information to be provided?", 7 out of the 8 participants preferred the Traffic Lights System, whilst 1 respondent preferred the Traditional Graphical System.

Participant views on Traditional Graphical Output and Traffic Light System

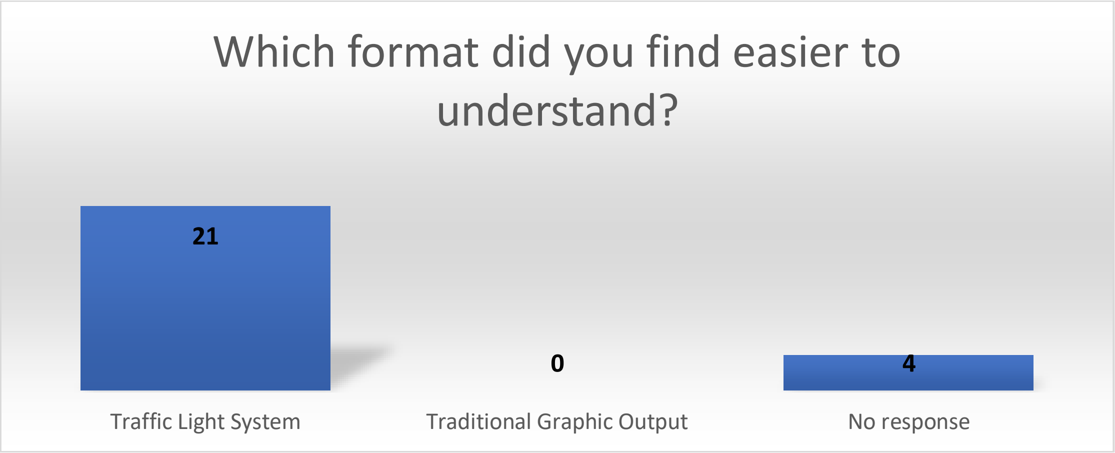


Figure 4.3: All participant responses on ease of understanding

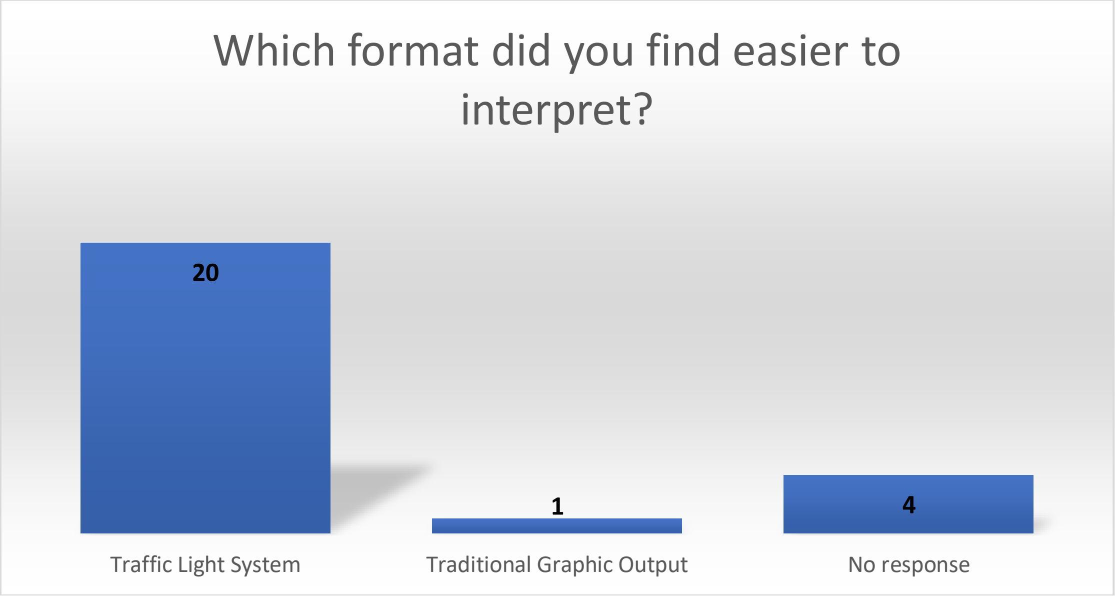


Figure 4.4: All participant responses on ease of interpretation

To the above questions, the Traffic Lights System achieved the highest scores; it is clear that according to health care professionals, they find this system both easier to understand and interpret.

Only 1 respondent preferred the Traditional System, for a very valid reason that this respondent claimed that s/he is colour blind and was unable to interpret results using this system. This is an important limitation highlighted by this respondent. However, it must be pointed out that even the Traditional Graphical System relies on two different colours for the assessor to be able to recognize left from right. Thus this limitation applies to both systems; however, as may be seen further on, in the discussion section, this limitation can be overcome rather easily by the use of patterns embedded in the different regions, by embedding different patterns for each of the 3 colours.

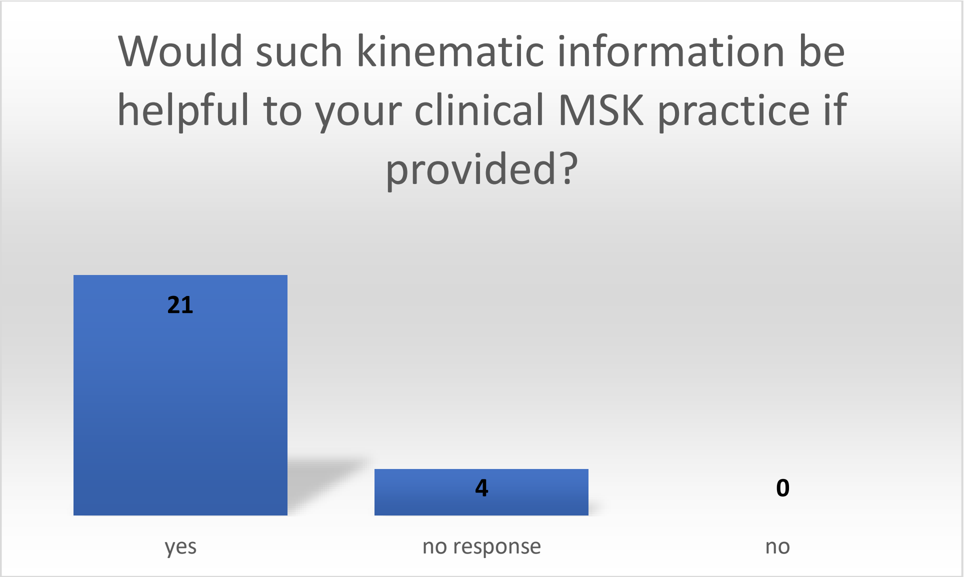


Figure 4.5: Participants' responses regarding usefulness of kinematic information

The majority of respondents also thought that kinematic information would be helpful for their musculoskeletal practice. Besides the 4 no-responses, no one thought that this information would not be helpful (figure 4.5).

From the above responses, it is clear that the Traffic Lights System is preferred by the majority of respondents, perhaps for the first time confirming that the Traditional Graphical System of reporting gait analysis data might not be the ideal method to present this data according to health professionals. It is important to note here that there were no engineers involved in this; perhaps they would have preferred looking at graphs. However, the main focus in this study was on health professionals, i.e. the ultimate users of such gait analysis systems who would utilise it for treating patients with musculoskeletal conditions.

4.2 Statistical Analyses

IBM SPSS (Statistical Package for the Social Sciences) version 28.0 was used to perform all statistical analyses pertaining to this section of the thesis.

4.2.1 Statistical Analysis for Validity

To statistically analyse the construct validity of the Traffic Lights System, Cronbach’s Alpha statistical test was applied to two responses, taken at random, for two similar responses (in this case, Studies 3 and 4 were taken); one response derived from a ‘Gold Standard’ response of the Traditional Graphical System, which was a consensus dataset agreed upon by two highly trained respondents trained in this system, and another dataset similarly derived for the Traffic Lights System. Cronbach's alpha is a measure of internal consistency, that is, how closely related a set of items are as a group. All responses in these studies were included in the analysis.

Cronbach's alpha findings should provide a value between 0 and 1, with 1 being a perfect correlation. Nunnally and Bernstein (1994) state that a Cronbach's Alpha value

below 0.6 is considered as low
above 0.6 is considered as highly reliability and acceptable
0.60 - 0.80 are considered moderate but acceptable.
Between 0.8 - 1.00 is considered very good.

This test resulted in a Cronbach’s Alpha of 0.92 (Table 4.1), meaning that the two systems are highly correlated; on the assumption that the Traditional Graphical System Gold Standard is the best correct response possible, the Traffic Lights System yielded the same responses, which makes it a valid system.

Cronbach's Alpha correlation between Traditional Graphical System and Traffic Lights System

Scale: ALL VARIABLES

Case Processing Summary

		N	%
Cases	Valid	41	100.0
	Excluded[a]	0	.0
	Total	41	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.920	.920	2

Item Statistics

	Mean	Std. Deviation	N
TGS	2.1707	.94611	41
TLS	2.1951	.98029	41

Inter-Item Correlation Matrix

	TGS	TLS
TGS	1.000	.853
TLS	.853	1.000

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Variances	.928	.895	.961	.066	1.074	.002	2
Inter-Item Correlations	.853	.853	.853	.000	1.000	.000	2

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
TGS	2.1951	.961	.853	.727	.
TLS	2.1707	.895	.853	.727	.

Scale Statistics

Mean	Variance	Std. Deviation	N of Items
4.3659	3.438	1.85413	2

Table 4.1: SPSS output for Cronbach's Alpha correlation between Traditional Graphical System and Traffic Lights System

4.2.2 Statistical Analysis of Intra-Rater Reliability

The process for analysis of intra-rater reliability involved the utilization of Cronbach’s Alpha statistical test to compute the correlations between the items in the datasets produced by the same raters.

For the purpose of intra-rater reliability, 3 raters provided responses; 1 rater only supplied 2 responses for the Traffic Light System, whilst 2 raters provided responses for both the Traditional Graphical System and the Traffic Light System. The data was obtained over a period of 2 months from the first dataset to the second. This was to ensure that the raters could not remember their previous responses.

For the sake of conciseness, all the SPSS workings for Rater 1 is provided below. The other raters' analysis is provided in a table at the end of this section. All the SPSS outputs for all 3 raters are provided in Appendix 4

The results are provided as follows:

Rater (x), Study(x), Response(x)

e.g

Thus, *Rater 1*, *Study1*, 1 relates to the first response for Study 1 of Rater 1

Rater 2, Study 4, 2 relates to the second response for Study 4 of Rater 2

Intra-Rater Reliability

Intra rater reliability for Rater1, Study 1,1 and Study 1,2: Traditional Graphical System

Traditional Graphical System: When comparing Rater 1's two responses, for Study 1 response 1 and Study 1 response 2, a Cronbach's Alpha of 0.918 , indicates a very good correlation between the two responses, implying excellent intra-rater reliability.

Case Processing Summary

		N	%
Cases	Valid	41	100.0
	Excluded[a]	0	.0
	Total	41	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.918	.918	2

Item Statistics

	Mean	Std. Deviation	N
Rater1_Study1_1	2.1220	.81225	41
Rater1_Study1_2	2.1707	.80319	41

Inter-Item Correlation Matrix

	Rater1_Study1_1	Rater1_Study1_2
Rater1_Study1_1	1.000	.849
Rater1_Study1_2	.849	1.000

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Variances	.652	.645	.660	.015	1.023	.000	2
Inter-Item Correlations	.849	.849	.849	.000	1.000	.000	2

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Rater1_Study1_1	2.1707	.645	.849	.720	.
Rater1_Study1_2	2.1220	.660	.849	.720	.

Scale Statistics

Mean	Variance	Std. Deviation	N of Items
4.2927	2.412	1.55312	2

Table 4.2: Intra rater reliability for Rater1, Study 1,1 and Study 1,2: TGS

Intra rater reliability for Rater1, Study 4,1 and Study4,2: Traditional Graphical System

Traditional Graphical System: When comparing Rater 1’s two responses, for Study 4 response 1 and Study 4 response 2, a Cronbach's Alpha of 0.755 , indicates a very good correlation between the two responses.

Case Processing Summary

		N	%
Cases	Valid	41	100.0
	Excluded[a]	0	.0
	Total	41	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.755	.779	2

Item Statistics

	Mean	Std. Deviation	N
Rater1_Study4_1	2.2439	.85967	41
Rater1_Study4_2	2.6341	.62274	41

Inter-Item Correlation Matrix

	Rater1_Study 4_1	Rater1_Study 4_2
Rater1_Study4_1	1.000	.638
Rater1_Study4_2	.638	1.000

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Variances	.563	.388	.739	.351	1.906	.062	2
Inter-Item Correlations	.638	.638	.638	.000	1.000	.000	2

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Rater1_Study4_1	2.6341	.388	.638	.407	.
Rater1_Study4_2	2.2439	.739	.638	.407	.

Scale Statistics

Mean	Variance	Std. Deviation	N of Items
4.8780	1.810	1.34527	2

Table 4.3: Intra rater reliability for Rater1, Study 4,1 and Study 4,2: TGS

Intra rater reliability for Rater1, Study 2,1 and Study2,2: TLS

Traffic Lights System: When comparing Rater 1’s two responses, for Study 2 response 1 and Study 2 response 2, a Cronbach's Alpha of 1, indicates a very good correlation between the two responses, implying a perfect intra-rater reliability.

Case Processing Summary

		N	%
Cases	Valid	41	100.0
	Excluded[a]	0	.0
	Total	41	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
1.000	1.000	2

Item Statistics

	Mean	Std. Deviation	N
Rater1_Study2_1	2.4146	.77381	41
Rater1_Study2_2	2.4146	.77381	41

Inter-Item Correlation Matrix

	Rater1_Study2_1	Rater1_Study2_2
Rater1_Study2_1	1.000	1.000
Rater1_Study2_2	1.000	1.000

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Variances	.599	.599	.599	.000	1.000	.000	2
Inter-Item Correlations	1.000	1.000	1.000	.000	1.000	.000	2

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Rater1_Study2_1	2.4146	.599	1.000	.	.
Rater1_Study2_2	2.4146	.599	1.000	.	.

Scale Statistics

Mean	Variance	Std. Deviation	N of Items
4.8293	2.395	1.54762	2

Table 4.4: Intra rater reliability for Rater1, Study 2,1 and Study 2,2: TLS

Intra rater reliability for Rater1, Study 3,1 and Study 3,2: TLS

Traffic Lights System: When comparing Rater 1’s two responses, for Study 3 response 1 and Study 3 response 2, a Cronbach's Alpha of 0.891, indicates a very good correlation between the two responses, implying a very good intra-rater reliability.

Case Processing Summary

		N	%
Cases	Valid	41	100.0
	Excluded[a]	0	.0
	Total	41	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.891	.891	2

Item Statistics

	Mean	Std. Deviation	N
Rater1_Study3_1	2.1463	.96335	41
Rater1_Study3_2	2.2683	.94933	41

Inter-Item Correlation Matrix

	Rater1_Study3_1	Rater1_Study3_2
Rater1_Study3_1	1.000	.803
Rater1_Study3_2	.803	1.000

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Variances	.915	.901	.928	.027	1.030	.000	2
Inter-Item Correlations	.803	.803	.803	.000	1.000	.000	2

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Rater1_Study3_1	2.2683	.901	.803	.645	.
Rater1_Study3_2	2.1463	.928	.803	.645	.

Scale Statistics

Mean	Variance	Std. Deviation	N of Items
4.4146	3.299	1.81625	2

Table 4.5: Rater1, Study 3,1 and Study 3,2: TLS

Intra rater reliability for Rater1, Study 5,1 and Study 5,2: TGS

Traditional Graphical System: When comparing Rater 1’s two responses, for Study 5 response 1 and Study 5 response 2, a Cronbach's Alpha of 0.733, indicates a very good correlation between the two responses, implying a very good intra-rater reliability.

Case Processing Summary

		N	%
Cases	Valid	41	97.6
	Excluded[a]	1	2.4
	Total	42	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.733	.739	2

Item Statistics

	Mean	Std. Deviation	N
Rater1_Study5_1	2.0000	.94868	41
Rater1_Study5_2	2.4634	.80925	41

Inter-Item Correlation Matrix

	Rater1_Study5_1	Rater1_Study5_2
Rater1_Study5_1	1.000	.586
Rater1_Study5_2	.586	1.000

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Variances	.777	.655	.900	.245	1.374	.030	2
Inter-Item Correlations	.586	.586	.586	.000	1.000	.000	2

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Rater1_Study 5_1	2.4634	.655	.586	.344	.
Rater1_Study 5_2	2.0000	.900	.586	.344	.

Scale Statistics

Mean	Variance	Std. Deviation	N of Items
4.4634	2.455	1.56681	2

Table 4.6: Intra rater reliability for Rater1, Study 5,1 and Study 5,2: TGS

Intra rater reliability for Rater1, Study 6,1 and Study6,2: TLS

Traffic Lights System: When comparing Rater 1's two responses, for Study 6 response 1 and Study 6 response 2, a Cronbach's Alpha of 0.819, indicates a very good correlation between the two responses, implying a very good intra-rater reliability.

Case Processing Summary

		N	%
Cases	Valid	40	95.2
	Excluded[a]	2	4.8
	Total	42	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.819	.819	2

Item Statistics

	Mean	Std. Deviation	N
Rater1_Study6_1	2.2500	.83972	40
Rater1_Study6_2	2.2750	.84694	40

Inter-Item Correlation Matrix

	Rater1_Study6_1	Rater1_Study6_2
Rater1_Study6_1	1.000	.694
Rater1_Study6_2	.694	1.000

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Variances	.711	.705	.717	.012	1.017	.000	2
Inter-Item Correlations	.694	.694	.694	.000	1.000	.000	2

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Rater1_Study6_1	2.2750	.717	.694	.482	.

Rater1_Study 6_2	2.2500	.705	.694	.482	.

Scale Statistics

Mean	Variance	Std. Deviation	N of Items
4.5250	2.410	1.55229	2

Table 4.7: Intra rater reliability for Rater1, Study 6,1 and Study 6,2: TLS

Summary of Results for Intra-rater reliability for all studies, both Traffic Lights System and Traditional Graphical System, for all 3 raters

Table 4.8 presents the results of statistical analysis, using Cronbach’s Alpha test, for intra-rater reliability for all 3 raters who provided two responses; i.e. they filled in the online Google Form twice, on two separate occasions, to determine how each response compares to the other. As may be seen in the table, both systems achieved quite high intra-rater reliability, with Rater 1 achieving a perfect correlation when utilising the Traditional Graphical System, and Rater 3 (who only filled in the Traffic Lights System part of the form) actually achieving a perfect correlation of 1.0 in two studies.

Here it must be emphasised that both Rater 1 and Rater 2 declared that they had previous training in using the Traditional Graphical System, whilst Rater 3 had no prior training in any of the two systems. Although one cannot generalise from just 1 response, there is an indication, from Rate 1’s scores, that the Traffic Lights System has the potential to have very good intra-rater reliability even when the rater had no prior training at all.

Unfortunately, no participants attempted to do the intra-rater reliability exercise utilising the Traditional Graphical System, so no results in this area can be presented.

	System	Rater 1 Cronbach's Alpha	Rater2 Cronbach's Alpha	Rater3 Cronbach's Alpha
Study 1,1 Study 1,2	TGS Bilateral Arthrodesis	0.918	0.903	NA
Study 2,1 Study 2,2	TLS Bilateral Arthrodesis	1.00	0.954	1.00
Study 3,1 Study 3,2	TLS Bilateral Equinus	0.891	0.974	1.00
Study 4,1 Study 4,1	TGS Bilateral Equinus	0.755	0.807	NA
Study 5,1 Study 5,2	TGS Bilateral footslap	0.733	0.841	NA
Study 6,1 Study 6,1	TLS Bilateral footslap	0.819	0.932	0.867

Table 4.8: Intra-Rater reliability Cronbach's Alpha for the 3 raters. One should note that Raters 1 and 2 were trained in the Traditional Graphical System, but untrained in the Traffic Lights System. Rater 3, who was untrained in both systems, preferred not to attempt to reply to questions about the Traditional system, yet obtained extremely high results in the Traffic Light System

4.2.3 Statistical Analysis of Inter-Rater Reliability

In order to determine inter-rater reliability, Fleiss Multirater Kappa Analysis was utilised as the statistical test of choice.

For reference purposes, the table below illustrates the strength of agreement for the value of **κ** in order to help in the interpretation of the Fless Multirater Kappa analysis.

Value of κ	**Strength of agreement**
0.21-0.40	Fair
0.41-0.60	Moderate
0.61-0.80	**Good**

0.81-1.00	**Very good**

Table 4.9: Interpreting the results from a Fleiss' kappa analysis (Laerd Statistics, 2019)

Comparing inter-rater reliability between Studies 1 (Traditional Graphical System) and 2 (Traffic Lights System)

In this section, the overall agreement between the responses of the participants were statistically analysed using the Fleiss Multirater Kappa statistical test. This determined the agreement between the responses relating to all the questions pertaining to each study. Thus the results presented for study 1, presented the inter-rater reliability for Study 1 that included responses for the Traditional Graphical System, for Study 2 determining the inter-rater reliability achieved in Study 2, that utilised the Traffic Lights System, and so forth.

When using the Fleiss Kappa Multirater statistical test, the alternative hypothesis is H_1 Kappa >0, whilst the null hypothesis is H_0 Kappa =0

Fleiss Multirater Kappa: Study 1 Traditional Graphical System

Alternative Hypothesis: The Traditional Graphical System produced reliable test results for Study 1. H_1 Kappa >0

Null Hypothesis: The Traditional Graphical System does not produce reliable test results for Study 1. H_0 Kappa =0

Kappa **κ** of 0.005, with p-value of 0.412 being >0.05 level of significance (Table 4.10), indicating very poor agreement when utilizing the Traditional Graphical System, thus the null hypothesis is accepted for this study.

Overall Agreement[a]

	Kappa	Asymptotic Standard Error	Asymptotic z	Asymptotic Sig.	Asymptotic 95% Confidence Interval Lower Bound	Asymptotic 95% Confidence Interval Upper Bound
Overall Agreement	.005	.005	.821	.412	-.006	.015

a. Sample data contains 41 effective subjects and 25 raters.

Agreement on Individual Categories[a]

Rating Category	Conditional Probability	Kappa	Asymptotic Standard Error	Asymptotic z	Asymptotic Sig.	Asymptotic 95% Confidence Interval Lower Bound	Asymptotic 95% Confidence Interval Upper Bound
Severe	.178	.047	.009	5.187	<.001	.029	.064
Mild	.214	.025	.009	2.731	.006	.007	.042
Null	.228	.022	.009	2.428	.015	.004	.040
Don’t know	.436	-.040	.009	-4.438	<.001	-.058	-.022

a. Sample data contains 41 effective subjects and 25 raters.

Table 4.10: Fleiss Kappa κ Traditional Graphical System, Study 1

Fleiss Multirater Kappa: Study 2: Traffic Lights System

Alternative Hypothesis: The Traffic Lights System produced reliable test results for Study 2. H_1 Kappa >0

Null Hypothesis: The Traffic Lights System did not produce reliable test results for Study 2. H_0 Kappa =0

Kappa of 0.276, with a p-value <0.001 being below the 0.05 level of significance, indicating fair agreement when utilizing the Traffic Lights System, thus the null hypothesis is rejected for this study.

Overall Agreement[a]

		Asymptotic			Asymptotic 95% Confidence Interval	
	Kappa	Standard Error	z	Sig.	Lower Bound	Upper Bound
Overall Agreement	.276	.006	44.567	.000	.264	.288

a. Sample data contains 36 effective subjects and 25 raters.

Agreement on Individual Categories[a]

			Asymptotic			Asymptotic 95% Confidence Interval	
Rating Category	Conditional Probability	Kappa	Standard Error	z	Sig.	Lower Bound	Upper Bound
Severe	.373	.290	.010	30.115	.000	.271	.309
Mild	.522	.364	.010	37.832	.000	.345	.383
Null	.677	.325	.010	33.746	.000	.306	.344
Don’t know	.089	-.026	.010	-2.706	.007	-.045	-.007

a. Sample data contains 36 effective subjects and 25 raters.

Table 4.11: Fleiss Kappa κ Traffic Lights System, Study 2

The overall Fleiss multi-rater kappa value of the Traffic Light System (0.276) is larger than the Traditional Graphics System (0.005), indicating higher inter-rater reliability for the former compared to the latter. This result also applies to the individual categories (severe, mild and null). Moreover, the response percentage ‘do not know’ was significantly higher in the Traditional graphics system compared to the Traffic Light System.

Comparing inter-rater reliability between Studies 3 (Traffic Lights System) and 4 (Traditional Graphical System)

The Fleiss Kappa Statistical Test was used to test the inter-rater reliability of both the Traffic Lights System and the Traditional Graphical System so that the correlations of the raters can be calculated for both systems.

Fleiss Multirater Kappa: Study 3: Traffic Lights System: Bilateral Equinus

Alternative Hypothesis: The Traffic Lights System produced reliable test results for Study 3.

H_1 Kappa >0

Null Hypothesis: The Traffic Lights System did not produce reliable test results for Study 3.

H_0 Kappa =0

Kappa of 0.296, with the p-value<0.001 being below the 0.05 level of significance, indicating fair agreement when utilizing the Traffic Lights System, thus the null hypothesis is rejected for this study.

Overall Agreement

		Asymptotic			Asymptotic 95% Confidence Interval	
	Kappa	Standard Error	z	P-value	Lower Bound	Upper Bound
Overall Agreement	0.296	0.006	50.823	0.000	0.285	0.307

Sample data contains 41 effective subjects and 25 raters.

Agreement on Individual Categories

Rating Category	Conditional Probability	Kappa	Asymptotic Standard Error	Asymptotic z	P-value
Severe	0.543	0.347	0.009	38.533	0.000
Mild	0.363	0.259	0.009	28.692	0.000
Null	0.671	0.385	0.009	42.664	0.000
Do not know	0.064	-0.034	0.009	-3.805	<0.001

Sample data contains 41 effective subjects and 25 raters.

Table 4.12: Fleiss Kappa κ Traffic Lights System, Study 3

Fleiss Multirater Kappa Study 4: Traditional Graphical System: bilateral equinus

Alternative Hypothesis: The Traditional Graphical System produces reliable test results for Study 4. H_1 Kappa >0

Null Hypothesis: The Traditional Graphical System did not produce reliable test results for Study 4. H_0 Kappa =0

Kappa of 0.021, p-value <0.001, indicating very poor agreement when utilizing the Traditional Graphical System, thus the null hypothesis is accepted for this study.

Overall Agreement

	Kappa	Asymptotic Standard Error	Asymptotic z	Asymptotic P-value	Asymptotic 95% Confidence Interval Lower Bound	Asymptotic 95% Confidence Interval Upper Bound
Overall Agreement	0.021	0.006	3.786	<0.001	0.010	0.032

Sample data contains 41 effective subjects and 25 raters.

Agreement on Individual Categories

				Asymptotic	
Rating Category	Conditional Probability	Kappa	Standard Error	z	P-value
Severe	0.176	0.050	0.009	5.521	<0.001
Mild	0.196	0.066	0.009	7.330	<0.001
Null	0.327	0.055	0.009	6.078	<0.001
Do not know	0.417	-0.042	0.009	-4.621	<0.001

Sample data contains 41 effective subjects and 25 raters.

Table 4.13: Fleiss Kappa κ Traditional Graphical System, Study4

The overall Fleiss multi-rater kappa value of the Traffic light system (0.296) is larger than the Traditional graphics system (0.021), indicating higher inter-rater reliability for the former compared to the latter. This result also applies to the individual categories (severe, mild and null). Moreover, the response percentage ‘do not know’ was significantly higher in the Traditional graphics system (44.0%) compared to the Traffic light system (9.5%).

Comparing inter-rater reliability between Studies 5 (Traditional Graphical System) and 6 (Traffic Lights System)

Fleiss Multirater Kappa Study 5: Traditional Graphical System: bilateral footslap

Alternative Hypothesis: The Traditional Graphical System produces reliable test results for Study 5. H_1 Kappa >0

Null Hypothesis: The Traditional Graphical System did not produce reliable test results for Study. H_0 Kappa =0

Kappa of -0.010, p-value 0.229 being >0.05 level of significance, indicating very poor agreement when utilizing the Traditional Graphical System, thus the null hypothesis is accepted for this study.

Overall Agreement^a

		Asymptotic			Asymptotic 95% Confidence Interval	
	Kappa	Standard Error	z	Sig.	Lower Bound	Upper Bound
Overall Agreement	-.010	.008	-1.202	.229	-.027	.006

a. Sample data contains 23 effective subjects and 25 raters.

Agreement on Individual Categories[a]

Rating Category	Conditional Probability	Kappa	Asymptotic			Asymptotic 95% Confidence Interval	
			Standard Error	z	Sig.	Lower Bound	Upper Bound
Severe	.048	-.010	.012	-.829	.407	-.034	.014
Mild	.164	.065	.012	5.375	<.001	.041	.088
Null	.352	-.007	.012	-.580	.562	-.031	.017
Do not know	.458	-.042	.012	-3.461	<.001	-.065	-.018

a. Sample data contains 23 effective subjects and 25 raters.

Table 4.14: Fleiss Kappa κ Traditional Graphical System, Study 5

Fleiss Multirater Kappa: Study 6: Traffic Lights System: Bilateral Footslap

Alternative Hypothesis: The Traffic Lights System produced reliable test results for Study 6.

H_1 Kappa >0

Null Hypothesis: The Traffic Lights System did not produce reliable test results for Study 6.

H_0 Kappa =0

Kappa of 0.232, with p-value of >0.001 being below the 0.05 level of significance, indicating fair agreement when utilizing the Traffic Lights System, thus the null hypothesis is rejected for this study.

Overall Agreement[a]

	Kappa	Asymptotic			Asymptotic 95% Confidence Interval	
		Standard Error	z	Sig.	Lower Bound	Upper Bound
Overall Agreement	.232	.007	34.228	.000	.219	.246

a. Sample data contains 30 effective subjects and 25 raters.

Agreement on Individual Categories[a]

Rating Category	Conditional Probability	Kappa	Asymptotic			Asymptotic 95% Confidence Interval	
			Standard Error	z	Sig.	Lower Bound	Upper Bound
Severe	.354	.287	.011	27.230	.000	.266	.308
Mild	.493	.355	.011	33.691	.000	.334	.376
Null	.671	.260	.011	24.671	.000	.239	.281
Do not know	.104	-.038	.011	-3.625	<.001	-.059	-.018

a. Sample data contains 30 effective subjects and 25 raters.

Table 4.15: Fleiss Kappa κ Traffic Lights System, Study 6

The overall Fleiss multi-rater kappa value of the Traffic light system (0.232) is larger than the Traditional graphics system (0.229), indicating higher inter-rater reliability for the former compared to the latter. This result also applies to the individual categories (severe, mild and null). Moreover, the response percentage ‘do not know’ was significantly higher in the Traditional graphics system compared to the Traffic light system.

From the above 3 comparisons, it is clear that the Traffic Lights System is better than the Traditional Graphics System for 2 reasons:

1. It is yielding a lower percentages of “do not know” responses
2. It is giving a higher Fleiss multi-rater Kappa value for those who provided a rating evaluation

Analysis of inter-rater reliability by profession

Since the participants were predominantly podiatrists (68%) when compared with medical physicians (16%) and physiotherapists (16%), it can be argued that the results were biased by the podiatrist sample population and that the results were mainly the influenced by the podiatrist participants. In order to offset this limitation, the results of the first two studies were also analysed in relation to the medical and physical therapy professions to assess how these participants fared.

Hypothesis: There is good overall agreement between responses from Medical physicians and physiotherapists. H_1 Kappa >0

Null Hypothesis: There is poor overall agreement between responses from Medical physicians and physiotherapists. H_0 Kappa =0

In order to test this hypothesis, the Fleiss Multirater Kappa test was applied separately to the responses of the medical physicians and physiotherapists. As may be seen by the outputs of this test below, the kappa for medical physicians was -0.163, with a p-value of 0.011. Thus it can be concluded that there is very poor correlation between the ratings, with negative correlation; this is significant since the p-value was <0.05.

The Kappa for physiotherapists was slightly better at 0.010; however this was statistically insignificant as the p-value was 0.8, above the 0.05 level of acceptance.

From this, it can be concluded that both medical physicians and physiotherapists who are untrained in the use of the Traditional Graphical Output had poor inter-rater agreement.

Fleiss Multirater Kappa: Medical Physicians responses Study1 : 4 raters

Overall Agreement[a]

	Kappa	Asymptotic Standard Error	z	Sig.	Asymptotic 95% Confidence Interval Lower Bound	Upper Bound
Overall Agreement	-.163	.064	-2.558	.011	-.288	-.038

a. Sample data contains 41 effective subjects and 4 raters.

Agreement on Individual Categories[a]

Rating Category	Conditional Probability	Kappa	Asymptotic Standard Error	z	Sig.	Asymptotic 95% Confidence Interval Lower Bound	Upper Bound
Null	.000	-.163	.064	-2.558	.011	-.288	-.038
Don’t know	.837	-.163	.064	-2.558	.011	-.288	-.038

a. Sample data contains 41 effective subjects and 4 raters.

Table 4.16: Fleiss Kappa κ

Fleiss Multirater Kappa: Medical Physician responses Study2: 4 raters

Overall Agreement[a]

	Kappa	Asymptotic Standard Error	z	Sig.	Asymptotic 95% Confidence Interval Lower Bound	Upper Bound
Overall Agreement	.010	.038	.253	.800	-.065	.085

a. Sample data contains 42 effective subjects and 4 raters.

Agreement on Individual Categories[a]

Rating Category	Conditional Probability	Kappa	Asymptotic			Asymptotic 95% Confidence Interval	
			Standard Error	z	Sig.	Lower Bound	Upper Bound
Severe	.415	.201	.063	3.186	.001	.077	.324
Mild	.248	-.079	.063	-1.258	.208	-.203	.044
Null	.309	-.019	.063	-.299	.765	-.142	.105
Don’t know	.000	-.120	.063	-1.905	.057	-.243	.003

a. Sample data contains 42 effective subjects and 4 raters.

Table 4.17: Fleiss Kappa κ Medical Physician responses

Fleiss Multirater Kappa: Physiotherapist responses Study1: 4 raters

Overall Agreement[a]

	Kappa	Asymptotic			Asymptotic 95% Confidence Interval	
		Standard Error	z	Sig.	Lower Bound	Upper Bound
Overall Agreement	-.071	.038	-1.882	.060	-.145	.003

a. Sample data contains 41 effective subjects and 4 raters.

Agreement on Individual Categories[a]

Rating Category	Conditional Probability	Kappa	Asymptotic			Asymptotic 95% Confidence Interval	
			Standard Error	z	Sig.	Lower Bound	Upper Bound
Severe	.250	.121	.064	1.905	.057	-.004	.246
Mild	.296	-.049	.064	-.771	.441	-.174	.076
Null	.296	.030	.064	.474	.636	-.095	.155
Don’t know	.000	-.333	.064	-5.228	<.001	-.458	-.208

a. Sample data contains 41 effective subjects and 4 raters.

Table 4.18: Fleiss Kappa κ Physiotherapists responses

Kappa of -0.071 with a p-value of 0.060.

This shows a negative correlation. The p-value, although not a significance level of 0.05, is quite near and this is invariably due to the very small sample size.

Fleiss Multirater Kappa: Physiotherapist responses Study2: 4 raters

Overall Agreement[a]

	Kappa	Asymptotic			Asymptotic 95% Confidence Interval	
		Standard Error	z	Sig.	Lower Bound	Upper Bound
Overall Agreement	.156	.039	4.019	<.001	.080	.233

a. Sample data contains 41 effective subjects and 4 raters.

Agreement on Individual Categories[a]

Rating Category	Conditional Probability	Kappa	Asymptotic			Asymptotic 95% Confidence Interval	
			Standard Error	z	Sig.	Lower Bound	Upper Bound
Severe	.528	.447	.064	7.008	<.001	.322	.572
Mild	.444	.335	.064	5.254	<.001	.210	.460
Null	.594	.268	.064	4.197	<.001	.143	.393
Don’t know	.000	-.323	.064	-5.059	<.001	-.448	-.198

a. Sample data contains 41 effective subjects and 4 raters.

Table 4.19: Fleiss Kappa κ Physiotherapist response

4.2.4 Analysis of Replies

To the question: In which format would you prefer information to be provided?

The majority (90%) preferred the Traffic Lights System (Figure 4.6).

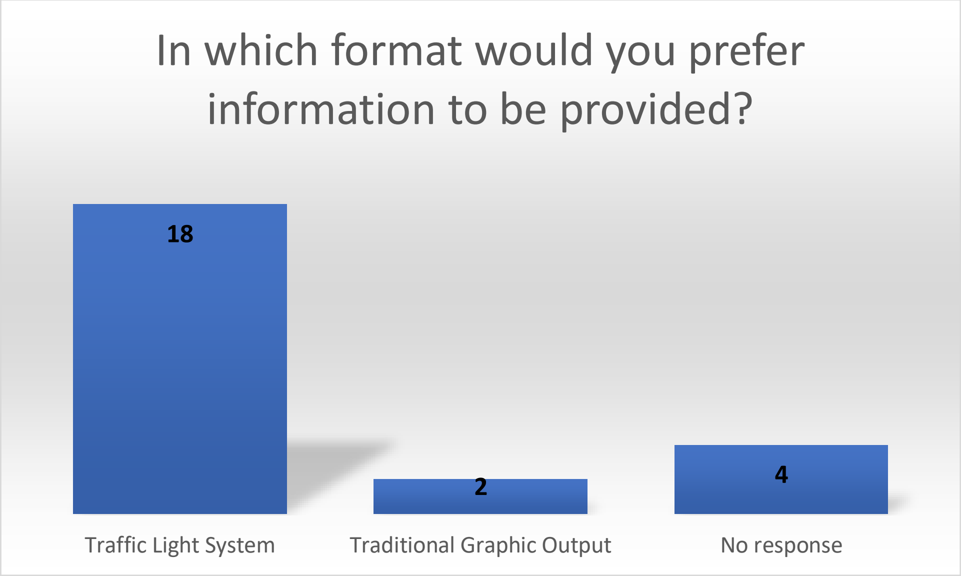


Figure 4.6 : Format of presentation

When asked 'why?', a 'qualitative' analysis of the responses brings up several themes in favour of the Traffic Lights System, with the main being:

- ➢ Ease of interpretation (8 respondents)
- ➢ User-friendliness
- ➢ Faster to interpret/instantly understandable

One typical answer stated that: "At least I can understand when and at which joints abnormal motion occurs".

One respondent, however, preferred the Traditional system as:

- "It is ineffective in colour blindness
- Traditional Graphical System would indicate cadence much clearer
- with practice other AHP would get more accustomed to reading the graph and noting any faults during the gait cycle

- Traffic Lights System system could have been simplified with being just a list of the movements of the joints accompanied with regular boxes of the different colours”

4.3 Summary of Results

4.3.1 Validity:

When comparing the responses for the Traffic Lights System to those from a Gold Standard Traditional Graphical System, the Cronbach’s Alpha of 0.92 demonstrated a very high correlation between the two systems. Thus, it may be concluded that the Traffic Lights System is a valid system.

4.3.2 Intra-Rater Reliability:

The Traditional Graphical System has been shown to have high intra-rater reliability in 2 raters who were **trained** in using this system, with a Cronbach’s Alpha ranging between 0.733 and 0.918.

The Traffic Lights System has resulted in Cronbach’s Alpha between 0.817 and 1.00 amongst the 3 raters who were **untrained** in its use (Table 4.8).

Thus, these results suggest that the intra-rater reliability of the Traditional Graphical System was high provided that raters were health professionals trained in its use, whilst the TLS also has high intra-rater reliability even when the health professionals were untrained in its use.

4.3.3 Inter-Rater Reliability:

The Fleiss Multirater Kappa Test has clearly demonstrated low inter-rater reliability amongst raters in the Traditional Graphical System, in all 3 studies. Out of these raters, there were 8 raters (32% of respondents) who were actually trained in its use, together with another 9 raters (36% of respondents) who had ‘some’ prior training in interpreting graphs. Furthermore, this system has resulted in the greatest “Do not know’ responses amongst raters.

On the other hand, the Traffic Lights System has been shown to be more reliable with consistently higher Fleiss Multirater Kappa Test results and lower percentages of “Do not know” responses. It should be kept in mind that **all** the raters were untrained in its use, whereas for the Traditional Graphical System 64% of respondents had some type of prior training.

Since the highest response was by podiatrists, (68%) in order to quantify the results by other professionals and thus investigate any possible bias that could have been caused by this high number of podiatrists, the Fleiss Multirater Kappa Test was applied also to responses by medical physicians and physiotherapists for Study 1 (Traditional Graphical System) and Study 2 (Traffic Lights System). Both these professions account for16% of respondents each. Both professions produced much lower results for the Traditional Graphical System (-0.066 and -0.071, respectively) than the Traffic Lights System (0.010 and 0.156, respectively). Indeed, the negative results for the Traditional Graphical System actually demonstrate a negative correlation.

A majority of health care professionals preferred the Traffic Lights System, finding it easier and faster to interpret, more user-friendly and instantly understandable.

Chapter 5

Discussion

This research study was based on two important premises: that the traditional method of reporting joint movement following gait analysis was not well understood by healthcare professionals and that an alternative, more intuitive and user-friendly method could be devised in order to overcome this important limitation.

As will be illustrated later on, all these postulations have been proven through the research method adopted and it is now clear that indeed the majority of health professionals do not reliably interpret and understand the traditional system of reporting. Additionally, the newly developed method of presenting these same results utilising a more visual approach appears to function better and is preferred by the majority of participants in this study, even those who had already had prior training in interpreting gait analysis results through the traditional graphical system.

Gait analysis provides important information relating to lower limb dynamics during gait. This is important because alterations in gait can produce significant conditions in any of the joints, including those of the pelvis and lower back; thus it stands to reason that clinicians managing any such conditions would benefit from knowledge gained from gait analysis. This was confirmed in this study since the absolute majority of participants replied ‘yes’ to the question “Would such kinematic information be helpful to your clinical MSK practice if provided?” Thus these health professionals who regularly treat lower limb musculoskeletal problems are of the opinion that such gait analysis information would help them manage their patients better, since gait analysis results would allow them to identify the segment where there is aberrant motion, which type of movement is beyond the normative range, and at what time during the gait cycle this is occurring.

However, the undeniable fact is that the majority of healthcare professionals do not receive any training relating to this field, thus rendering these instrumented gait analysis results only accessible to those who had undergone extensive training in this field. Indeed, this is clearly a missed opportunity to utilise gait labs more (implying expensive resources that are not used to their full potential, i.e. as much as they should be) and, more importantly, to provide test results that could potentially help those patients with lower limb musculoskeletal conditions, which often lead to pain, activity limitation and even disability. This is an extremely important point that will be discussed later since this undoubtedly illustrates the potential of the Traffic Light System to help out those patients who deserve better management options through better informing the treating health professional as to what is actually happening in the affected joint/s and how other abnormal joint movement may be directly or indirectly affecting the pathological joint. This may only be possible through tangible proof provided by the sophisticated laboratory gait analysis equipment that is mostly there, nowadays becoming cheaper, and thus more accessible, but being only utilised for severe neurological conditions such as cerebral palsy in children or, sometimes, in stroke.

To give an example, in diabetes there is a plethora of evidence in literature that glycosylation affects the tissue characteristics of muscles and tendons, resulting in altered and limited joint function (Francia et al. 2018). There is also evidence that restricted joint motion can cause altered gait that affects plantar pressure (Bartolo et al. 2021), thus predisposing the high risk patient living with peripheral neuropathy or neuroischaemia to life- and limb-threatening ulcerations. Although these altered joint motions can be quantified utilising instrumented gait analysis, at the moment of writing this dissertations there are no laboratories analysing gait using instrumented gait analysis of this important group of patients. It appears that only foot pressure measurement is being investigated in this group, most often forgetting that an increase in foot pressure could be the result of altered lower limb joint function, as confirmed by Bartolo et al. 2021.

Although one might say that it is natural that to use a system one requires appropriate training, one should also keep in mind that these health professionals all have extensive training in the management of said musculoskeletal conditions, and all can understand terms such as flexion and extension, adduction and abduction. Indeed, for a health professional, these are quite basic terms when relating to joint movements which, at the end of the day, are the basis of gait analysis results and understanding what is occurring in the lower limb segments during walking.

It is a reality that none of these health professionals receive an adequate amount of training during their undergraduate course to be able to understand and interpret graphs representing motion on 3 body planes. Visualising 3D movement from 3 graphs can be extremely difficult to do. One must keep in mind that these systems are designed by engineers, who undoubtedly would understand such concepts as representing a single joint’s movement on 3 graphs. Again, it has emerged quite clearly from the results of this study that untrained health professionals may not be so adept at interpreting 3D movement graphs and would prefer a more visual and colourful approach to presenting the results.

One must emphasise at this point on the issue of training. Again, as highlighted above, one must expect a person to be suitably trained before using a system, but in reality such training can be very difficult to obtain, requiring specialized courses, most often abroad, just to work on this system. In reality, not many health professionals may be so inclined to spend a lot of time and financial resources just on understanding this one concept and most of them indeed do not do this. It is also unrealistic to expect all health professionals to be trained in such systems. This, however, has left a lacuna in the use of instrumented gait analysis because of which it is ultimately patients who would lose out as they cannot get the optimal treatment for their significant, and often life-changing, musculoskeletal condition that could range from simple but painful osteo-arthritis, rheumatoid arthritis, the other arthritides and a host of other conditions that seriously degrade the quality of life of the patient.

This researcher can confidently state that the main aim and the majority of objectives of this research study have been reached. It has been demonstrated that

- An alternative method of presenting a more user-friendly and understandable gait analysis test results is possible
- Test results presented utilizing a more visual approach are preferred by health professionals
- The Traffic Lights System can be used by healthcare professionals with no prior training in utilizing the system
- The validity of the Traffic Lights System has been verified
- Intra- and inter-rater reliability of the Traffic Lights System is higher than that of the Traditional Graphical System. As will be discussed later, this reliability has the potential to be increased in various ways (Section 5.4)
- All but one of the raters preferred the Traffic Light System

5.1 Interpretation of Study Results

5.1.1 Validity

A measure is valid to the extent that it measures what it purports to measure (Brach et al. 2008). Concurrent validity refers to the extent to which the results of a measure correlate with the results of an established measure of the same or a related underlying construct assessed within a similar time frame (Frey, 2018).

In order for a newly devised system such as the Traffic Lights System to be utilisable as a tool for which it was designed, i.e. to present results derived from the Traditional Graphical System in a more user-friendly format that can be easily understood and utilised by the majority of interested health care professionals, it must first be proven to be valid. This means that the results presented by the Traffic Lights System must be the same as those produced by the Traditional Graphical System and not alter the results in any way. Thus it must be proven that its concurrent validity must be high. In order to do this, its outputs were compared to a Gold Standard report from the Traditional Graphical System. It must be noted that, even as demonstrated by the reliability studies pertaining to the Traditional Graphical System, these can vary because these depend on the amount of experience by the raters and these said results can be different because the Traditional Graphical System is such a complex system that requires interpretation. Thus a Gold Standard response of both the Graphical System and the Traffic Lights System had to be produced. This was done by a consensus response, ‘an ideal response’ which was agreed upon by two experienced gait analysts. So it may be considered that this would be the best possible response relative to the analysis in question. The same was done for the Traffic Lights System; indeed the TLS responses were actually based on those of the Traditional Graphical Output graphs and, thus, technically, they should be identical.

