An Experimental Examination into the History and Perception of Two Nineteenth Century Military Lower-Limb Prostheses with a Biomechanical Analysis of their Functionality and Long-Term Effects

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Abstract

The role of experiment within archaeological research has become an important mechanism through which we can explore past cultures, their traditions, architecture, material culture and skill sets (Mathieu, 2001). However, the experimental process has not been used to the same extent in archaeological experiments to investigate artefacts and inform us about the past experiences of physically impaired individuals. This thesis explores nineteenth-century lower-limb amputation and prostheses, using a combination of documentary, artefactual and experimental approaches, to gain insight into the lived experiences of impaired individuals and the identities they possessed. Concentrating on military amputation and the artificial appliances they may have used post-injury, this research explores the design, construction and social implications of prostheses, through the documentary analysis and detailed study of existing artifactual evidence. This is followed by a reconstruction of two appliances intended for different groups of people; the Box-leg, a peg-leg variation generally intended for working-class soldiers and the Anglesey leg, the first articulated design reserved for the wealthy. Their efficiency is also explored through biomechanical analysis, and comparisons are drawn regarding their kinetics and possible gait complications. In undertaking this research, the importance of the techniques and approaches used here are demonstrated, and the unique and novel dataset produced offers us a fascinating glimpse into the lived experiences of amputees during the nineteenth century and how status affected these experiences, socially and physically. These findings offer an insight into the importance of experimental techniques and how these could be developed to further expand upon our understanding of disability history and their connected artefacts.

Contents

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Chapter 1: Introduction

Archaeology studies the material remains of past societies, whilst also employing various investigative processes to understand these materials more thoroughly. The artefacts under investigation in this thesis are two nineteenth-century military artificial lower limb prostheses; the Anglesey leg and the Box-leg. These two prosthetic limbs represent two contrasting variations of artificial legs available, or used, at the time by different members of society. The Anglesey leg, named after the Marquis of Anglesey who lost his leg at Waterloo, was an elite variation available to the very wealthy and the first example of an appliance which aimed to replicate natural gait phases of stance and swing via the use of articulated knee and ankle joints. Contrastingly, the Box-leg, a variation of the peg-leg, was rudimentary in design and available to wounded soldiers at the expense of the government. The period of interest in this research is the nineteenth century, focussing on key dates relating to prosthetic design and medical care innovations, whilst also incorporating military conflicts such as Waterloo and the Crimean War. The focus of the research is on British artificial legs that were available, and the reintegration of impaired soldiers back into British society.

1.1 Research Aims and Objectives

This research aims to investigate whether the Anglesey leg and the peg leg offered their wearers varying levels of functionality due to their differing levels of build sophistication, and cost and whether these two appliances were perceived differently within different social groups? At a time when industrialisation and long-term military conflict were driving the need for new and improved prosthetic appliances, an investigation into two contrasting appliances used by different social groups can inform us of both their efficiency and usability. Did their contrasting construction produce two differently performing limbs and did the difference in cost mirror their performance levels? Finally, did either of the artificial limbs generate changes in biomechanics that could be identified as detrimental to the health of the wearer and if so, could these changes in gait have affected an individual's reintegration into society? This research will answer these questions using a combination of historical and artefactual analysis before discussing the results of biomechanical data, from experimentally produced prosthetics. Without a historically accurate reconstruction of both artificial legs, the biomechanical analysis would not be possible because using surviving artefacts to complete the experiments would be unsafe due to their fragility. Therefore, a reconstruction of both artificial limbs and the processes involved in this will be recorded and tested (presented in appendices A and B). Ultimately the research objectives are as follows;

1. to develop experimental models of two prosthetic limbs to represent those worn by military amputees in the nineteenth- century.

2. to establish through the experiment whether these two models require very different skills in production and so time consumed/specialist skills/cost.

3. To explore possible links in the models between construction, functionality and the wearer's gait through testing on individuals.

4. To test the influence on the wearer by measuring the gait, and gait changes and comparing them between models to produce a controlled dataset.

5. To compare the findings of the analysis to historical data such as military medical records, diaries, trade catalogues and published contemporary literature to assess the influence of the two limbs on daily tasks and to assess contemporary perceptions about individuals wearing prosthetic limbs.