The correlation between the two systems, analysed utilising Cronbach's Alpha, returned an alpha of 0.920. According to Gliem and Gliem (2003), the closer Cronbach's alpha coefficient is to 1.0 the greater the internal consistency of the items in the scale. Thus it is clear that there is almost a perfect agreement between the two systems; i.e. the Traffic Lights System is valid when compared with the Traditional Graphical System.

5.2.2 Intra-Rater Reliability

As stated in the Methodology Chapter, Intra-rater reliability refers to the ability of a rater to the degree of agreement among repeated administrations of a test performed by a single rater. Intra-rater reliability and inter-rater reliability are also aspects of test validity (Scheel et al. 2018). In order to perform these tests, a number of respondents agreed to answer the questionnaire twice, so that the second response could be compared to the first. In order to ensure that the respondents would not remember their previous responses, a period of time greater than 1 month was left between responses. Two of the raters answered relating to both the Traditional and the Traffic Lights Systems, whilst one rater replied to only the Traffic Lights System questionnaires.

From these responses, it was thus possible to test the intra-rater reliability of both systems. It must be noted here that both raters who answered both questionnaires had prior training in the

Traditional System, and no training whatsoever in the Traffic Lights System, whilst the rater who rated only the Traffic Lights System also had no training in this system.

Results confirm that the Traditional Graphical System has indeed high intra-rater reliability (Cronbach's alpha ranging between 0.733 to 0.918), provided that the raters were well trained. This is emphasized here because, as will be shown in the inter-rater reliability section, those who had no prior training had very poor reliability results. On the other hand, the intra-rater reliability of the Traffic Lights System was actually higher (ranging between 0.817 and 1.00), however this time all the 3 raters had no prior training whatsoever.

This observation is indeed very important, instantly demonstrating the advantages of the Traffic Lights System over the Traditional Graphical System, that no previous training is necessary in the former system in order to have an acceptable amount of intra-rater reliability.

5.2.3 Inter-Rater Reliability

Like with any newly developed instrument aimed at patient management, another issue that required investigation was inter-rater reliability. This implies agreement between different raters when utilizing the same instrument or dataset.

In order to compare this type of reliability, the Fleiss Multirater Kappa test was employed on all the 3 studies utilizing the Traditional Graphical System and the 3 equivalent studies utilizing the Traffic Lights System. It is important that each study had its equivalent in both systems to ensure fair comparison; also that the comparison was on exactly the same dataset, however produced using the two different systems.

It can be surmised that in order for the newly developed Traffic Lights System to be considered reliable to permit its utilisation with real patient data, the reliability of this system must be at least equal to the reliability of the other system. However, perhaps disappointingly, this study has clearly demonstrated that the system that has been accepted and used for so many years, has such poor reliability issues amongst those ‘inexperienced’ health professionals that it has to be emphatically recommended that this system should **never be used without prior training**.

On the other hand, the Traffic Lights System has been shown to be significantly superior to it being understood and interpreted even by those health professionals **without** prior training. In truth, these persons are the most likely group of people who really require the use of such a system. In our dataset, 36% had no prior training, when compared to the 32% who had some prior training and the 32% who had prior training. When translated to real life scenarios, it becomes clear that the people who really should be using this system do not use it because gait analysis data is not available to them.

From the inter-rater reliability analyses, it is clear that the Traffic Lights System is much more reliable than the Traditional System. The kappa rating obtained, whilst being better than those of the Traditional System, are not considered to be the ideal by this researcher, however this was a first step and they can certainly be improved, as discussed in section 5.4.

For the purpose of this dissertation, it has been demonstrated that the Traffic Lights System has higher inter-rater reliability than the Traditional Graphical System, even when used by health professionals who are untrained in its specific use.

5.2.4 Analysis of reliability by profession

Whilst doing the analysis of the responses, it became very apparent that the fact that 68% of the respondents were podiatrists could perhaps lead to some bias when interpreting the results. As it stood, one could then state that the results were mainly influenced by podiatrists. Unfortunately this ‘bias’ could not be avoided because only the Association of Podiatrists (APM) agreed to disseminate the link for the Google Form and the medical and physiotherapists’ associations did not even reply to the researcher’s query to act as an intermediary. As mentioned in the methodology chapter, in order to try to offset this bias, the APM also disseminated the link to other health professionals besides podiatrists, but naturally through this method not all physiotherapists and physicians could be reached.

Thus to determine whether the lack of inter-rater reliability of the Traditional Graphical System was not primarily caused by podiatrists, the medical physicians’ and physiotherapists’ responses were also analysed separately utilising the Fleiss Multirater Kappa test, since all respondents listed their profession and it was thus possible to also group each participant by profession to be able to do the analysis.

The results of these analyses, however, confirm that even amongst the medical physicians and physiotherapy responses, the inter-rater reliability of the Traditional Graphical System was extremely poor whilst that of the Traffic Lights System was much better. Additionally, even amongst these two participant populations, the overall preferences were for the Traffic Lights System, with only 1 physiotherapist preferring the Traditional System out of the two systems.

The Traditional Graphical System reliability: novel findings that have never been previously reported.

Given the context on the use of the Traditional System of reporting gait analysis results, these results are indeed rather worrying.

As pointed out previously, whilst it is understandable that training is preferred in order to utilise any medically-oriented test, health professionals have all the requirements in order to be able to understand and interpret these results. As it stands, currently gait analysis results can only be interpreted by experienced gait analysts who then translate these graphs into plain language in order for the clinician to be able to act upon those results. This may cause issues with, for example, subjectivity arising out of the interpretations and thus could complicate matters.

More importantly, this makes gait analyses available only to a few trained specialists whose job is only to interpret such graphs. Over the years, this has resulted in significant under-utilization of gait analysis laboratories and their potential is clearly not being fully exploited. There are a large number of categories of patients that would benefit from these tests but not being given the opportunity to have their gait pattern investigated because they do not fall under the categories of patients currently eligible for gait analysis. Currently, the gait analysis laboratory at the Faculty of Health Sciences, University of Malta, is loaned to Mater Dei Hospital for gait analysis of children with, primarily, cerebral palsy and some other neurological conditions as deemed appropriate by the consultant orthopaedic surgeon. This is because, following capture of the patient’s gait, the interpretation of the result is quite labour intensive and a prolonged process in order to write a whole document explaining these results.

Thus these patients with significant lower extremity musculoskeletal conditions, which in themselves may be very debilitating and indeed crippling to some patients, are being left without the proper instrumented gait analysis that they so rightly deserve.

These categories of patients may include, for example, patients with rheumatoid arthritis, other arthritides such as psoriatic arthritis, patients with neuropathy living with, or at risk of, ulceration and consequent amputation, patients with musculoskeletal conditions such as knee problems and those with sports injuries.

Thus it is believed that, once health professionals become aware that they themselves can understand and interpret the test results of gait analysis, the need for this service would expand exponentially. One must also keep in mind that the cost of technologies nowadays are coming down, making instrumented gait analysis, as opposed to simple video gait analysis or observational gait analysis, more reachable to institutions and clinics. Indeed, one such system only utilises 3 bonita (lower cost) cameras and a treadmill to capture and analyse running strategies in runners (www.run3d.co.uk). This is a clear indication that in the not too distant future, these technologies will not only be limited to hospitals, but will be available to clinics with the required interest in the subject matter.

It is firmly believed that this novel method of presenting gait analysis data will be a key to make this a reality by causing health professionals to have a keener interest in the science of gait analysis itself.

5.3 Comparison with other studies

Unfortunately it is not possible to compare the results of this study with those of other studies. A comprehensive literature search did not reveal any such studies on similar lines. Although this might sound unlikely, this shows the innovative aspects of this study.

All studies referring to validity and reliability of gait analysis results do so in terms of gait analysis systems. This researcher has no doubt as to the validity and reliability of optoelectronic motion capture systems similar to the Vicon system used throughout this study. There are various research studies that confirm this (). However, as stated, this present study refers to the reliability of the results themselves, and not the systems.

In order to perform gait analysis, multiple walking trials are normally collected within a single session. Variability between these trials can be regarded as ‘intrinsic variation’, and reflects the inherent variation within unimpaired individuals or those with pathology. Schwartz, Trost and Wervey, 2004, looked at variation within these trials since patients will not walk exactly the same way during each capture. Repeated gait measurements typically show some differences, thus these can be assumed to contain a proportion of error (McGinley et al. 2008). Variability between ‘before’ and ‘after’ measurements may be due to treatment effects or measurement variation, or a combination of both. Knowledge of the error magnitude can enable clinical teams to minimise the risk of over-interpreting small differences as meaningful (Schwartz, Trost and Wervey, 2004).

This is one important aspect as to why researchers would want to study reliability in gait analysis; namely to determine if the variability is due to any intervention or to the small differences in walking itself so as not come to erroneous conclusions.

McGinley et al (2008) point out that they could not locate standardised or established guidelines for reviews of reliability. The QUADAS tool, for example, can be used to appraise studies of diagnostic accuracy (Whiting et al. 2004), however this tool is normally applied to check the accuracy of one instrument against another. In the case of the TLS, this is just an alternative representation of test results that have been already acquired, so the accuracy of those results would ultimately depend on the accuracy of the Traditional System itself; the Traffic Lights System is just an alternative method of representing the same results.

Validity and reliability as scientific quality criteria have to be considered when using optical motion capture in research (Eichelberger, 2016). This is such an important issue amongst the biomechanics community that there are various studies relating to this issue (Pia et al. 2017; Zugner et al. 2018; Larosche et al. 2010; Fairus et al. 2018). For example, Pia et al (2017) looked at the reliability of 3D kinematic system using the plugin Gait model in patients with spinal cord injuries, concluding that three-dimensional gait analysis seems to be a reliable tool to evaluate kinematic gait in adults with spinal cord injury.

Functional characteristics of any optoelectronic motion capture system, namely accuracy, repeatability and resolution, needs to be determined to report data with confidence Miller et al (2002). All these can vary from laboratory to another, with accuracy being highly dependent on the number of cameras used and their positioning; for example, for lower body assessment during level walking, 10 cameras are the optimal minimum number when assessing the foot

(Eichelberger, 2016); the laboratory at the Faculty of Health Sciences currently has 16 optimally-placed infra-red cameras, far exceeding this minimum requirement.

As may be seen by the extensive amount of literature, all validity and reliability studies were performed to assess these criteria for gait analysis systems; whether optoelectronic, instrumented treadmills (Weart et al. 2020), accelerometer based systems (Jarchi, 2018) and a plethora of other emerging technologies (Salchow-Hömmen et al. 2022l.

This present study is so novel that no other similar studies could be found. No studies that research the actual *presentation* of results, and whether they can be understood by the evaluator. This makes comparison with available literature impossible as there are simply no similar studies to be found, at least as far as this researcher can conclude.

In a way, this is rather worrying because the actual output is the interface between the system and the user; the use of 3 graphs to represent triplanar movement of a segment that was initially proposed by the first systems that were developed have never been challenged and assessed for their suitability to be understood by clinicians. It must be understood that these systems were initially designed by, obviously, engineers. Graphs are a typical engineering format to present data, which engineers can understand very well. As for non-engineers, whilst it may be easy to understand and interpret simple 2-axis graphs, here it must be pointed out that each graph, composed of 100 data points, represents a movement in a single plane; thus 3 graphs have to be ‘amalgamated’ together to be able to visualise the segment angle, together, for each data point.

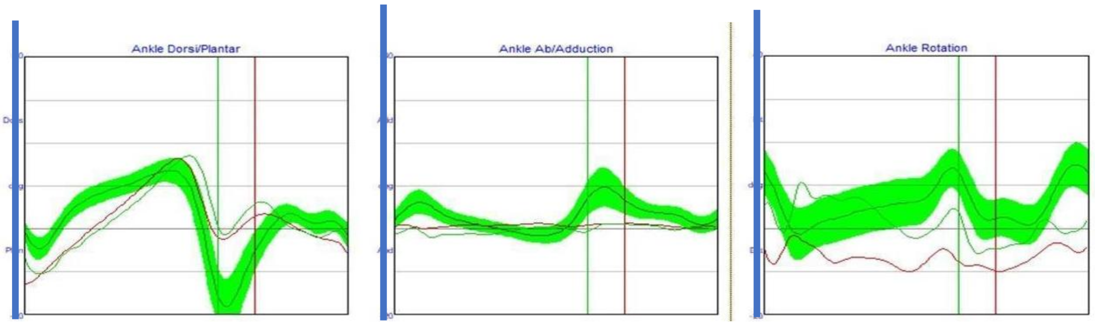


Figure 5.1: Ankle kinematics representation in the Traditional System, on 3 planes

For example, in figure 5.1 above, at the point of the blue cursor, the right (green) ankle is plantarflexed, slightly abducted and beginning to internally rotate. This may be difficult to visualise for most health professionals who have not had a chance to understand these graphs by undergoing a proper training programme.

5.4 Possible developments of the Traffic Lights System

Although the Traffic Lights System has obtained a better reliability profile than the Traditional Graphical System, which implies that if the latter is presently used in clinical practice, the Traffic Lights System may also be used for this purpose, during the course of this study and the write-up of this dissertation, the researcher was able to reflect and come up with ways that could possibly improve this system of reporting.

One of the greatest aims would be to improve the inter-rater reliability since, from the results of this study, there are no doubts that both validity and intra-rater reliability are sufficiently high. A certain amount of ‘variability’ is acceptable, and indeed to be expected, as outlined by

Herssens et al (2018); whilst this could be construed as ‘errors’, these would be in fact natural variations that would arise due when a large number of raters are rating a particular instrument.

Some comments from the participants also helped to identify some limitations, such as the use of colour itself to denote the movement. This is an issue that the researcher had not initially considered because, after all, the use of colour was the main primary characteristic of this new system. Also, other systems such as 3D representation of foot pressure when using platform or inshoe pressure mapping apparatus rely heavily on colours to illustrate the amount of pressure on a particular area.

5.4.1 Adaptation for Colour blindness

The comment regarding colour blindness by one of the participants denoted a shortcoming that had to be improved. In this system, this can easily be done by the use of different patterns associated with colour; for example, a striped region could be associated with the red colour, dotted with the green colour and small boxes associated with the yellow colour, as shown in Figure 5.2.

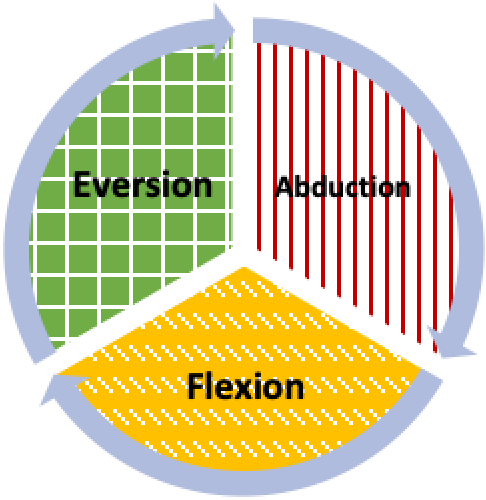


Figure 5.2: Transformation of TLS node from simple colour to textured for colour blindness

It is hoped that this layout would be more appropriate for persons living with colour blindness since they can associate the pattern with the respective colour.

5.4.2 Simplifying the presentation of results

Although in this researcher’s opinion the suggested method of presenting this data has been simplified extensively when compared in relation to the traditional graphs, it is hypothesized that simplifying the outputs even further would be more immediately understandable.

The method is to visualise the results as two layers; a simple layer on top and a more complex layer underneath. On a compute, this can be displayed as a simplified graphic; when the user clicks on the image, the more complex presentation can come up, as displayed in Figure 5.3. If the results are printed on paper, these two can be printed on two separate sheets, with the first sheet denoting the ‘simple’ output and the second sheet denoting the ‘full’ result.

Here it is being hypothesized as well that it could be sufficient for the output to represent the most severe movement in a colour representing that movement. This is because if there is a major deviation on one plane, movements on the other plane are most often bound to be affected as well. For example, if in the pelvis node, anterior tilt would be red, rotation would be green and obliquity would be yellow, it is sufficient for most health professionals to instantly recognize that the major problem is anterior tilt. If that professional would require further explanation, s/he could refer to the more complex output denoting the 3 movements. This is illustrated in figure 5.3 below.

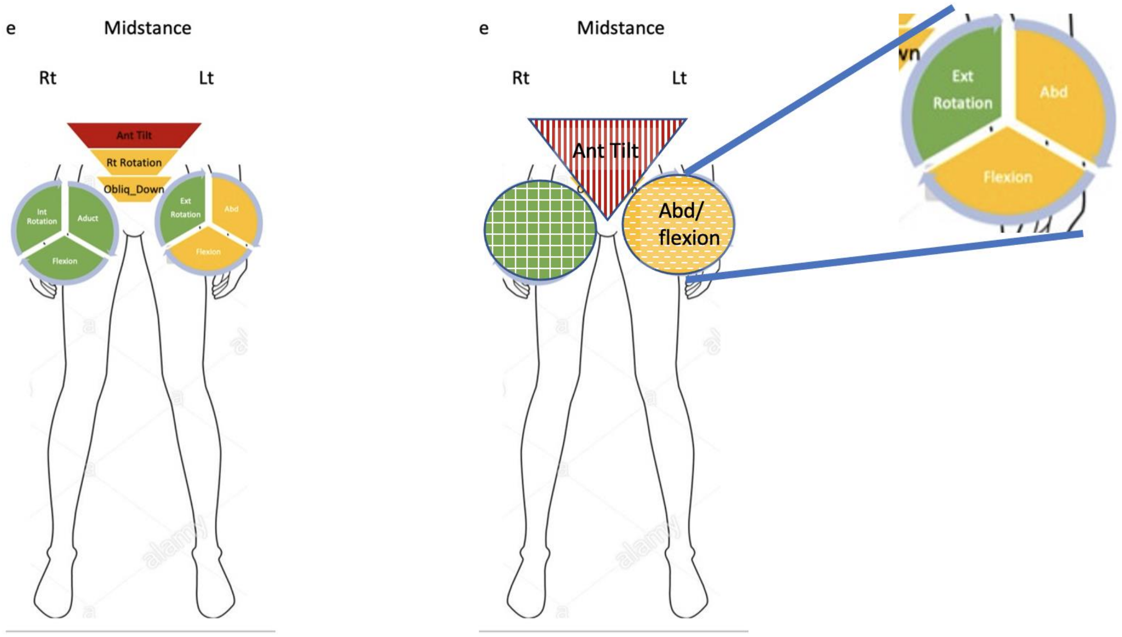


Figure 5.3: Simplifying the presented results by presenting only the major component. Once clicked with a mouse, a tooltip would open on the respective node to further explain the movements

5.4.3 Software

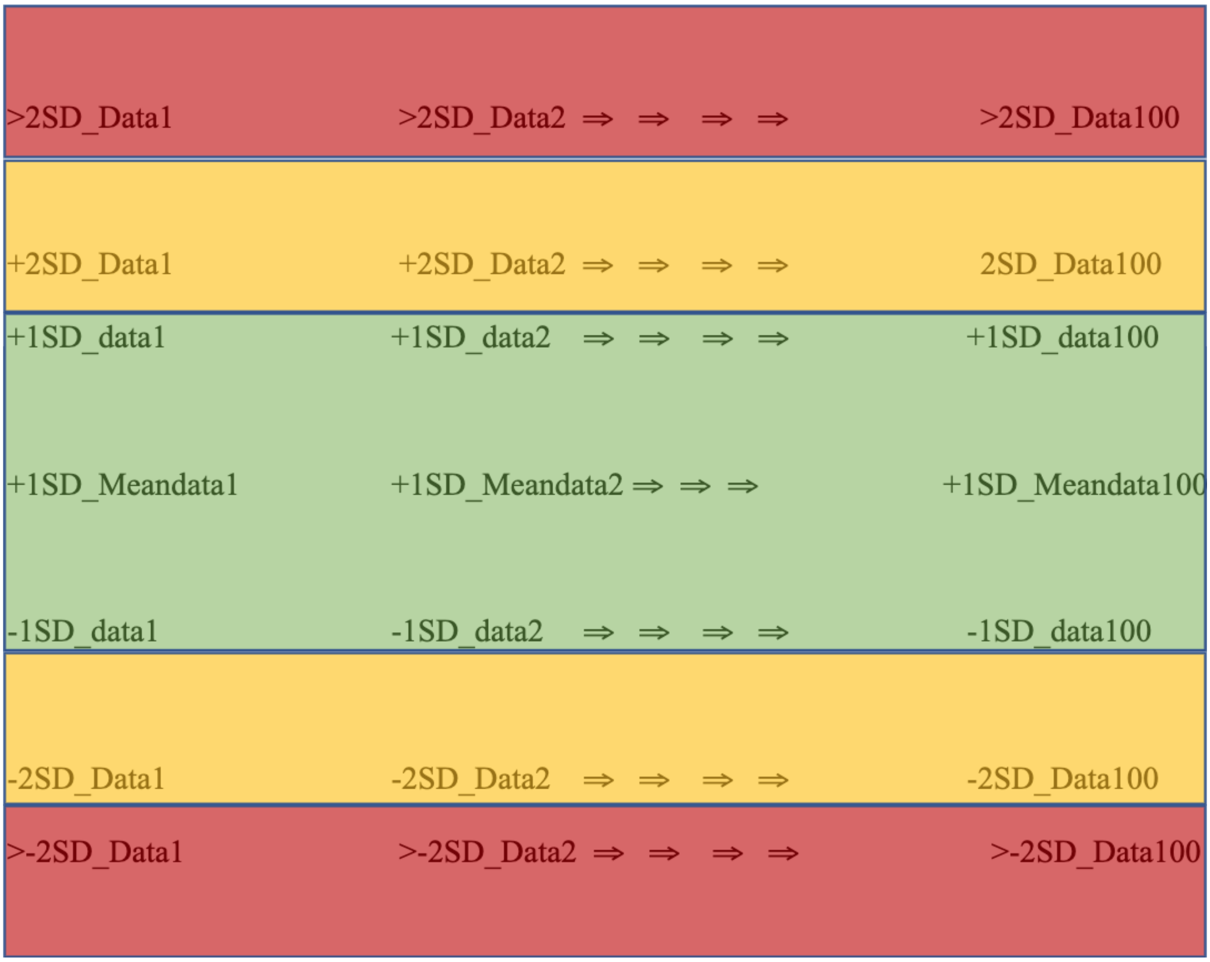
As already outlined in the methods section, a software version for interpreting the outputs from the graphs to the Traffic Lights System was attempted, with a small degree of success. This was largely due to the researcher's limited knowledge of the programming language used, however, upon consultation with an experienced programmer, it was confirmed as a relatively simple process to write a Python program to perform this task.

When exporting the Vicon Nexus data as a .cvs (text) file, there are 100 data points since the system records at 100Hz. The previously obtained .pcx file (a file that all gait labs should have to define normal gait) would also contain 100 data points for mean value and 100 data points for standard deviation, with each data point for the mean and SD being related (figure 5.4).

Thus:

Datapoint1 -------- mean1---------SD1
Up to
Datapoint100 ----- mean100-------SD100

Thus the minimum and maximum normative value for each datapoint can be calculated, providing the green band.



>2SD_Data1	>2SD_Data2 ⇒ ⇒ ⇒ ⇒	>2SD_Data100
+2SD_Data1	+2SD_Data2 ⇒ ⇒ ⇒ ⇒	2SD_Data100
+1SD_data1	+1SD_data2 ⇒ ⇒ ⇒ ⇒	+1SD_data100
+1SD_Meandata1	+1SD_Meandata2 ⇒ ⇒ ⇒	+1SD_Meandata100
-1SD_data1	-1SD_data2 ⇒ ⇒ ⇒ ⇒	-1SD_data100
-2SD_Data1	-2SD_Data2 ⇒ ⇒ ⇒ ⇒	-2SD_Data100
>-2SD_Data1	>-2SD_Data2 ⇒ ⇒ ⇒ ⇒	>-2SD_Data100

Figure 5.4: Calculating the 3 regions

This will provide us with the 3 regions: normal (green), within +/- 1SD(Yellow), above 2SD (red). Each datapoint from the file relating to the patient can thus be calculated to fall within a certain region.

Utilizing software to interpret and present the data would certainly increase the validity and reliability of this system. This is because in this study, this system was interpreted by hand, which could have led to some subjective decisions being held. This is an obvious limitation that can be resolved in this matter.

The system can be utilised by importing the exported file from the optoelectronic motion capture system. One important point is that this is not dependent on what system was used to capture the data, since all such systems can export their data in this manner. This makes the Traffic Lights System an important software tool that can be used by most labs; otherwise each system can incorporate this method of presenting data into their own reporting software.

An example of a possible algorithm to develop a software programme for automation of the Traffic Lights system:

```
Read 100 data points of gait cycle
Input number of frames for IC-LP
Input number of frames for Midstance
Input number of frames for Terminal Stance
Read PTX file: 100 data points, 100 SD values


For loop =initial point of phase to last point of phase

Data point:
Calculate normative range for that point (mean ptx point -1SD to mean ptx point + 1SD)
Calculate normative range for that point (mean ptx point -2SD to mean ptx point + 2SD)

Calculate green ptx point range (ptx point -1SD to ptx point +1 SD)

Calculate yellow ptx point range ((ptx point -1SD to ptx point -2 SD)OR(ptx point +1SD to ptx point +2 SD)

Calculate red ptx point range (ptx point >-2SD)OR(>+2SD)

Determine data point position in relation to green, yellow and red ranges and assign appropriate colour

Repeat for all data points in the current phase

Display in appropriate colour for current phase

Repeat for all three movements for each joint

Repeat for all three phases

Display final model
```

5.4.4 Training

This research was intentionally aimed at assessing reliability without prior training as it was hypothesized that the majority of health professionals would have no prior training in this respect. However, reliability would be undoubtedly increased if interested clinicians would undergo some kind of explanatory training before assessing the test results. Fortunately, training clinicians who already have good knowledge of joint movements because, at the end of the day, it is these professionals who actually treat the patient, should not prove to be a prolonged affair as when, for example, compared with training required to interpret the 3 graphs for each body plane generated by the Traditional System. Training may take the form of a simple sheet of instructions that can be printed out before looking at the result, or this can take the form of a short video explaining the methodology of assessing each joint using the Traffic Light System.

Appendix 5 lists the text required to be read as explanation how to use the Traffic Lights System for interpreting patient results.

5.5 Implications for clinical practice

Without wanting to sound too enthusiastic, needless to say this researcher sees great possibilities for this system if incorporated into routine clinical practice.

There is undoubtedly under-utilization of instrumented 3D gait analysis. Because of the complexity of reading the results, and the high costs of 3D infra-red motion camera systems, practitioners prefer to use observational and simple 2D video gait analysis. However, both these systems have significant problems associated with them, since observational gait analysis is a purely subjective process and depends entirely on the clinician's experience in this field, whilst 2D systems have perspective errors and only simple movements on one plane can be measured.

Once health professionals realize how relatively easy it is to understand where and how their patients' joint movements are being affected, they should instantly appreciate the importance of utilizing valid and reliable gait data. The more that clinicians are exposed to this modality of investigating patient musculoskeletal conditions, the more they are likely to request such laboratory investigations.

As previously pointed out, there is a huge market for these investigations; the diabetic field, for example, is not explored at all even though there are currently investigations being carried out locally (Bartolo et al. 2021) to influence the effect of altered joint motion on foot plantar pressure, which is a risk-factor for neuropathic ulceration. Two other local studies investigated both the effect of neuropathy on muscle function (Bartolo et al. 2019) and the effect of peripheral arterial disease on joint kinematics (Saliba Thorne et al. 2021). Both these papers have found significant influence of diabetes on gait, which were measured utilizing electromyography in the Bartolo et al (2019) paper and 3d motion capture in the Saliba Thorne et al (2021) study. These studies clearly demonstrate the possible application of instrumented gait analysis in the field of diabetes, with this field being of such importance for Malta when considering the high proportion of amputations carried out annually (Kevin paper).

Besides this proposed use of gait analysis in patients living with diabetes, which can be recommended on a national level, one cannot ignore other important fields of neurology, rheumatology, sports medicine and gerontology. These are all very important fields, however there is minimal evidence in literature relating to large population studies, possibly because these 3d gait laboratories are not so available to the average researcher and clinician.

Besides the great importance for clinicians, 3D gait laboratories can now have a wider scope of practice, since their clientele would invariably increase dramatically once more clinicians would request further use of gait analysis, simply because they can now understand the results better, without having the need to refer to highly trained gait analysts who would be available to utilise their skills in other important fields, such as pre-surgical investigations.

The Traffic Lights System is not intended to fully-replace the Traditional Graphical System, but rather to augment the usefulness of gait analysis results and thus make these investigations more accessible to those clinicians, and thus their patients, in order to improve their health status.

5.6 Limitations of the study

As with any research study, some limitations have been identified. Those that could be handled before were addressed through methodological measures, however there were some limitations over which the researcher had little control and which could have influenced the final outcome of the project.

5.6.1 Sample Size

Every researcher wishes to recruit the largest sample of participants possible in order to obtain a representative sample. The number of participants, 25, could not be defined as a representative sample as there are over 1000 medical physicians, over 150 podiatrists and 374 physiotherapists in Malta. Thus, the sample size was rather small for this population, however several attempts were made to contact more and more health professionals from the medical, podiatry and physical therapy communities through emails by the intermediary, the President of the Association of Podiatrists of Malta who sent emails and reminders on several occasions in order to attempt to recruit more participants.

Notwithstanding this limitation, however, the outcome of this study was quite explicit, demonstrating superiority in all reliability measures. Additionally, all but one of the participants preferred the Traffic Lights System over the Traditional Graphical representation of the results.

5.6.2 Sample population; possible bias

The majority of respondents were podiatrists. This limitation unfortunately could not be overcome since neither the Malta Medical Association and the Malta Physiotherapy Association declined from acting as intermediaries towards their members by not even replying to emails sent. This created an undesired imbalance over which the researcher had no control.

This limitation would have been significant if a work-around of this situation was not thought of during statistical analysis. Thus, in order to ensure that no bias was created by having 68% of respondents who were podiatrists, the inter-rater reliability of the other two professions were also analysed separately.

5.6.3 Induced errors

Bias may be defined as the unintentional skewing of results through an intervention done by the researcher. Since the changes from the Traditional System to the Traffic Lights System was performed by hand, it could be possible that the researcher introduced undesirable errors when drawing up the TLS nodes. In order to limit this limitation, each output was checked numerous times and a ‘back’ translation method was utilised to ensure that all outputs were indeed representative of both systems.

5.7 Recommendations for future research

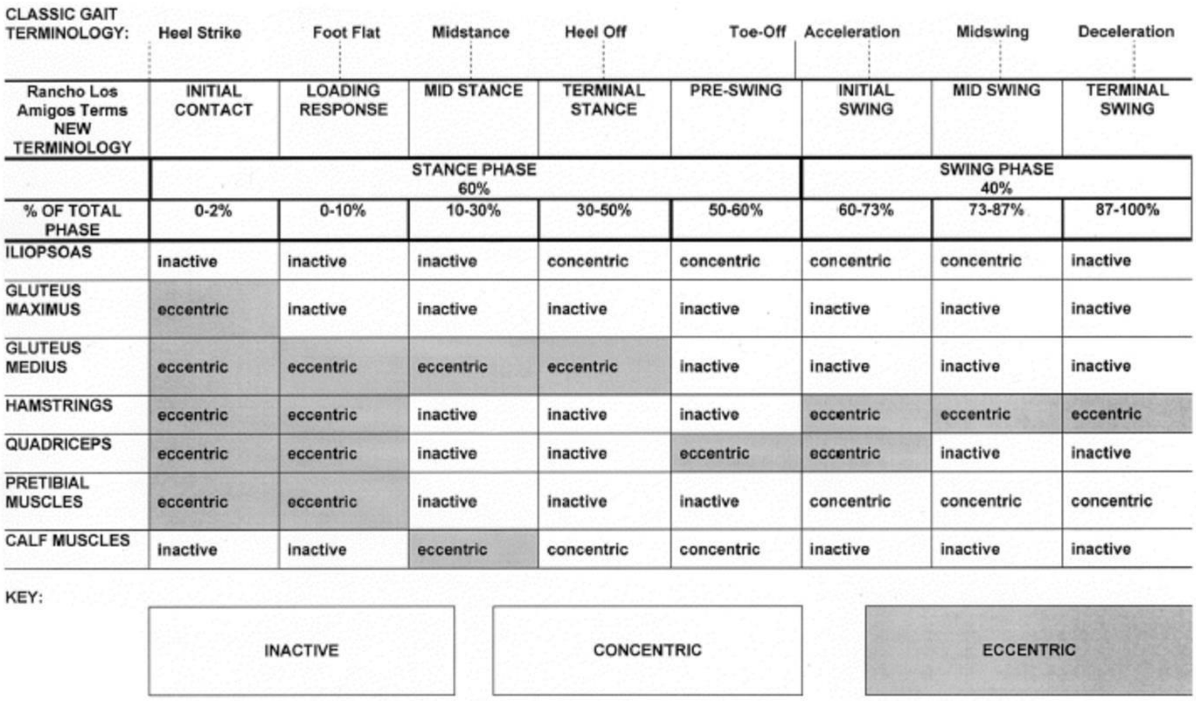
This study was an initial research into the possibilities of presenting gait analysis test results in a more user-friendly and visual method. It has been shown that there are great possibilities for improving the outcomes of this method, however clearly more development work and further research is required.

Once further development of the system is achieved, ideally utilizing software to make the transition from the Traditional Graphical System to the Traffic Lights System easier and in a more automated process to eliminate human errors, with the aim of making the new system easier to read and interpret by health care professionals, this study should be performed once again, ideally by

1. recruiting a much larger sample size
2. ensuring a more even mixture of professionals
3. trying to recruit international participants as well

Further development work could also include the integration of electromyography data in the results. EMG is another aspect of gait analysis that is gaining in popularity because of the greater availability of equipment.

This is feasible because the activation period of each lower limb muscle is known, and at what time this activation occurs during the gait cycle, as per figure 5.5 below.



CLASSIC GAIT TERMINOLOGY:	Heel Strike	Foot Flat	Midstance	Heel Off	Toe-Off	Acceleration	Midswing	Deceleration
Rancho Los Amigos Terms NEW TERMINOLOGY	INITIAL CONTACT	LOADING RESPONSE	MID STANCE	TERMINAL STANCE	PRE-SWING	INITIAL SWING	MID SWING	TERMINAL SWING
	STANCE PHASE 60%					SWING PHASE 40%		
% OF TOTAL PHASE	0-2%	0-10%	10-30%	30-50%	50-60%	60-73%	73-87%	87-100%
ILIOPSOAS	inactive	inactive	inactive	concentric	concentric	concentric	concentric	inactive
GLUTEUS MAXIMUS	eccentric	inactive	inactive	inactive	inactive	inactive	inactive	inactive
GLUTEUS MEDIUS	eccentric	eccentric	eccentric	eccentric	inactive	inactive	inactive	inactive
HAMSTRINGS	eccentric	eccentric	inactive	inactive	inactive	eccentric	eccentric	eccentric
QUADRICEPS	eccentric	eccentric	inactive	inactive	eccentric	eccentric	inactive	inactive
PRETIBIAL MUSCLES	eccentric	eccentric	inactive	inactive	inactive	concentric	concentric	concentric
CALF MUSCLES	inactive	inactive	eccentric	concentric	concentric	inactive	inactive	inactive

KEY:

INACTIVE

CONCENTRIC

ECCENTRIC

Figure 5.5: activation of muscles during the gait cycle

With this information, it becomes possible to plot the activation of each muscle in relation to its normative activation period in order to quickly determine whether there are any abnormalities in these muscles. However, this project is definitely another subject for another Master’s Study.

Chapter 6

Conclusions

This research study has come to several important conclusions, which are listed hereunder:

6.1 Validity:

When comparing the Traffic Lights System to a Gold Standard Traditional Graphical System, the Cronbach's Alpha of 0.92 demonstrated a very high correlation between the two systems. Thus, it may be concluded that the TLS is a valid system.

6.2 Intra-Rater Reliability:

- Results suggest that the intra-rater reliability of the Traditional Graphical System was high provided that the raters were health professionals trained in its use, whilst the Traffic Lights System also has high intra-rater reliability even when the health professionals were untrained in its use. This can be demonstrated by the results below:

    a. The Traditional Graphical System has been shown to have high intra-rater reliability in 2 raters who are **trained** in the system, with a Cronbach's Alpha ranging between 0.733 and 0.918.

    b. The Traffic Lights System has resulted in Cronbach's Alpha between 0.817 and 1.00 amongst the 3 raters who were **untrained** in its use (Table 4.8).

This is clearly a big advantage of the Traffic Lights System, demonstrating its ease of use with minimal or no training at all.

6.3 Inter-Rater Reliability:

1. The Fleiss Multirater Kappa Test has clearly demonstrated low inter-rater reliability amongst raters in the Traditional Graphical System, in all 3 studies. Furthermore, this system has resulted in the greatest “Do not know’ responses amongst raters. This clearly confirms the need to explore other systems of reporting gait datasets in order for health professionals to fully understand the results.

2. On the other hand, the Traffic Lights System has been shown to be more reliable with consistently higher Fleiss Multirater Kappa Test results and lower percentages of “Do not know” responses. It should be kept in mind that **all** the raters were untrained in its use, whereas for the Traditional Graphical System, some of the raters had prior training.

6.4 Inter-rater reliability by professions:

3. Since the highest response was by podiatrists, (68%) in order to quantify the results by other professionals and thus investigate any possible bias that could have been caused by this high number of podiatrists, the Fleiss Multirater Kappa Test was applied also to responses by medical physicians and physiotherapists for Study 1 (Traditional Graphical System) and Study 2 (Traffic Lights System). Both these professions account for 16% of respondents each. Both professions produced much lower results for the TGS (-0.066 and -0.071, respectively) than the Traffic Lights System (0.010 and 0.156, respectively). Indeed, the negative results for the Traditional Graphical System actually demonstrate a negative correlation.

4. The majority of health care professionals preferred the Traffic Lights System, finding it easier and faster to interpret, more user-friendly and instantly understandable.

This research study has clearly demonstrated the need to update the method by which gait analysis results are presented, so that health professionals including medical physicians, podiatrists and physiotherapists, have a better understanding of gait events when treating their patients. The system can be further developed to make it even simpler to understand, making it more accessible to a wider range of health professionals; additionally, the increased use by health care professionals would benefit all patients with musculoskeletal related conditions where joint movement is important to assess, whilst on the other hand providing a wider scope of practice for gait laboratories to increase the number of tests, thus potentially helping more and more patients.

Although due to the limited responses, this study may be classified as a pilot study, further development especially relating to software development, together with further studies are required to adopt a proper and comprehensive Traffic Lights System for reporting of gait analysis results, it is clear that this system has higher benefits than the Traditional System, for the benefit of the patient.

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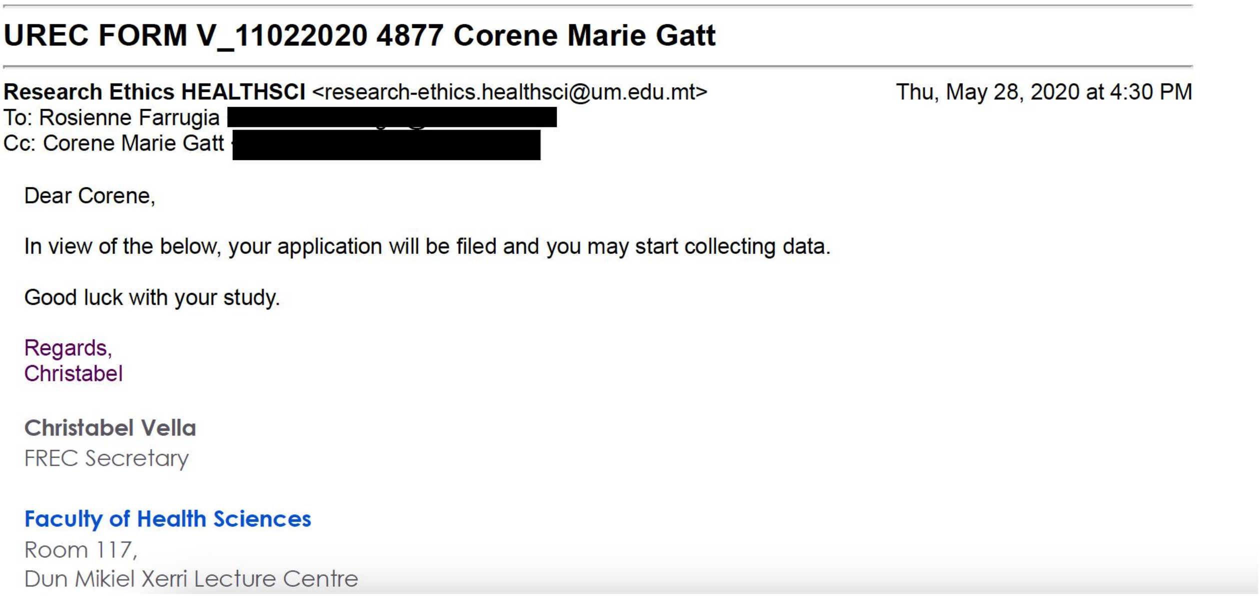
Appendices

Appendix 1: Ethics Approval and Intermediary Letters



UREC FORM V_11022020 4877 Corene Marie Gatt

Research Ethics HEALTHSCI <research-ethics.healthsci@um.edu.mt> Thu, May 28, 2020 at 4:30 PM
To: Rosienne Farrugia [redacted]
Cc: Corene Marie Gatt [redacted]

Dear Corene,

In view of the below, your application will be filed and you may start collecting data.

Good luck with your study.

Regards,
Christabel

Christabel Vella
FREC Secretary

Faculty of Health Sciences
Room 117,
Dun Mikiel Xerri Lecture Centre

Mr Andrew Scicluna
Professional Lead (Podiatry)
Podiatry Department
B'Kara Civic Centre

26th March, 2020

Dear Mr Scicluna,

I am Dr Corene Gatt and I am performing a research project entitled *"A Novel method of presenting Kinematic Gait Analysis data for Health Care Professionals – the TRAFFIC LIGHTS System"* as part of my Master's degree in Clinical Biomechanics.

As you are aware, currently health professionals do not get any in-depth gait analysis training throughout their course of studies. Additionally, gait analysis data is often presented in an engineering graphical format that may not be so intuitive to interpret and thus may be quite difficult to diagnose gait-related conditions that often may affect the hip, knee and ankle joints. Thus, health professionals often diagnose these conditions 'in the blind', without appreciating the kinematic variations that occur during gait. This makes treating these conditions often difficult, to the detriment of the patient.

Together with my supervisor, we have developed a more visual method of presenting gait data relating to lower extremity joint movement based on a "traffic light system", with the 3 colours of the traffic lights depicting the extent and nature of variation of movement of each individual joint in the 3 body plates, i.e. sagittal, coronal and transverse planes. This system is not intended to replace traditional graphical outputs, however we are hypothesizing that using this new system the health professional who has not undergone extensive gait analysis training will be able to pinpoint abnormally functional joints quicker and more reliably than using the traditional system of representation.

Professional colleagues' participation in the study will involve evaluating a set of gait analysis outputs, and their 'traffic lights' counterparts, suitably randomized, in order to determine whether the participants will be able to pinpoint abnormal joint movement in an easier and more effective manner. These outputs will be put on an online survey, which can be filled in anywhere, and should take less than 1 hour to complete.

The data will be presented on a google form and the participant will note down responses in the online survey. At no time will any personal data be collected during this session. A similar session, using similar data set, will be held 1 month after the first session, at a time suitable for the participants, in order to asses intra-rater and test-retest reliability.

All online responses will be in anonymous format and at no time will any personal data be collected or made available to anyone. Only the researcher and the supervisor will have access to data. If required, examiners will have access to coded data only. On completion of the study data will be retained in anonymous form.

I would like to enquire whether you can act as intermediary in this project and forward the link to the survey when it becomes available to colleagues who are interested in the field of biomechanics and who examine, diagnose and treat patients with lower limb musculoskeletal conditions in their practice.

Should you have any queries regarding this study please do not hesitate to contact me or my supervisor Professor Ruben Gatt.

Dr Corene Marie Gatt MD
[redacted]

Professor Ruben Gatt PhD
[redacted]

Date: 2/4/20

[redacted]

Mr Darren Sillato
Allied Health Professional
Mater Dei Hospital

26th March 2020

Dear Mr Sillato,

I am Dr Corene Gatt and I am performing a research project entitled "*A Novel method of presenting Kinematic Gait Analysis data for Health Care Professionals – the TRAFFIC LIGHTS System*" as part of my Master's degree in Clinical Biomechanics.

As you are aware, currently health professionals do not get any in-depth gait analysis training throughout their course of studies. Additionally, gait analysis data is often presented in an engineering graphical format that may not be so intuitive to interpret and thus may be quite difficult to diagnose gait-related conditions that often may affect the hip, knee and ankle joints. Thus, health professionals often diagnose these conditions 'in the blind', without appreciating the kinematic variations that occur during gait. This makes treating these conditions often difficult, to the detriment of the patient.

Together with my supervisor, we have developed a more visual method of presenting gait data relating to lower extremity joint movement based on a "traffic light system", with the 3 colours of the traffic lights depicting the extent and nature of variation of movement of each individual joint in the 3 body plates, i.e. sagittal, coronal and transverse planes. This system is not intended to replace traditional graphical outputs, however we are hypothesizing that using this new system the health professional who has not undergone extensive gait analysis training will be able to pinpoint abnormally functional joints quicker and more reliably than using the traditional system of representation.

Professional colleagues' participation in the study will involve evaluating a set of gait analysis outputs, and their 'traffic lights' counterparts, suitably randomized, in order to determine whether the participants will be able to pinpoint abnormal joint movement in an easier and more effective manner. These outputs will be put on an online survey, which can be filled in anywhere, and should take less than 1 hour to complete.

The data will be presented on a google form and the participant will note down responses in the online survey. At no time will any personal data be collected during this session. A similar session, using similar data set, will be held 1 month after the first session, at a time suitable for the participants, in order to asses intra-rater and test-retest reliability.

All online responses will be in anonymous format and at no time will any personal data be collected or made available to anyone. Only the researcher and the supervisor will have access to data. If required, examiners will have access to coded data only. On completion of the study data will be retained in anonymous form.

I would like to enquire whether you can act as intermediary in this project and forward the link to the survey when it becomes available to colleagues who are interested in the field of biomechanics and who examine, diagnose and treat patients with lower limb musculoskeletal conditions in their practice.

Should you have any queries regarding this study please do not hesitate to contact me or my supervisor Professor Ruben Gatt.

Dr Corene Marie Gatt MD
[redacted]

Professor Ruben Gatt PhD
[redacted]

Date: 2/4/20

[redacted]

Appendix 2: Google Form Questions

A Novel method of presenting Kinematic Gait Analysis data for Health Care Professionals – the TRAFFIC LIGHTS System

Dear Health Professional,

My name is Corene Gatt and I am performing a research project entitled "A Novel method of presenting Kinematic Gait Analysis data for Health Care Professionals – the TRAFFIC LIGHTS System" as part of my Master's degree in Clinical Biomechanics.

You are being invited to participate in a research project because you regularly treat patients with lower limb conditions often associated with gait deviations. As you are aware, currently health professionals do not get any in-depth gait analysis training throughout their course of studies. Additionally, gait analysis data is often presented in an engineering graphical format that may not be so intuitive to interpret and thus, may be quite difficult to diagnose gait-related conditions that often may affect the hip, knee and ankle joints.

Together with my supervisor, we have developed a more visual method of presenting gait data relating to lower extremity joint movement based on a "traffic light system", with the 3 colours of the traffic lights depicting the extent and nature of variation of movement of each individual joint in the 3 body plates, i.e. sagittal, coronal and transverse planes. This system is not intended to replace traditional graphical outputs, however we are hypothesizing that using this new system the health professional who has not undergone extensive gait analysis training will be able to pinpoint abnormally functional joints quicker and more reliably than using the traditional system of representation.

Your participation in the study will involve evaluating a set of gait analysis outputs, and their 'traffic lights' counterparts, suitably randomized, in order to determine whether the participants will be able to pinpoint abnormal joint movement

All your responses in the online survey that follows will be in anonymous format and at no time will any personal data be collected or made available to anyone.

You are free to withdraw from the study at any time you wish to do so without any justification required.

Kindly note that this exercise will in no way be a critical analysis of your gait analysis skills.

Should you have any queries regarding this study please do not hesitate to contact me or my supervisor Professor Ruben Gatt.

Dr Corene Marie Gatt MD
[redacted]

Professor Ruben Gatt PhD
[redacted]

Instructions to Participants

The Traffic Lights System of visual reporting gait analysis results:

Each node represents a joint: pelvis, hip, knee, ankle. Each node presents movement in 3 body planes; e.g. for the ankle, plantarflexion/dorsiflexion; inversion/eversion; abduction/adduction.
Thus:
Each joint has 3 movements marked. The listed movement in each represents the direction of predominant motion in that joint.
The colour represents the amount of motion:

GREEN within normative values (+/- 1 Standard Deviation)
YELLOW just outside of normative ranges, but within +/- 2SD
RED if highly increased range of motion beyond +/-2SD

These may be interpreted as:

GREEN: within normal values;
YELLOW: just outside normative ranges;
RED: highly increased range of motion

The traditional system of reporting gait analysis results:
A graph representing a normalized gait cycle for each joint is presented, from heel strike to the next heel strike. 3 graphs are provided per body plane of movement. Normative values are presented as a shaded range.

Please identify any abnormal lower limb joint – pelvis, hips, knees, ankles – motion of each ‘subject’ as presented by the Traffic Lights System and normal gait analysis graphs. All graphs are presented in random order.

All presented outputs have been divided into pelvis/knees and knees/ankles for clarity.

1. Consent

As data is collected anonymously, filling in and returning a questionnaire constitutes giving consent.

Tick all that apply.

☐ I consent to participate in this study
☐ If you do not consent, kindly do NOT fill in this survey

2. Occupation

Mark only one oval.

○ Medical Physician
○ Physiotherapist
○ Podiatrist
○ Other: ____________________

3. Prior Training in Gait Analysis

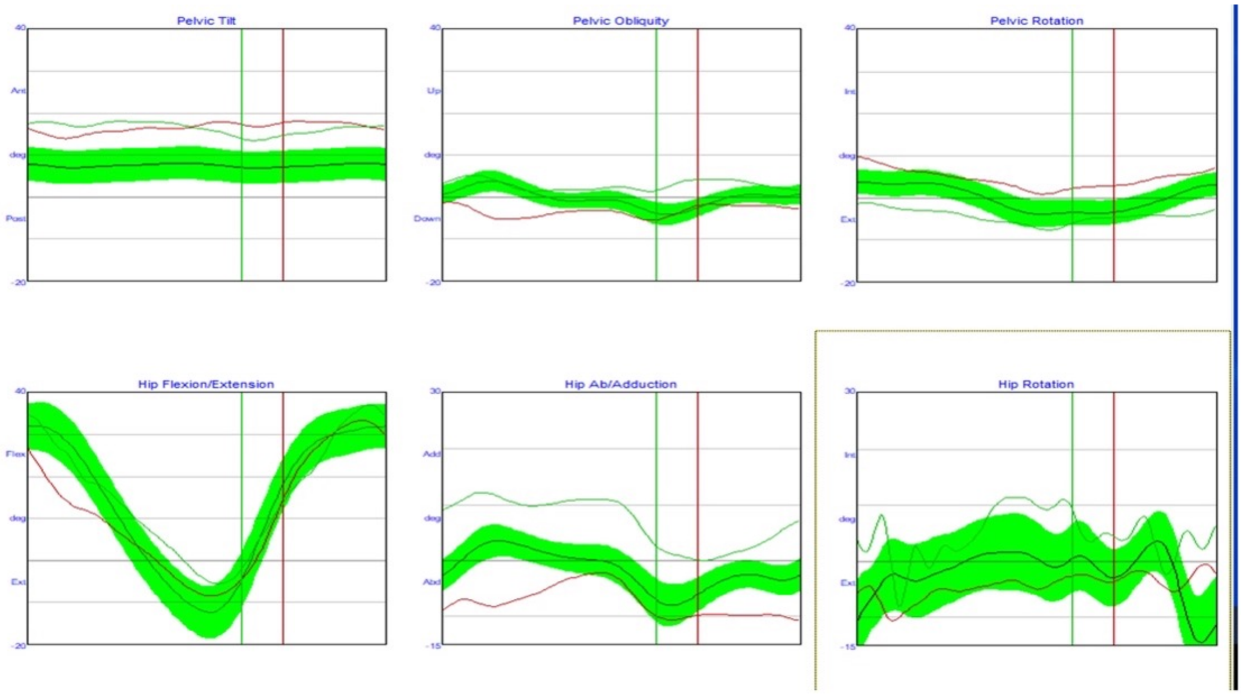
Mark only only one oval.

○ I had prior training in instrumented gait analysis
○ I had some prior training in instrumented gait analaysis
○ I had no prior training in instrumented gait analysis

Pelvis and Hips

Scenario 1a: Traditional Graphical output Results

Patient had bilateral arthrodesis



4. Do you think there are any altered joint motions in this subject?

Mark only one oval.

○ Yes
○ No
○ I do not know (if you do not know, please pass on to the next scenario)

5. If yes, which joints do you think are affected?

Tick all that apply.

☐ Pelvis
☐ Right Hip
☐ Left Hip

6. PELVIS

Tick all that apply.

	Mild	Severe
Anterior Tilt	☐	☐
Posterior Tilt	☐	☐
Right Obliquity	☐	☐
Left Obliquity	☐	☐
Right Rotation	☐	☐
Left Rotation	☐	☐

7. RIGHT HIP

Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Flexion	☐	☐
Extension	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

8. LEFT HIP

Tick all that apply.

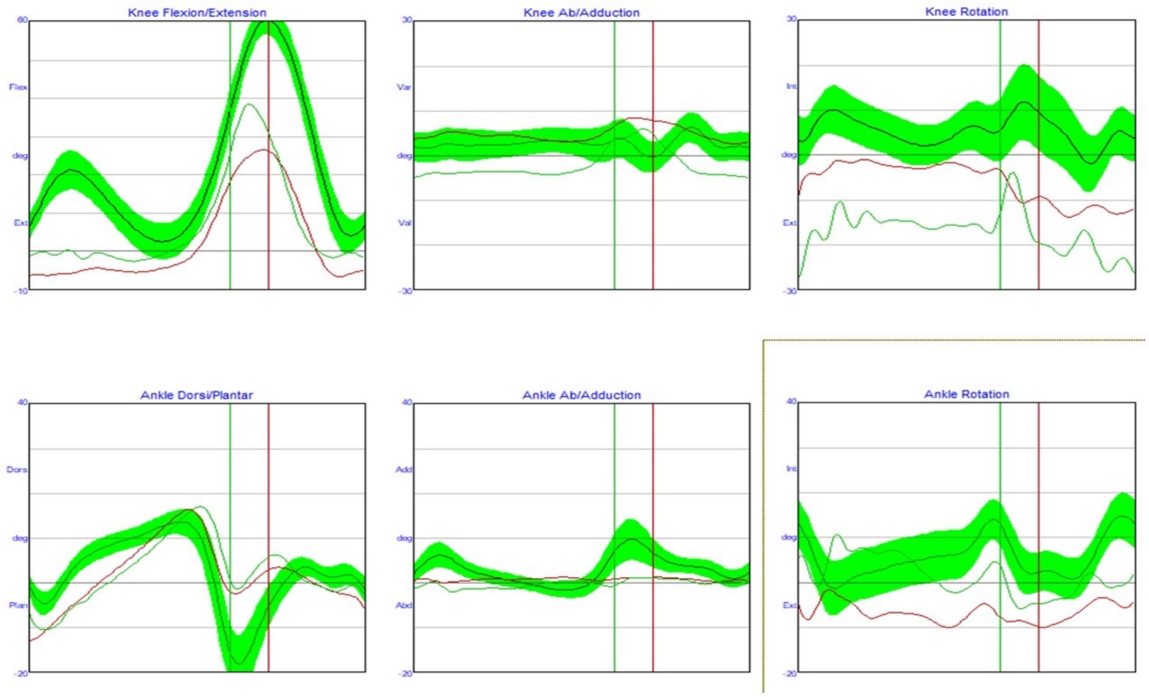
	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Flexion	☐	☐
Extension	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

9. Any additional observations as to which part of the gait cycle these problems may be occurring?

____

Knees and Ankles

Scenario 1B: Traditional Graphical output Results



10. Do you think there are any altered joint motions in this subject?

Mark only one oval.

○ Yes
○ No
○ I do not know (if you do not know, please pass on to the next scenario)

11. If yes, which joints do you think are affected?

Tick all that apply.

☐ Right Knee
☐ Left Knee
☐ Right Ankle
☐ Left Ankle

12. RIGHT KNEE

Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Flexion	☐	☐
Extension	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

13. LEFT KNEE

Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Flexion	☐	☐
Extension	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

14. RIGHT ANKLE

Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Dorsiflexion	☐	☐
Plantarflexion	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

15. LEFT ANKLE

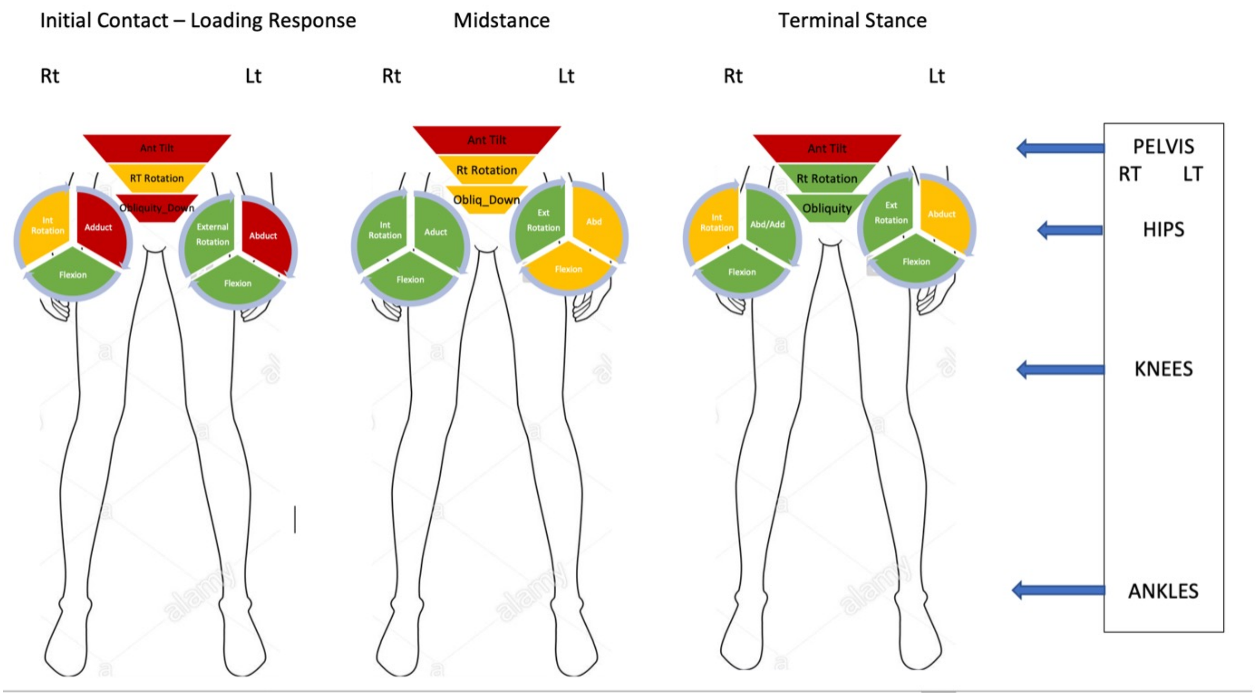
Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Dorsiflexion	☐	☐
Plantarflexion	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

16. Any additional observations as to which part of the gait cycle these problems may be occurring?

Scenario 2A: Traffic Lights System Output Results

Pelvis and Hips



17. Do you think there are any altered joint motions in this subject?

Mark only one oval.

○ Yes

○ No

○ I do not know (if you do not know, please pass on to the next scenario)

18. If yes, which joints do you think are affected?

Tick all that apply.

☐ Pelvis
☐ Right Hip
☐ Left Hip

19. PELVIS

Tick all that apply.

	Mild	Severe
Anterior Tilt	☐	☐
Posterior Tilt	☐	☐
Right Obliquity	☐	☐
Left Obliquity	☐	☐
Right Rotation	☐	☐
Left Rotation	☐	☐

20. RIGHT HIP

Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Flexion	☐	☐
Extension	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

21. Left HIP

Tick all that apply.

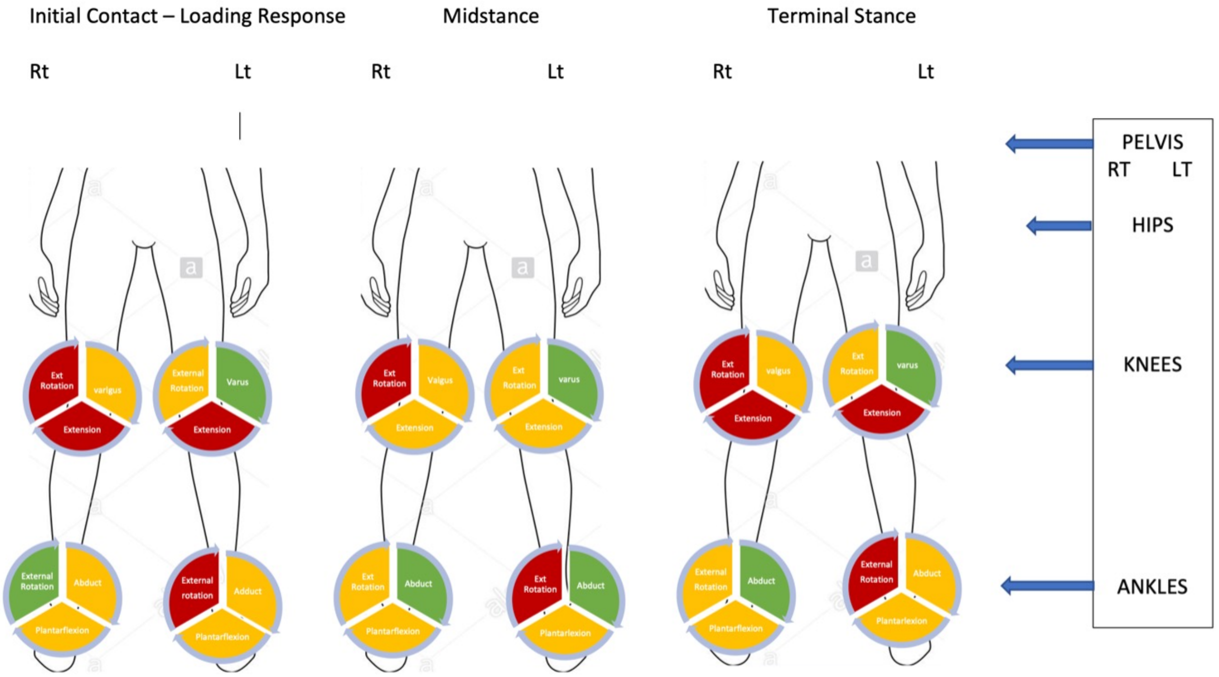
	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Flexion	☐	☐
Extension	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

22. Any additional observations as to which part of the gait cycle these problems may be occurring?

____

Scenario 2B: Traffic Lights System Output Results

Scenario 2: Knees and Ankles



23. Do you think there are any altered joint motions in this subject?

Mark only one oval.

○ Yes
○ No
○ I do not know (if you do not know, please pass on to the next scenario)

24. If yes, which joints do you think are affected?

Tick all that apply.

☐ Right Knee
☐ Left Knee
☐ Right Ankle
☐ Left Ankle

25. RIGHT KNEE

Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Flexion	☐	☐
Extension	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

26. LEFT KNEE

Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Flexion	☐	☐
Extension	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

27. RIGHT ANKLE

Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Dorsiflexion	☐	☐
Plantarflexion	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

28. LEFT ANKLE

Tick all that apply.

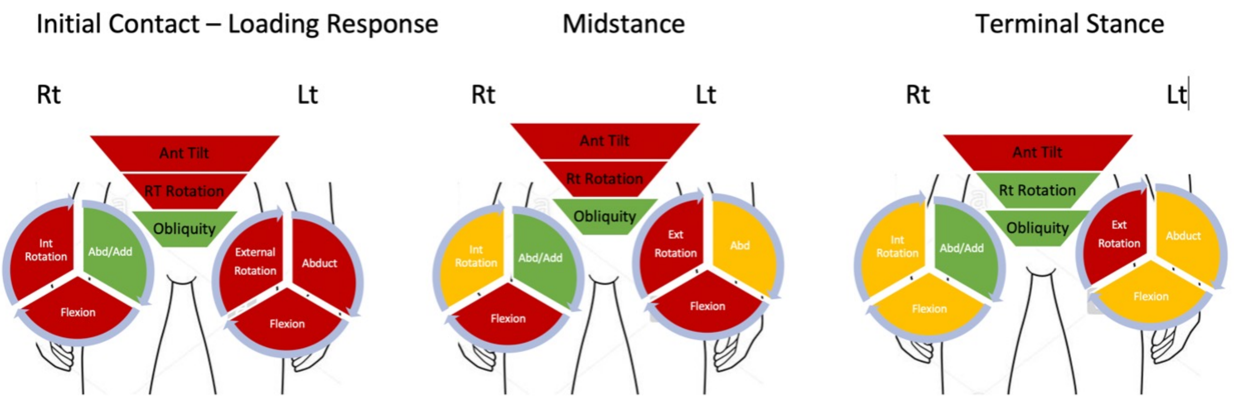
	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Dorsiflexion	☐	☐
Plantarflexion	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

29. Any additional observations as to which part of the gait cycle these problems may be occurring?

Pelvis and Hips

Scenario 3A: Traffic Lights System Output Results

Bilateral Equinus



30. Do you think there are any altered joint motions in this subject?

Mark only one oval.

○ Yes
○ No
○ I do not know (if you do not know, please pass on to the next scenario)

31. If yes, which joints do you think are affected?

Tick all that apply.

☐ Pelvis
☐ Right Hip
☐ Left Hip

32. PELVIS

Tick all that apply.

	Mild	Severe
Anterior Tilt	☐	☐
Posterior Tilt	☐	☐
Right Obliquity	☐	☐
Left Obliquity	☐	☐
Right Rotation	☐	☐
Left Rotation	☐	☐

33. RIGHT HIP

Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Flexion	☐	☐
Extension	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

34. LEFT HIP

Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Flexion	☐	☐
Extension	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

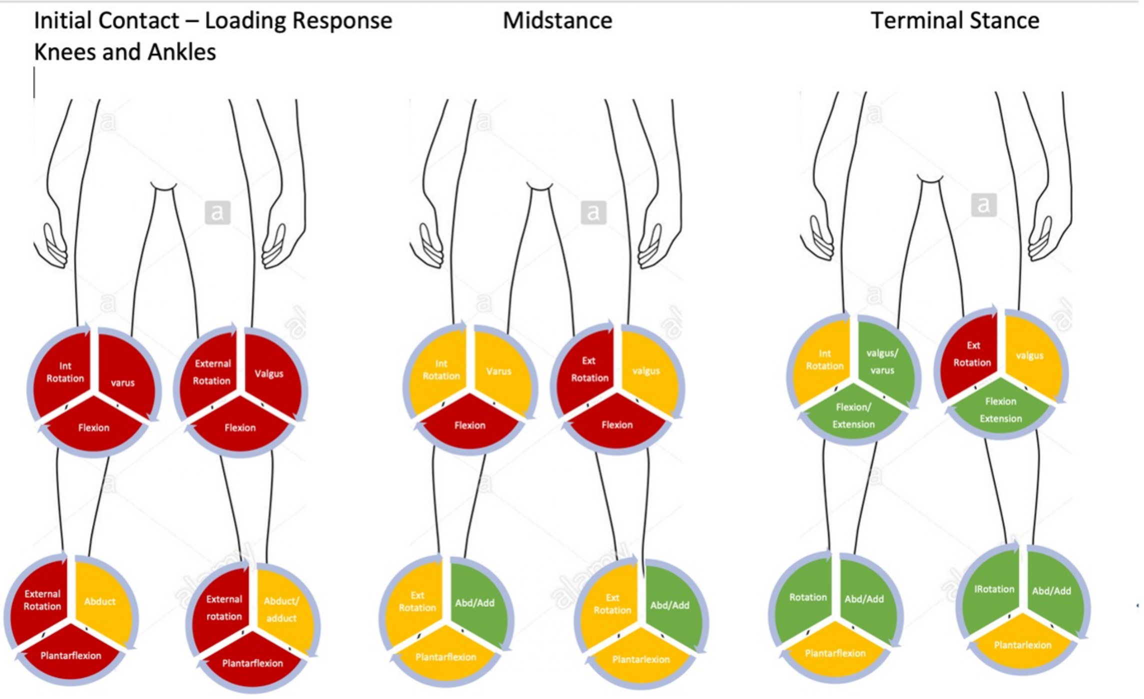
35. Any additional observations as to which part of the gait cycle these problems may be occurring?

____

Knees and Ankles

Scenario 3B: Traffic Lights System Output Results

Bilateral Equinus



36. Do you think there are any altered joint motions in this subject?

Mark only one oval.

○ Yes
○ No
○ I do not know (if you do not know, please pass on to the next scenario)

37. If yes, which joints do you think are affected?

Tick all that apply.

☐ Right Knee
☐ Left Knee
☐ Right Ankle
☐ Left Ankle

38. RIGHT KNEE

Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Flexion	☐	☐
Extension	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

39. LEFT KNEE

Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Flexion	☐	☐
Extension	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

40. RIGHT ANKLE

Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Dorsiflexion	☐	☐
Plantarflexion	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

41. LEFT ANKLE

Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Dorsiflexion	☐	☐
Plantarflexion	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

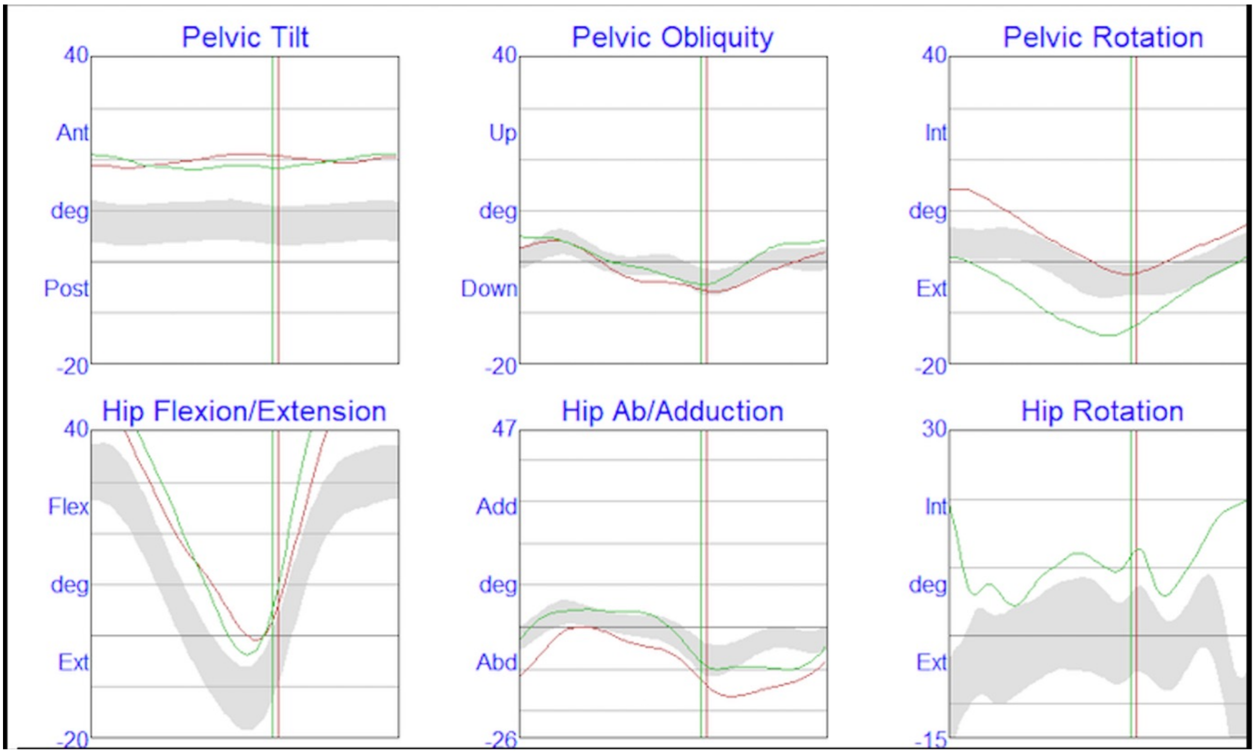
42. Any additional observations as to which part of the gait cycle these problems may be occurring?

____

Pelvis and hips

Scenario 4A: Traditional Graphical output Results

Bilateral Equinus



43. Do you think there are any altered joint motions in this subject?

Mark only one oval.

○ Yes

○ No

○ I do not know (if you do not know, please pass on to the next scenario)

44. If yes, which joints do you think are affected?

Tick all that apply.

☐ Pelvis
☐ Right Hip
☐ Left Hip

45. PELVIS

Tick all that apply.

	Mild	Severe
Anterior Tilt	☐	☐
Posterior Tilt	☐	☐
Right Obliquity	☐	☐
Left Obliquity	☐	☐
Right Rotation	☐	☐
Left Rotation	☐	☐

46. RIGHT HIP

Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Flexion	☐	☐
Extension	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

47. LEFT HIP

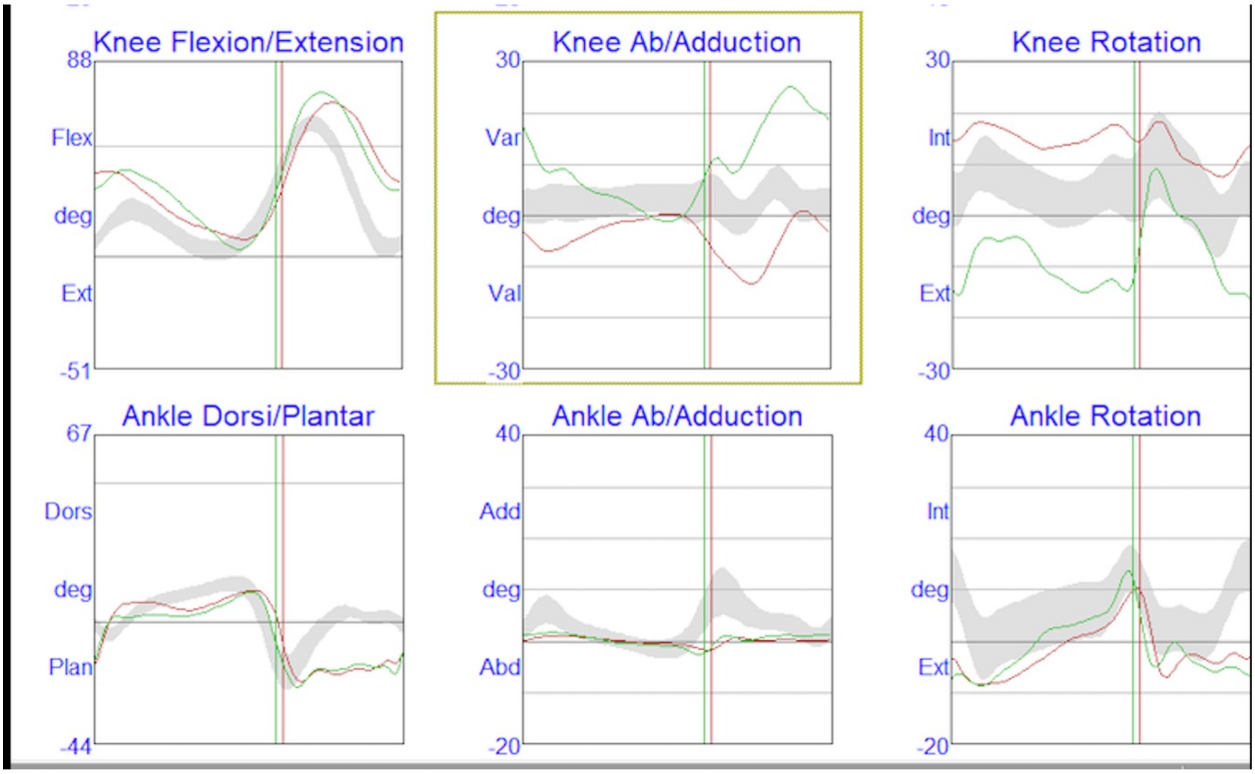
Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Flexion	☐	☐
Extension	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

48. Any additional observations as to which part of the gait cycle these problems may be occurring?

Scenario 4B: Traditional Graphical output Results

Knees and Ankles



49. Do you think there are any altered joint motions in this subject?

Mark only one oval.

○ Yes
○ No
○ I do not know (if you do not know, please pass on to the next scenario)

50. If yes, which joints do you think are affected?

Tick all that apply.

☐ Right Knee
☐ Left Knee
☐ Right Ankle
☐ Left Ankle

51. RIGHT KNEE

Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Flexion	☐	☐
Extension	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

52. LEFT KNEE

Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Flexion	☐	☐
Extension	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

53. RIGHT ANKLE

Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Dorsiflexion	☐	☐
Plantarflexion	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

54. LEFT ANKLE

Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Dorsiflexion	☐	☐
Plantarflexion	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

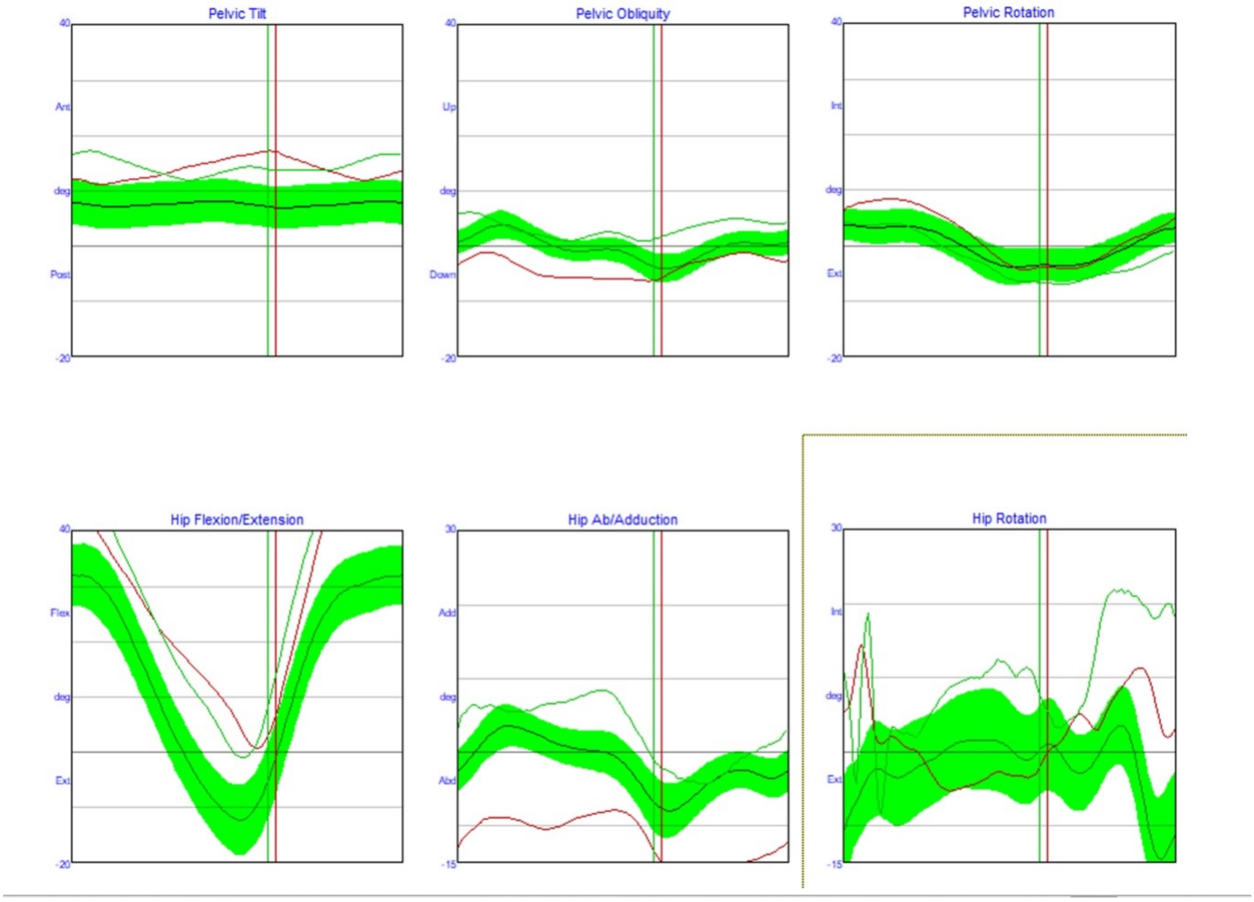
55. Any additional observations as to which part of the gait cycle these problems may be occurring?

____

Pelvis and hips

Scenario 5A: Traditional Graphical output Results

Bilateral footslap



56. Do you think there are any altered joint motions in this subject?

Mark only one oval.

○ Yes
○ No
○ I do not know (if you do not know, please pass on to the next scenario)

57. If yes, which joints do you think are affected?

Tick all that apply.

☐ Pelvis
☐ Right Hip
☐ Left Hip

58. PELVIS

Tick all that apply.

	Mild	Severe
Anterior Tilt	☐	☐
Posterior Tilt	☐	☐
Right Obliquity	☐	☐
Left Obliquity	☐	☐
Right Rotation	☐	☐
Left Rotation	☐	☐

59. RIGHT HIP

Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Flexion	☐	☐
Extension	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

60. LEFT HIP

Tick all that apply.

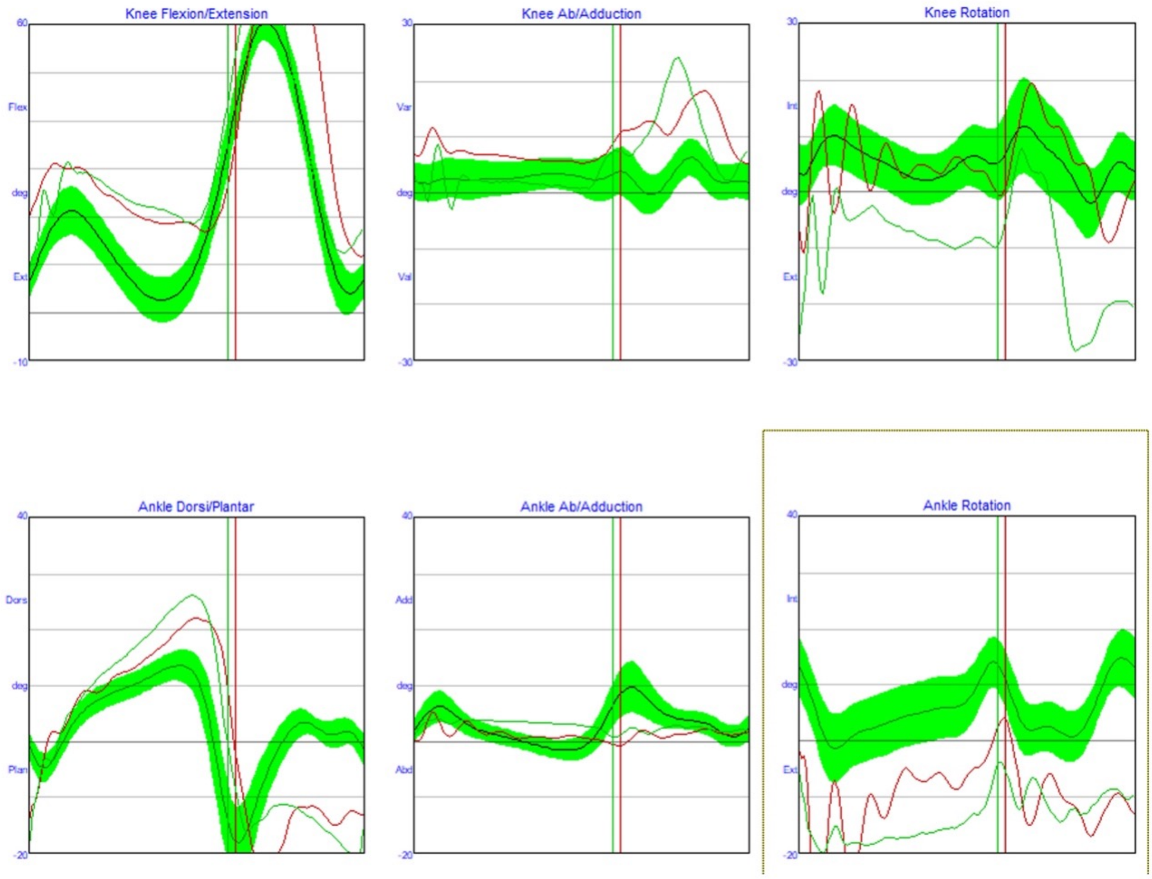
	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Flexion	☐	☐
Extension	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

61. Any additional observations as to which part of the gait cycle these problems may be occurring?

Knees and Ankles

Scenario 5B: Traditional Graphical output Results

Bilateral Footslap



---

62. Do you think there are any altered joint motions in this subject?

Mark only one oval.

○ Yes

○ No

○ I do not know (if you do not know, please pass on to the next scenario)

63. If yes, which joints do you think are affected?

Tick all that apply.

☐ Right Knee
☐ Left Knee
☐ Right Ankle
☐ Left Ankle

64. RIGHT KNEE

Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Flexion	☐	☐
Extension	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

65. LEFT KNEE

Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Flexion	☐	☐
Extension	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

66. RIGHT ANKLE

Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Dorsiflexion	☐	☐
Plantarflexion	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

67. LEFT ANKLE

Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Dorsiflexion	☐	☐
Plantarflexion	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

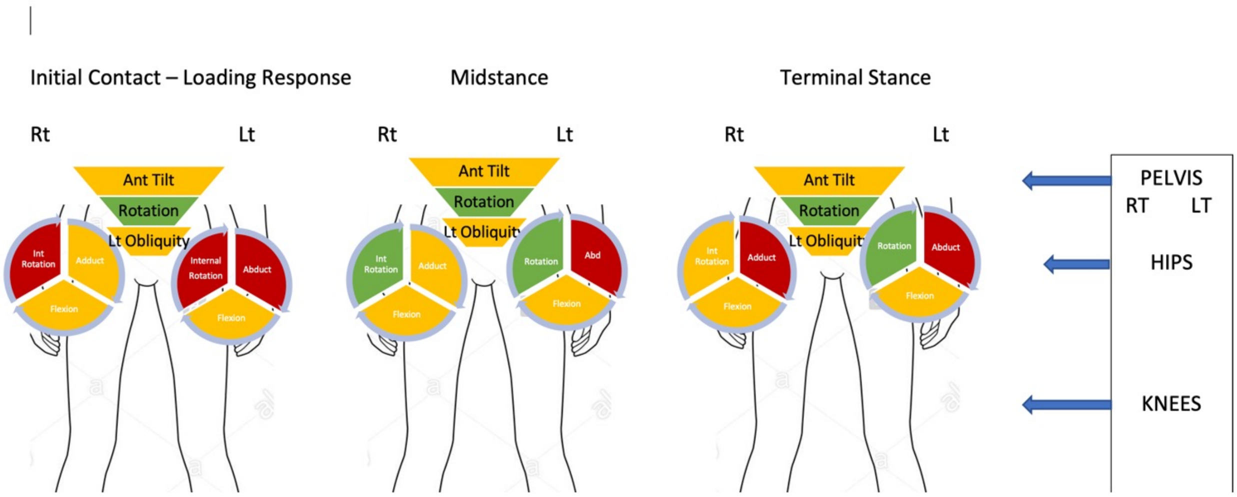
68. Any additional observations as to which part of the gait cycle these problems may be occurring?

____

Scenario 6A: Traffic Lights System Output Results

Pelvis and hips

Bilateral footslap



69. Do you think there are any altered joint motions in this subject?

Mark only one oval.

○ Yes
○ No
○ I do not know (if you do not know, please pass on to the next scenario)

70. If yes, which joints do you think are affected?

Tick all that apply.

☐ Pelvis
☐ Right Hip
☐ Left Hip

71. PELVIS

Tick all that apply.

	Mild	Severe
Anterior Tilt	☐	☐
Posterior Tilt	☐	☐
Right Obliquity	☐	☐
Left Obliquity	☐	☐
Right Rotation	☐	☐
Left Rotation	☐	☐

72. RIGHT HIP

Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Flexion	☐	☐
Extension	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

73. LEFT HIP

Tick all that apply.

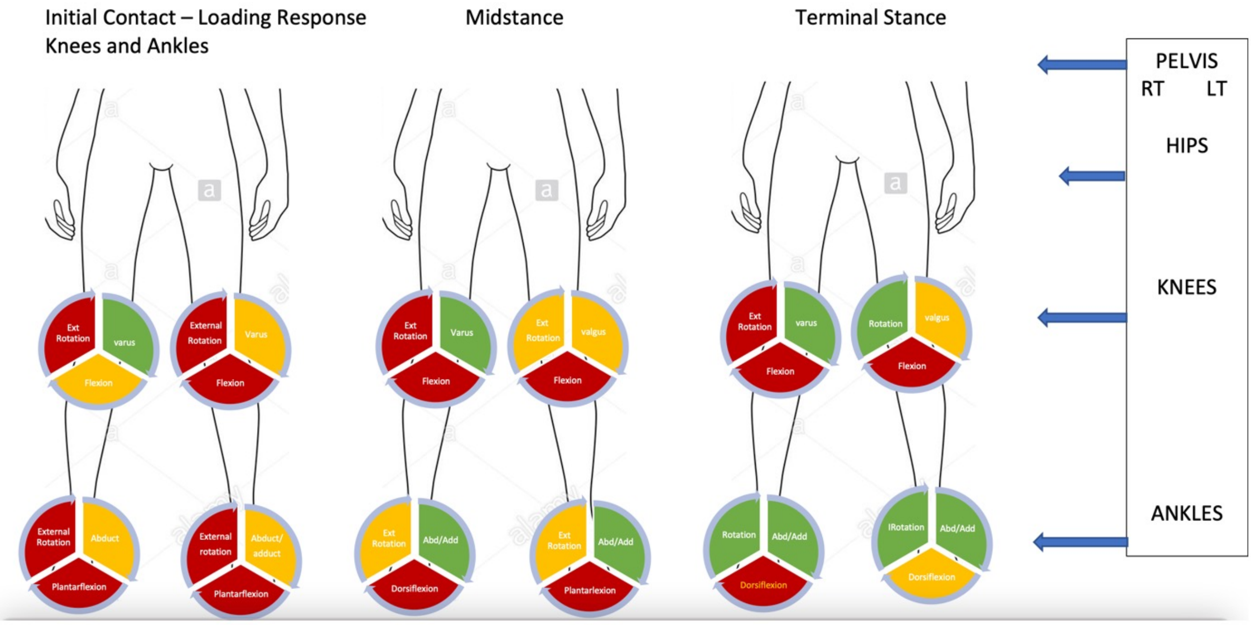
	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Flexion	☐	☐
Extension	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

74. Any additional observations as to which part of the gait cycle these problems may be occurring?

Scenario 6B: Traffic Lights System Output Results

Knees and Ankles

Bilateral footslap



75. Do you think there are any altered joint motions in this subject?

Mark only one oval.

○ Yes
○ No
○ I do not know (if you do not know, please pass on to the next scenario)

76. If yes, which joints do you think are affected?

Tick all that apply.

☐ Right Knee
☐ Left Knee
☐ Right Ankle
☐ Left Ankle

77. RIGHT KNEE

Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Flexion	☐	☐
Extension	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

78. LEFT KNEE

Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Flexion	☐	☐
Extension	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

79. RIGHT ANKLE

Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Dorsiflexion	☐	☐
Plantarflexion	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

80. LEFT ANKLE

Tick all that apply.

	Mild	Severe
Adduction	☐	☐
Abduction	☐	☐
Dorsiflexion	☐	☐
Plantarflexion	☐	☐
Internal Rotation	☐	☐
External Rotation	☐	☐

81. Any additional observations as to which part of the gait cycle these problems may be occurring?

____

Section B: Feedback

82. Which format did you find easier to understand?

Mark only one oval.

○ Traffic Light System
○ Traditional Graphical Format

83. Which format did you find easier to interpret?

Mark only one oval.

○ Traffic Lights System
○ Traditional Graphical Format

84. Would such kinematic information be helpful to your clinical MSK practice if provided?

Mark only one oval.

○ Yes
○ No

85. If Yes, in which format would you prefer this information to be provided?

Mark only one oval.

○ Traffic Lights Sytem
○ Traditional Graphical Format

86. Why?

____

87. Do you see any particular cases where you would wish your patients to undergo gait analysis, and be supplied with such data?

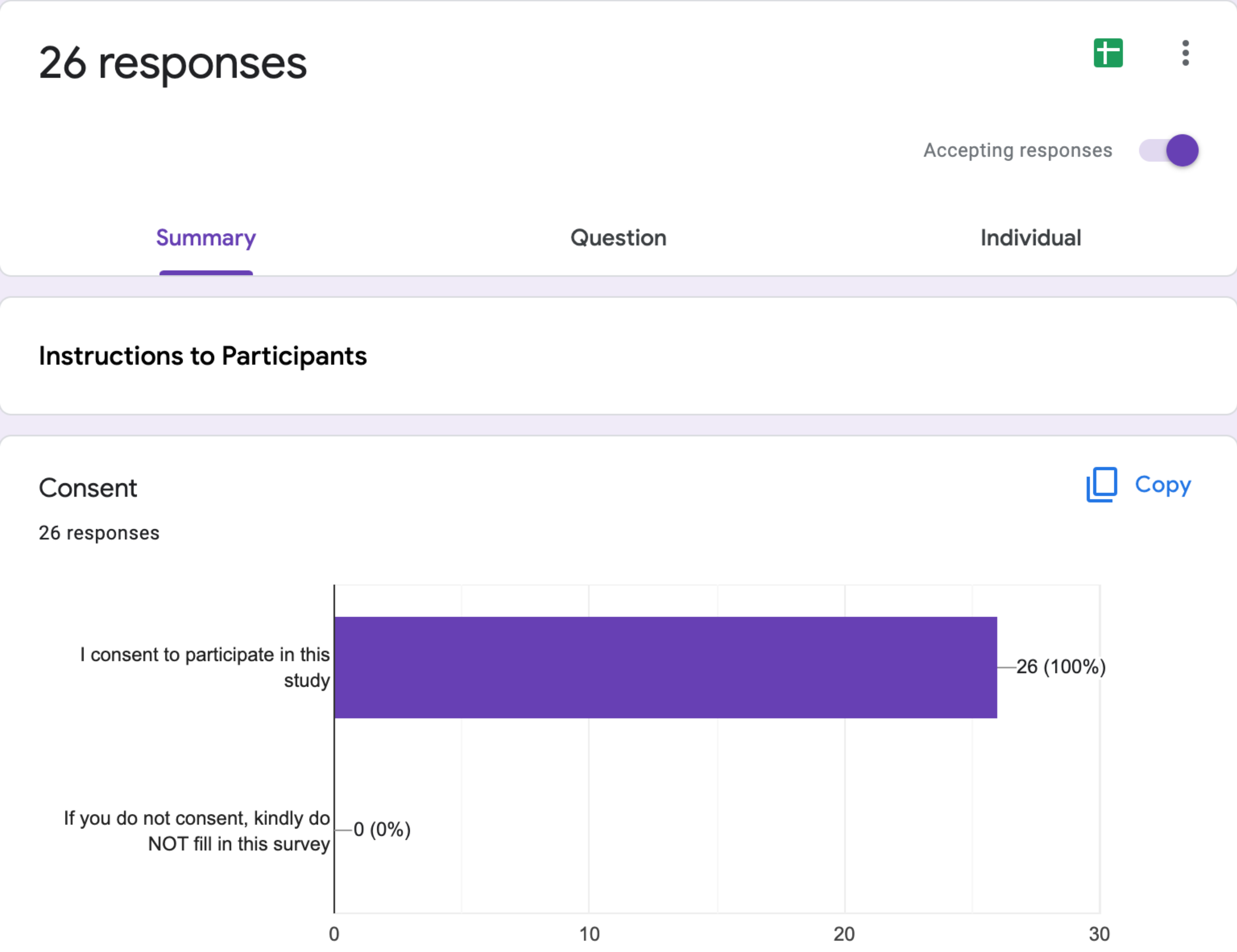
____

Reliability

88. Thank you for your participation. We will be repeating this exercise in a few weeks time, in order to confirm inter rater reliability. If you would like to participate again, kindly enter your email address. Your participation is highly appreciated!