This research will assess prostheses and the social agency they possess, as a consequence of the complex meanings and relationships they had within people’s daily lives. Prostheses are complex objects to study because they are not just material, inanimate objects, rather, they represent loss, pain, suffering, struggle, and conflict as well as class divisions, employment, industry and technology. Revealing stories about illness, conflicts or accidents, prostheses have a symbolic prevalence that reveals a story to onlookers, deeper than we can learn just from our observations of those without prostheses. Prostheses, therefore, can be said to be of significant social, political and economic importance due to their intrinsic relationship with an individual and their body.

The study of prostheses in history has attracted growth in interest recently, from a variety of disciplines, including academics of literature and disability studies to portrayals in popular television shows such as *Ivar the Boneless* in the History Channel's series *Vikings* and his use of assistive technology like crutches and leg braces. This thesis suggests that attaining a greater understanding and knowledge of nineteenth-century prostheses adds to our understanding of how artificial limb wearers are depicted today. Insight into the efficiency of artificial limbs during the early phases of design standardisation can lead to increased appreciation of design evolution throughout the last two centuries. Similarly, appreciating how artificial limb wearers as members of the wider ‘disability’ group (and within society), were treated and perceived, can inform us about the lived experiences of these individuals and their place within society.

1.2 Justification for Methodology

There is evidence provided by Lazenby (1993) which suggests that the long-term wearing of an artificial limb would influence femoral morphology. His theory is based on findings of a study of 'Madie Brown', a convicted murderer who had been hanged in 1899 and was recorded as having been the wearer of an artificial peg in place of his left leg (left fibula and foot were absent). Although there is research that has been conducted into the bone tissue response of prostheses (see Spence, 1985), there is limited historical research into the effects of artificial limb wearing as well as the initial amputation. Lazenby's (1993) research offers a detailed assessment of a specific limb on a specific wearer, with information relating to their age, weight and height.

Lazenby and Pfeiffer's (1993) analysis of a nineteenth-century below-knee amputee, who had worn hardwood ectoprostheses for an extended time prior to death, demonstrated a reduction in size and geometric strength of the femur. This was combined with secondary ankylosis at the apophyseal joint and right centra, lytic erosion in the right sacroiliac joint forming cavities in the subchondral bone surface and exposed dense coarse trabecular bone and sequestra formation all indicate the development of osteoarthritis however also suggest that the midshaft and distal regions from the affected femur were partially shielded from functional strain.

As Niinimaki (2011) has stated, bone reacts to its mechanical environments, such as physical activity, repeated movements and muscle moments. Predicting activity patterns, such as repeated stress from altered loads during gait by using muscular-skeletal markers, in combination with estimating movement restrictions at the joints, such as osteoarthritis, as well as the level of joint impairment and then establishing a timeline for the disease, are all good ways of investigating the type of disability the individual under study was confronted with (Hawkey, 1998). The evidence garnered from these two examples provides a backdrop on which to compare and analyse the data produced within this thesis because it tells us that there is evidence for morphological alterations, but no data as yet which demonstrates the reasons these changes may take place.

The findings that Lazenby discovered provide a justification for the aims of this experimental research. Not only did his research conclude that the partial amputation of a leg undoubtedly affected the pattern of loading and weight bearing on the remaining limb, but the use of a primitive peg-leg affected the morphology of the femur it was appended to; 'Wearing the prostheses apparently permitted transfer of weight-bearing and locomotor force through the left hip' (1993: 26). Lazenby's data was produced via the osteological analysis of the skeletal remains and whilst conclusions have been effectively drawn, explicit consideration of the specific movement patterns that occasioned the skeletally-visible changes was not speculated upon. The study of amputation in osteological studies rarely considers in depth the specifics of prostheses or the exact movements that would have been made, due to the lack of evidence that is usually available if just working with the skeleton alone.

Research into gait analysis instead, generally takes two forms, the first and most prevalent is that relating to the modern medical world, Esquenazi (2014) for instance has considered the importance of gait analysis in conjunction with clinical judgement to elucidate factors involved with pathological prosthetic gait. His research, much like that of Yeung et al (2014) and Kark (2011), aims to establish the effects of gait deviation (through the use of prostheses) using kinematic three-dimensional analysis, such as using Kinect (see Moevus, 2015, Gabel et al, 2005 and Clark et al, 2013) and Vicon (see Tugui et al 2012). The aim of the experiment here is therefore to demonstrate physically, how artificial limbs changed how their users moved, providing for the first time a digitised visual dataset from which physical changes in gait are generated. Likewise, whilst doing so, the functionality of the individual legs will be ascertained. Finally, if the legs can be identified as changing natural gait, it will be possible to determine the type of long-term damage that may have been at the root of the chronic pain, discussed by both Bigg (1885) and Gray (1857) because of wearing limbs that did not fit properly.