____

Appendix 3: Analysis of Google Form Responses



26 responses

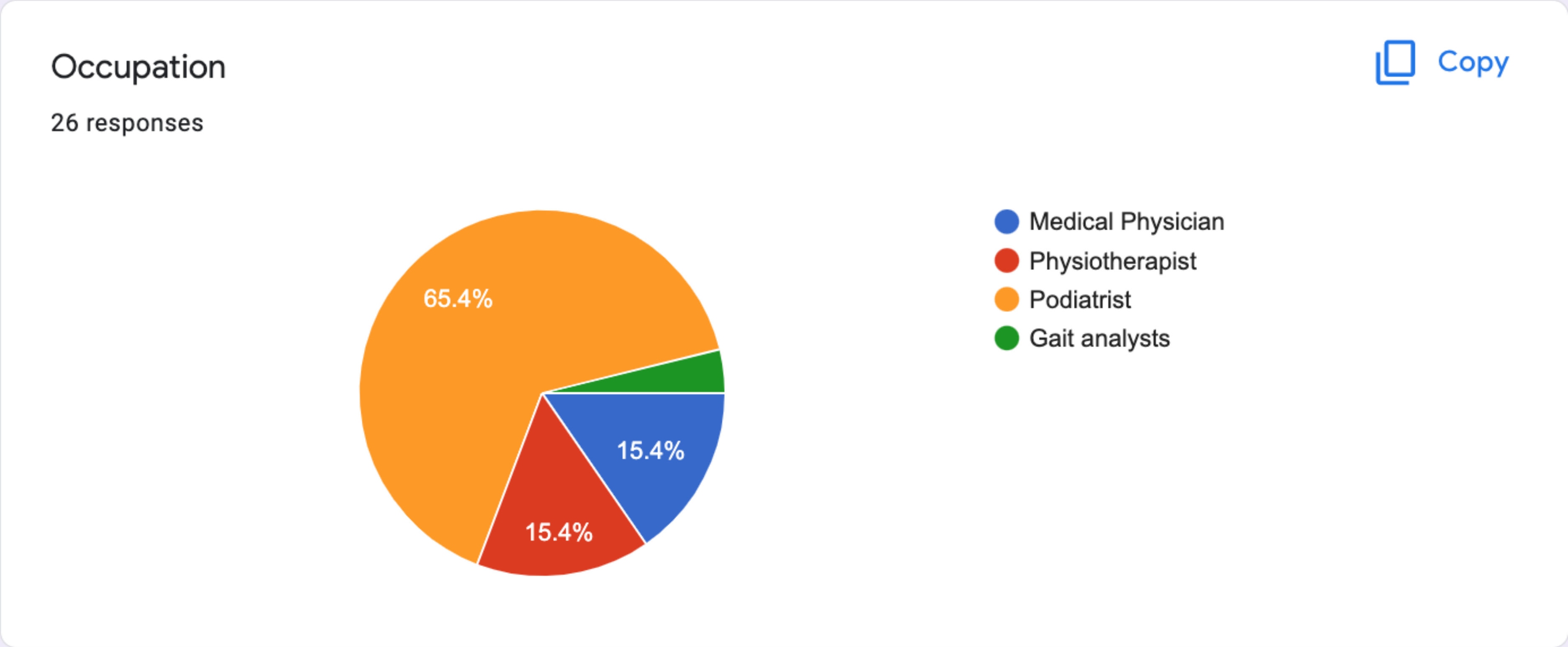
Accepting responses

Instructions to Participants

Consent

26 responses

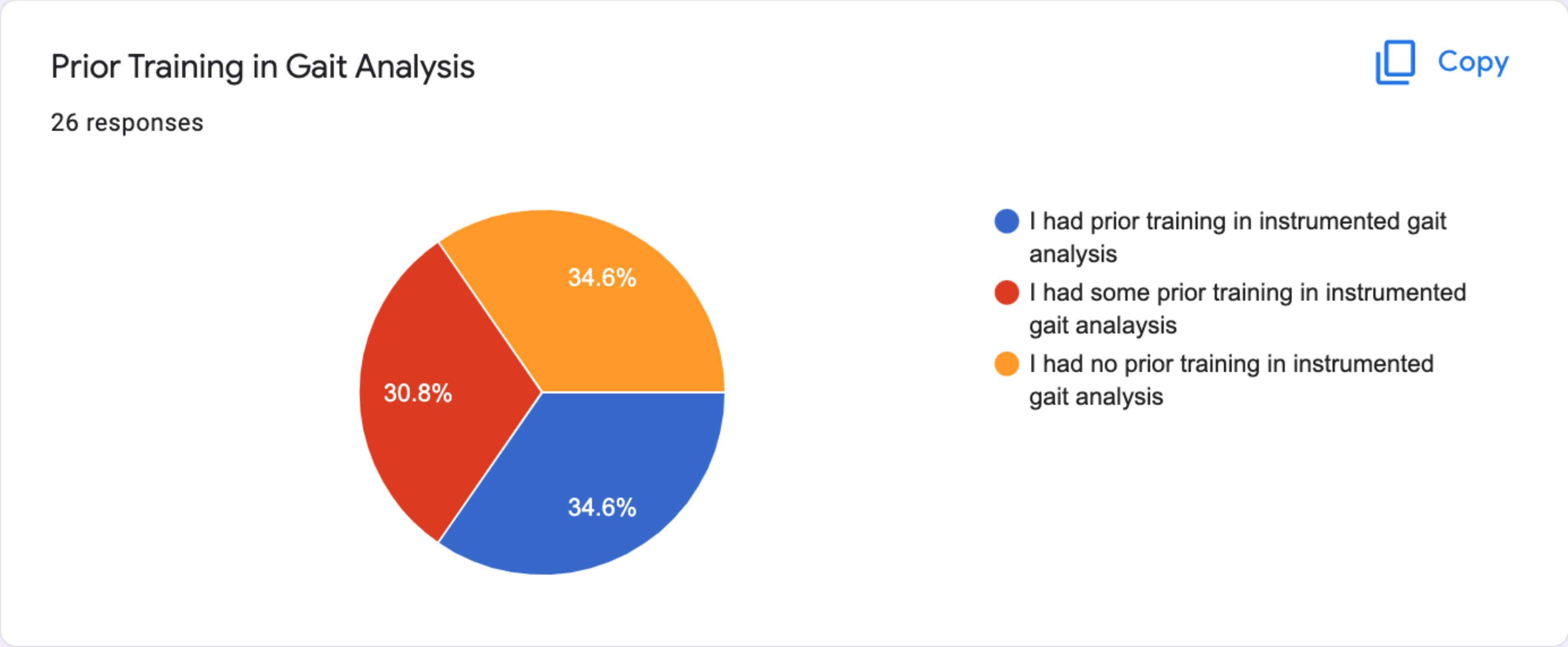
I consent to participate in this study	26 (100%)
If you do not consent, kindly do NOT fill in this survey	0 (0%)



Occupation

26 responses

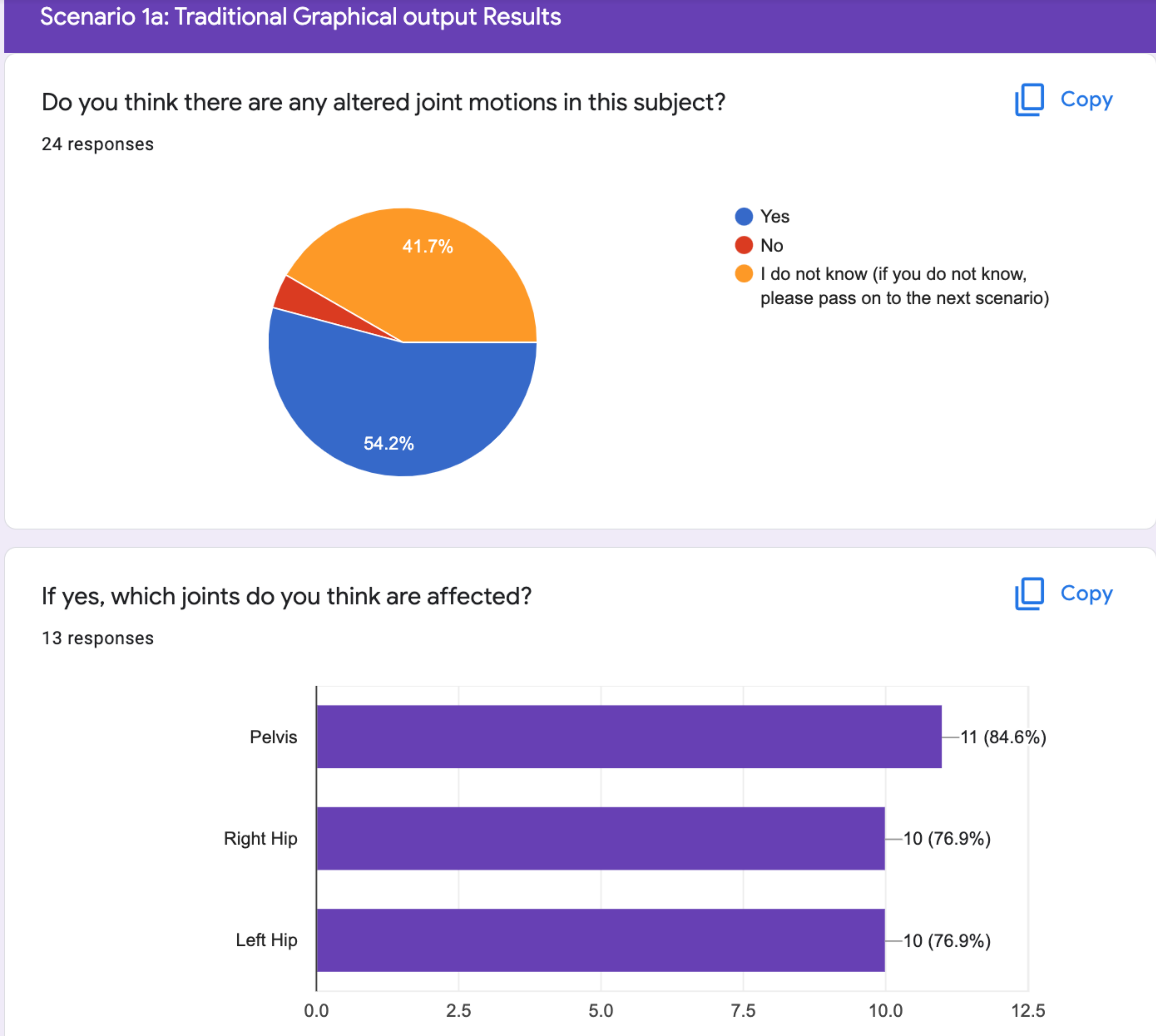
- ● Medical Physician
- ● Physiotherapist
- ● Podiatrist
- ● Gait analysts



Prior Training in Gait Analysis

26 responses

- ● I had prior training in instrumented gait analysis
- ● I had some prior training in instrumented gait analaysis
- ● I had no prior training in instrumented gait analysis



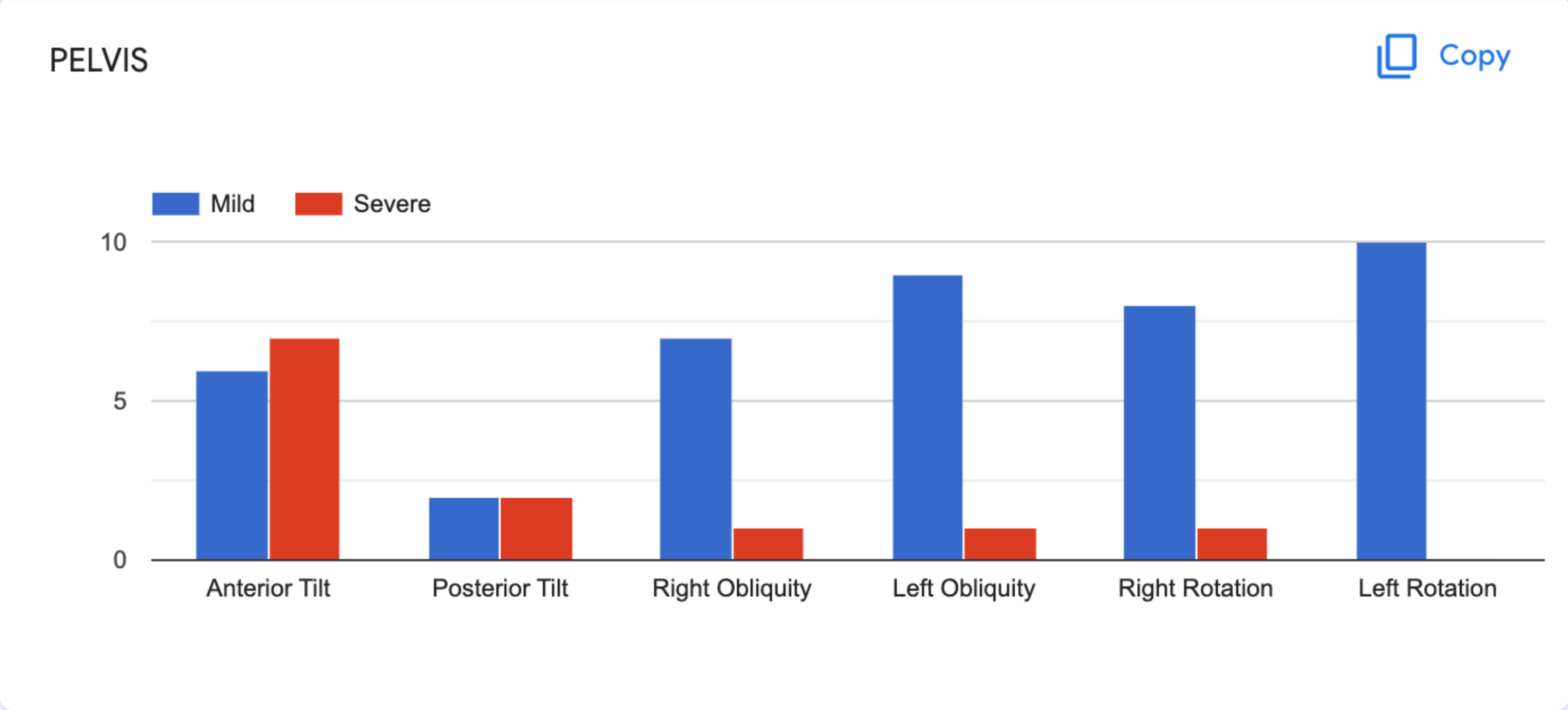
Scenario 1a: Traditional Graphical output Results

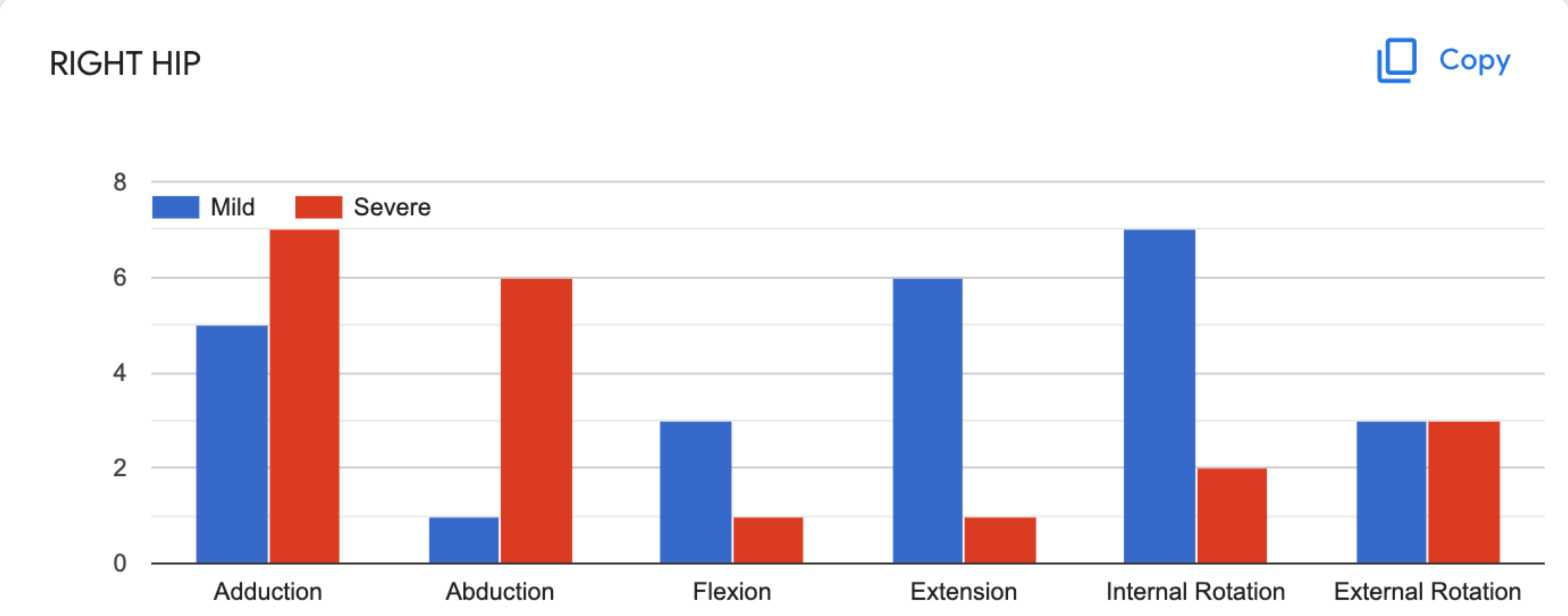
Do you think there are any altered joint motions in this subject?

24 responses

If yes, which joints do you think are affected?

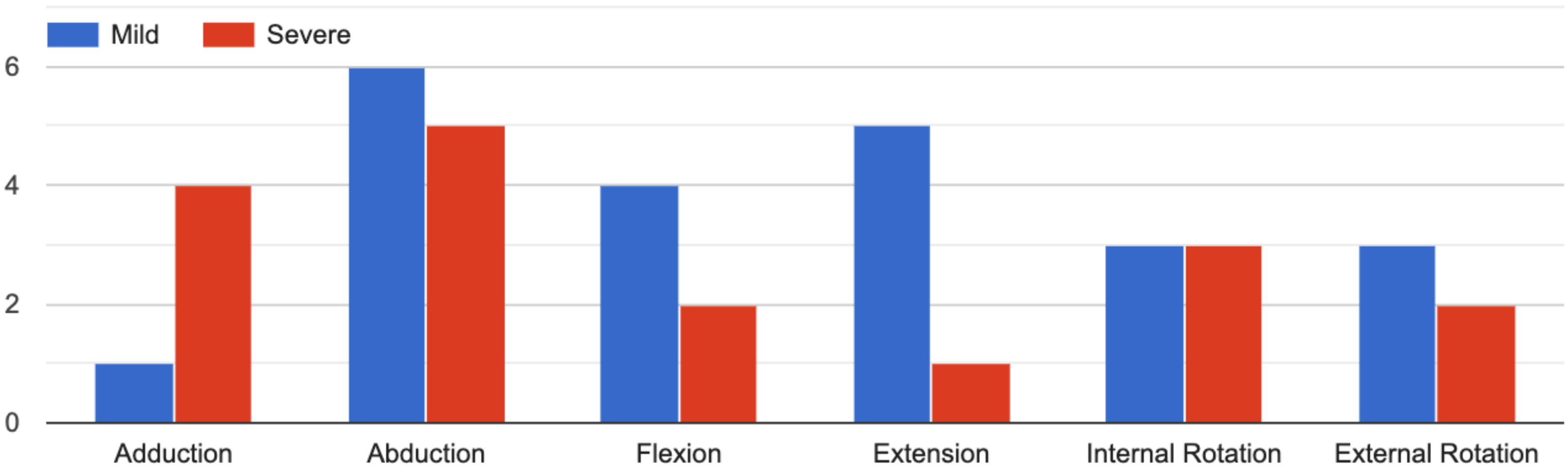
13 responses


PELVIS
Copy
Mild
Severe
10
5
0
Anterior Tilt
Posterior Tilt
Right Obliquity
Left Obliquity
Right Rotation
Left Rotation


RIGHT HIP
Copy
Mild
Severe
8
6
4
2
0
Adduction
Abduction
Flexion
Extension
Internal Rotation
External Rotation

LEFT HIP

Copy



Any additional observations as to which part of the gait cycle these problems may be occurring?

5 responses

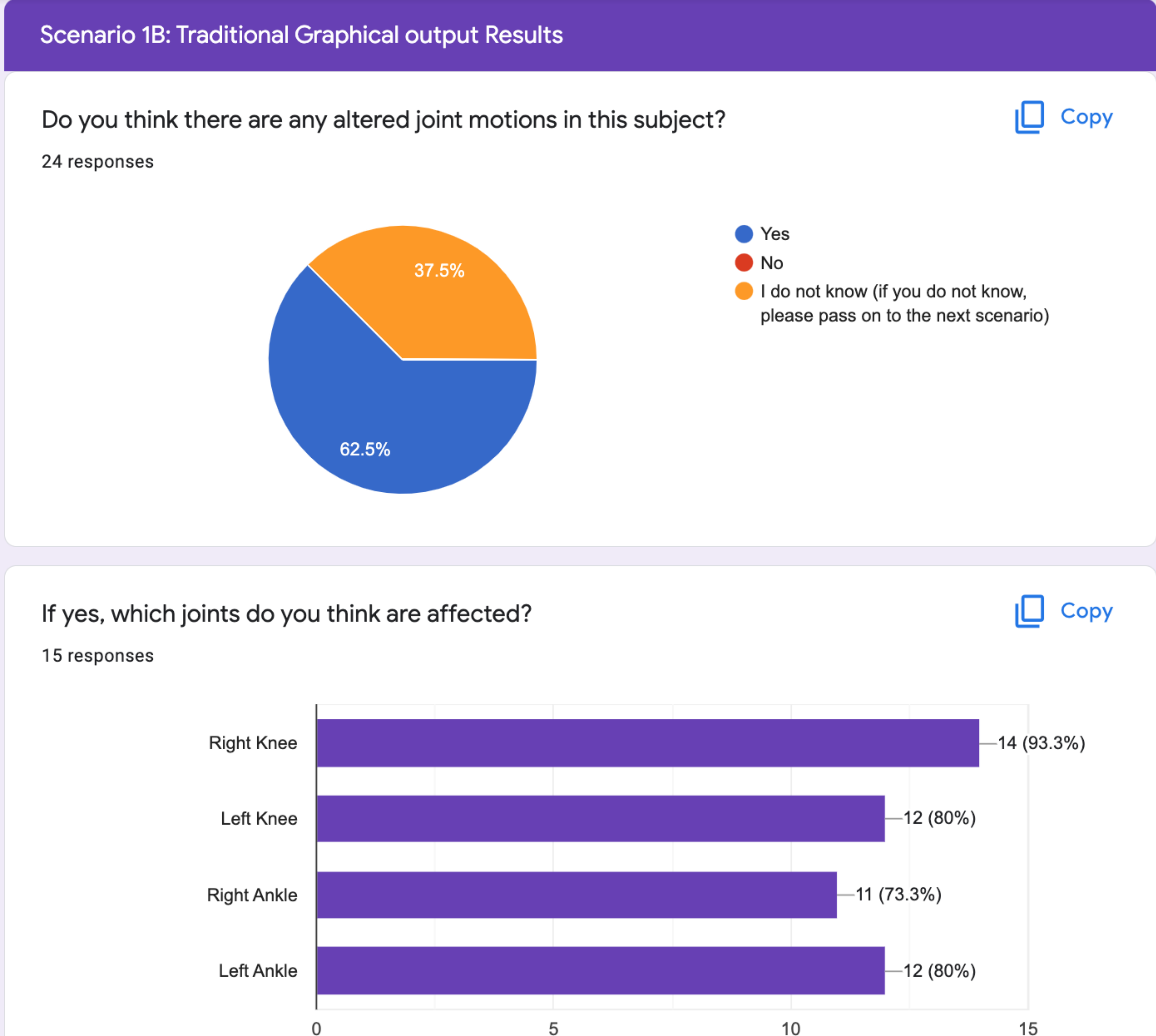
HS to MS

throughout the whole cycle

pelvic tilt and hip abd/adduction through the whole cycle

hip rotation abnormal even though within normal range

Throughout whole gait cycle



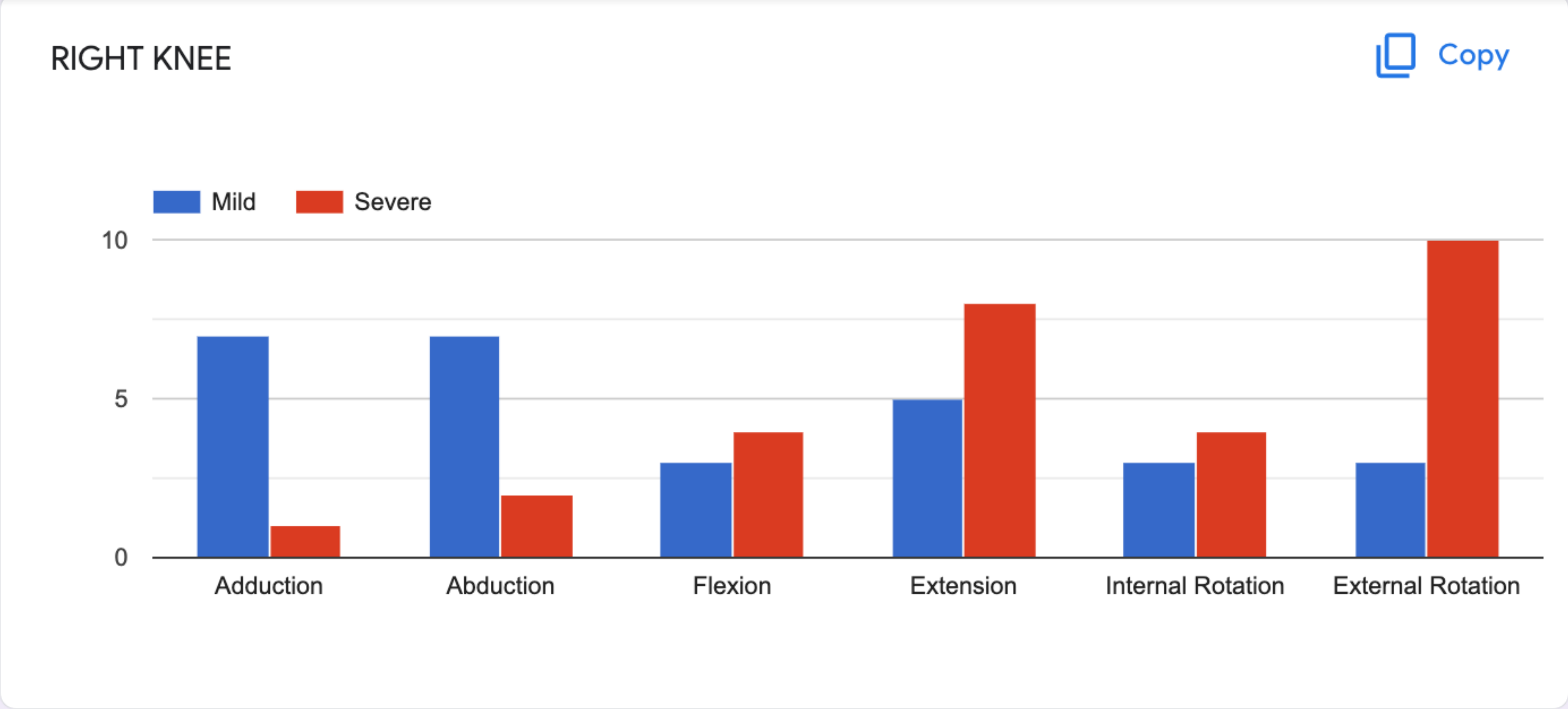
Scenario 1B: Traditional Graphical output Results

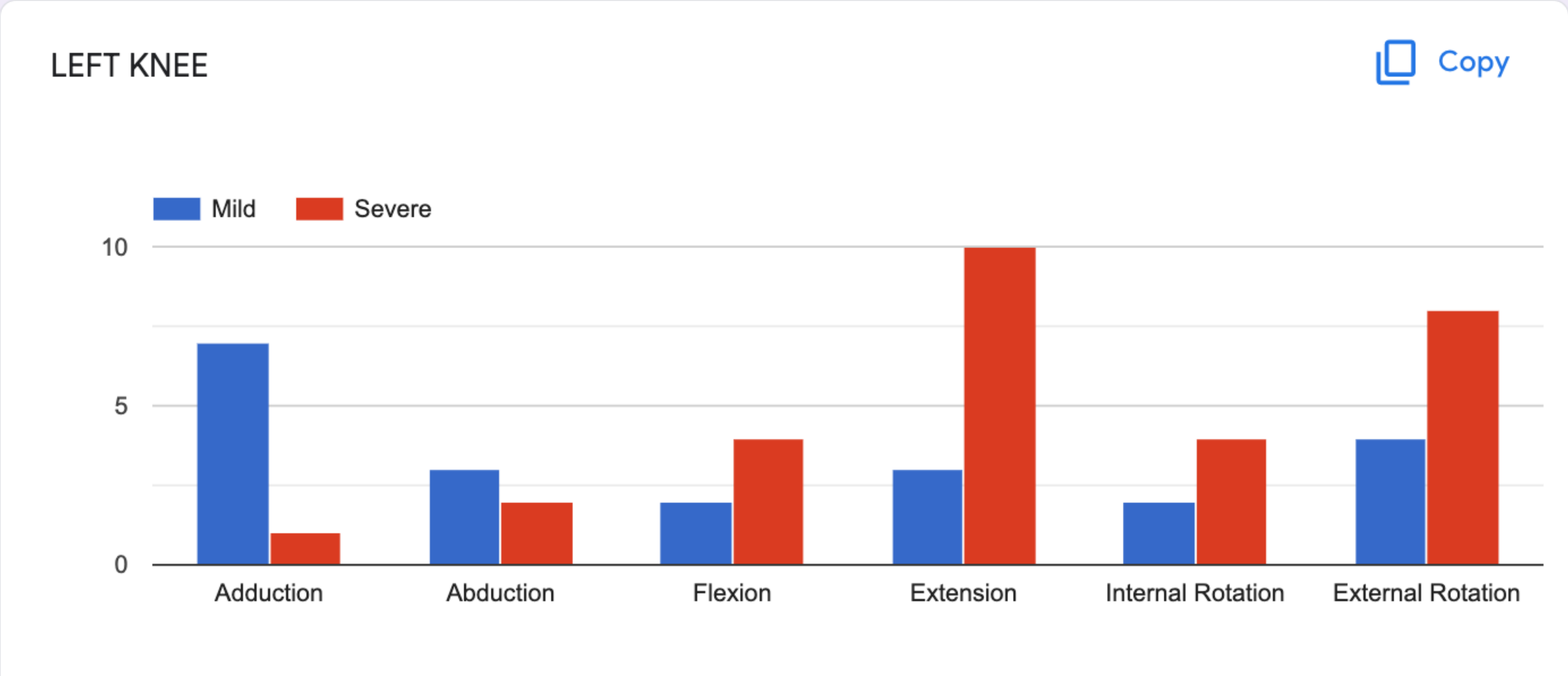
Do you think there are any altered joint motions in this subject?

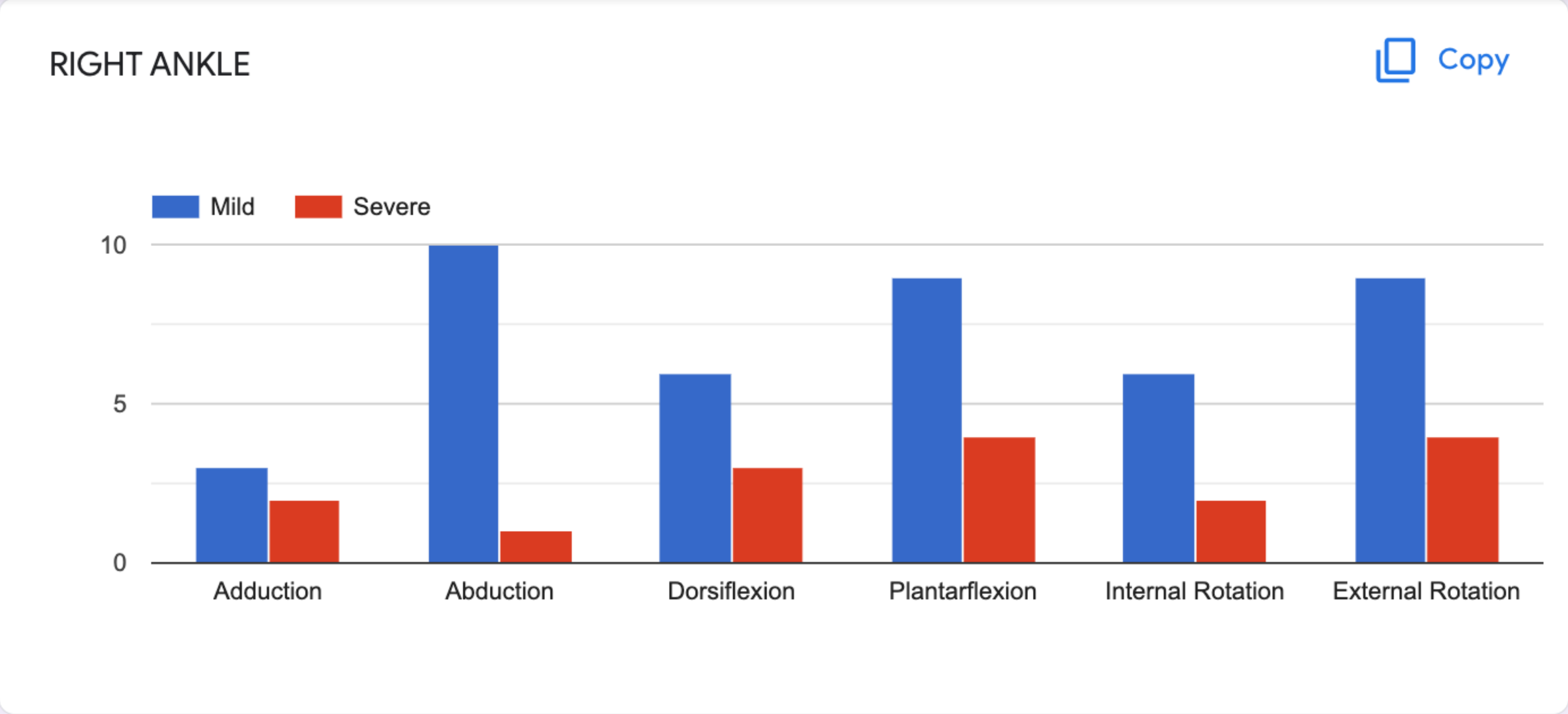
24 responses

If yes, which joints do you think are affected?

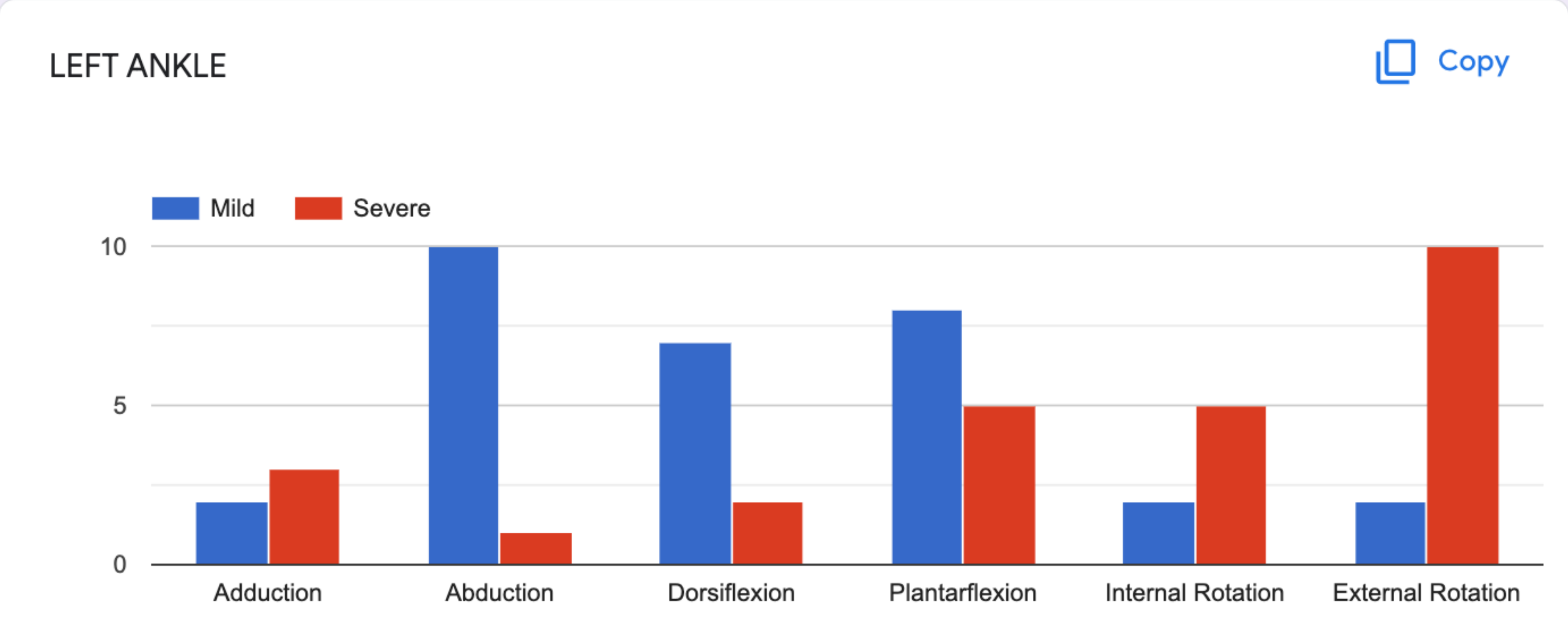
15 responses


RIGHT KNEE

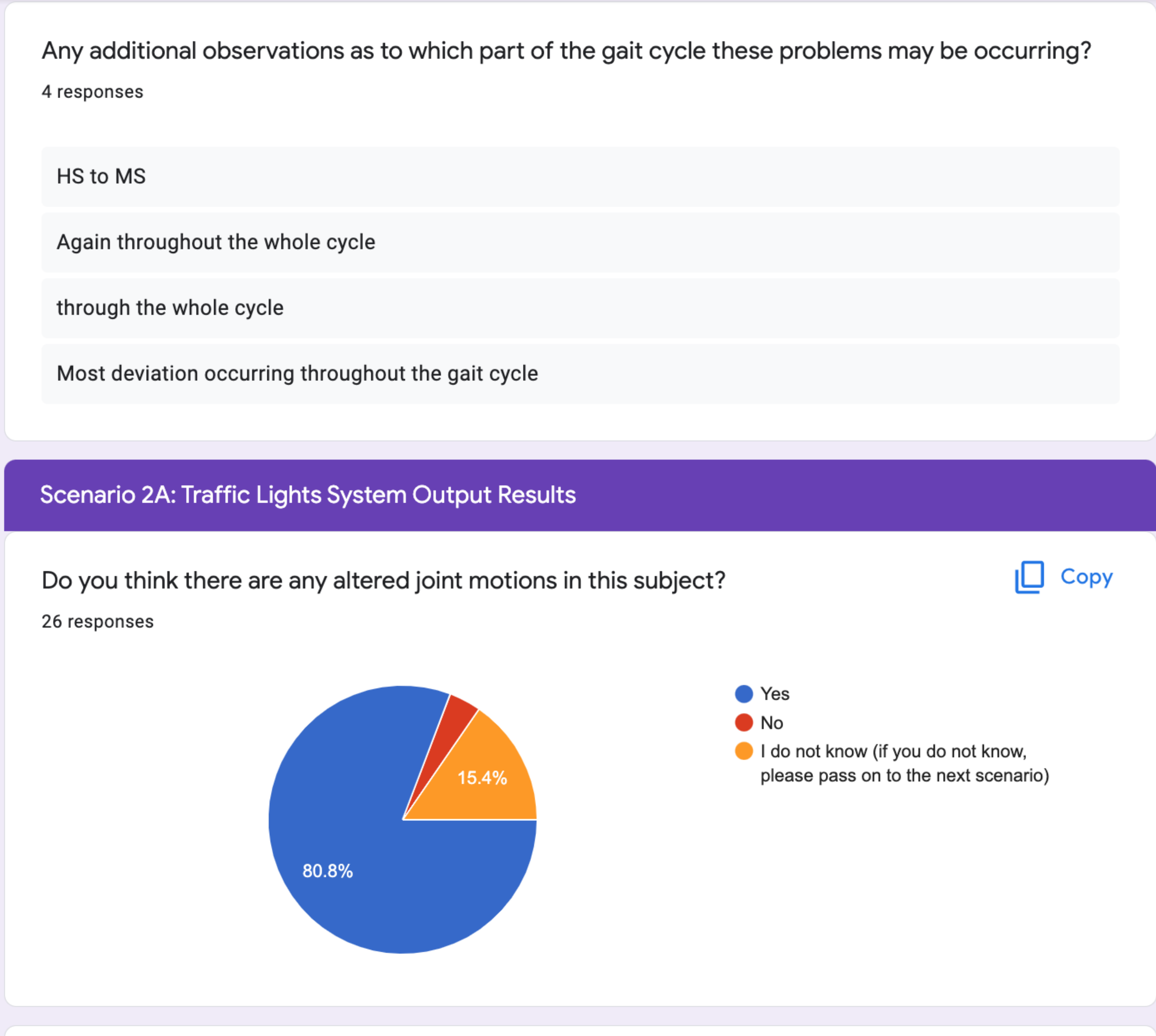

LEFT KNEE



RIGHT ANKLE



LEFT ANKLE



Any additional observations as to which part of the gait cycle these problems may be occurring?

4 responses

HS to MS

Again throughout the whole cycle

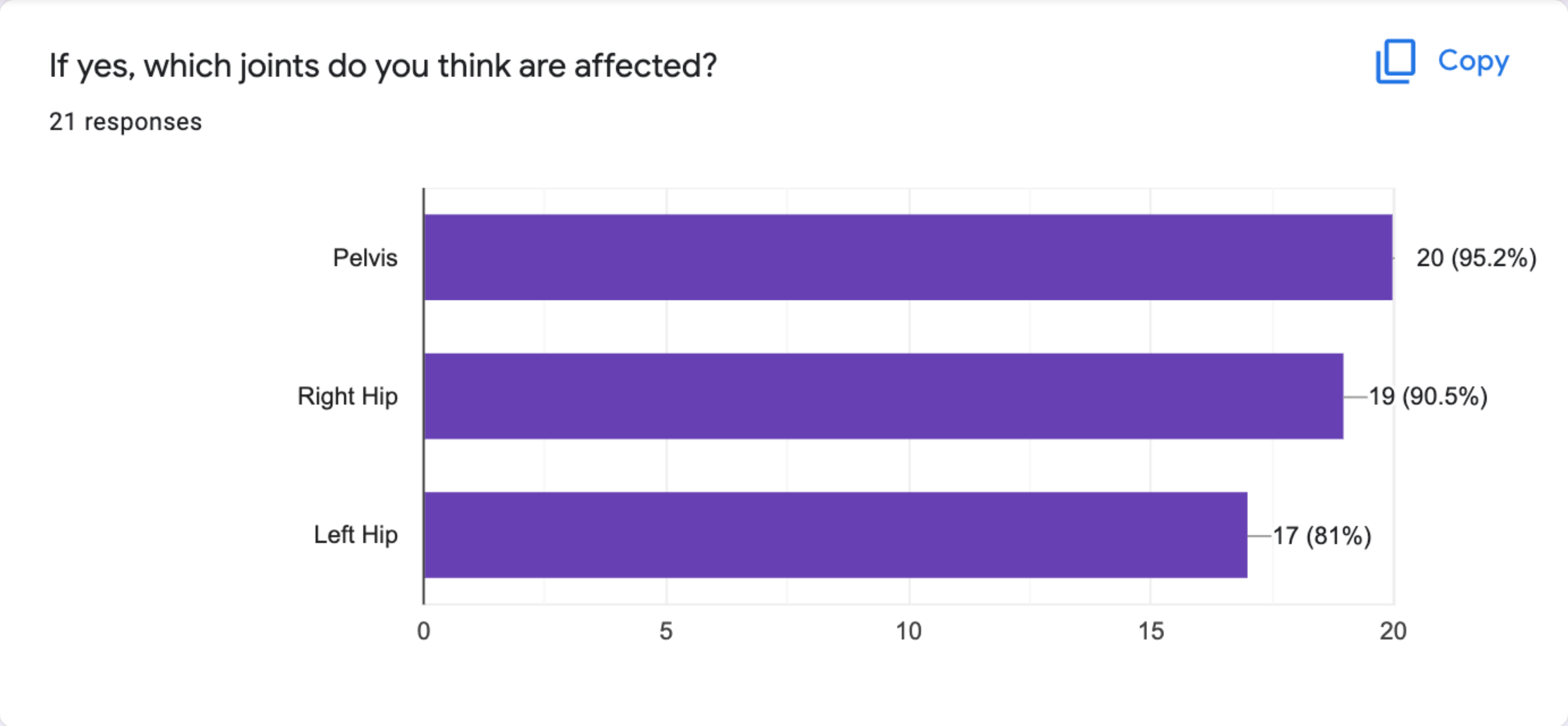
through the whole cycle

Most deviation occurring throughout the gait cycle

Scenario 2A: Traffic Lights System Output Results

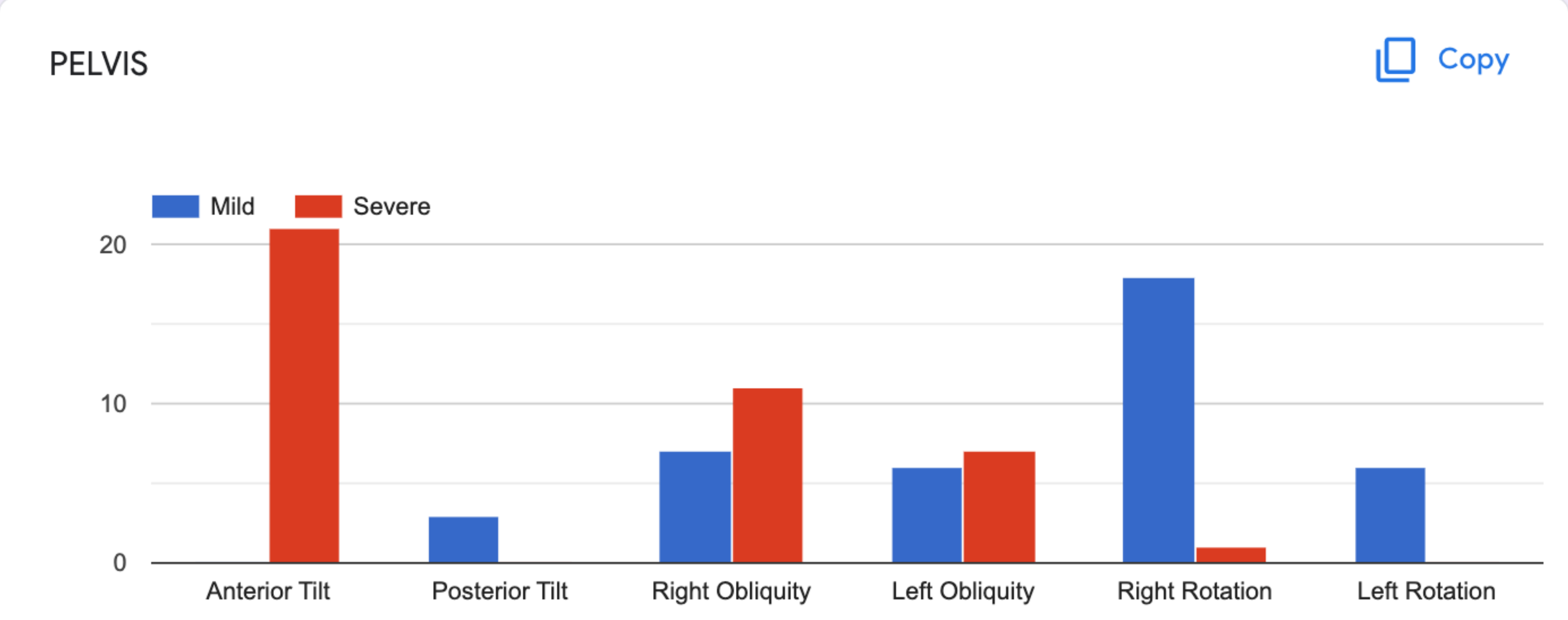
Do you think there are any altered joint motions in this subject?

26 responses



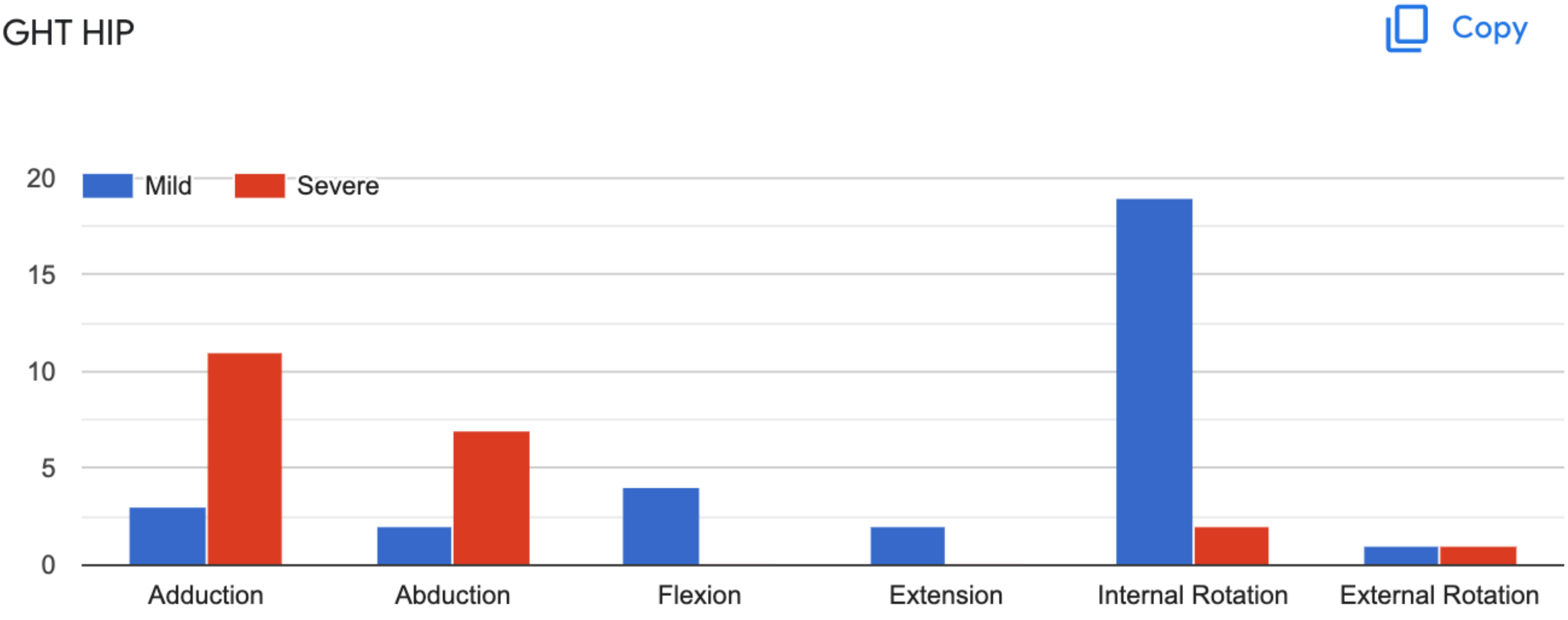
If yes, which joints do you think are affected?

21 responses

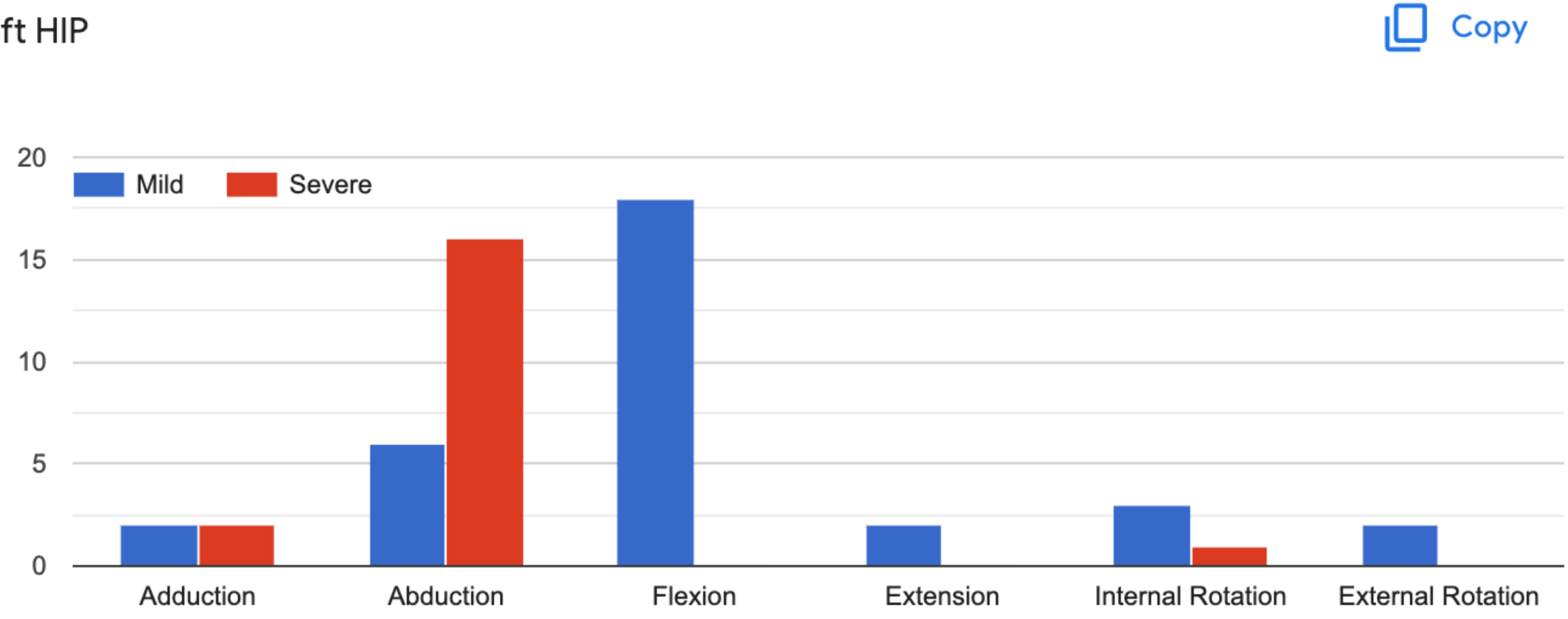


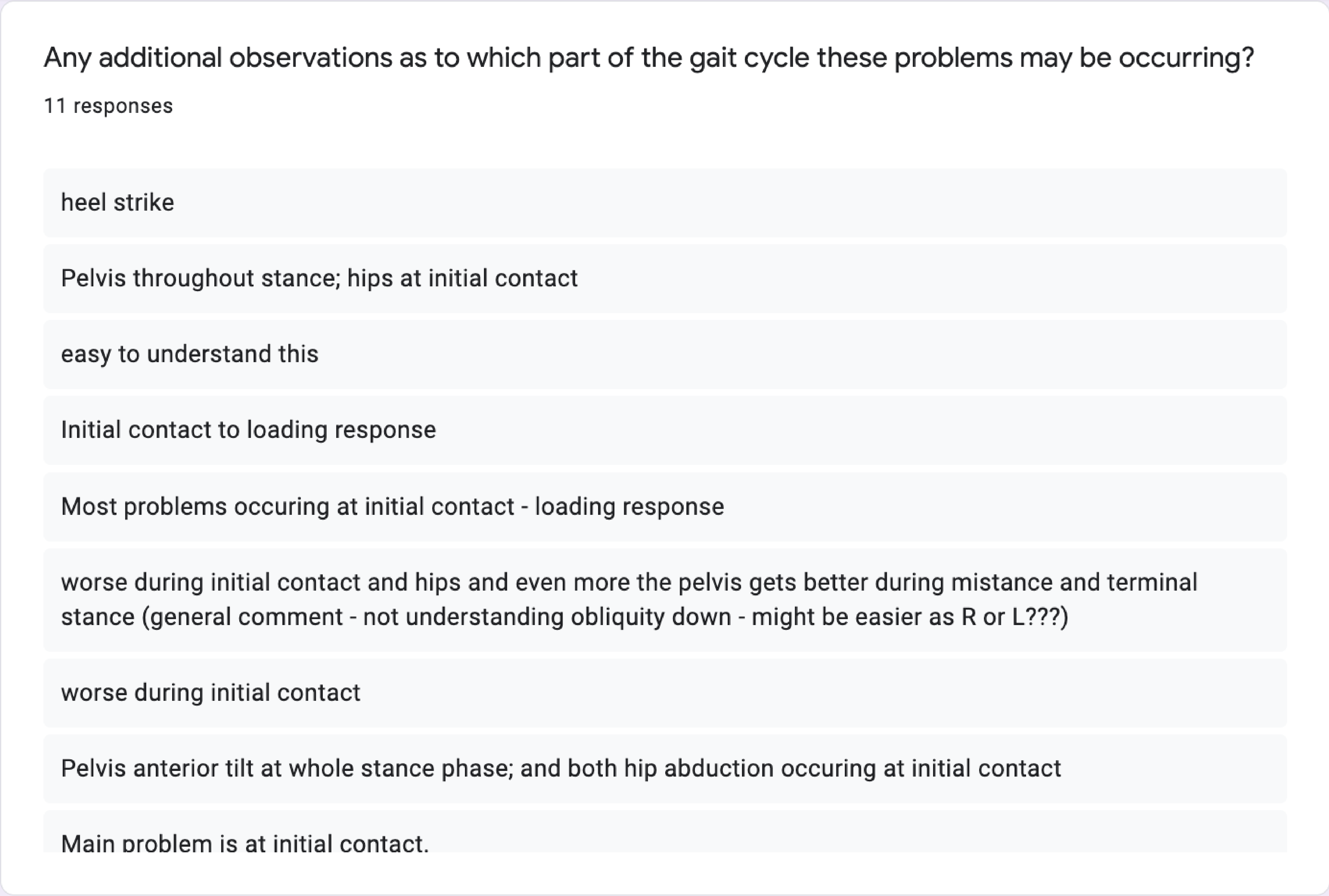
PELVIS

RIGHT HIP



Left HIP





Any additional observations as to which part of the gait cycle these problems may be occurring?

11 responses

heel strike

Pelvis throughout stance; hips at initial contact

easy to understand this

Initial contact to loading response

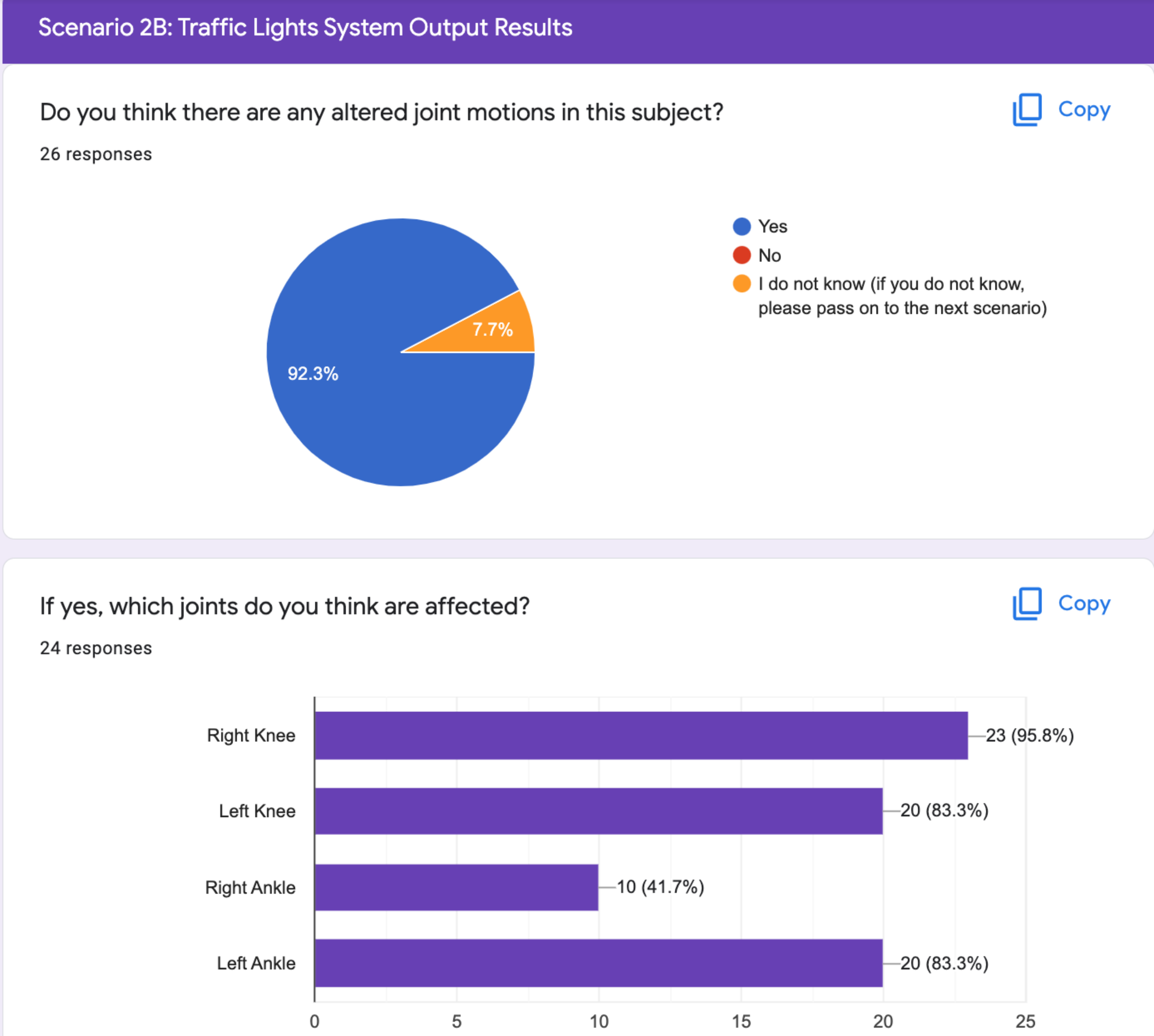
Most problems occuring at initial contact - loading response

worse during initial contact and hips and even more the pelvis gets better during mistance and terminal stance (general comment - not understanding obliquity down - might be easier as R or L???)

worse during initial contact

Pelvis anterior tilt at whole stance phase; and both hip abduction occuring at initial contact

Main problem is at initial contact.



Scenario 2B: Traffic Lights System Output Results

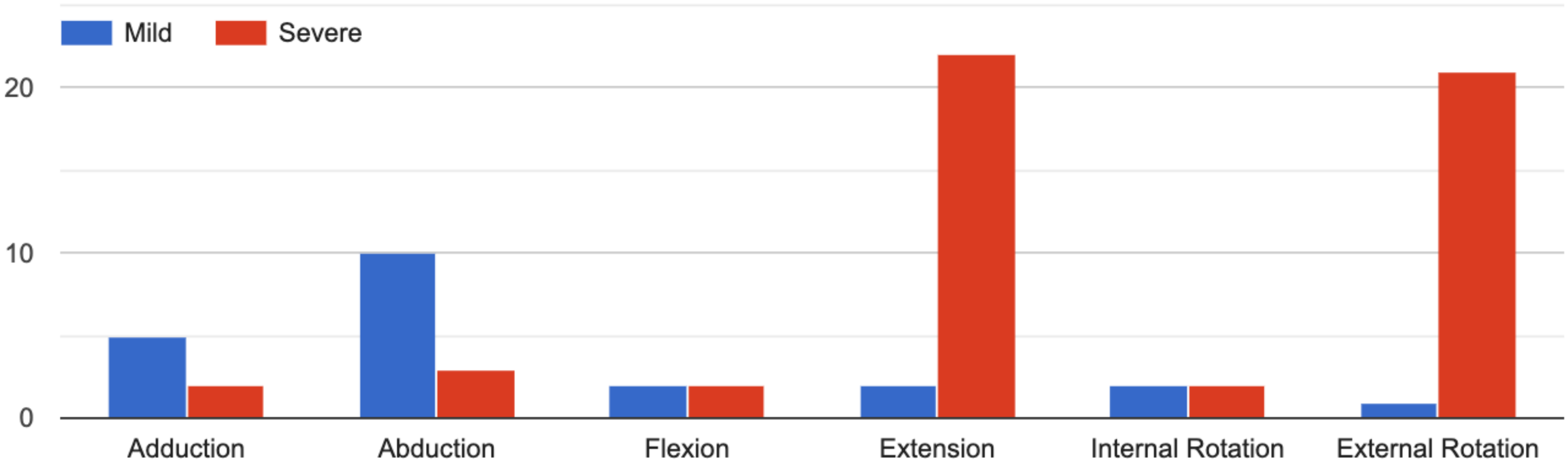
Do you think there are any altered joint motions in this subject?

26 responses

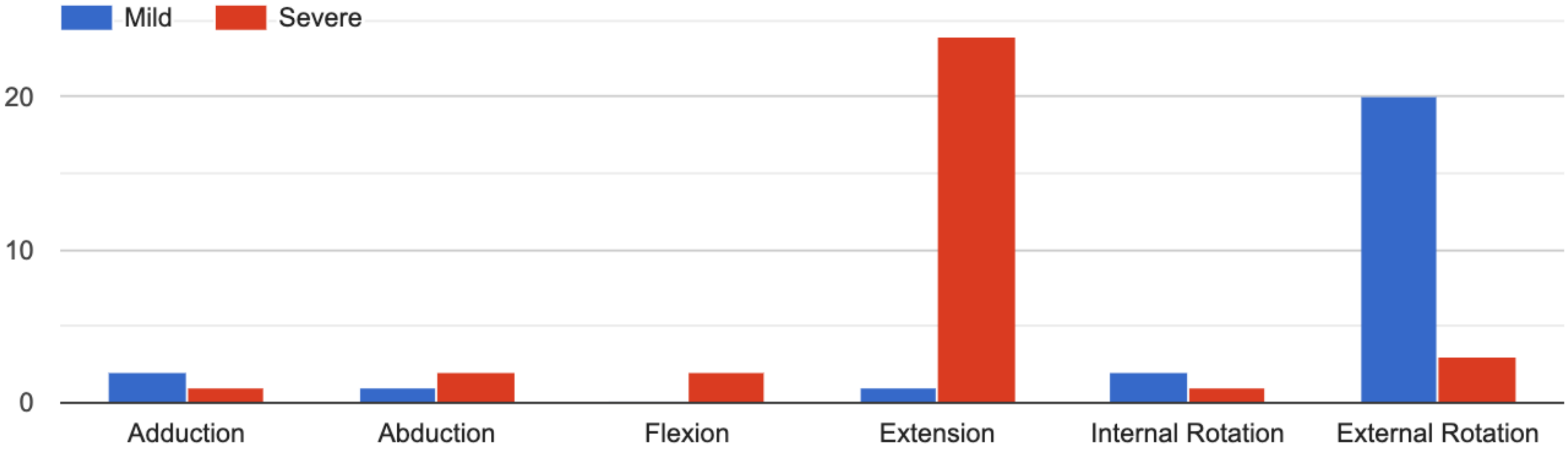
If yes, which joints do you think are affected?

24 responses

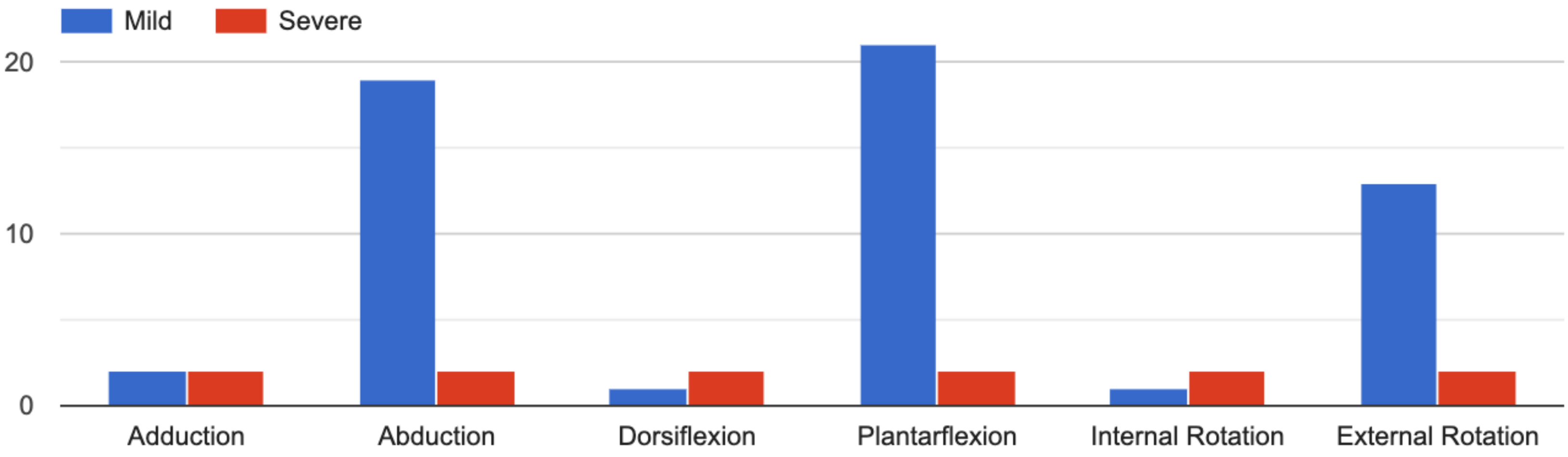
RIGHT KNEE



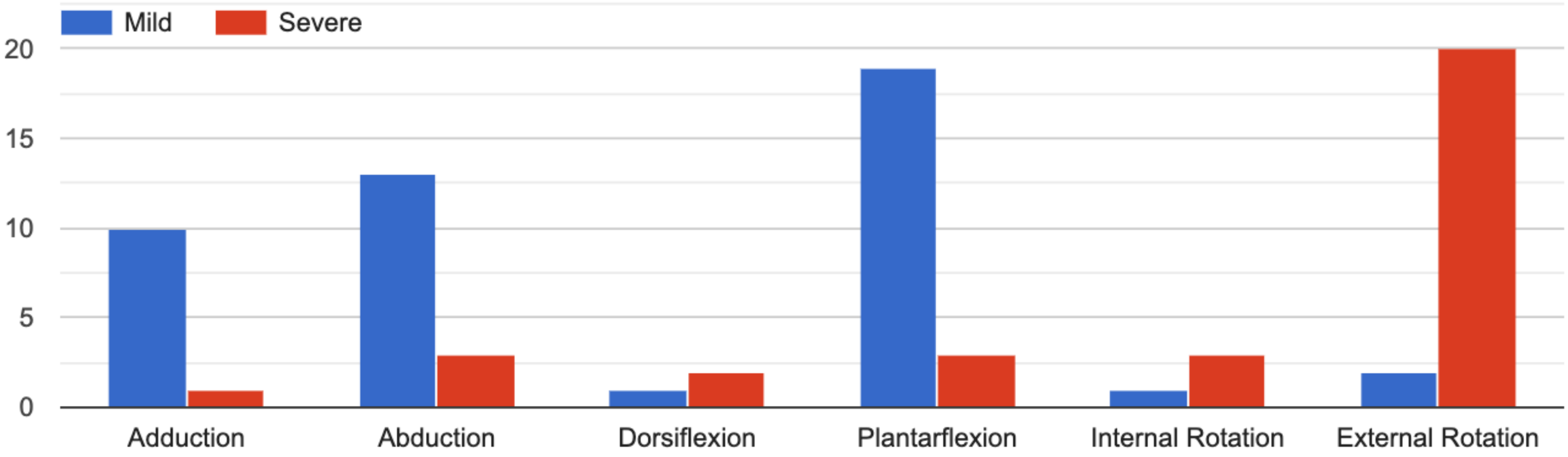
LEFT KNEE

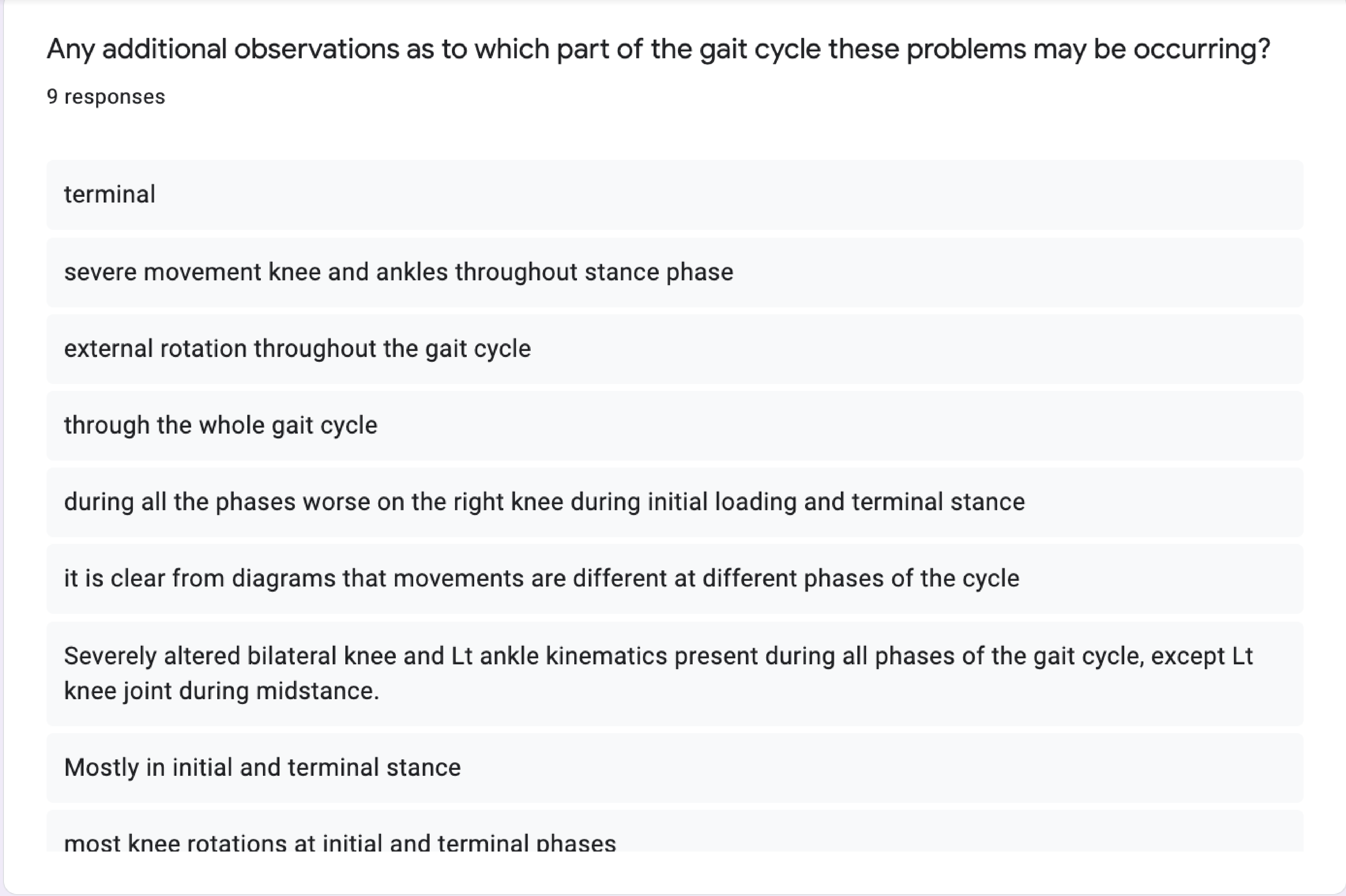


RIGHT ANKLE



LEFT ANKLE





Any additional observations as to which part of the gait cycle these problems may be occurring?

9 responses

terminal

severe movement knee and ankles throughout stance phase

external rotation throughout the gait cycle

through the whole gait cycle

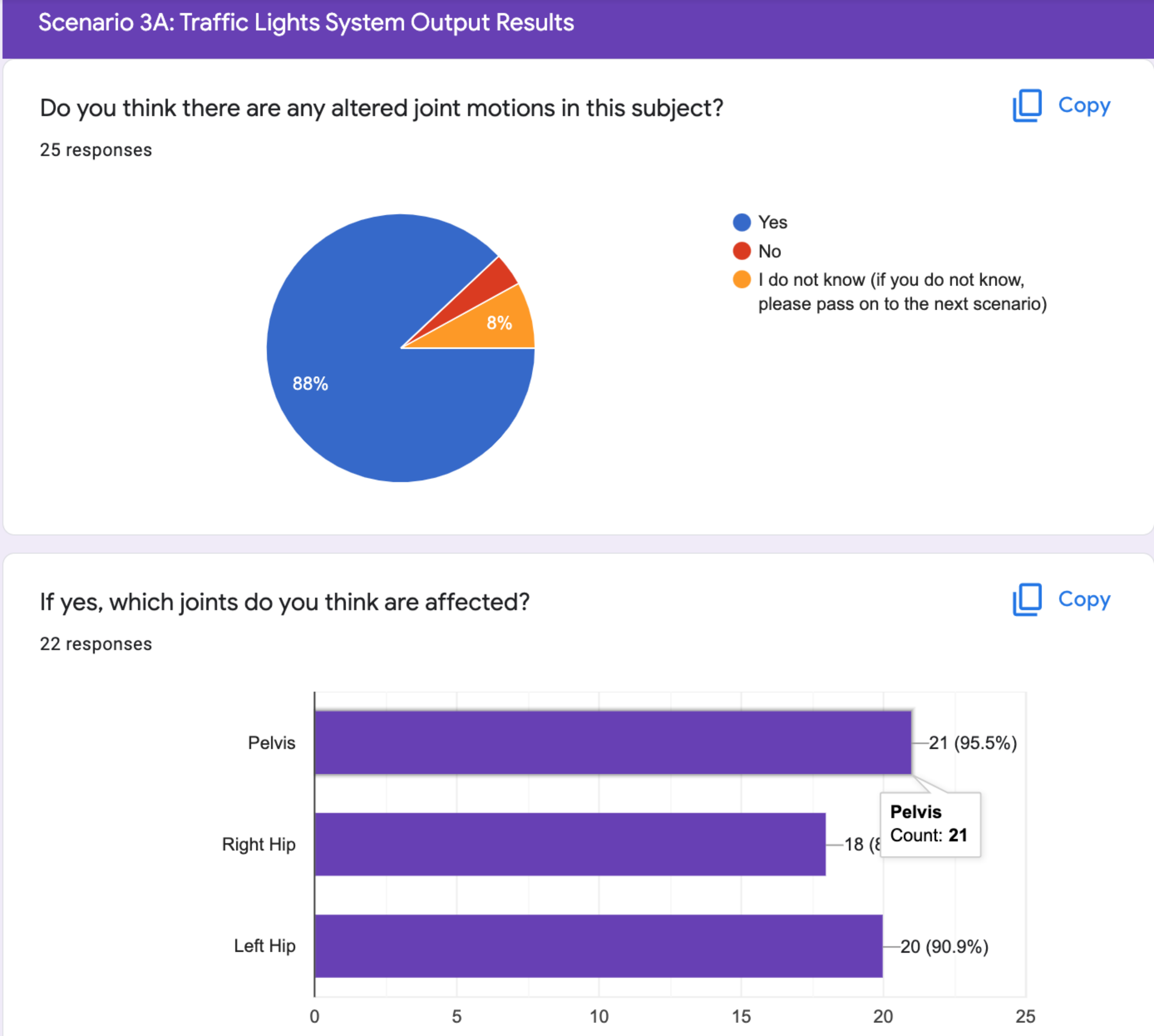
during all the phases worse on the right knee during initial loading and terminal stance

it is clear from diagrams that movements are different at different phases of the cycle

Severely altered bilateral knee and Lt ankle kinematics present during all phases of the gait cycle, except Lt knee joint during midstance.

Mostly in initial and terminal stance

most knee rotations at initial and terminal phases



Scenario 3A: Traffic Lights System Output Results

Do you think there are any altered joint motions in this subject?

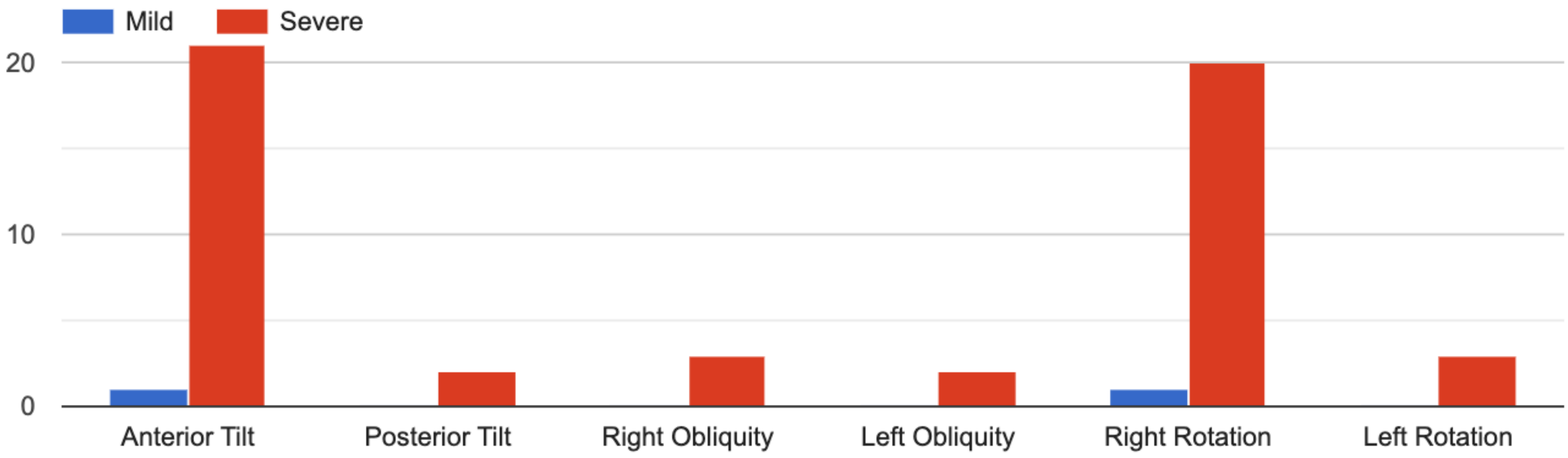
25 responses

If yes, which joints do you think are affected?

22 responses

PELVIS

Copy



RIGHT HIP

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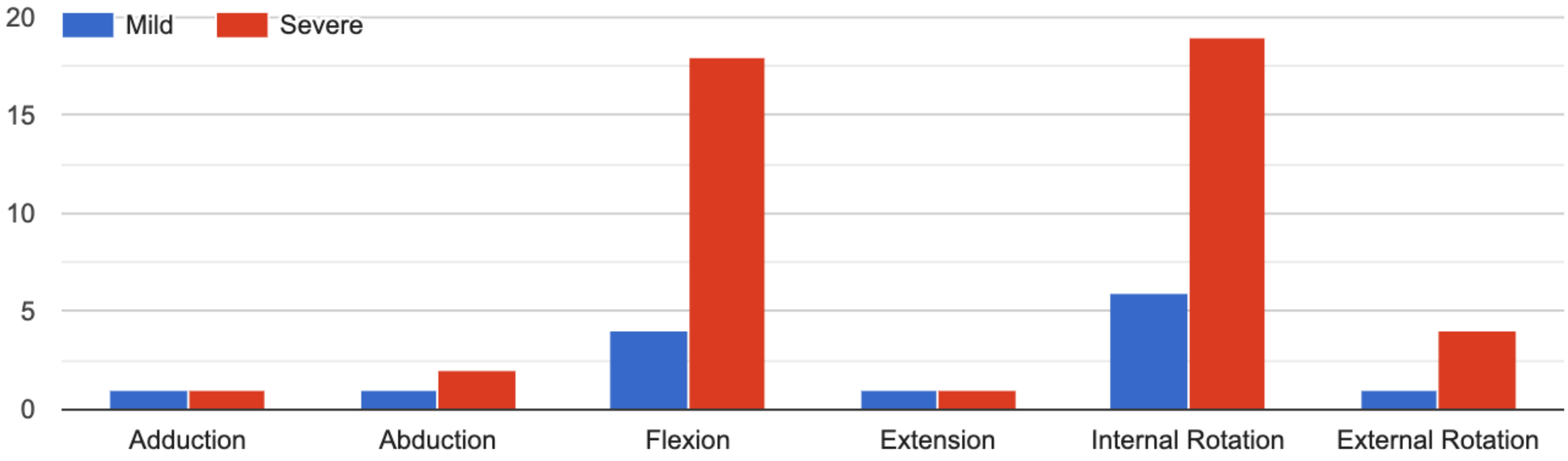

LEFT HIP

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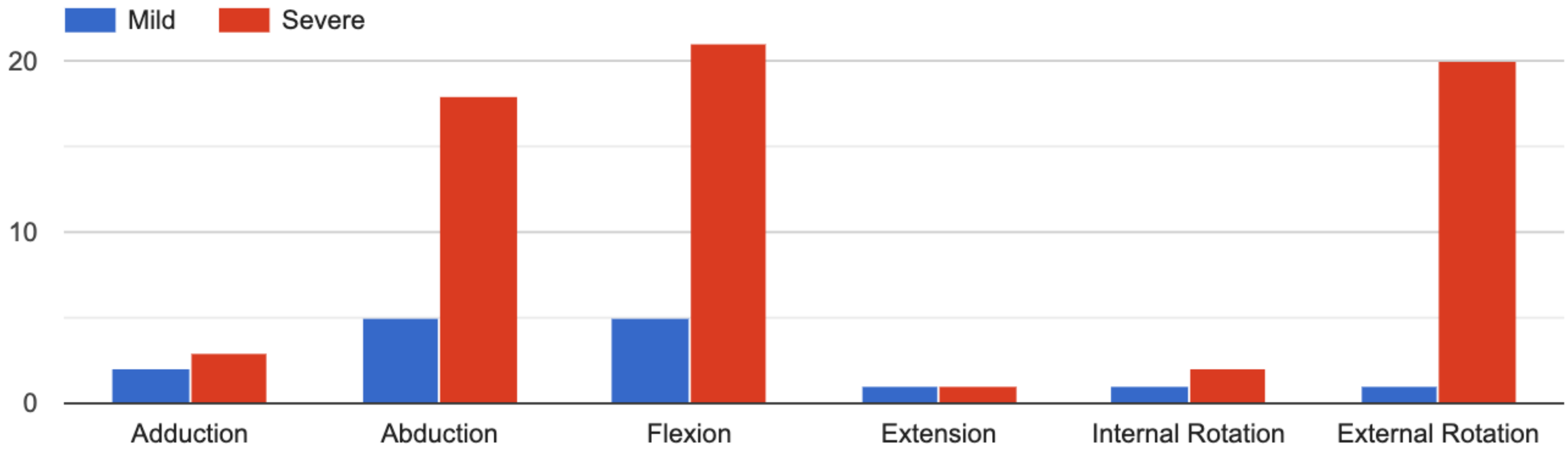


Any additional observations as to which part of the gait cycle these problems may be occurring?

9 responses

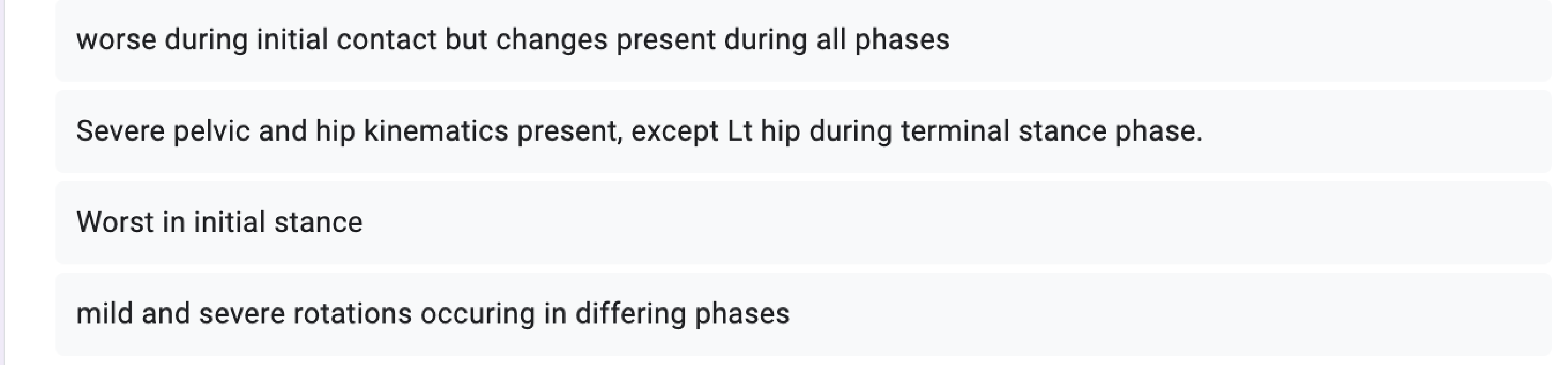
initial contact

throughout stance phase

Initial contact to loading response mostly

problems to some extent in all part of gait cycle however mostly at initial contact and midstance

all phases

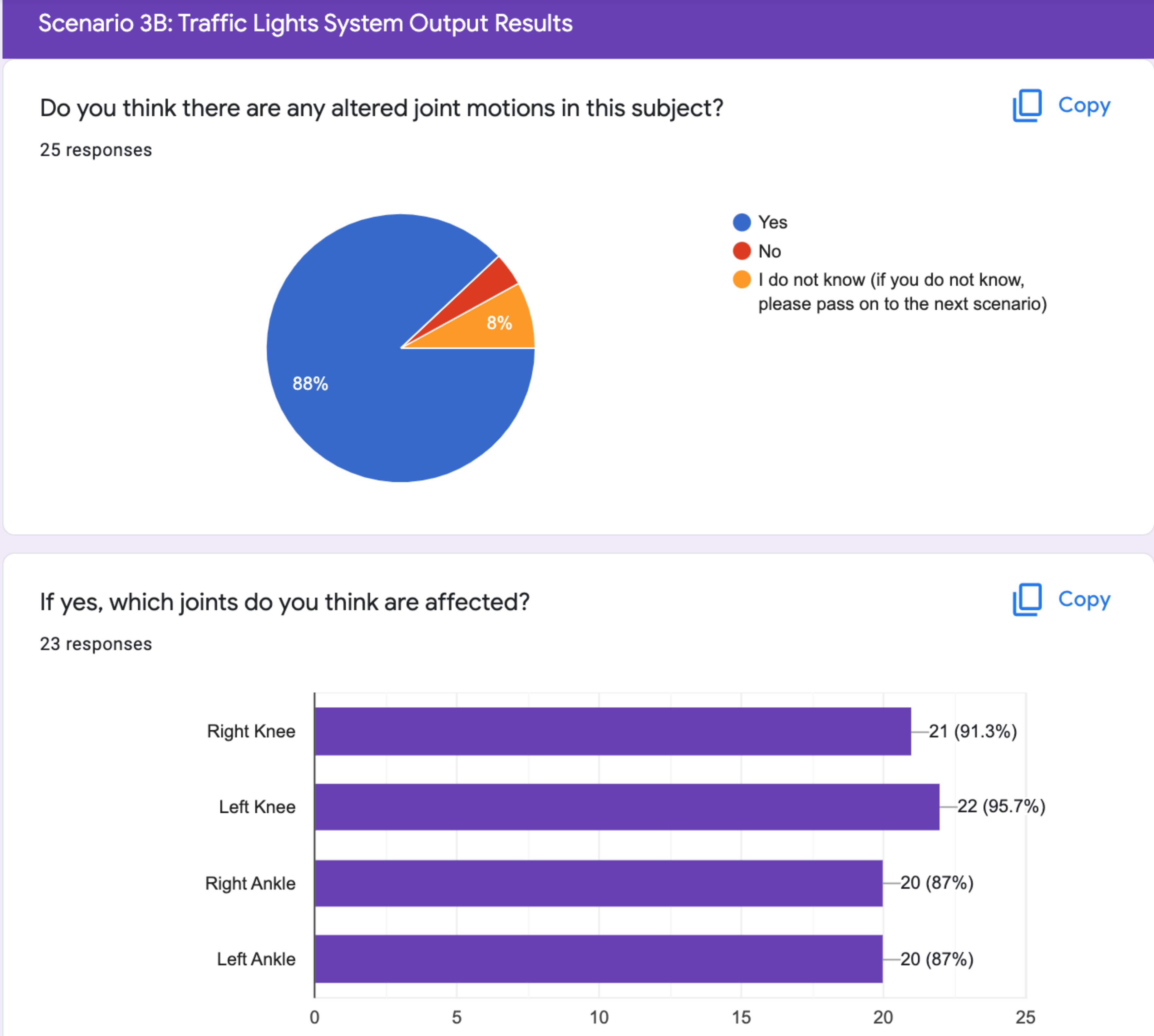


worse during initial contact but changes present during all phases

Severe pelvic and hip kinematics present, except Lt hip during terminal stance phase.