The methodology utilised within this research has been designed to ensure Coles' experimental 'Rules' (1979) are employed effectively and authentically. For instance, honesty is maintained where original materials cannot be used. Vanessa Warne's (2008) research into nineteenth-century perceptions of disability, portrayed by contemporary literature, has provided this thesis with the foundations for further discussions into perceptions of prostheses in the social imagination. Warne (2008: 32) writes that the 'tension between literary representations and the lived experiences of amputees constitutes something of a problem for the study of prostheses in the Victorian period, she implores other academics to approach the study of the history of prosthetics literally, rather than metaphorically. As such, this research uses a methodology which reanimates historical prostheses to create an understanding of the lived experiences of those who may have worn them; their movements, sensations, comfort, sounds and emotions. In considering the value of this archaeological reconstruction, it could be argued it has three main benefits: firstly, similar material conditions to those of the past are constructed; secondly, it offers a possible visual as to how people have may have physically moved through their environments; and finally, it creates a direct material connection with the past. Whilst these objectives are principal to the role of experimental archaeology and the study of material culture, they often come under criticism for mainly considering contexts of consumption (materials) and ignoring contexts of production (spatiality). Regarding Reynolds

(1999) who regards the term ‘reconstruction’ as misleading, the aim of this research is not to reconstruct a perfect replica because there are remaining variations held in museums from which we can learn about form and mechanics. The point is to engage with the technological process and to understand the skill level involved in the production, so when combined with digital and wider artifactual and documentary evidence, this type of prostheses can be understood in a more varied and reliable way. These artefacts give a direct link to the manufacturer and their origins. For the period studied here, the use of digital socket customisation is inappropriate and therefore we must consider artificial limb production as a ‘hand-made’ creation, as Cooper (2013) explains it is in other words very much a ‘technique of the body’.

The concentration here is primarily on male wearers of artificial limbs during the nineteenth century who lost their limbs during military conflict. This is where this research also differs from other work on historical prostheses, for example, O’Connor (1997), among many scholars, tends to discuss the growth of the prostheses industry from the perspective of technological development. Sweet (2013) takes this approach further by utilising literary documentation noting the social implications surrounding the use of particular legs. Within this thesis, there is a focus on the potential importance of the military and conflict acting as a primary driving force for the industry's growth, the interconnections between the government and an improvement in medicine and medical care simultaneously. As Sweet (2013: 45) himself states the ‘…physical difficulties, pain and mental anguish occasioned by losing a body part…’ are undeniable, but better understood by focusing on the social conditions which promote physical wholeness and diminish physical differences. This research acknowledges Sweet’s perspective but argues that the most effective way of understanding the daily experiences of those with limb loss, is to recreate the experiences which generate a physical sensation that mirrors those originally experienced. It is for this reason that this thesis approaches this topic from both a historical and literary perspective and combines this information with findings generated from lab-based analysis, as this provides a more thorough exploration of historical prostheses.

1.3 Format of Thesis

This introductory chapter is followed by Chapter 2 which provides a background to the research topic by discussing the origins of prostheses and their development over time leading to the designs that come under close investigation within this research. Societal factors are reviewed that influenced design changes or necessity, such as industrialisation and particularly in this context of war. Assessing representations of disability and prostheses can help determine perspectives and attitudes that existed toward disabled individuals during the nineteenth century. The term ‘prostheses’ can be used to describe a variety of objects of extension to the human body. In this thesis, prostheses are used to describe artificial appliances, in particular an artificial leg, that attaches to the body to aid an individual’s ability to perform tasks in daily life, and the many complex definitions (Stoddart-Holmes 2004) are discussed in Chapter 2 along with a short chronology of the development of prosthetic leg appliances throughout history. Focussing on the background of both limbs under investigation in this research, whose origins are military, Chapter 2 also discusses prostheses in the aftermath of military conflict, with a brief introduction to the Napoleonic Wars, the wounds that were observed and the type of medical treatment that was available for soldiers. The two different prosthetic limbs, the peg leg and Anglesey leg are analysed in Chapters 3 and 4; how they originated, their construction and manufacture. These chapters form the basis for the design of the experimental work to construct artificial limbs (detailed in Appendices A and B).