Worst in initial stance

mild and severe rotations occuring in differing phases



Scenario 3B: Traffic Lights System Output Results

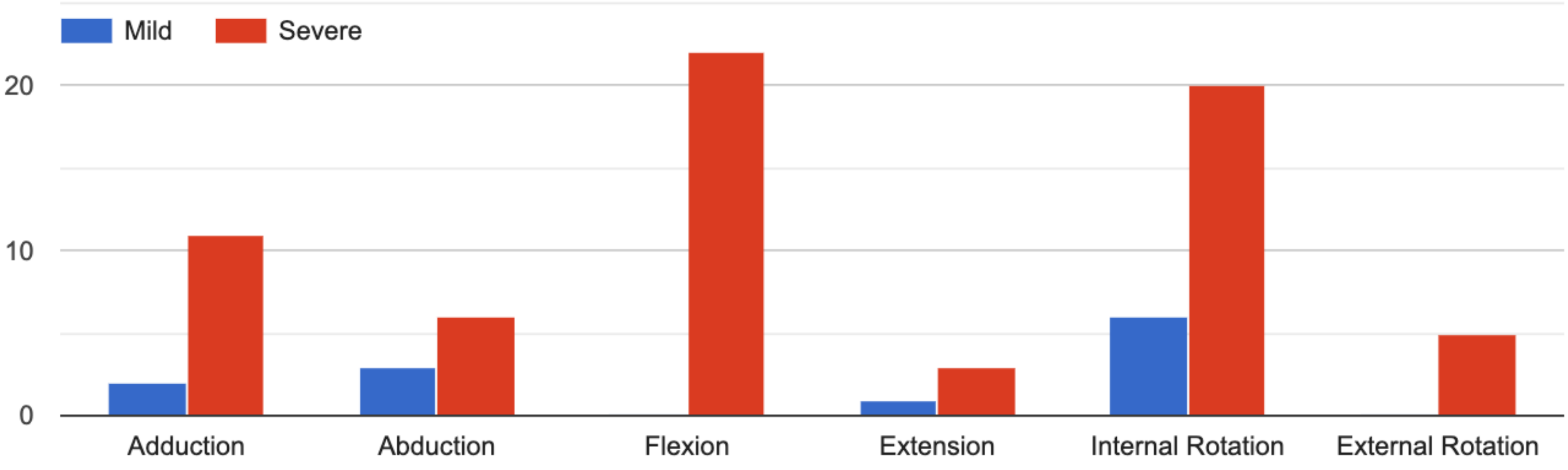
Do you think there are any altered joint motions in this subject?

25 responses

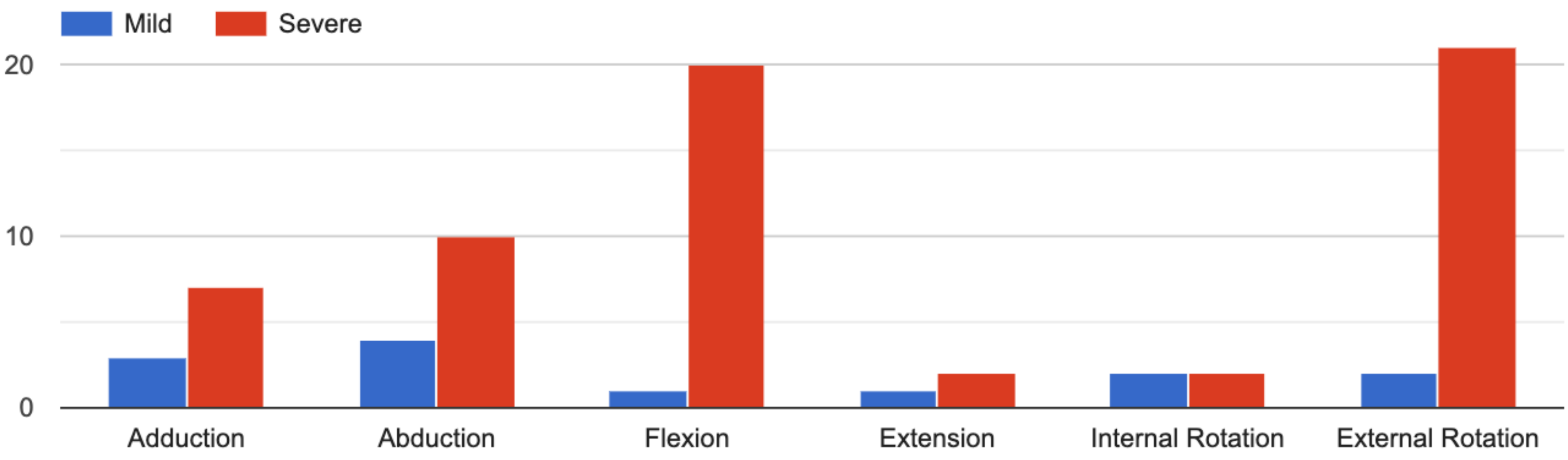
If yes, which joints do you think are affected?

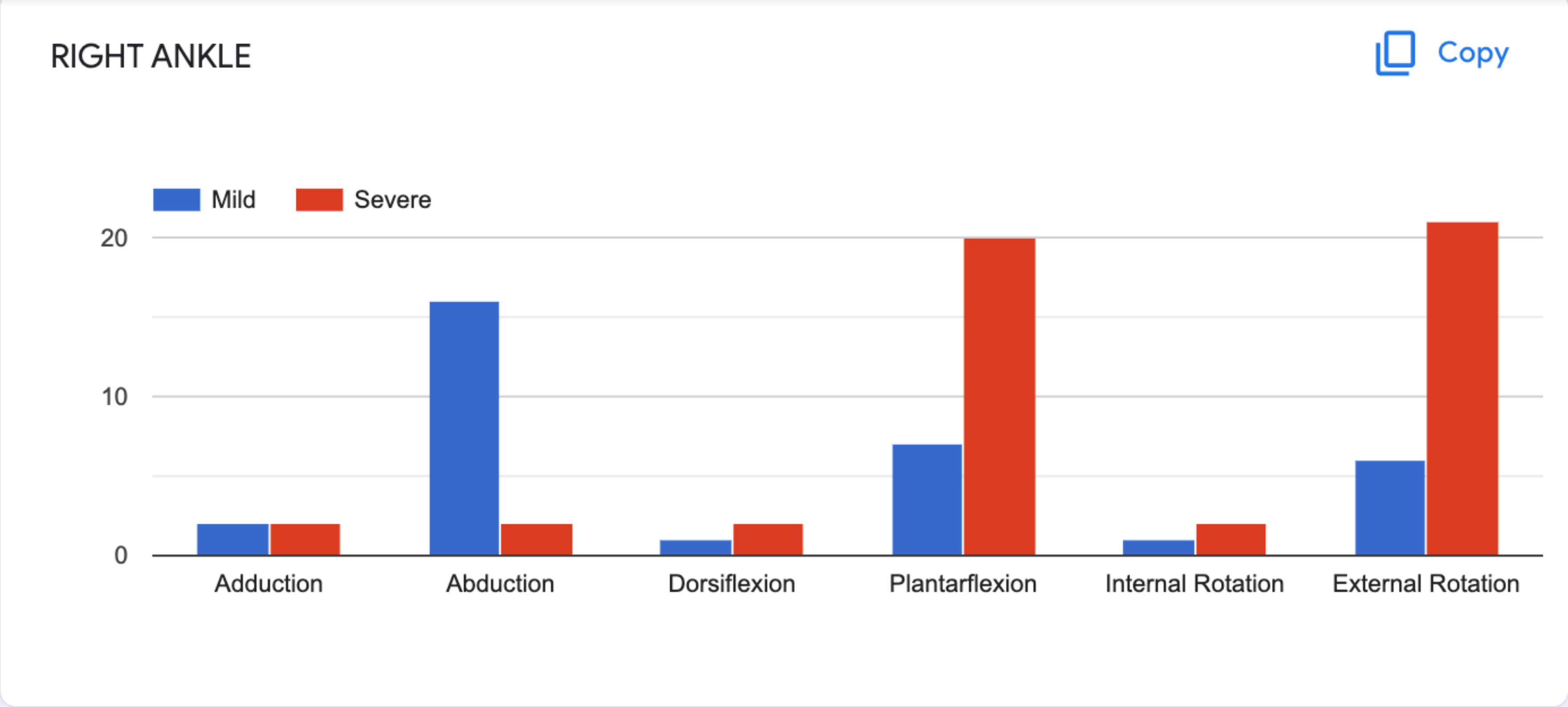
23 responses

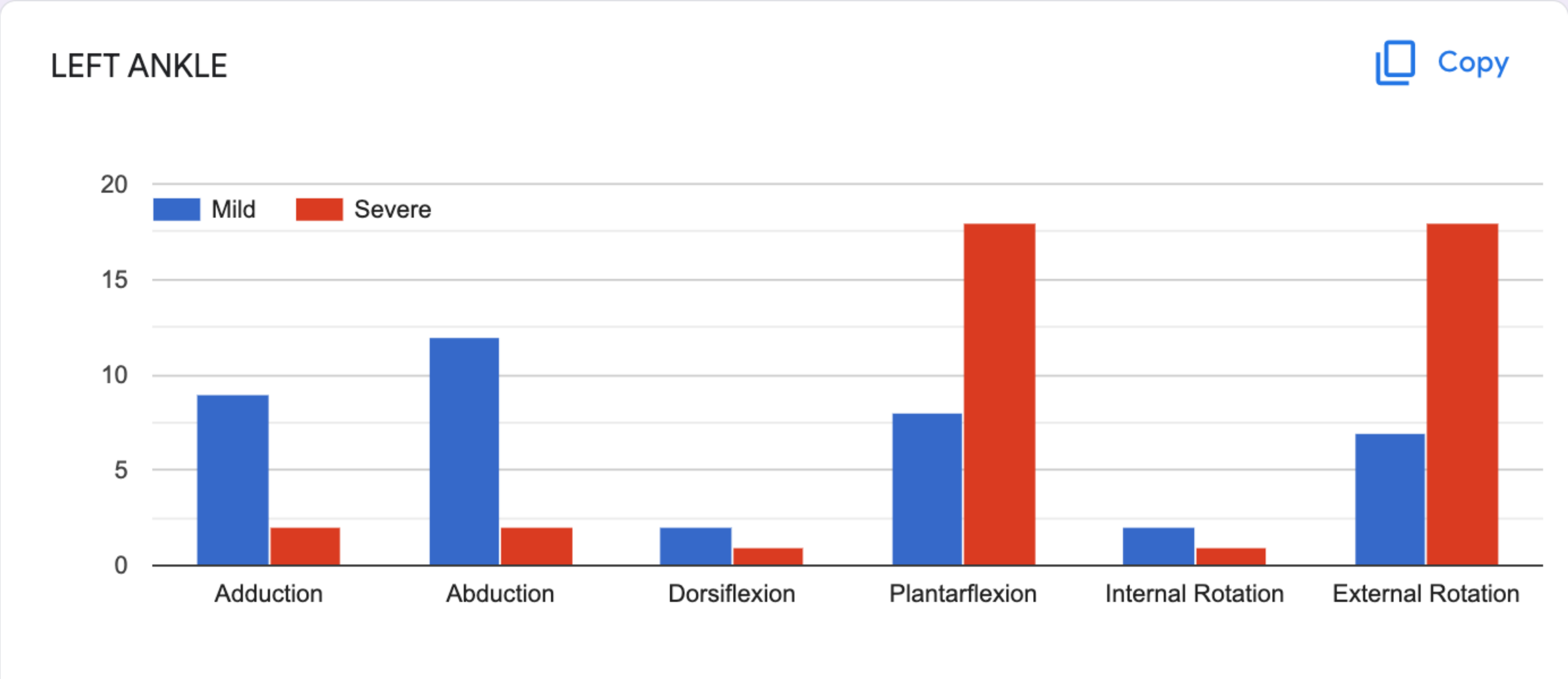
RIGHT KNEE

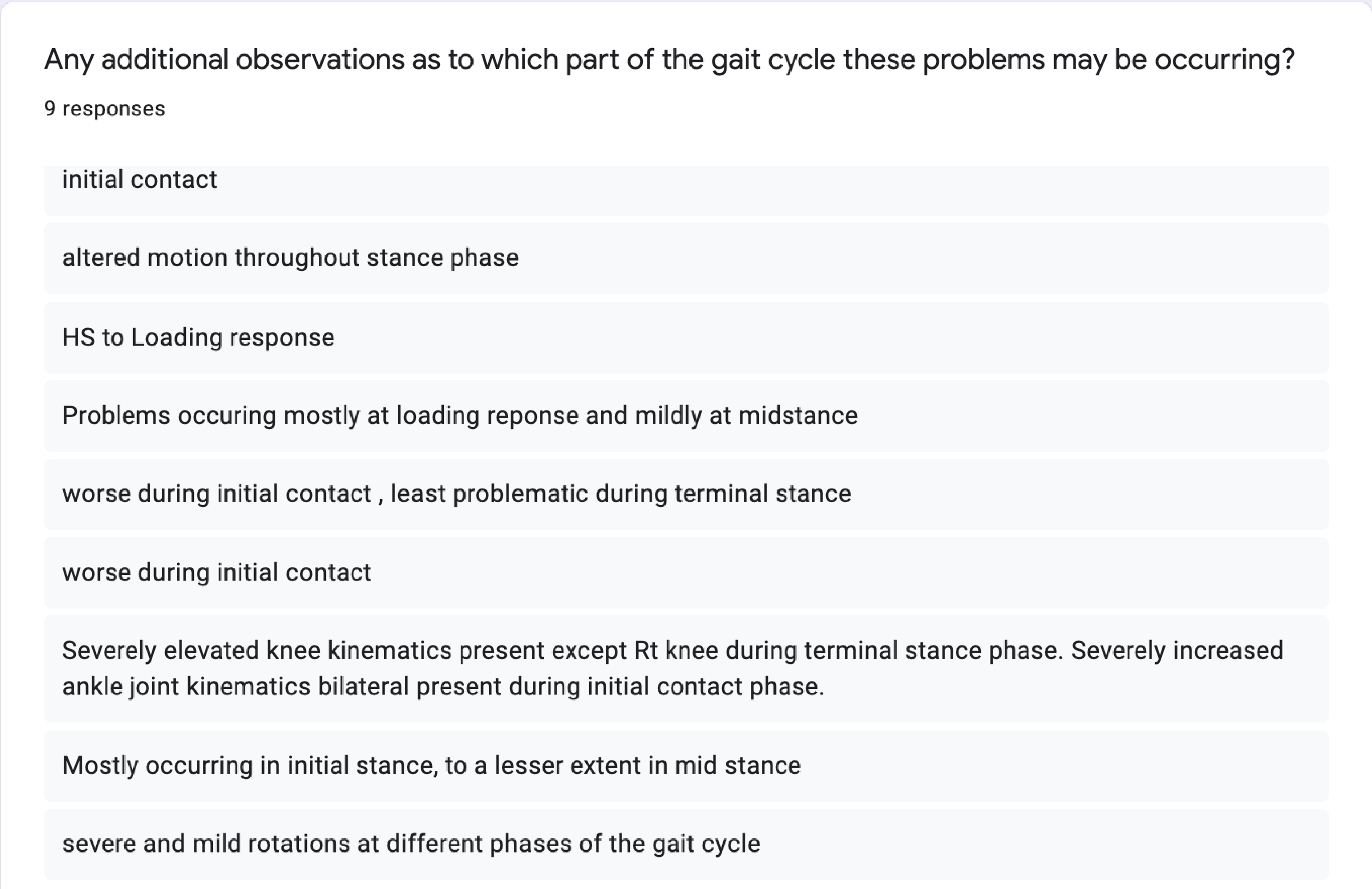


LEFT KNEE




RIGHT ANKLE
Copy
Mild
Severe
20
10
0
Adduction
Abduction
Dorsiflexion
Plantarflexion
Internal Rotation
External Rotation


LEFT ANKLE
Copy
Mild
Severe
20
15
10
5
0
Adduction
Abduction
Dorsiflexion
Plantarflexion
Internal Rotation
External Rotation



Any additional observations as to which part of the gait cycle these problems may be occurring?

9 responses

initial contact

altered motion throughout stance phase

HS to Loading response

Problems occuring mostly at loading reponse and mildly at midstance

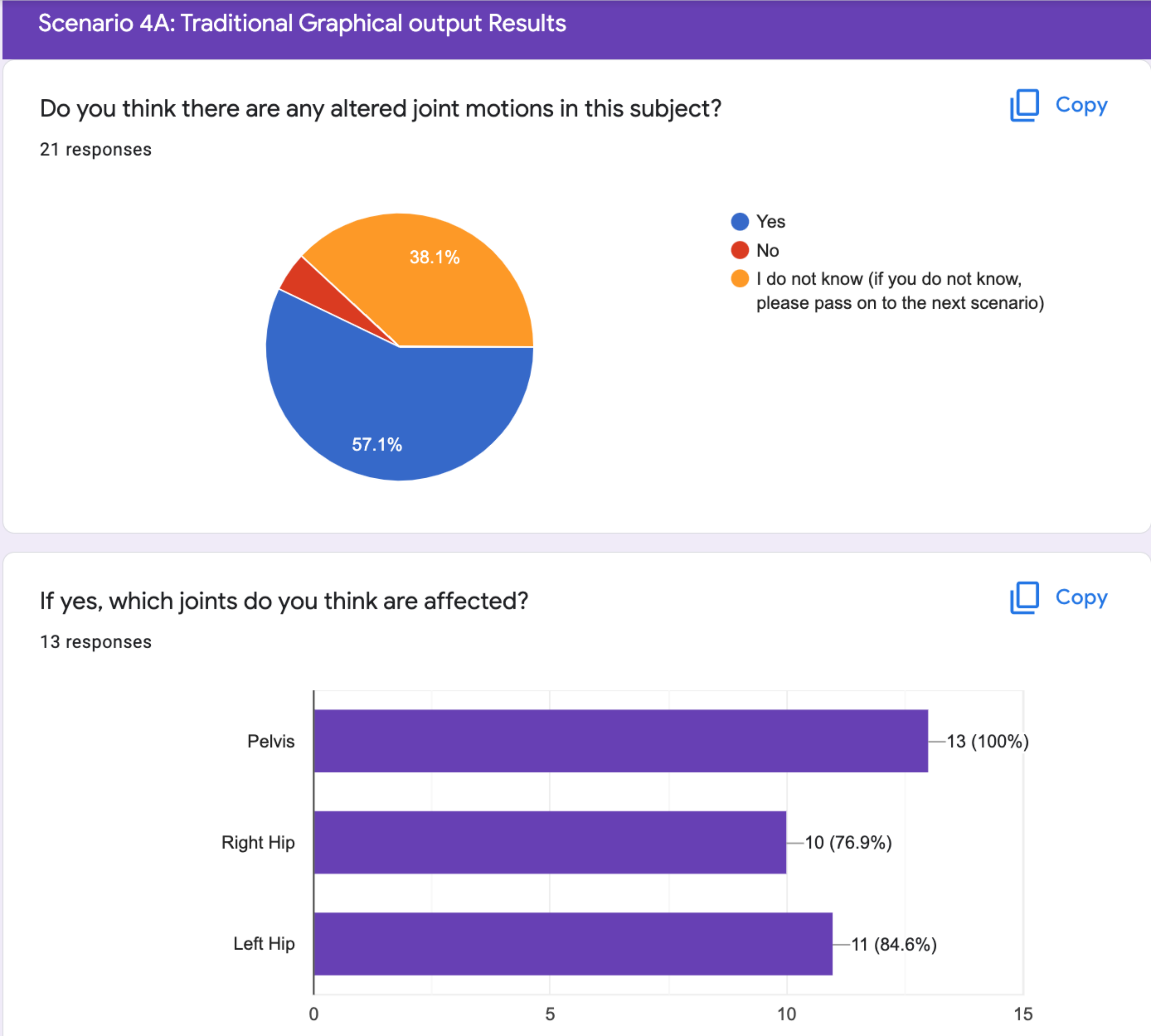
worse during initial contact , least problematic during terminal stance

worse during initial contact

Severely elevated knee kinematics present except Rt knee during terminal stance phase. Severely increased ankle joint kinematics bilateral present during initial contact phase.

Mostly occurring in initial stance, to a lesser extent in mid stance

severe and mild rotations at different phases of the gait cycle



Scenario 4A: Traditional Graphical output Results

Do you think there are any altered joint motions in this subject?

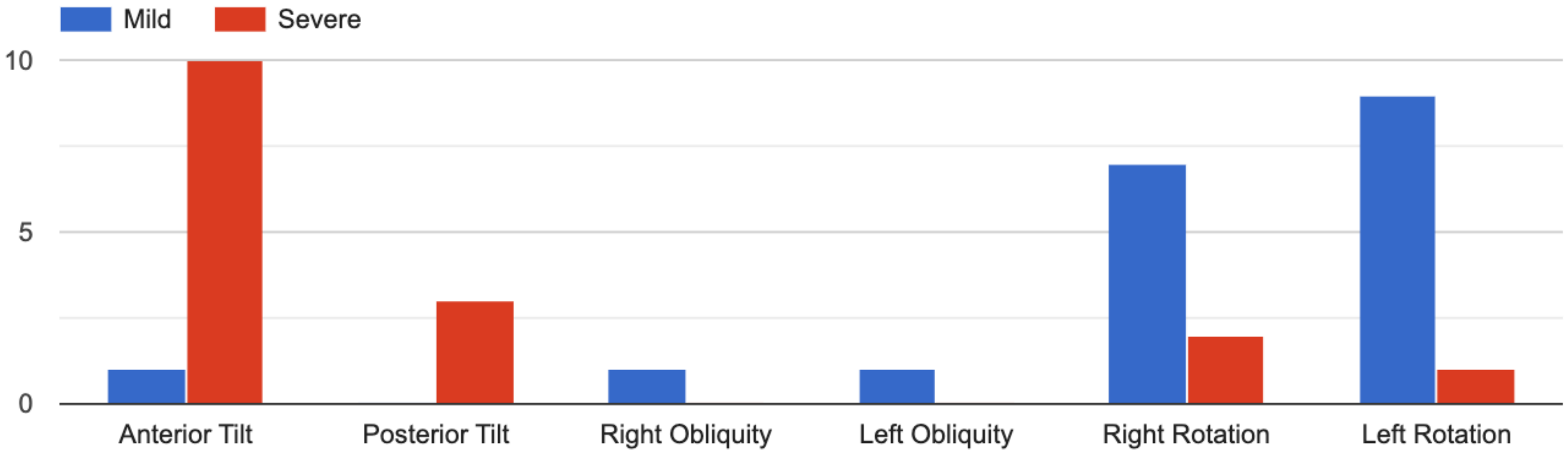
21 responses

If yes, which joints do you think are affected?

13 responses

PELVIS

Copy



RIGHT HIP

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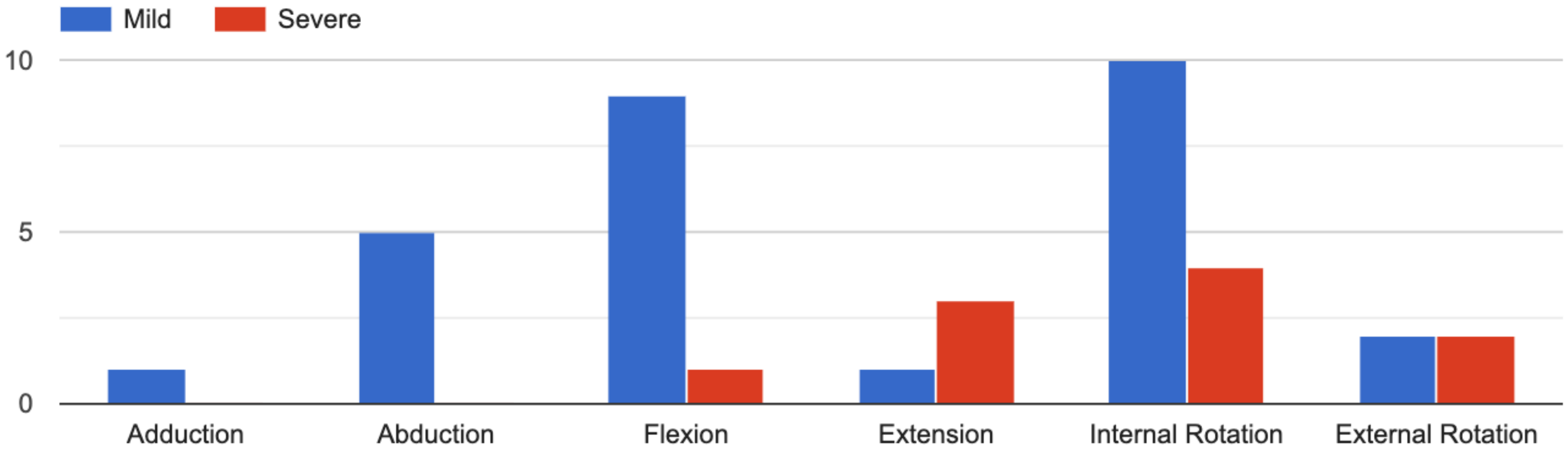

LEFT HIP

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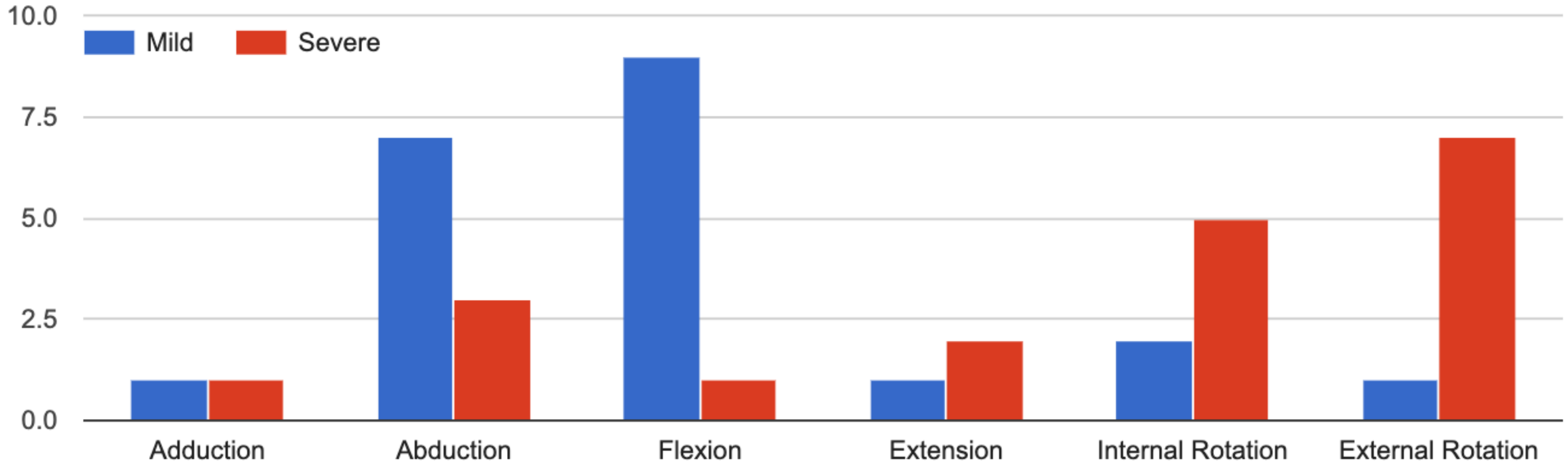


Any additional observations as to which part of the gait cycle these problems may be occurring?

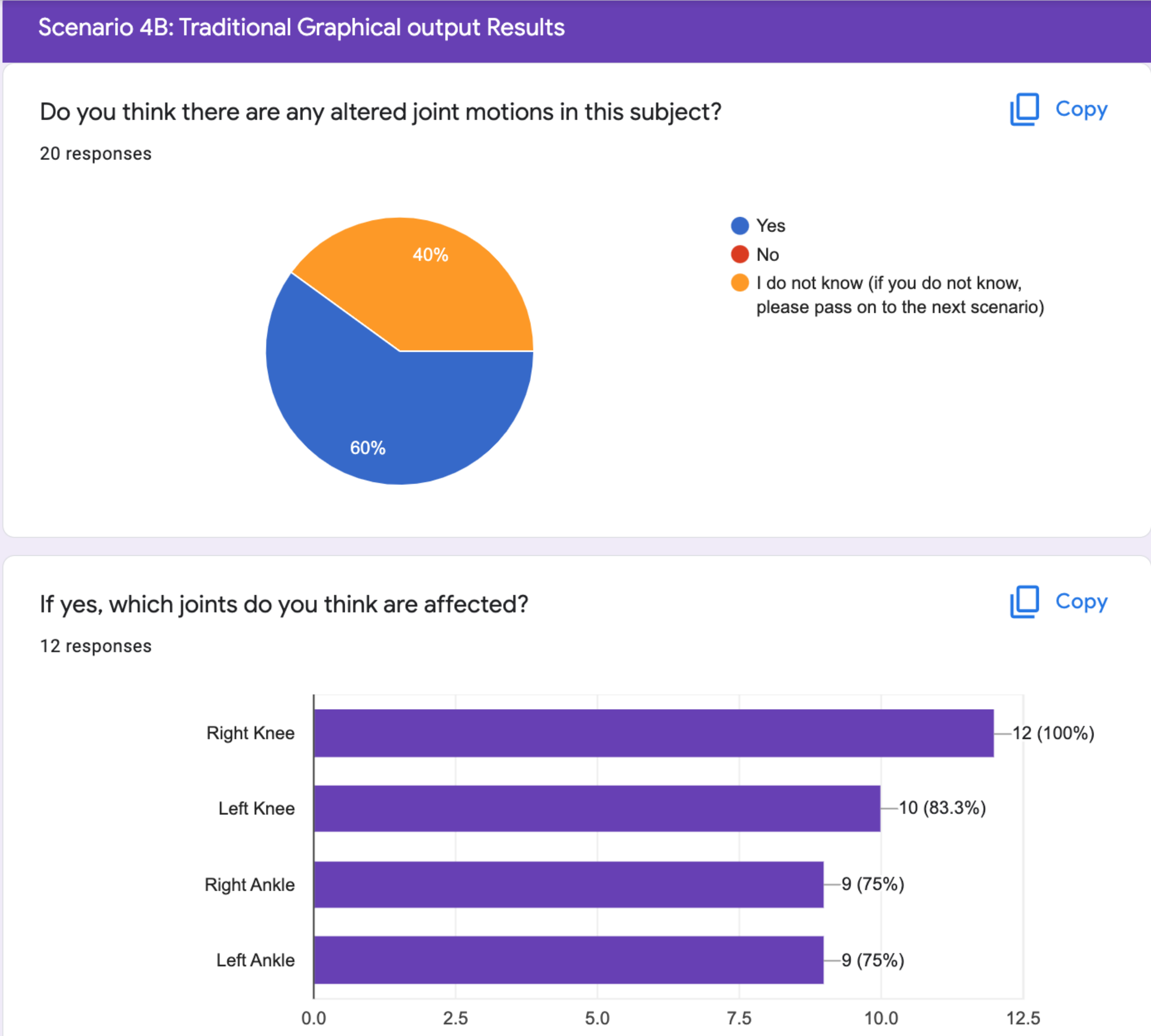
4 responses

HS to loading response

all parts

whole cycle

Most deviations occur throughout the cycle, left hip rotation is out of the scale



Scenario 4B: Traditional Graphical output Results

Do you think there are any altered joint motions in this subject?

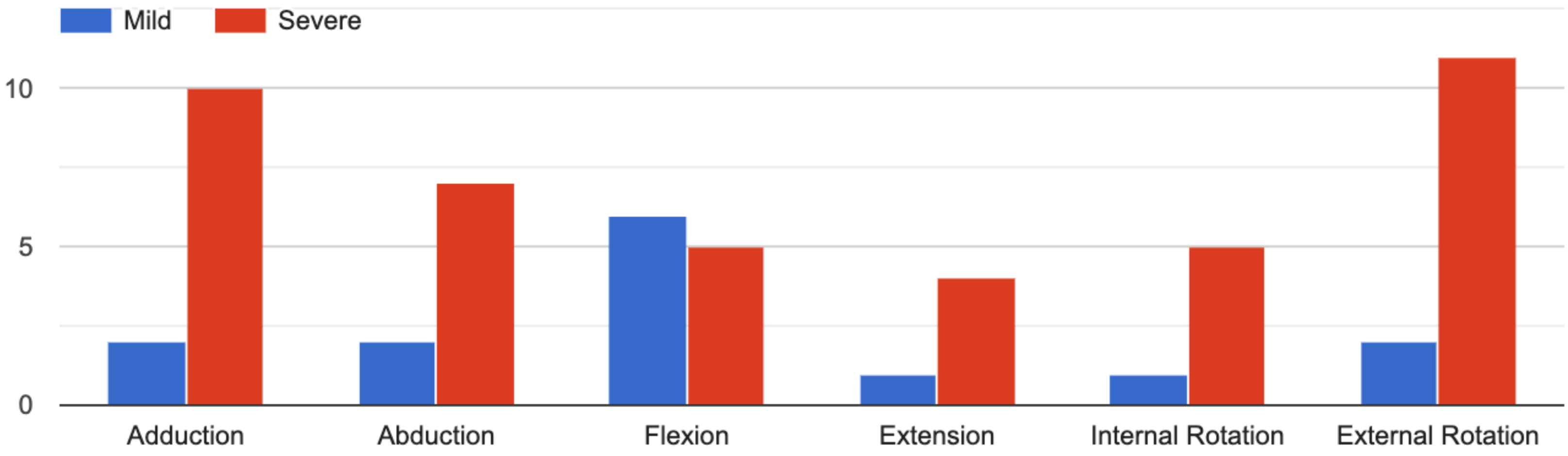
20 responses

If yes, which joints do you think are affected?

12 responses

RIGHT KNEE

Copy



LEFT KNEE

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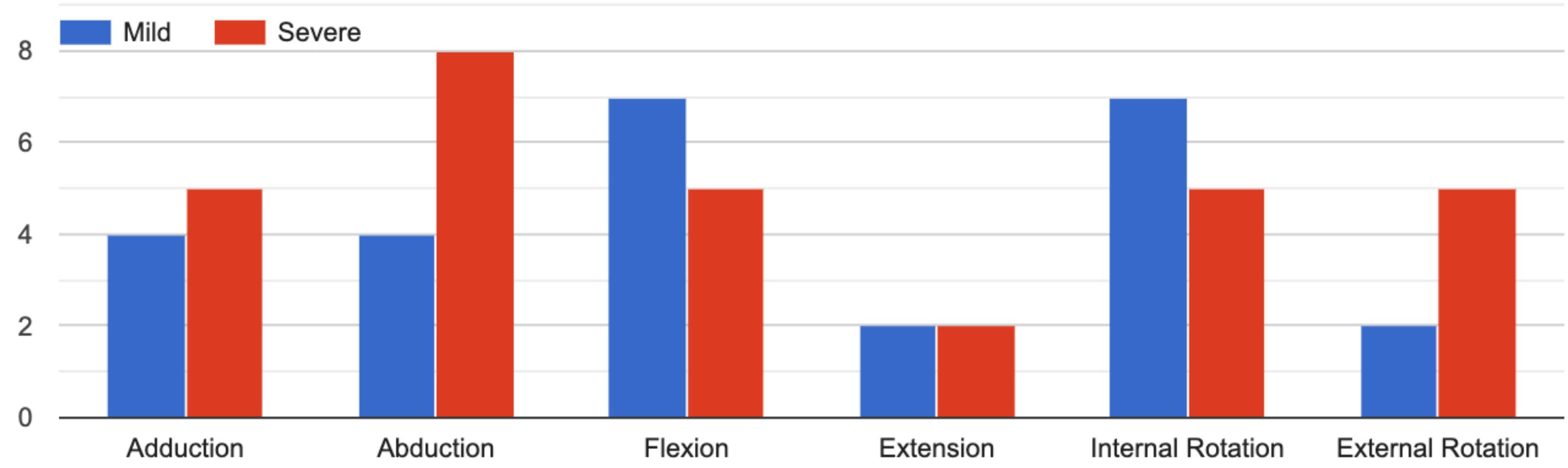
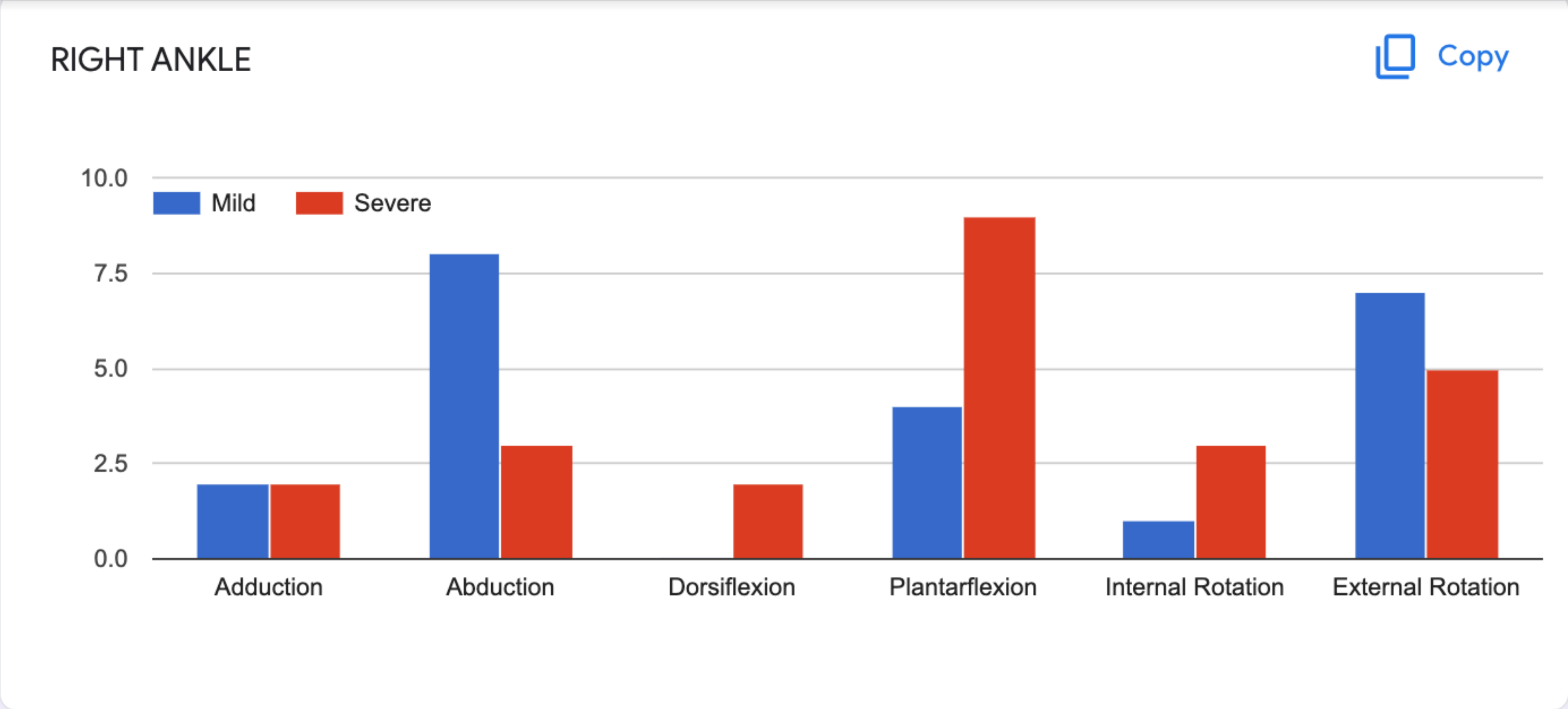
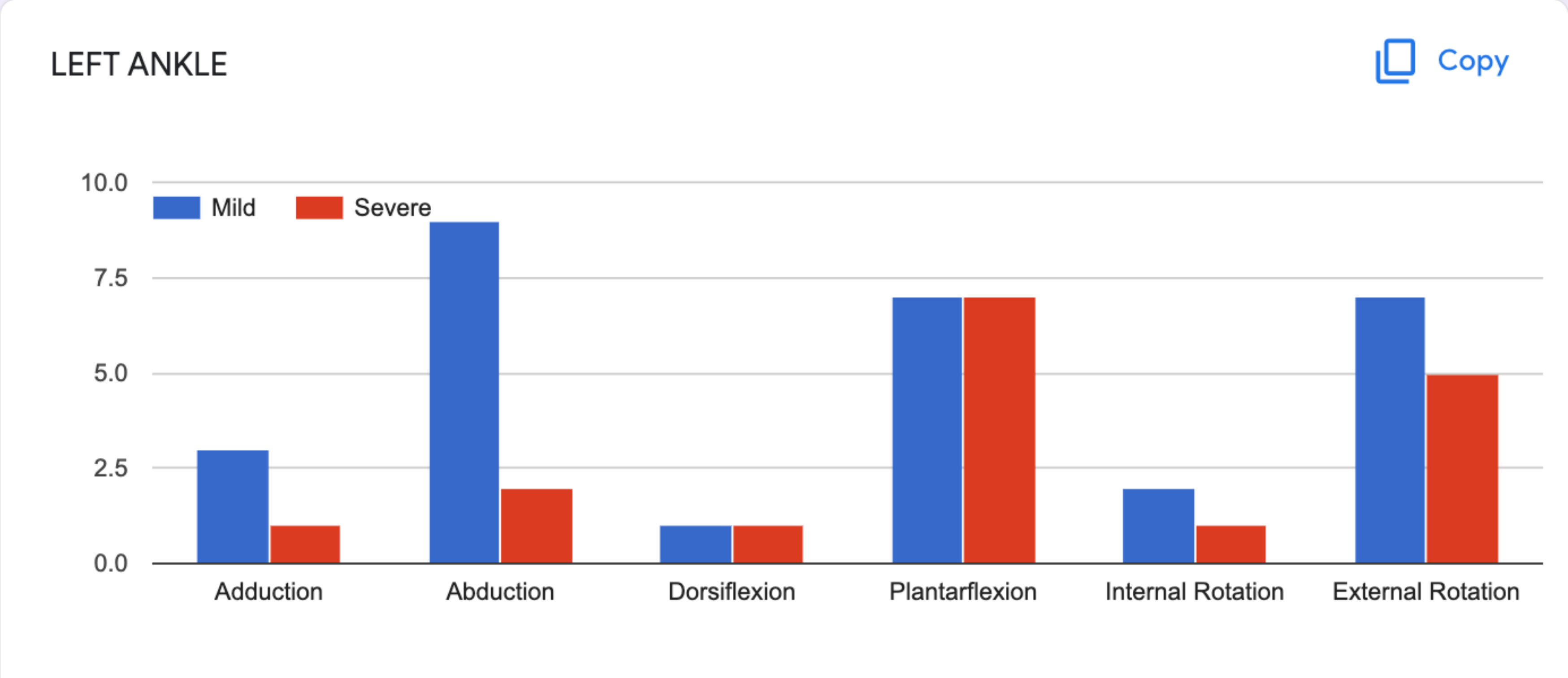
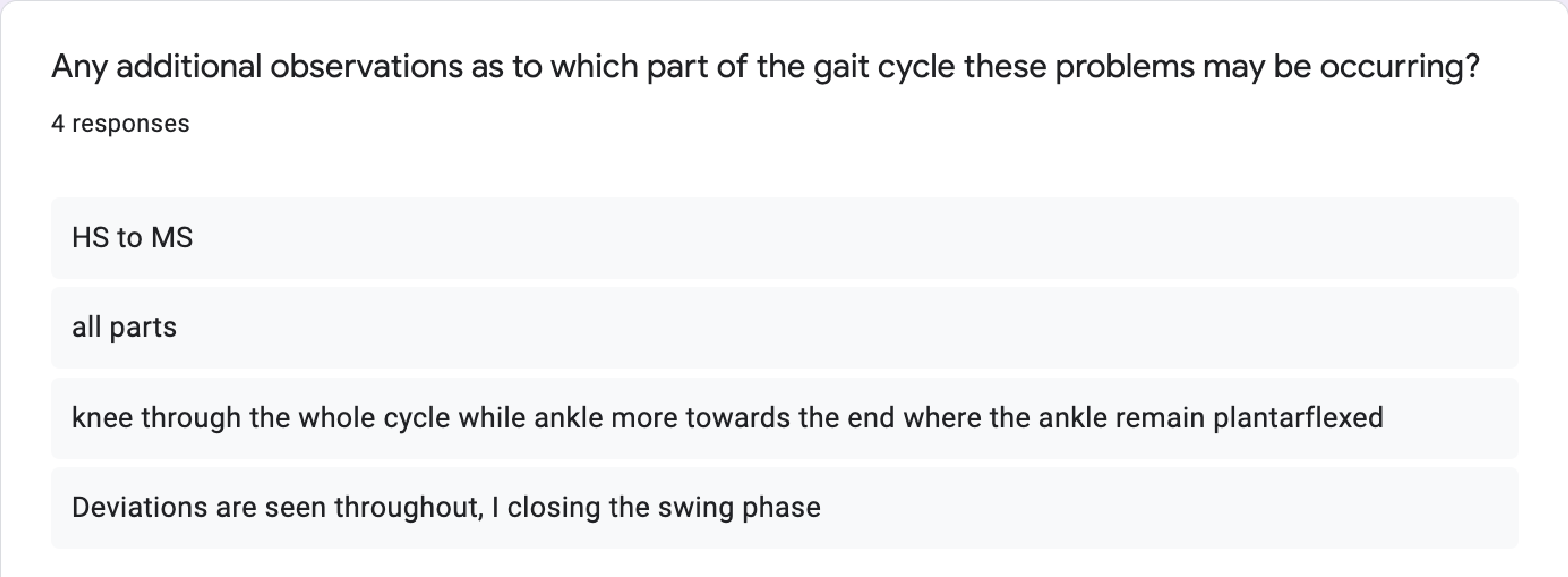



RIGHT ANKLE


LEFT ANKLE



Any additional observations as to which part of the gait cycle these problems may be occurring?