A new wave of prosthetic interest has seen researchers such as Jaqueline Finch (2011) begin to dissect early forms of prostheses, from a new scientific approach. Finch’s methodology utilises a combination of reconstruction and lab-based biomechanical analysis to assess the usability of an artificial toe found on a mummy dating from 600bc. The gait analysis within this thesis, presented in Chapters 5 and 6, draws on the methodological processes employed by Finch in her 2011 analysis as discussed in Chapter 2. The examination of surviving post-medieval prosthetic devices offers greater insight into the origins of the state-of-the-art engineered prosthetics used today – for it is here we see the developments of a specialised industry with the opening of the first stores primarily dedicated to the manufacturing of prostheses. The lack of written information about production methods and manufacturing techniques of post-medieval devices, however, highlights a gap in the use of similar methods to those used by Finch (2011). Unlike Finch’s (2011) research, the goal within this research is not to establish whether artificial limbs were intended to be functioning appliances, as we already know they were, the goal instead is to use similar methodologies to establish how well the limbs aided gait. Combining this new scientific element with historical research will illuminate not only attitudes to disability and prostheses, aesthetic perceptions and value but also, cognitive themes for the producer, wearer and wider society. Chapter 6 embarks on a discussion which draws on the results presented in Chapter 5 of the gait analysis to understand what the findings may suggest in terms of the lived experiences and perceptions surrounding amputees wearing these limbs may have been. Chapter 6 brings together the findings of the experimental work and analysis and presents a discussion in the context of nineteenth-century society. Comparative archaeological data is drawn upon to observe patterns in the bone that may mimic the suggestions from the data produced here. An analysis of the historical data from Chapter 2 is also reviewed and conclusions from this research are presented in Chapter 7, where further research suggestions are offered.

Chapter 2: Prostheses, Medicine, War and Aftermath

Lennard Davis (1995), discusses the terminology associated with impairment in 'Enforcing Normalcy', arguing that any form of language that ultimately describes 'difference', immediately creates a concept of the 'other'. The terminology surrounding disability is embroiled in the politics of disability. The term 'disability' stems from an ableist society. The deaf for instance largely reject the idea that they have a disability, not wishing to be associated under the umbrella term that also describes schizophrenia and autism, instead they see their state as being defined not medically but socially and politically. Acknowledging the social and medical models of disability as we understand them today highlights the changes in approaches and attitudes that have occurred over the past 200 years toward those with impairment, leading to the discussion about what disability is and how it differs from impairment. Under the medical model of disability, an individual with impairment is considered disabled because of impairment, contrastingly, the Social model suggests an individual's environment and social experiences affect the intensity of a person's impairment or difference in everyday life. For instance, if a wheelchair user wanted to access a building with a step entrance, the social model would see a ramp added so the wheelchair user could access the building with ease. The medical model would fail to acknowledge a solution for wheelchair users to climb stairs and ultimately exclude them from both essential and leisure activities through the lack of accessibility (Haegele and Hodge, 2016). Accessibility is still a concern in today's society, with many London tube stations, not impairment friendly for instance, particularly the older stations with origins in the latter nineteenth century. Barriers are not just physical, however. Attitudes found in society, based on prejudice or stereotype (or 'disablism'), also disable people from having equal opportunities to be part of society (Haegele and Hodge, 2016). This thesis considers these modes of thought using evidence from the nineteenth century to understand which model best explains the experiences of impaired individuals during this century.

Davis (1995) explains that the term 'disabled' is not a good one, because it relates to a lack of ability, such as physical, mental, legal, fiscal etc, linking impairments (not just physical) together without creating a discourse of disability. Davis goes on to explain how other terms such as 'differently abled' or 'person with disabilities' have also been used to refer to those with impairments, but 'differently abled' could be considered as referring to everyone, as everyone is differently abled at different things regardless of whether they have an impairment. Whereas a person with disabilities implies an additional quality that the individual possesses rather than a reduction in personhood. This research recognises the ongoing discussions that surround terminology and does not wish to offend through the use of words such as disability within this thesis. Where possible, impairment and physical differences will be used, however, it is hoped that acknowledging the challenges surrounding terminology, much like the discussions surrounding pronouns used to describe gender, demonstrates the importance of ongoing discussions relating to appropriate ‘disability’ terminology.

Turning to the dictionary for the etymology and definition of the term ‘prostheses’ places its origins in the mid-sixteenth century with Latin roots referring to the addition of a letter or syllable to a word. If we consider Wigley’s (1991) definition of prostheses ‘…a means of supplementing our natural capabilities…’, artificial limbs could be viewed in a dualistic manner; they denote oppositional constructs such as mind/body, natural/artificial and culture/nature. These paradigms define an ontological separation of humans from the environment, and now extend to phenomena once thought to be unique to humans such as cognition, society and language (Foley, 2014). For instance, today a prosthesis is described as ‘an artificial device that replaces a missing body part, which may be lost through trauma, disease or congenital conditions’ (Oxford Dictionary, 2016), this may refer to glass eyes, artificial limbs, false breasts, even wigs and dentures. Within this research, therefore, the term prostheses will be used to identify ‘artificial appliances’ that act as extensions to the body in the form of legs and arms, as a means of recreating original aesthetics and movements, producing a ‘whole body’ (Sweet, 2016).

However, nineteenth-century terminology differed from our modern understanding of the words prosthesis and disability. Warne (2009) notes that the term ‘artificial limb’ during the mid-nineteenth century was reserved for prostheses that imitated both the appearance and movement of the natural leg; it did not refer to peg-legs or rudimentary leg-shaped prostheses. The term leg was even considered an inappropriate term during the nineteenth century. Comparatively, the language used in historical sources can also be considered offensive or derogatory by today's standards, in fact before the First World War the term disabled was used infrequently to describe people with physical impairments. Words such as afflicted, defective, infirm and cripple, which appear in many nineteenth-century writings, will only be used within this thesis if within the source context and will appear in quotation marks to delineate this. The terminology used in the sources demonstrates the challenging relationships and attitudes to physical losses at the time. Whilst disconcerting, these terms express a socially constructed attitude to bodily difference, based on the understanding that during this time physically whole was the accepted norm (discussed below).

2.1 Short Chronology of Prostheses

In studying the history of the construction of artificial limbs or prostheses, which has been possible through the artefacts, art and literature left behind by past societies, it is possible to gauge the foundations of modern prostheses. Putti (1930) has suggested that '. . . the history of artificial limbs is probably as old as humanity, as it is supposed that a maimed fellow would try to find a remedy for his imperfections.' (Putti, 25, 40-43). Within this research, the focus is on military and conflict-inflicted amputation, with an interest in the artificial appliances that were developed as a consequence of an increase in demand for prosthetics. A brief history of prosthetic limbs will now be presented to demonstrate the variety of perceptions that existed within different historical eras and societies to understand how technology developed into what was observed during the nineteenth century.

2.1.1 First Evidence of Lower Leg Prostheses: Antiquity

The first situation where a person required a prosthesis for their injury is unknown and is likely to have been the result of a congenital impairment. Motivations for an amputation may have been a ritual sacrifice, curing a disease, an injury, magic or punishment. Archaeological examples of lower limb prostheses from antiquity are exceptionally rare, partly due to the organic nature of the appliances and partly due to the fact very few people who required prostheses were likely to survive the injury which rendered the need initially. Despite their rarity, there is evidence of some lower limb prostheses surviving from classical and late antiquity, with some suggesting that those with physical deformities in ancient cultures were revered and looked upon as godly (Draycott, 2017). Recently the oldest known form of prostheses was unearthed in Egypt, that of a wooden right big toe discovered on a female mummy, which was found to not only be aesthetically beneficial but functional as well (fig. 2.3). However, the lack of physical remains leaves the style and design of original appliances largely up to conjecture and overly reliant on what limited written information exists from this period.

Thurston writes; that early examples of prostheses: '...were developed for function, cosmetic appearance and a psycho-spiritual sense of wholeness…' (2007, 1114). Amputation could be feared more than death in some cultures largely because the amputee was feared to be affected on earth and in the afterlife. '...The ablated limbs were buried and then disinterred and reburied at the time of the amputee's death so the amputee could be whole for eternal life.' (Thurston, 2007: 1114). Old Testament scholars have struggled to find hard evidence of reference to prostheses. The earliest written record of prostheses is from India in the Rig-Vida (1500-800 BCE) where the use of artificial legs is mentioned (Putti, 1930). The widely quoted story of the mystical seer Hegesistratus by Herodotus (485-425 BCE) also mentions a wooden foot which became useful after the seer had to hack his foot off after being captured and immobilised in stocks.