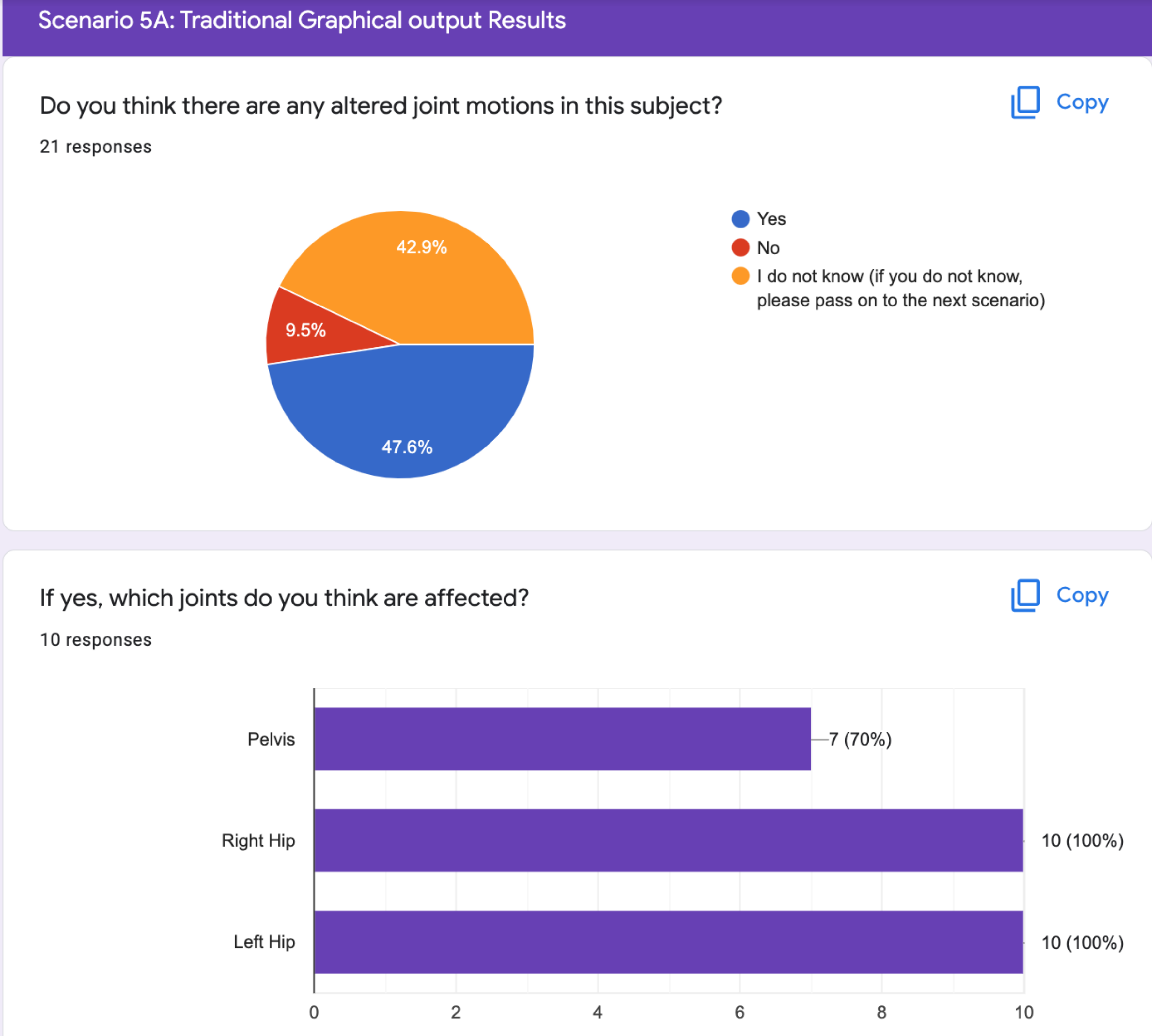
4 responses

HS to MS

all parts

knee through the whole cycle while ankle more towards the end where the ankle remain plantarflexed

Deviations are seen throughout, I closing the swing phase



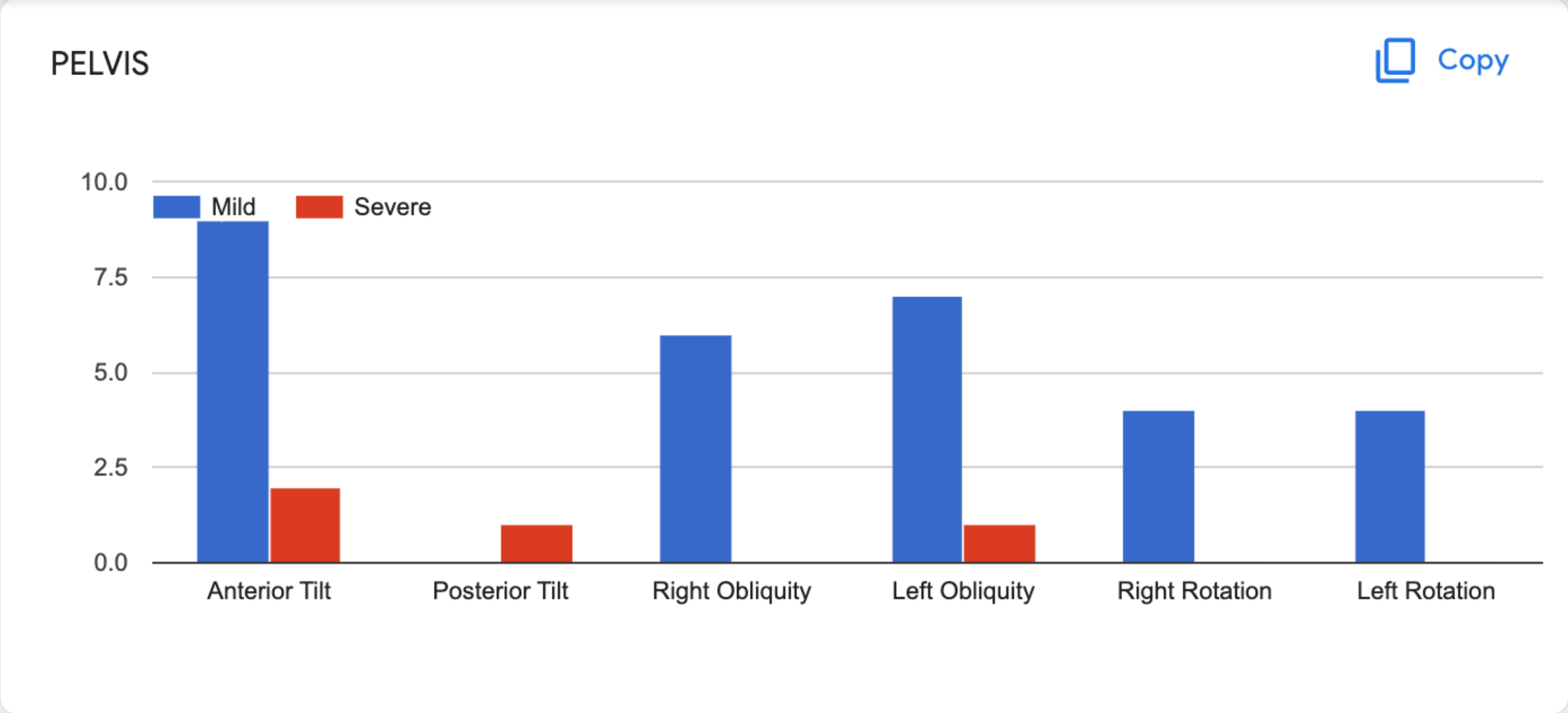
Scenario 5A: Traditional Graphical output Results

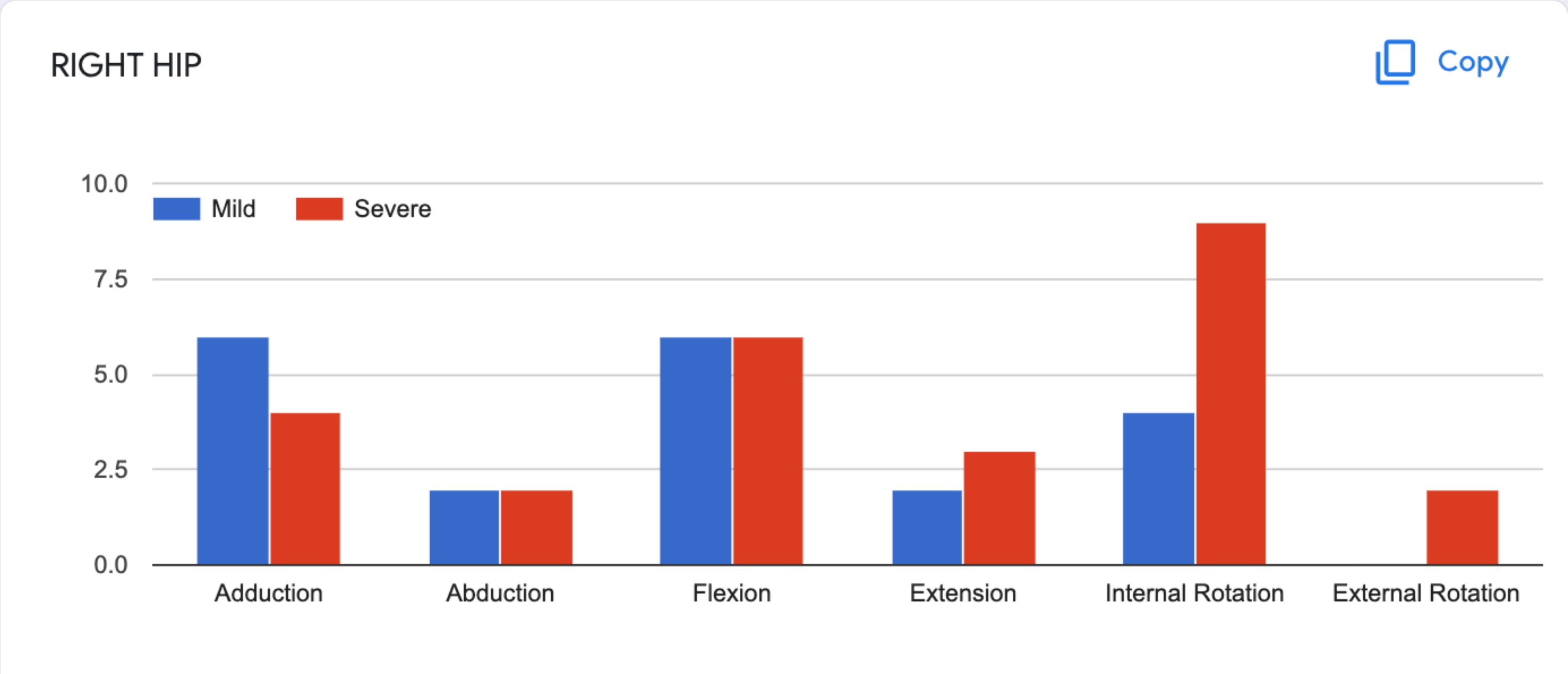
Do you think there are any altered joint motions in this subject?

21 responses

If yes, which joints do you think are affected?

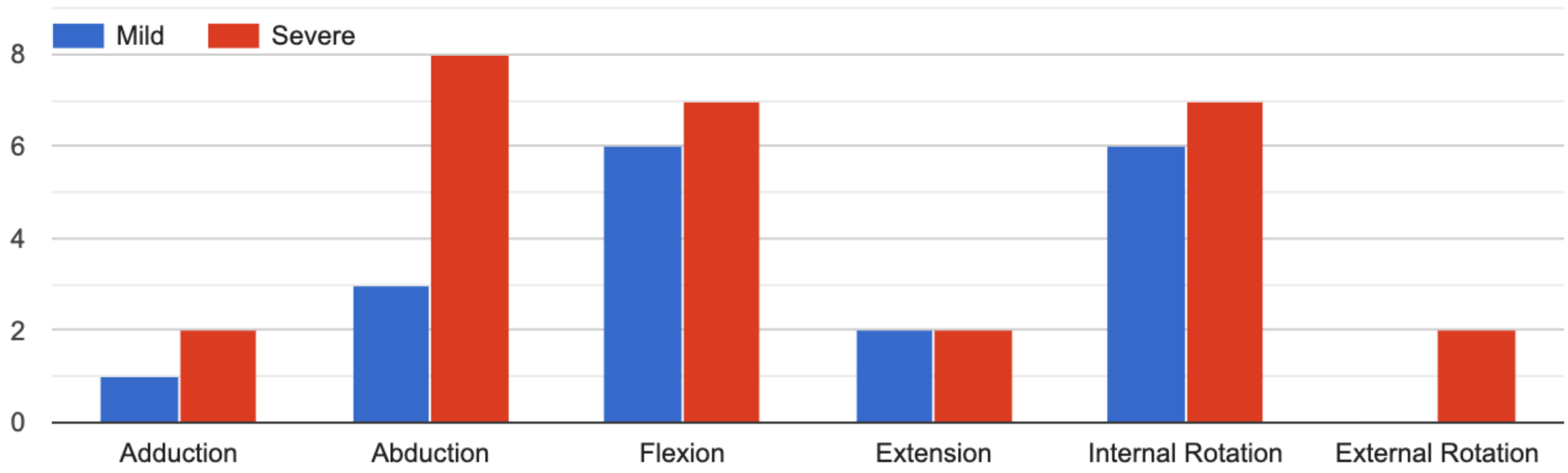
10 responses


PELVIS
Copy
10.0
7.5
5.0
2.5
0.0
Mild
Severe
Anterior Tilt
Posterior Tilt
Right Obliquity
Left Obliquity
Right Rotation
Left Rotation


RIGHT HIP
Copy
10.0
7.5
5.0
2.5
0.0
Mild
Severe
Adduction
Abduction
Flexion
Extension
Internal Rotation
External Rotation

LEFT HIP

Copy



Any additional observations as to which part of the gait cycle these problems may be occurring?

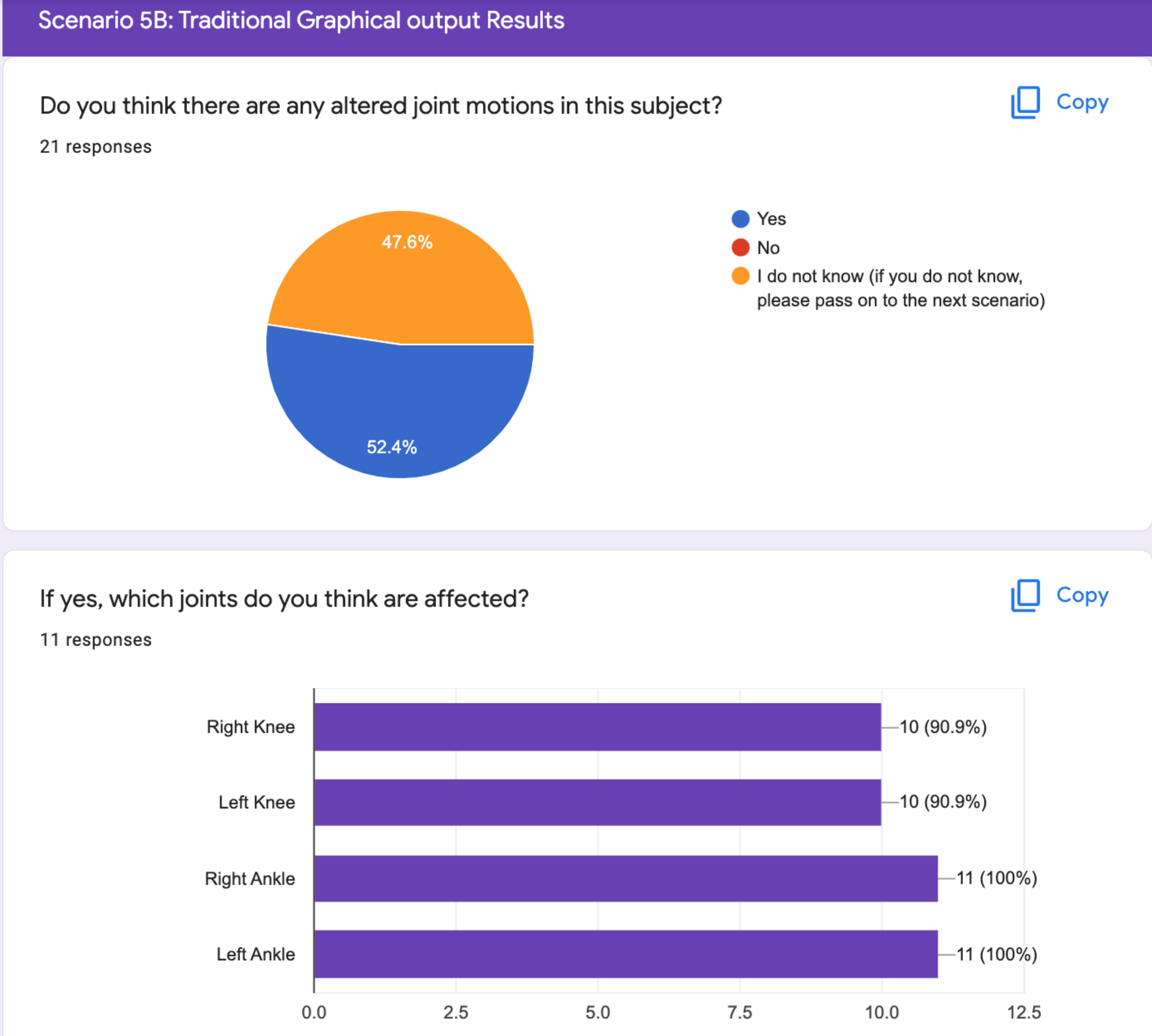
4 responses

MS to TO

all parts

all phases

Mild deviations throughout gait cycle



Scenario 5B: Traditional Graphical output Results

Do you think there are any altered joint motions in this subject?

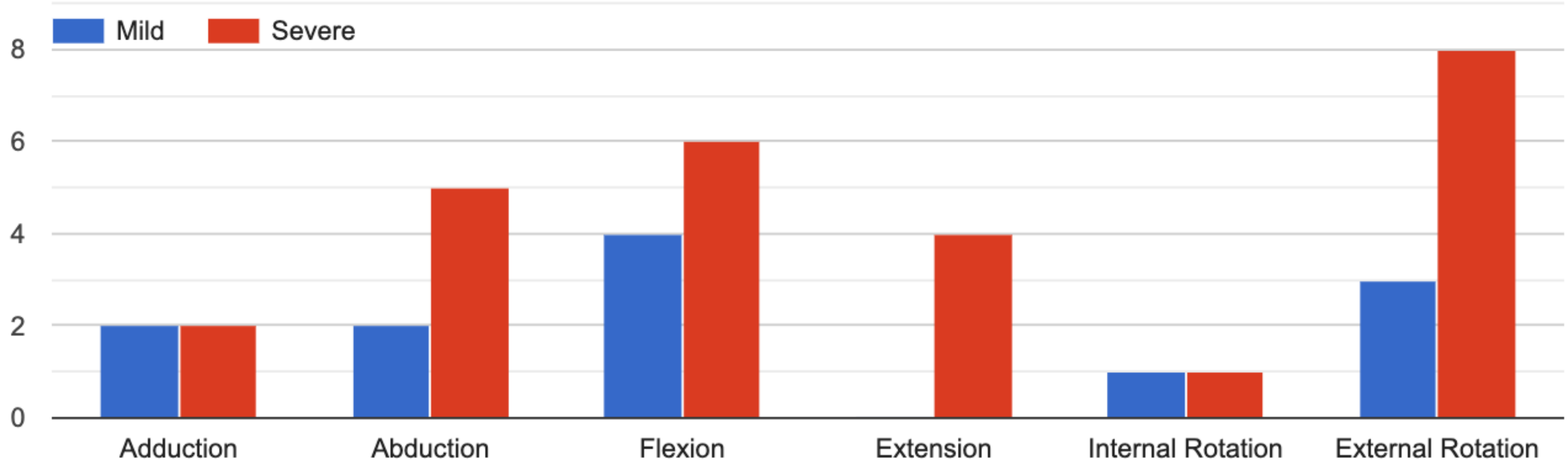
21 responses

If yes, which joints do you think are affected?

11 responses

RIGHT KNEE

Copy



LEFT KNEE

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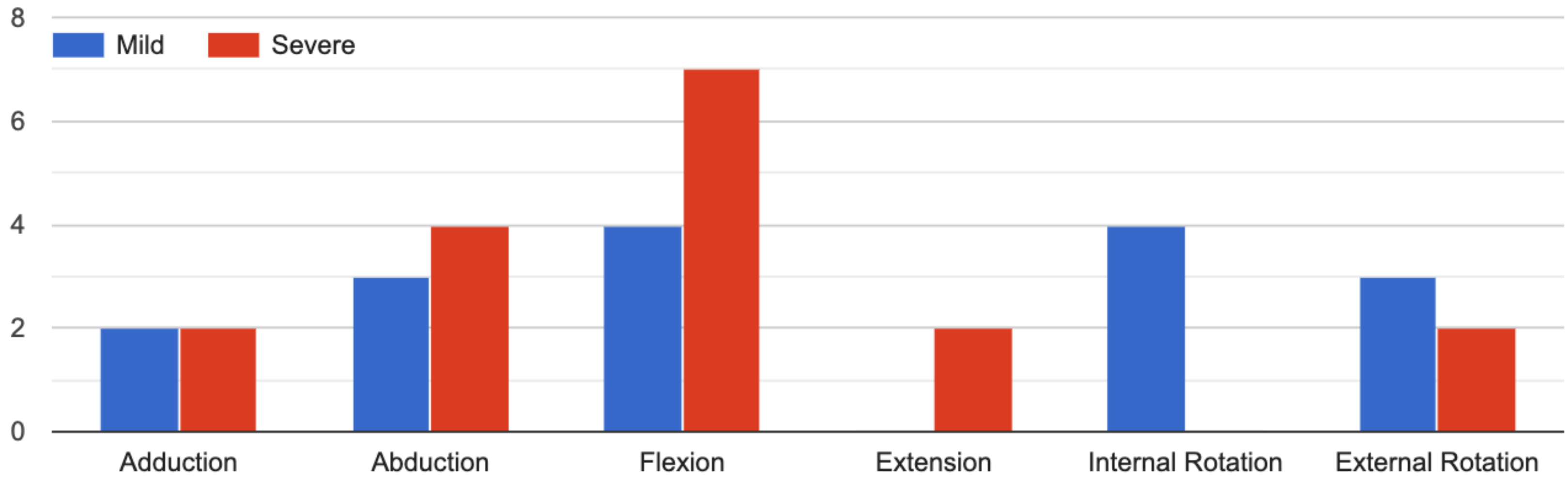
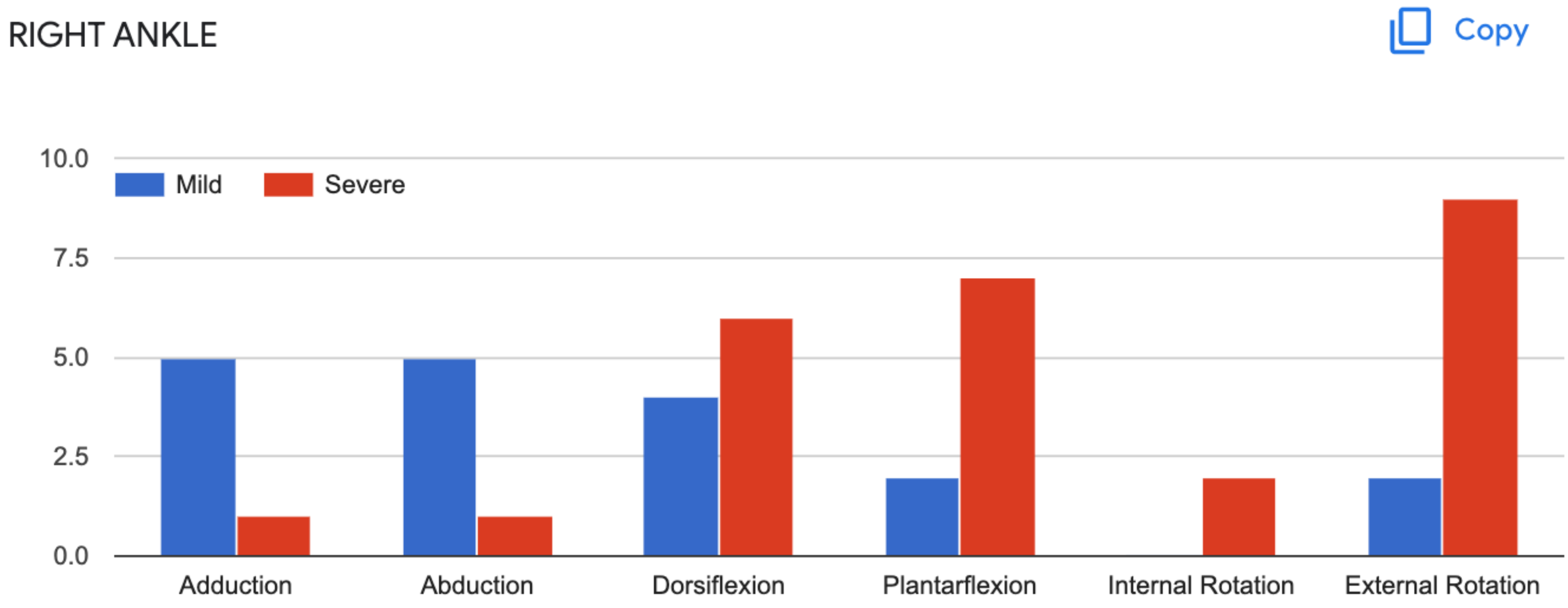
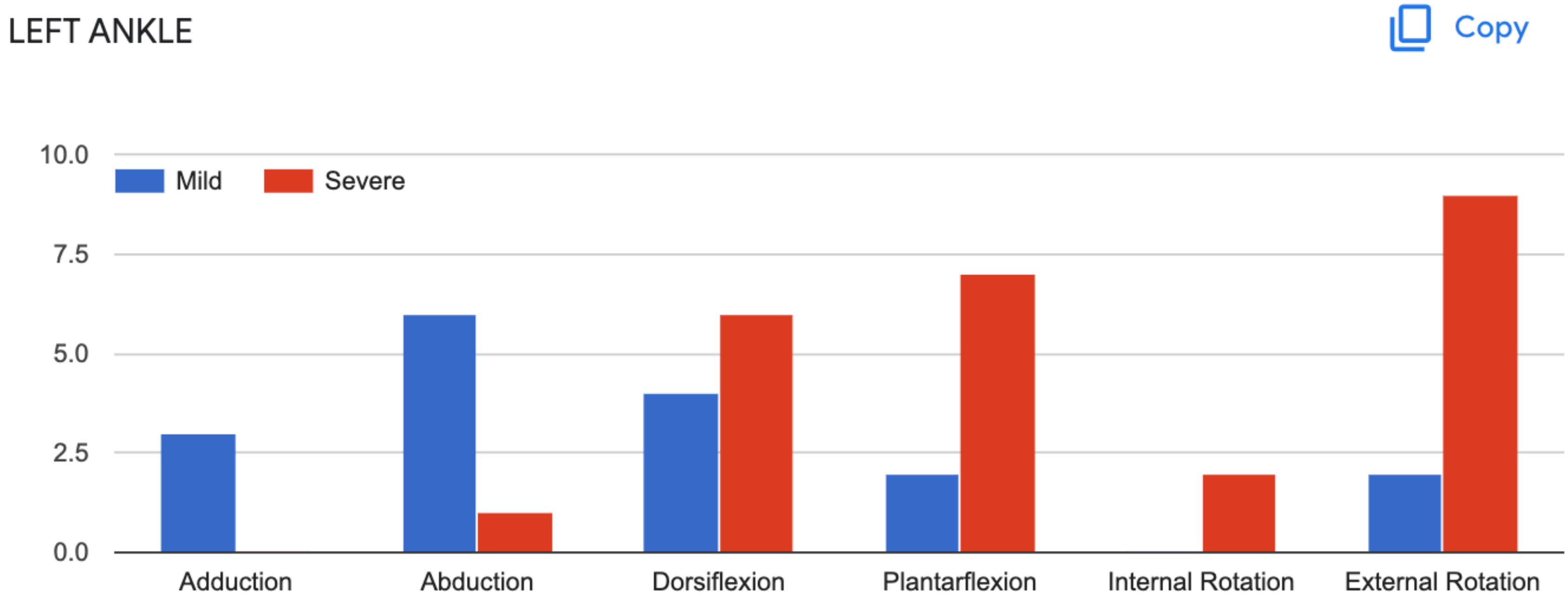
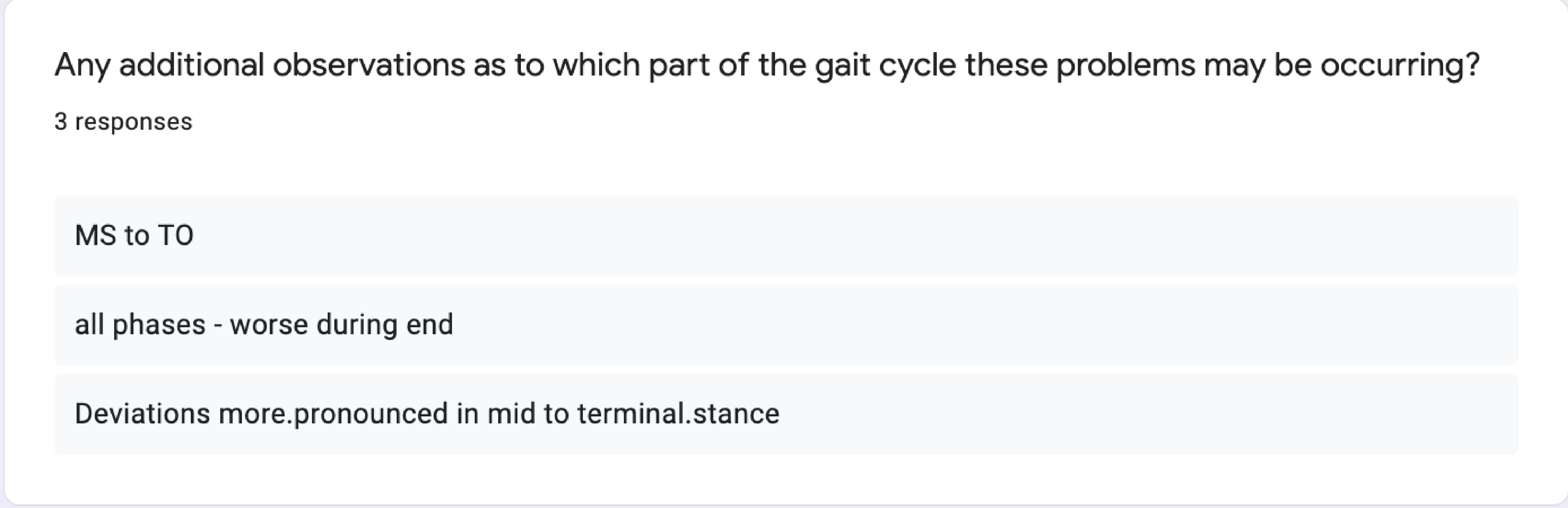




RIGHT ANKLE



LEFT ANKLE



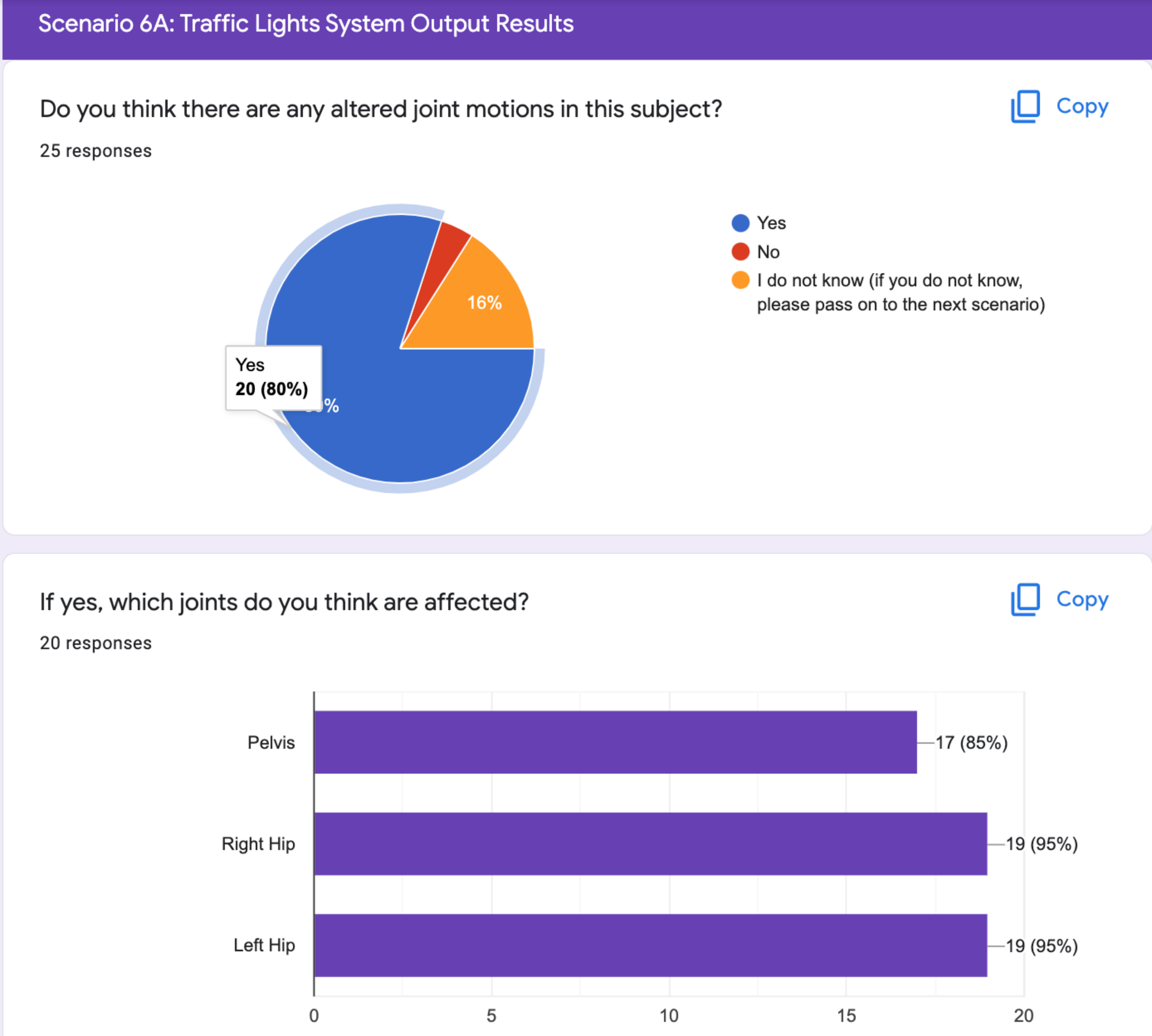
Any additional observations as to which part of the gait cycle these problems may be occurring?

3 responses

MS to TO

all phases - worse during end

Deviations more.pronounced in mid to terminal.stance



Scenario 6A: Traffic Lights System Output Results

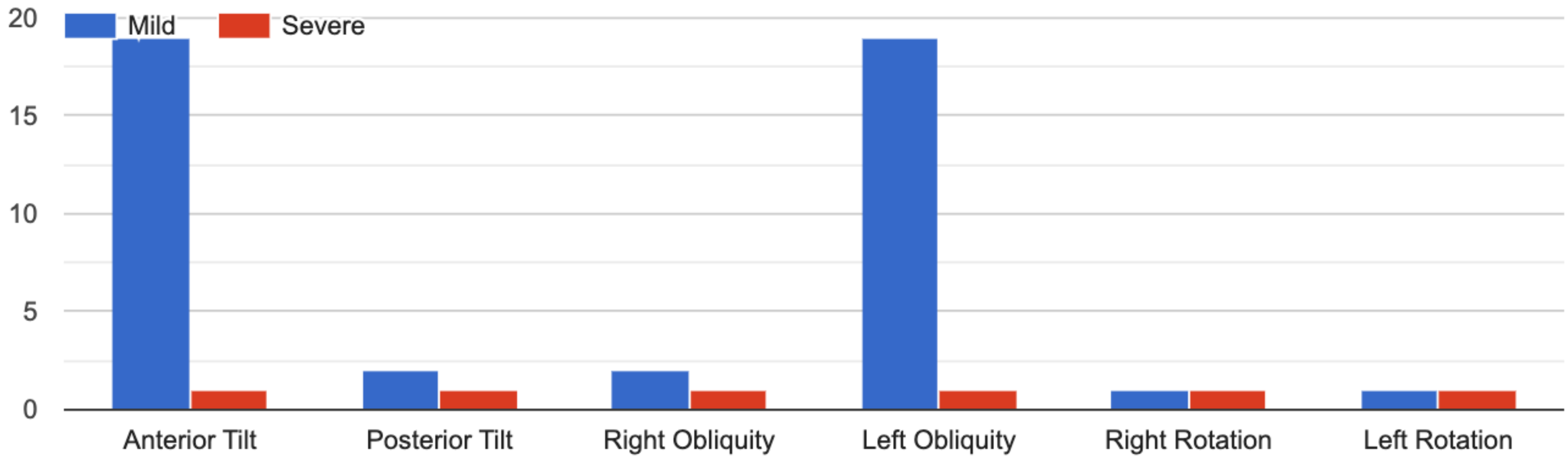
Do you think there are any altered joint motions in this subject?

25 responses

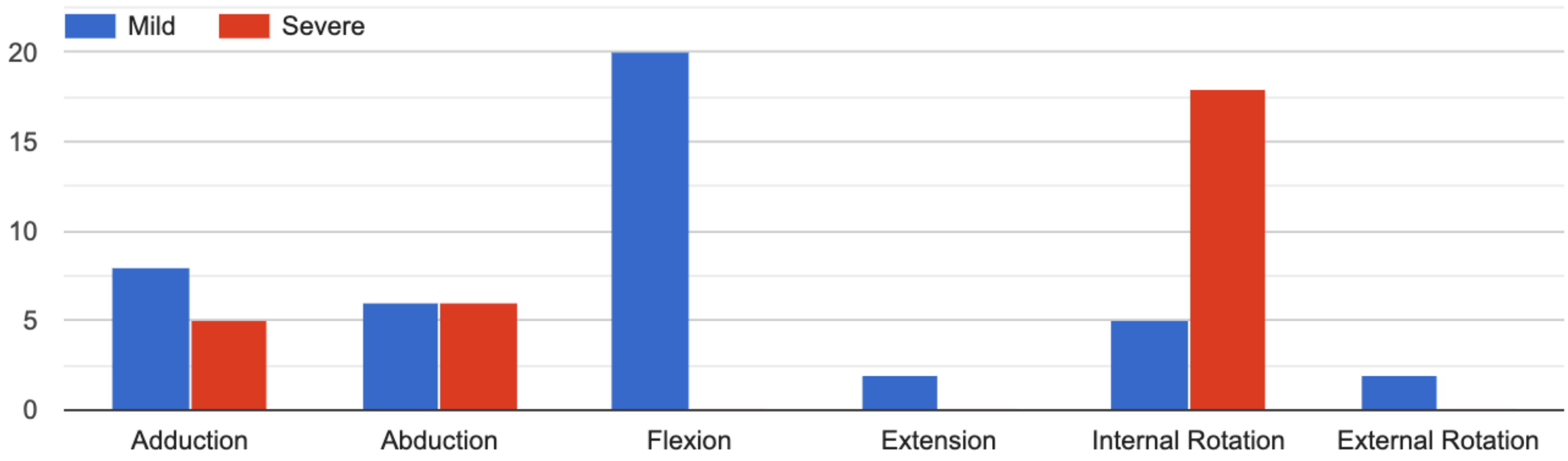
If yes, which joints do you think are affected?

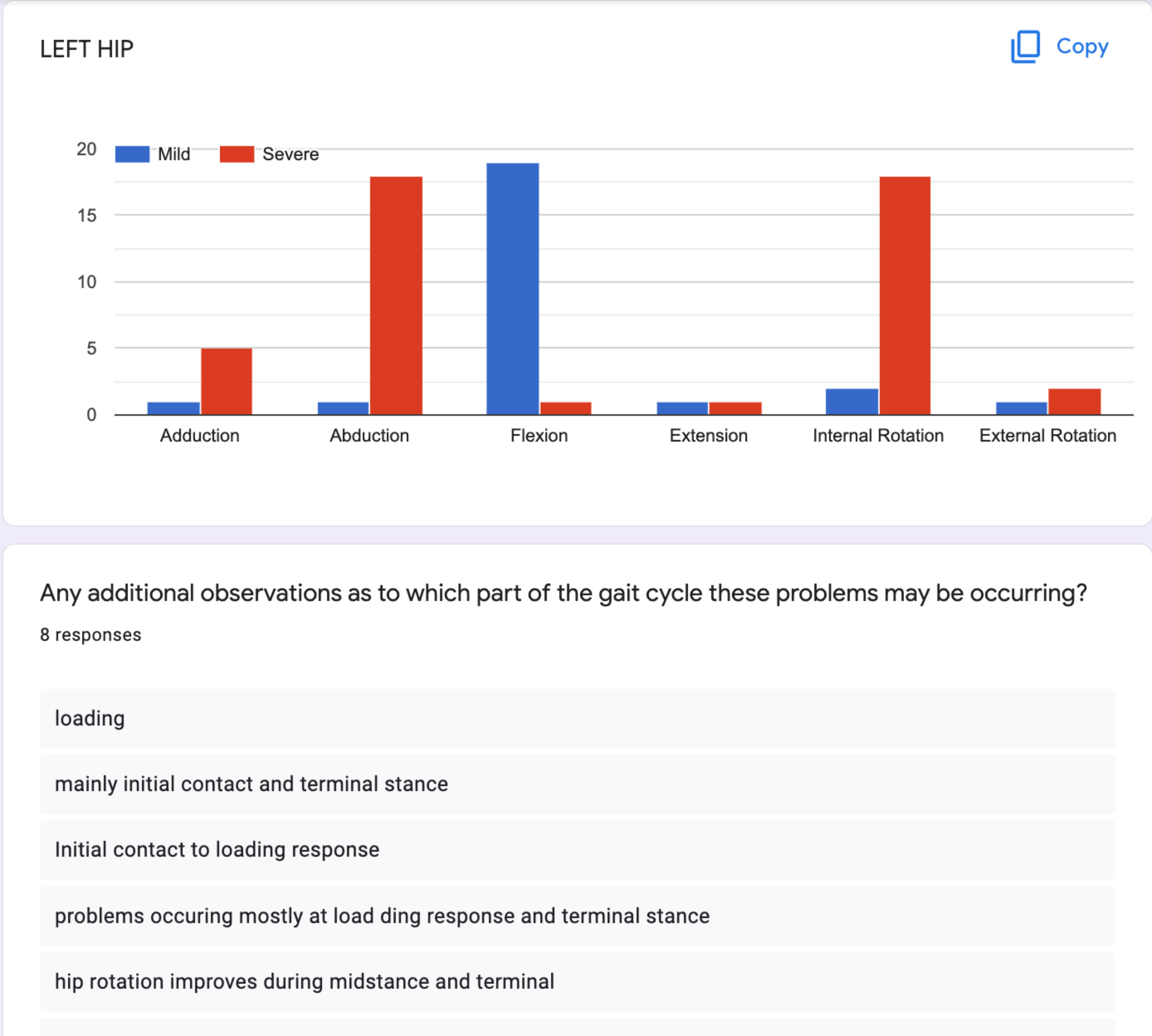
20 responses

PELVIS



RIGHT HIP





LEFT HIP

Any additional observations as to which part of the gait cycle these problems may be occurring?

8 responses

loading

mainly initial contact and terminal stance

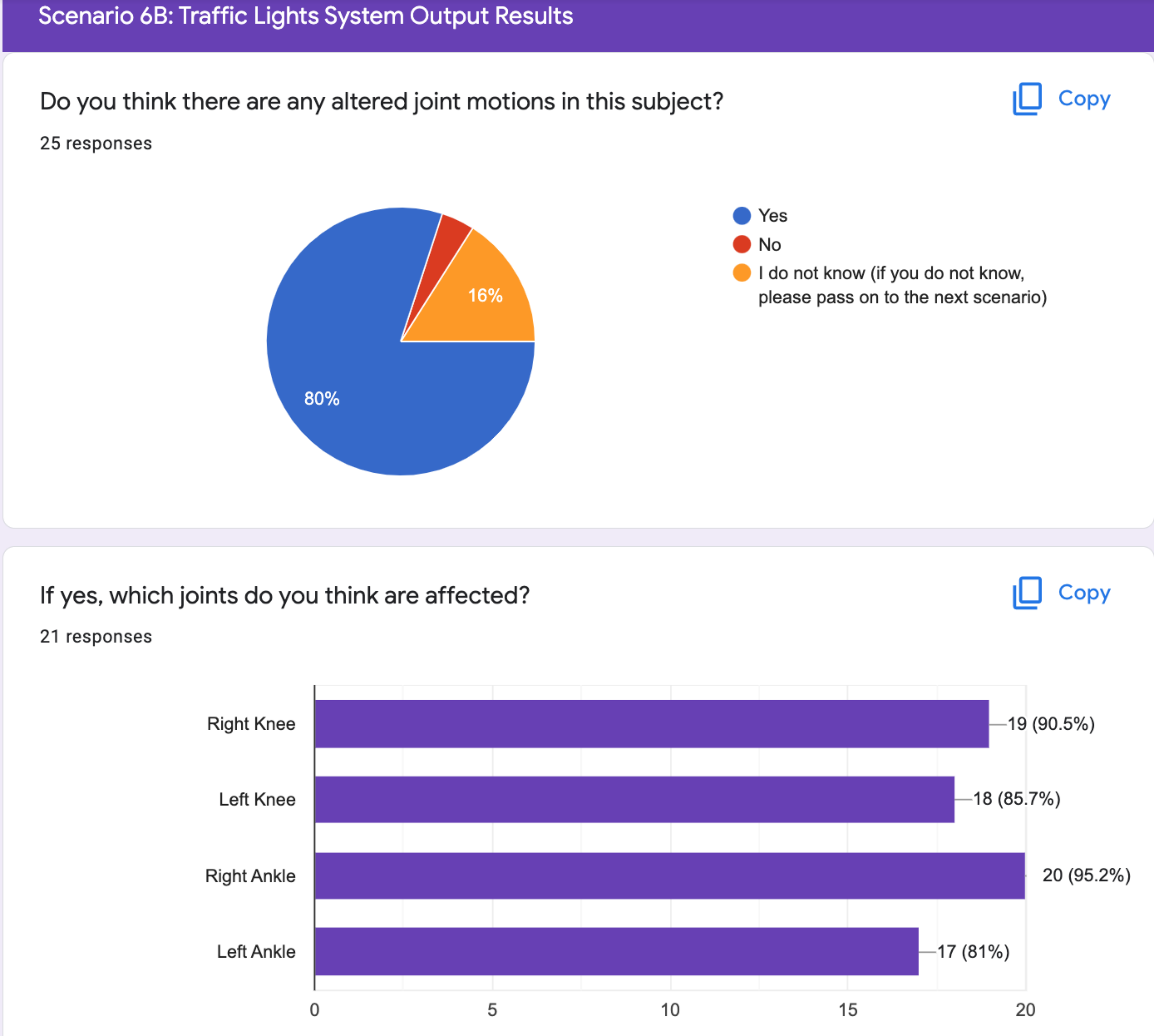
Initial contact to loading response

problems occuring mostly at load ding response and terminal stance

hip rotation improves during midstance and terminal all phases worse during initial contact bil hips

Deviations pronounced in initial stance and loading

Severe and mild rotations occurring at different phases of the gait cycle



Scenario 6B: Traffic Lights System Output Results

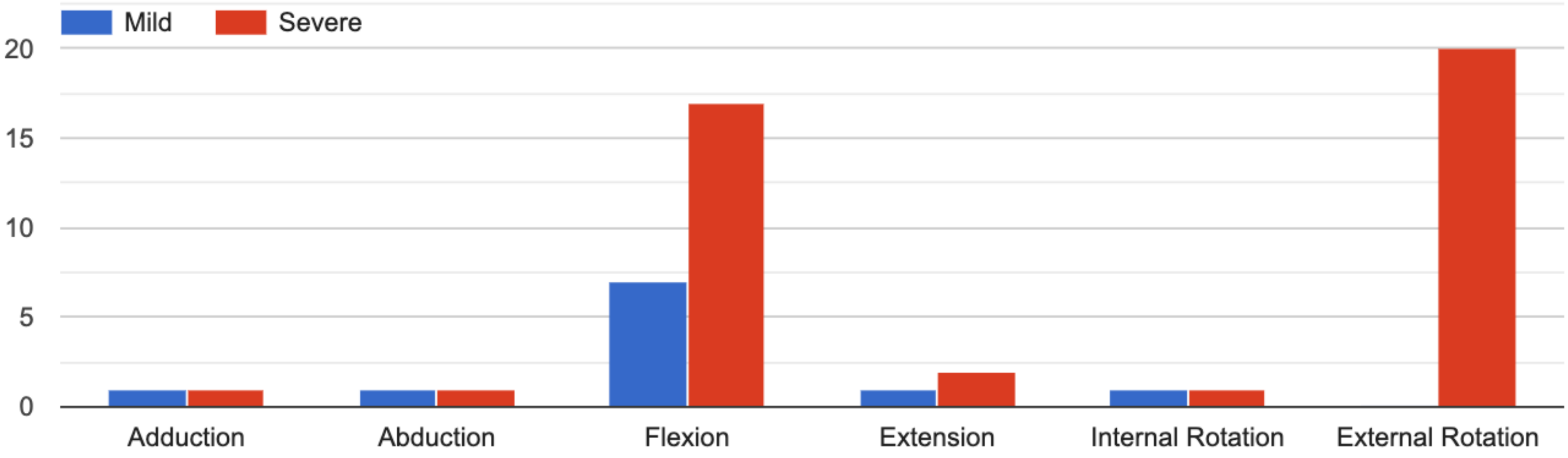
Do you think there are any altered joint motions in this subject?