The Peg-leg's earliest known representation is from a fourth-century vase fragment depicting a satyr with a peg-leg at the knee (fig. 2.1). Viking sagas hail a hero known as Trefote or 'Wooden Foot', likewise a Roman mosaic in the Pyrenees depicts an 'amputee whose leg is supported by a wooden pylon' (Fleigel and Feuer, 1966). It is safe to assume that original designs were basic in form and function, utilising the environment around them, wooden crutches were likely to have been most frequently used, as well as simple peg-legs variations.

Whilst most references to artificial limbs in antiquity are seen in written or artistic depictions, there is some physical evidence of Roman lower limb prostheses dating from 300 BCE discovered in 1858 in Capua, with a core made of wood and an outer of bronze (fig. 2.2). Whilst the original, housed at the Royal College of Surgeons, London, was destroyed in 1941 during a bombing raid, a replica was created in 1920 by Karl Sudhoff. The depiction of artificial limbs in archaeology, whether fictional or not, shows a cultural engagement with the idea of prostheses and that the technology may not be alien to those writing them.

(Fig. 2.1 peg-leg depicted on antique vase shard found 1862 in Paris, image courtesy of Putti, 1930: 312)

(Fig. 2.2 Capua Leg replica housed at the Science Museum, image courtesy of http://broughttolife.sciencemuseum.org.uk/broughttolife/objects/display?id=91684)

(Fig. 2.3 Egyptian prosthetic toe, Jaqueline Finch, 2011: 549)

2.1.2 Medieval Examples of Lower leg Prostheses

Fliegel and Fueur (1966) claim that there was very little advancement in prosthetic appliances during the medieval period and that the cost of appliances drove the decision regarding what type of appliance to wear, with crutches and peg-legs being the most common options, ascertained from contemporary pictorial depictions (see figures 2.4-2.6). Disability in general was not considered extraordinary, as it was a common occurrence amongst the peasantry and even amongst the clergy and nobility, and was rarely documented. Figures 2.4-2.6 depict some medieval examples of artificial appliances used to aid the mobility of disabled peasants. Stiker (1999: 67) states that people living with disabilities during the medieval period were 'no less distinguished from the economically poor'. Terms such as disability do not appear in documentation from this period as it was not classified as a category of impairment, instead, more specific terminology such as 'blynde', 'dumbe' and 'lame' appear more frequently (Jarrett, 2012: 7).

(Fig. 2.4 The Romance of Alexander (MS Bodl. 264), 14th-century Photo: Bodleian Libraries, University of Oxfordhttps://digital.bodleian.ox.ac.uk/inquire/p/b89c6a78-c12b-453b-9abb-fa78e4e92dd9 [accessed 07/06/19])

(Fig. 2.5 A Crippled Man, 1196-1223, Gerald of Wales, Henry of Saltry, Royal 13 B VIII, f. 30v, Catalogue of Illuminated Manuscripts, The British Library online at https://www.bl.uk/catalogues/illuminatedmanuscripts/ILLUMIN.ASP?Size=mid&IllID=43352 [accessed 07/08/19])

(Fig. 2.6 Studies of Beggars and Vagrants, Pieter Bruegel the elder, 1465-1559, Fourcaud 1912: 272)

2.1.3 The Sixteenth - Eighteenth Centuries

The early modern era is when we first start to see advances in prosthesis design and technology. Provisions of prostheses were chiefly used to conceal the loss of the limb, their inspiration for production and design innovation came as a result of congenital deformities, war injuries, punishment of lawbreakers and endemic disease (Phillips, 1991). Ambroise Paré (1509-1590) made a profound contribution to the development of more sophisticated artificial appliances. Turner and Withey (2014) state that as early as the sixteenth century ‘a growing division between devices that were strictly functional, such as peg-legs and more sophisticated prosthetics that not only restored movement but resembled the missing body part’ (2014, 784) was occurring within society. This led individuals such as Paré to develop better appliances, essentially sparking the beginning of a more specialised trade. Paré’s functional limb designs were spurred on by the stories of men committing suicide because they would rather be dead than live without a limb (Hernigou, 2013). Many of Paré’s designs influenced the development of the Anglesey leg, for example, an above-knee prosthetic leg which had a kneeling peg and a prosthetic foot which operated via the use of 'a locking knee and suspension harness.' (Section 3.2-3-4) (also see fig. 2.7). The materials used for Paré’s designs include wood, leather, copper, iron and textile.