25 responses

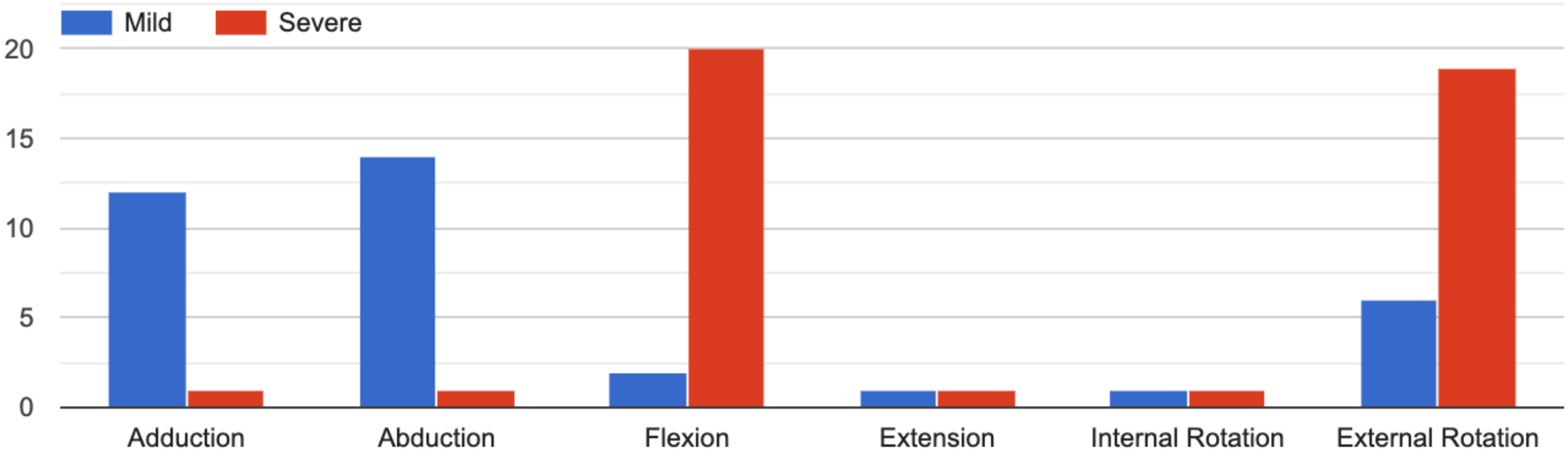
If yes, which joints do you think are affected?

21 responses

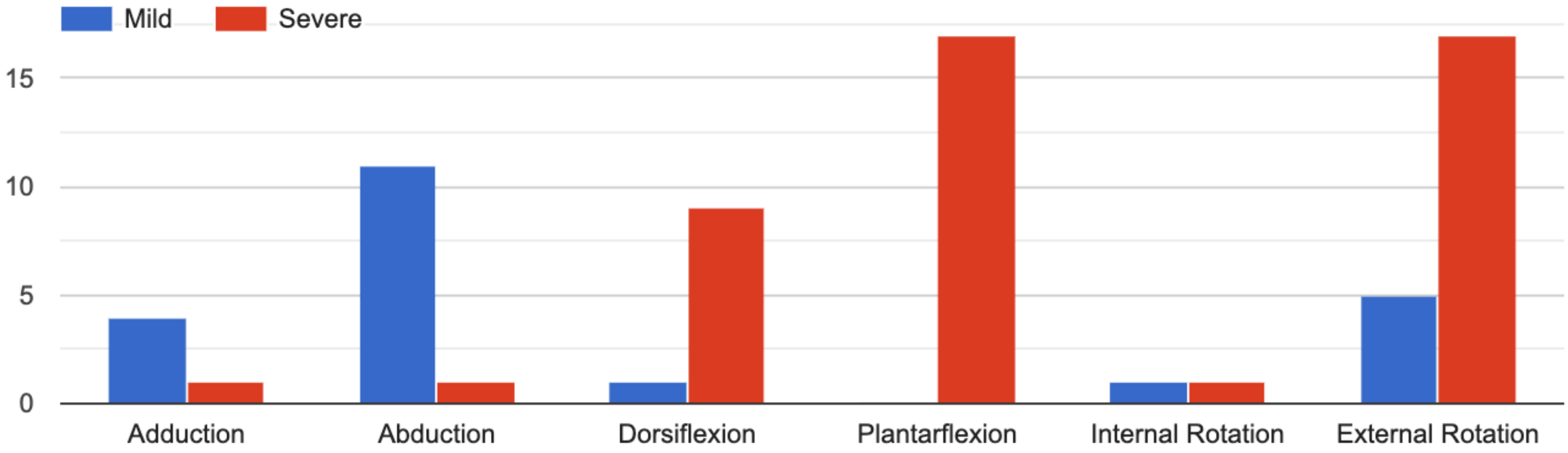
RIGHT KNEE



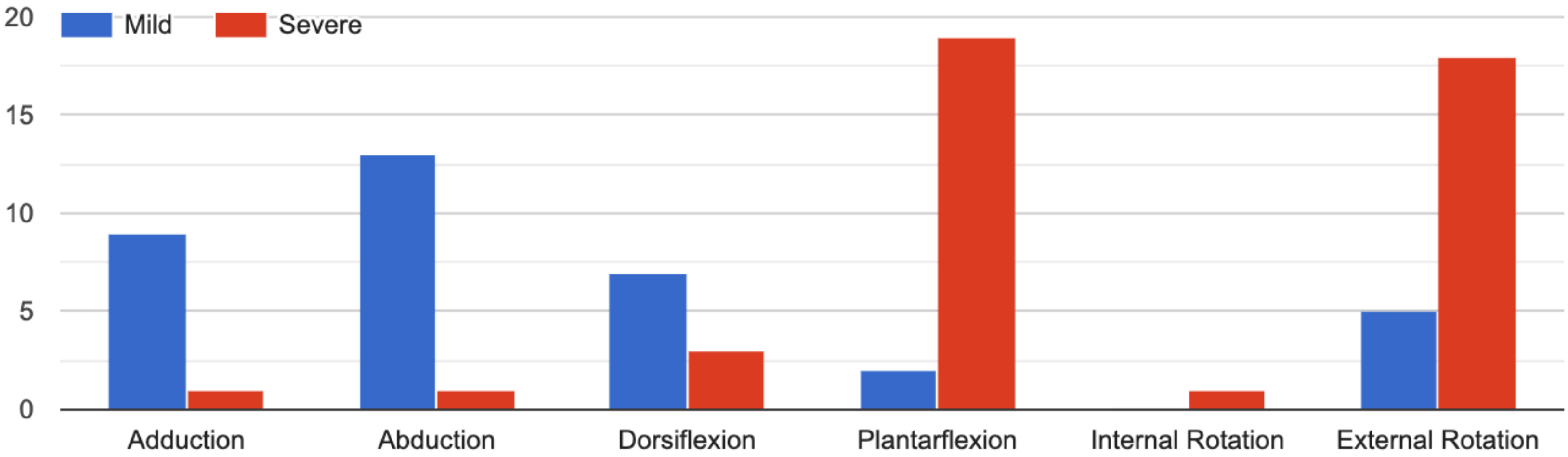
LEFT KNEE

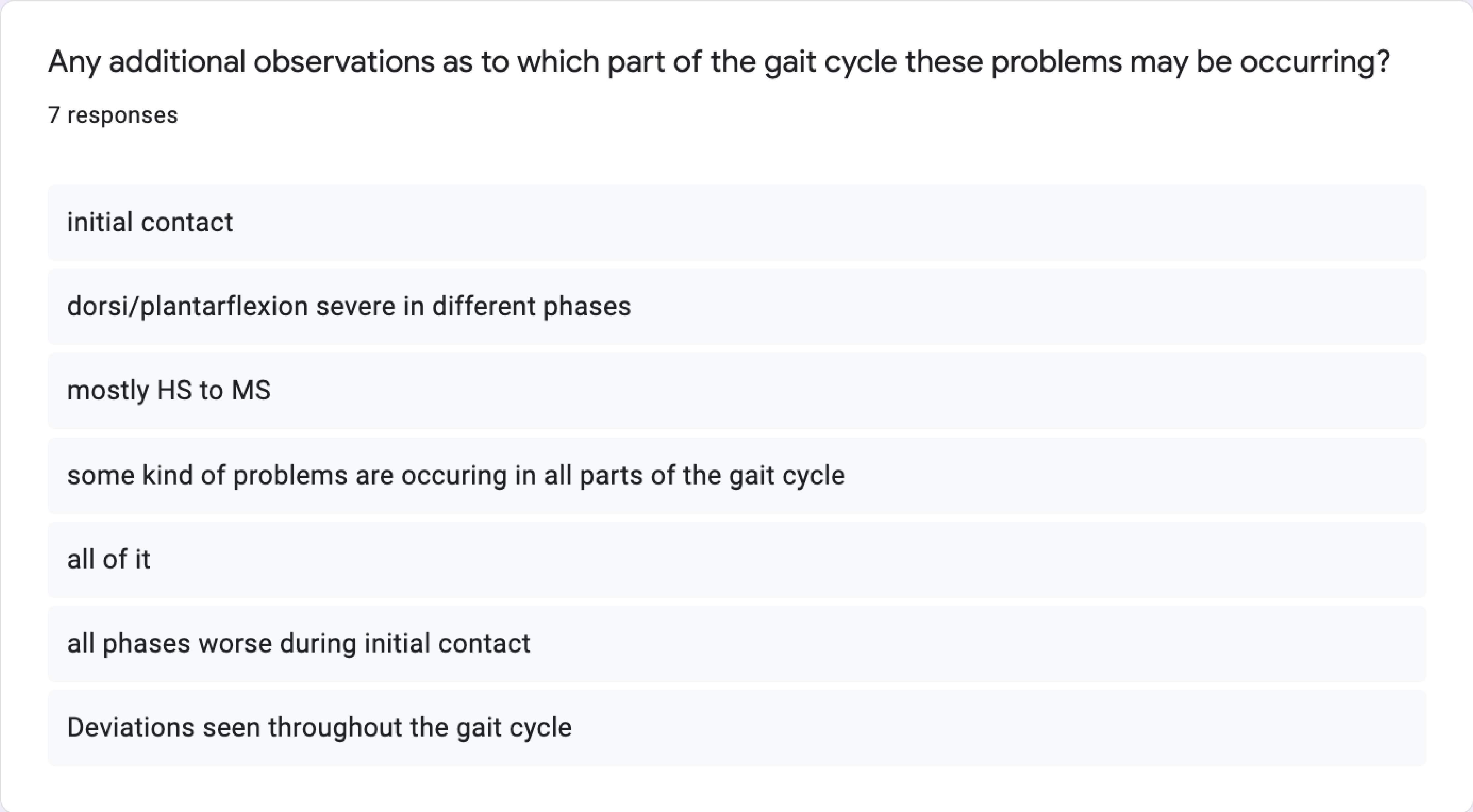


RIGHT ANKLE



LEFT ANKLE





Any additional observations as to which part of the gait cycle these problems may be occurring?

7 responses

initial contact

dorsi/plantarflexion severe in different phases

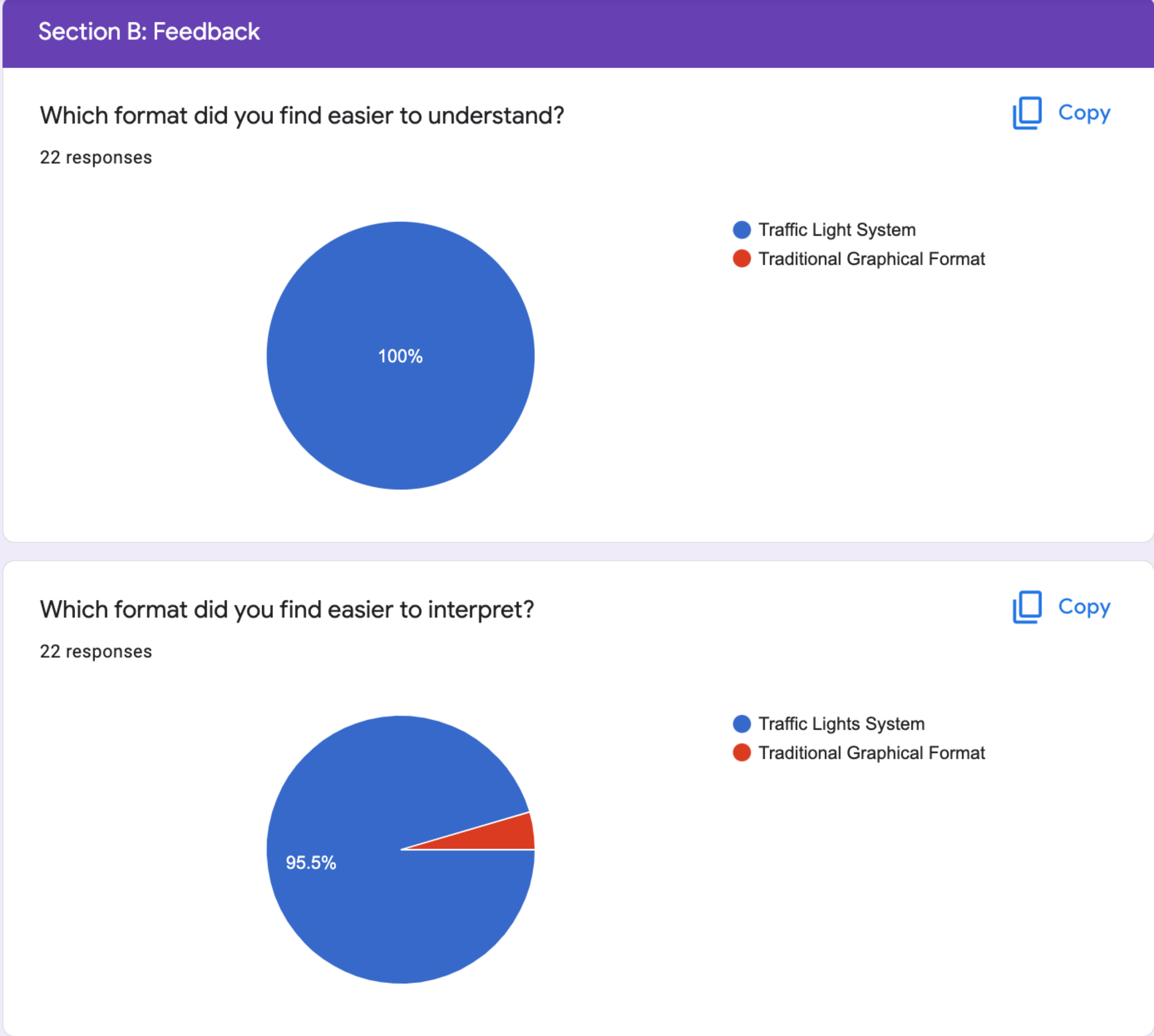
mostly HS to MS

some kind of problems are occuring in all parts of the gait cycle

all of it

all phases worse during initial contact

Deviations seen throughout the gait cycle



Section B: Feedback

Which format did you find easier to understand?

22 responses

● Traffic Light System
● Traditional Graphical Format

Which format did you find easier to interpret?

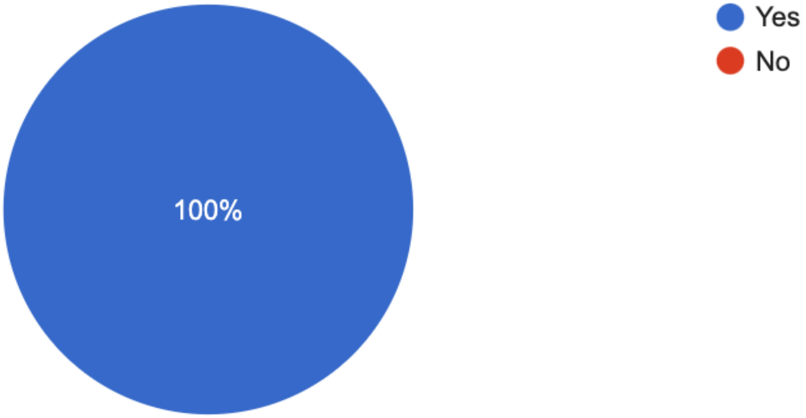
22 responses

● Traffic Lights System
● Traditional Graphical Format

Would such kinematic information be helpful to your clinical MSK practice if provided?

Copy

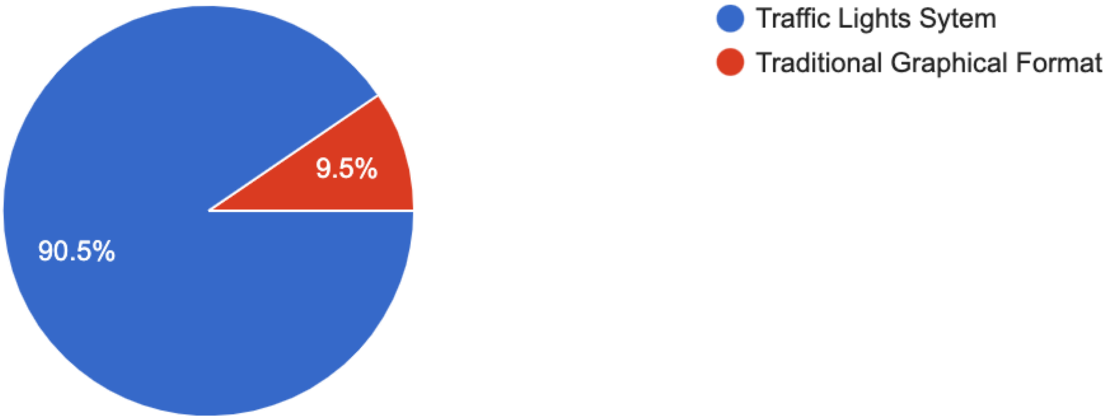
22 responses

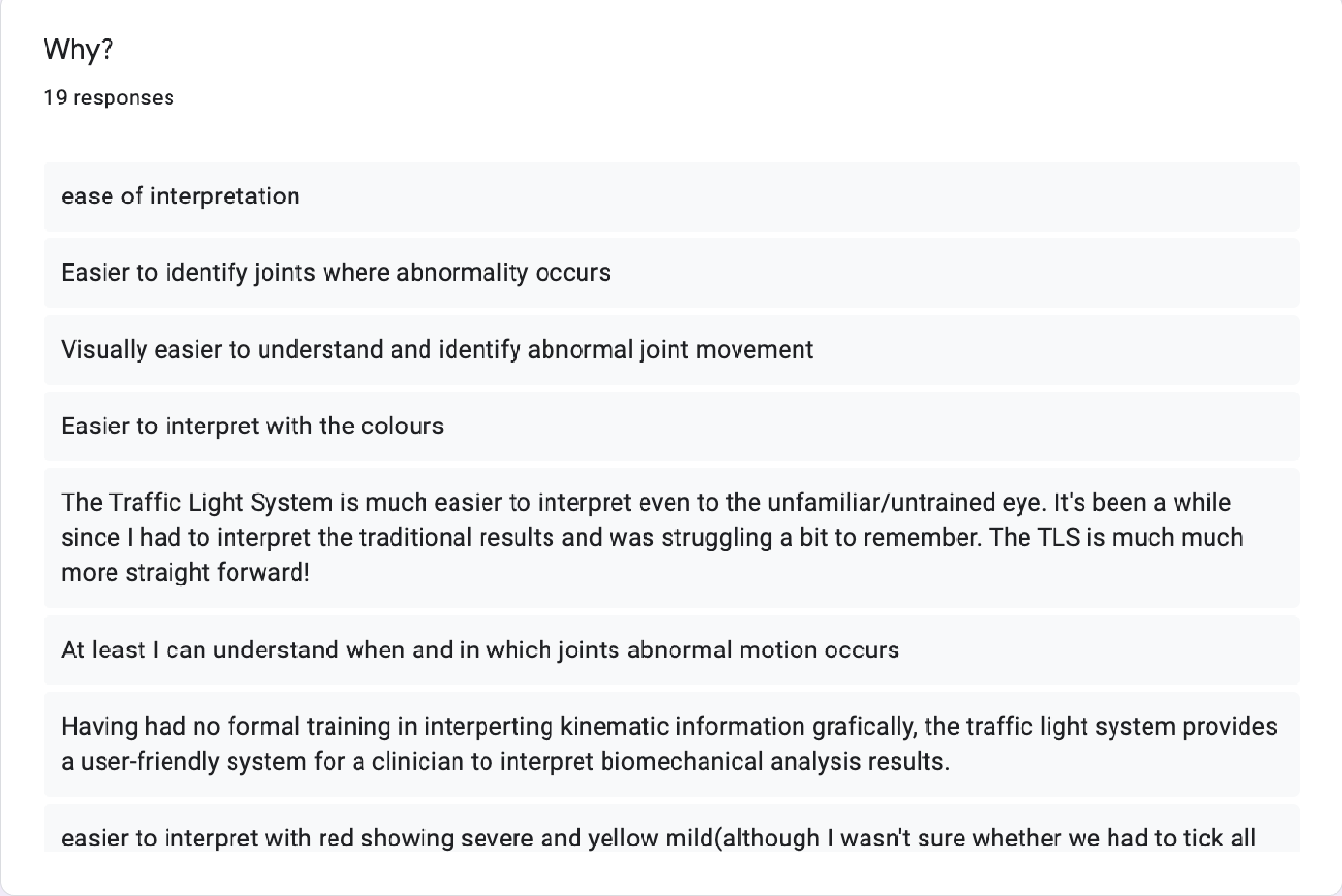


If Yes, in which format would you prefer this information to be provided?

Copy

21 responses





Why?

19 responses

ease of interpretation

Easier to identify joints where abnormality occurs

Visually easier to understand and identify abnormal joint movement

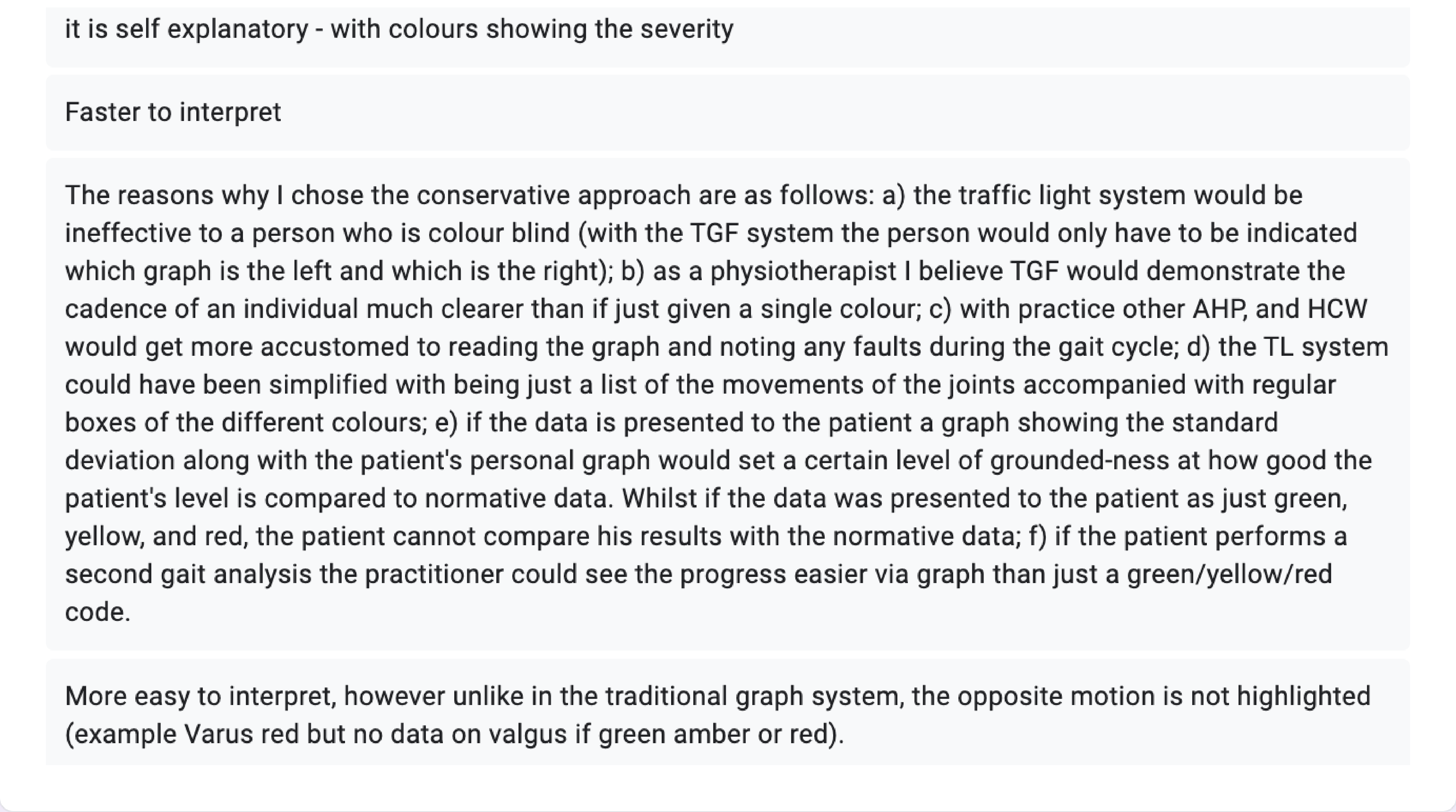
Easier to interpret with the colours

The Traffic Light System is much easier to interpret even to the unfamiliar/untrained eye. It's been a while since I had to interpret the traditional results and was struggling a bit to remember. The TLS is much much more straight forward!

At least I can understand when and in which joints abnormal motion occurs

Having had no formal training in interperting kinematic information grafically, the traffic light system provides a user-friendly system for a clinician to interpret biomechanical analysis results.

easier to interpret with red showing severe and yellow mild(although I wasn't sure whether we had to tick all

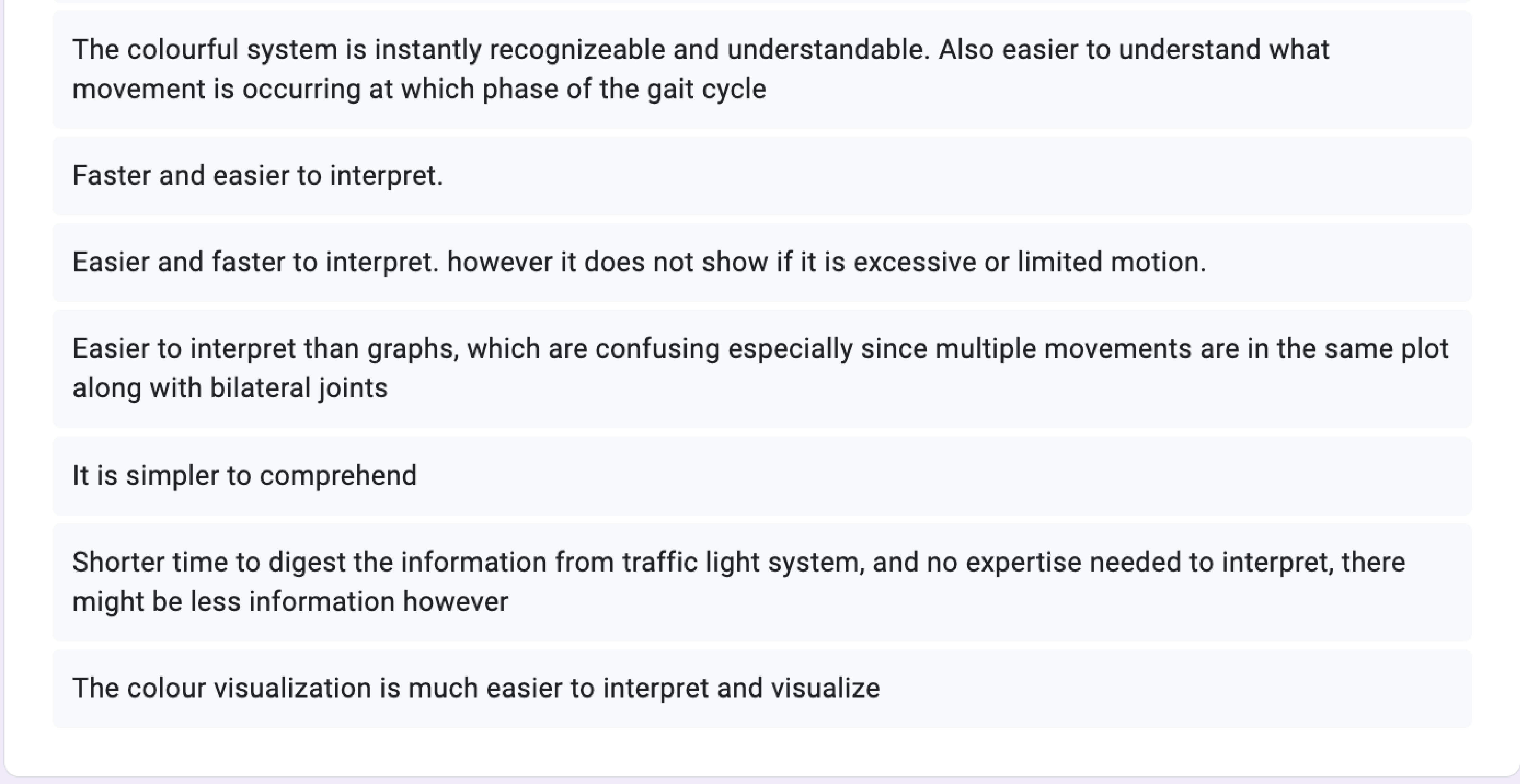


it is self explanatory - with colours showing the severity

Faster to interpret

The reasons why I chose the conservative approach are as follows: a) the traffic light system would be ineffective to a person who is colour blind (with the TGF system the person would only have to be indicated which graph is the left and which is the right); b) as a physiotherapist I believe TGF would demonstrate the cadence of an individual much clearer than if just given a single colour; c) with practice other AHP, and HCW would get more accustomed to reading the graph and noting any faults during the gait cycle; d) the TL system could have been simplified with being just a list of the movements of the joints accompanied with regular boxes of the different colours; e) if the data is presented to the patient a graph showing the standard deviation along with the patient's personal graph would set a certain level of grounded-ness at how good the patient's level is compared to normative data. Whilst if the data was presented to the patient as just green, yellow, and red, the patient cannot compare his results with the normative data; f) if the patient performs a second gait analysis the practitioner could see the progress easier via graph than just a green/yellow/red code.

More easy to interpret, however unlike in the traditional graph system, the opposite motion is not highlighted (example Varus red but no data on valgus if green amber or red).



The colourful system is instantly recognizeable and understandable. Also easier to understand what movement is occurring at which phase of the gait cycle

Faster and easier to interpret.

Easier and faster to interpret. however it does not show if it is excessive or limited motion.

Easier to interpret than graphs, which are confusing especially since multiple movements are in the same plot along with bilateral joints

It is simpler to comprehend

Shorter time to digest the information from traffic light system, and no expertise needed to interpret, there might be less information however

The colour visualization is much easier to interpret and visualize

Appendix 3: Statistical testing results for intra-rater reliability

Intra rater reliability for Rater2, Study 1,1 and Study1,2

Case Processing Summary

		N	%
Cases	Valid	41	97.6
	Excluded[a]	1	2.4
	Total	42	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.903	.908	2

Item Statistics

	Mean	Std. Deviation	N
Rater2_Study1_1	2.4146	.74080	41
Rater2_Study1_2	2.4878	.63726	41

Inter-Item Correlation Matrix

	Rater2_Study1_1	Rater2_Study1_2
Rater2_Study1_1	1.000	.832
Rater2_Study1_2	.832	1.000

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Variances	.477	.406	.549	.143	1.351	.010	2
Inter-Item Correlations	.832	.832	.832	.000	1.000	.000	2

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Rater2_Study1_1	2.4878	.406	.832	.692	.
Rater2_Study1_2	2.4146	.549	.832	.692	.

Scale Statistics

Mean	Variance	Std. Deviation	N of Items
4.9024	1.740	1.31918	2

Intra rater reliability for Rater2, Study 2,1 and Study 2,2

Case Processing Summary

		N	%
Cases	Valid	36	85.7
	Excluded[a]	6	14.3
	Total	42	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.954	.954	2

Item Statistics

	Mean	Std. Deviation	N
Rater2_Study2_1	2.4722	.69636	36
Rater2_Study2_2	2.4444	.69465	36

Inter-Item Correlation Matrix

	Rater2_Study2_1	Rater2_Study2_2
Rater2_Study2_1	1.000	.912
Rater2_Study2_2	.912	1.000

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Variances	.484	.483	.485	.002	1.005	.000	2
Inter-Item Correlations	.912	.912	.912	.000	1.000	.000	2

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Rater2_Study2_1	2.4444	.483	.912	.832	.
Rater2_Study2_2	2.4722	.485	.912	.832	.

Scale Statistics

Mean	Variance	Std. Deviation	N of Items
4.9167	1.850	1.36015	2

Intra rater reliability for Rater2, Study 3,1 and Study3,2

Case Processing Summary

		N	%
Cases	Valid	29	69.0
	Excluded[a]	13	31.0
	Total	42	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.974	.975	2

Item Statistics

	Mean	Std. Deviation	N
Rater2_Study3_1	2.5517	.78314	29
Rater2_Study3_2	2.4828	.82897	29

Inter-Item Correlation Matrix

	Rater2_Study3_1	Rater2_Study3_2
Rater2_Study3_1	1.000	.950
Rater2_Study3_2	.950	1.000

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Variances	.650	.613	.687	.074	1.120	.003	2
Inter-Item Correlations	.950	.950	.950	.000	1.000	.000	2

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Rater2_Study3_1	2.4828	.687	.950	.903	.
Rater2_Study3_2	2.5517	.613	.950	.903	.

Scale Statistics

Mean	Variance	Std. Deviation	N of Items
5.0345	2.534	1.59201	2

Intra rater reliability for Rater2, Study 4,1 and Study4,2

Case Processing Summary

		N	%
Cases	Valid	31	73.8
	Excluded[a]	11	26.2
	Total	42	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.807	.816	2

Item Statistics

	Mean	Std. Deviation	N
Rater2_Study4_1	2.4839	.67680	31
Rater2_Study4_2	2.6129	.55842	31

Inter-Item Correlation Matrix

	Rater2_Study4_1	Rater2_Study4_2
Rater2_Study4_1	1.000	.689
Rater2_Study4_2	.689	1.000

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Variances	.385	.312	.458	.146	1.469	.011	2
Inter-Item Correlations	.689	.689	.689	.000	1.000	.000	2

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Rater2_Study4_1	2.6129	.312	.689	.474	.
Rater2_Study4_2	2.4839	.458	.689	.474	.

Scale Statistics

Mean	Variance	Std. Deviation	N of Items
5.0968	1.290	1.13592	2

Intra rater reliability for Rater2, Study 5,1 and Study5,2

Case Processing Summary

		N	%
Cases	Valid	22	52.4
	Excluded[a]	20	47.6
	Total	42	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.841	.841	2

Item Statistics

	Mean	Std. Deviation	N
Rater2_Study5_1	2.5455	.50965	22
Rater2_Study5_2	2.5909	.50324	22

Inter-Item Correlation Matrix

	Rater2_Study5_1	Rater2_Study5_2
Rater2_Study5_1	1.000	.726
Rater2_Study5_2	.726	1.000

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Variances	.256	.253	.260	.006	1.026	.000	2
Inter-Item Correlations	.726	.726	.726	.000	1.000	.000	2

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Rater2_Study5_1	2.5909	.253	.726	.527	.
Rater2_Study5_2	2.5455	.260	.726	.527	.

Scale Statistics

Mean	Variance	Std. Deviation	N of Items
5.1364	.885	.94089	2

Intra rater reliability for Rater2, Study 6,1 and Study6,2

Case Processing Summary

		N	%
Cases	Valid	35	83.3
	Excluded[a]	7	16.7
	Total	42	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.932	.932	2

Item Statistics

	Mean	Std. Deviation	N
Rater2_Study6_1	2.4000	.77460	35
Rater2_Study6_2	2.4286	.73907	35

Inter-Item Correlation Matrix

	Rater2_Study6_1	Rater2_Study6_2
Rater2_Study6_1	1.000	.873
Rater2_Study6_2	.873	1.000

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Variances	.573	.546	.600	.054	1.098	.001	2
Inter-Item Correlations	.873	.873	.873	.000	1.000	.000	2

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Rater2_Study6_1	2.4286	.546	.873	.763	.
Rater2_Study6_2	2.4000	.600	.873	.763	.

Scale Statistics

Mean	Variance	Std. Deviation	N of Items
4.8286	2.146	1.46500	2

Intra rater reliability for Rater3, Study 2,1 and Study2,2

Case Processing Summary

		N	%
Cases	Valid	41	97.6
	Excluded[a]	1	2.4
	Total	42	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
1.000	1.000	2

Item Statistics

	Mean	Std. Deviation	N
Rater3_Study2_1	2.3902	.80244	41
Rater3_Study2_2	2.3902	.80244	41

Inter-Item Correlation Matrix

	Rater3_Study2_1	Rater3_Study2_2
Rater3_Study2_1	1.000	1.000
Rater3_Study2_2	1.000	1.000

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Variances	.644	.644	.644	.000	1.000	.000	2
Inter-Item Correlations	1.000	1.000	1.000	.000	1.000	.000	2

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Rater3_Study2_1	2.3902	.644	1.000	.	.
Rater3_Study2_2	2.3902	.644	1.000	.	.

Scale Statistics

Mean	Variance	Std. Deviation	N of Items
4.7805	2.576	1.60487	2

Intra rater reliability for Rater3, Study 3,1 and Study3,2

Case Processing Summary

		N	%
Cases	Valid	41	97.6
	Excluded[a]	1	2.4
	Total	42	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
1.000	1.000	2

Item Statistics

	Mean	Std. Deviation	N
Rater3_Study3_1	2.1951	.98029	41
Rater3_Study3_2	2.1951	.98029	41

Inter-Item Correlation Matrix

	Rater3_Study3_1	Rater3_Study3_2
Rater3_Study3_1	1.000	1.000
Rater3_Study3_2	1.000	1.000

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Variances	.961	.961	.961	.000	1.000	.000	2
Inter-Item Correlations	1.000	1.000	1.000	.000	1.000	.000	2

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Rater3_Study3_1	2.1951	.961	1.000	.	.
Rater3_Study3_2	2.1951	.961	1.000	.	.

Scale Statistics

Mean	Variance	Std. Deviation	N of Items
4.3902	3.844	1.96059	2

Intra rater reliability for Rater3, Study 3,1 and Study3,2

Inter-Item Correlation Matrix

	Rater3_Study3_1	Rater3_Study3_2
Rater3_Study3_1	1.000	1.000
Rater3_Study3_2	1.000	1.000

Case Processing Summary

		N	%
Cases	Valid	41	97.6
	Excluded[a]	1	2.4
	Total	42	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
1.000	1.000	2

Item Statistics

	Mean	Std. Deviation	N
Rater3_Study3_1	2.1951	.98029	41
Rater3_Study3_2	2.1951	.98029	41

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items
Item Variances	.961	.961	.961	.000	1.000	.000	2
Inter-Item Correlations	1.000	1.000	1.000	.000	1.000	.000	2

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Rater3_Study3_1	2.1951	.961	1.000	.	.
Rater3_Study3_2	2.1951	.961	1.000	.	.

Scale Statistics

Mean	Variance	Std. Deviation	N of Items
4.3902	3.844	1.96059	2

Intra rater reliability for Rater3, Study 6,1 and Study6,2

Case Processing Summary

		N	%
Cases	Valid	41	97.6
	Excluded[a]	1	2.4
	Total	42	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.867	.869	2

Item Statistics

	Mean	Std. Deviation	N
Rater3_Study6_1	2.2683	.86673	41
Rater3_Study6_2	2.4146	.80547	41

Inter-Item Correlation Matrix

	Rater3_Study6_1	Rater3_Study6_2
Rater3_Study6_1	1.000	.768
Rater3_Study6_2	.768	1.000

Summary Item Statistics

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance	N of Items

Item Variances	.700	.649	.751	.102	1.158	.005	2
Inter-Item Correlations	.768	.768	.768	.000	1.000	.000	2

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Rater3_Study6_1	2.4146	.649	.768	.589	.
Rater3_Study6_2	2.2683	.751	.768	.589	.

Scale Statistics

Mean	Variance	Std. Deviation	N of Items
4.6829	2.472	1.57224	2

Appendix 5: How to use the Traffic Lights System to interpret gait analysis results

How to use the Traffic Lights System to interpret gait analysis results

This brief instruction manual on how to use the Traffic Light System to interpret gait analysis results is aimed at healthcare professionals who treat or manage musculoskeletal conditions which would benefit from instrumented gait analysis. It is understood that the great majority of these health professionals do not receive formal training in interpreting gait analysis results, hence the Traffic Lights System was created to provide these results in a more visual and colourful approach which can be readily interpreted by most people with a basic knowledge of human movement.

Disclaimer: At this moment in time, the results of the Traffic Lights System should be interpreted with caution, preferably by comparing to the traditional graphs as output by the gait analysis motion capture systems.

The Traffic Lights System does not change the data output by these systems; it just represents the graphs in an alternative, easier to interpret manner.

Each segment in the lower extremities has 3 types of movements associated with it. These movements are produced in the joints and will mostly by in each cardinal plane of the body.

The SEGMENTS and JOINTS are:

PELVIS

LEFT HIP **RIGHT HIP** → THIGH MOVEMENT
LEFT KNEE **RIGHT KNEE** → LEG MOVEMENT
LEFT ANKLE **RIGHT ANKLE** → FOOT MOVEMENT

The Traffic Lights System will produce the results in an **INVERTED TRIANGLE** (to represent the pelvis) and **CIRCULAR NODES** (to represent the joints).

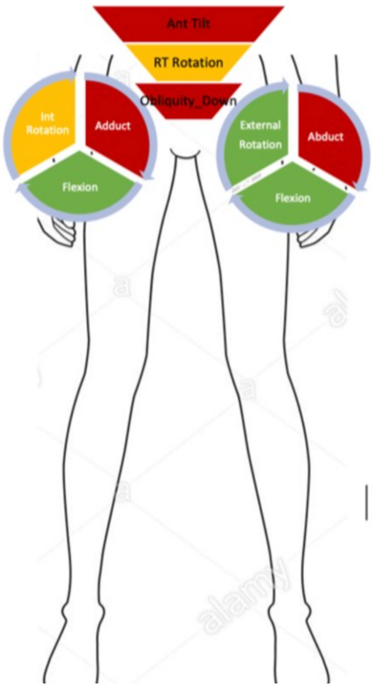
Each NODE will have 3 segments to represent the 3 different movements available in that joint; e.g. for the KNEE joint, the 3 divisions will represent ABDUCTION/ADDUCTION; FLEXION OR EXTENSION; INTERNAL or EXTERNAL ROTATION.

The AMOUNT of movement will be represented by 3 colours:

GREEN represents normal amount of movement
YELLOW represents slightly increased movement (up to 2 Standard Deviations)
RED represents highly increased movement (more than 2 Standard Deviations)

For most clinical applications, the RED result will be the most significant result that needs to be addressed.

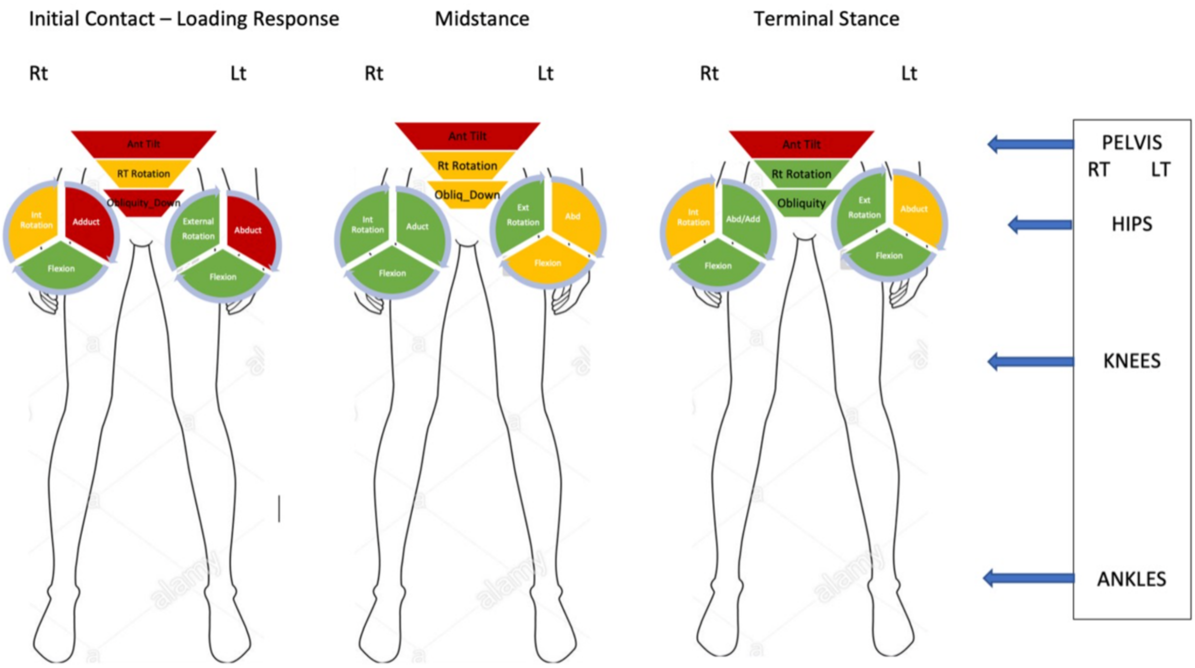
In the graphic below, it is evident that the most significant abnormal movements are ANTERIOR TILT and OBLIQUITY in the Pelvis, whilst both hip joints exhibit abnormal amount of ABDUCTION. The pelvis is also SLIGHTLY ROTATED to the right, whilst the Left hip exhibits some INTERNAL ROTATION.



Additionally, the Traffic Lights System provides temporal, or time-related, information where these movements happen by dividing the stance phase of gait into 3 sections:

Initial Loading to Loading Response
Midstance Phase
Terminal Phase

It is clear WHEN abnormal motion is occurring in the figure below:



PELVIC ANTERIOR TILT: throughout the whole stance phase of gait
PELVIC OBLIQUITY: only from Initial Contact to Loading Response
LT HIP ABDUCTION: only from Initial Contact to Loading Response
RT HIP ABDUCTION: Initial Contact to Loading Response

This clearly tells the clinician that the most severe hip abduction movement are occurring at the beginning of the stance phase of gait, with anterior pelvic tilt throughout the whole stance phase.

It is now up to the clinician to decide what is causing these aberrant movements, whether they should be addressed or not, and by what means. However, the Traffic Lights System provides a quantitative starting point in order to inform clinical management.