(Fig. 2.7 Paré's knee locking artificial leg, image courtesy of Herginou, 2013)

An increase in the frequency of advertisements for appliances aimed at remedying physical concerns such as ‘bow-legs’, ‘knock knees’, ‘posture’ and ‘bodily deformities’ (Withey and Turner, 2014: 775) during the eighteenth century, had the goal of disguising and hiding what was not aesthetically pleasing. The people using these items were not considered patients, instead, the language placed them as consumers, with a distinct lack of medicalisation (Withey and Turner, 2014). Technologies were advertised as ‘moulding to the body in a socially agreeable form, fit for social interaction, remedying the body's unsightliness that held it back from social or commercial success’ (Withey and Turner, 2014: 776).

It has been suggested that the nineteenth century carried a ‘spirit of invention’ (Phillips, 1991). According to Wardle (1917) before the outbreak of World War One (WW1, 1914) the artificial limb industry was small, with few manufacturers and little demand. However, evidence suggests the industry was on an outwardly expanding trajectory throughout the nineteenth century in Britain, thanks mainly to one crucial factor – war. The Napoleonic Wars at the beginning of the century followed by the Crimean Wars of the 1850s both created the physical consequences that acted as catalysts for the manufacturing and technological development of artificial limbs.

Holmes (1860: 577 in Warne 2008: 85) discusses how artificial limbs were manufactured during the nineteenth-century, noting on his visit to a known limb manufacturer that he was shocked to discover no mechanised lathes or steam power involved, instead finding a manufacturer shaping the leg by hand ‘…it is shaped very much as a sculptor finished his marble, with an eye to artistic effect…’, imagining a future user comforted by their restored mobility and wholeness. Holmes’ description of artificial legs manufacture, paints the amputee as an ‘aesthete’ (Warne, 2008: 85) and by doing so associates prostheses ownership with sophistication, thereby highlighting the aesthetic appeal of prostheses and as such assigning artificial limbs with a value which is distinct and separate to that of a mobility aid. Holmes’ passionate description of artificial limbs and romanticised narrative, mirrors that of the advertisements from the day, where manufacturers attempted to stand out from the crowd by inventing their unique selling points and pushing these as better than anything else available in pamphlets, newspapers and also at exhibitions such as the Great Exhibition in 1851 where there were 8 different manufacturers present. The market got crowded with people pushing their prostheses as the best, leading one amputee to complain in 1871 that; ‘…you almost gather the impression that it would be better to be born with legs, arms and a head perhaps, all wood ready patented.’ (One Legged Men, 1851: 355) (discussed in section 2.6).

Researching archaeological and historical findings of artificial appliances is crucial to the discussion of assistive technology throughout history because the information the appliances convey acts as examples of conscious choices being made in recognising a need and generating a remedy to this need. The Anglesey and box-leg under investigation within this research are known to have been functional, therefore changing the aim of the experimental analysis here. Establishing how the artificial legs affected the movement of the individual wearing them, is crucial to help inform us about perceptions of disability and prostheses during the nineteenth century. Literary evidence alone offers biases that do not present a complete picture, however, the addition of archaeological artefacts and experimental reconstruction and testing will remedy the previous shortfalls in data collection and inform the subsequent analysis.

2.2 Medical Consequences of Waterloo

The Battle of Waterloo came as a conclusion to 25 years of fighting between Napoleon's forces, the British and their allies. After 4 days of fighting, Waterloo happened on the 18th of June 1815. Of roughly 100,000 men that fought under the command of Wellington (Crumplin, 2014), 15,000 of these died, roughly 7000 were severely injured and around 500 needed amputations (250 at Waterloo alone) – many of which were performed within hours of battle (Crumplin, 1988: 39). It is claimed that 'In the one day of fighting there were around 55,000 either killed, wounded, or missing in action from both sides. The sheer density of the injured - around 2,291 people per mile of front compared with 234 over the same area on the first day of the Battle of the Somme in 1916 – meant many of the casualties were left simply to bleed to death on the battlefield.' (Shute, 2015). Rutherford states that medical care in the military was primarily at the hands of the surgeon, amputations, trepanning, wound redressing and fractures being reset, were all performed around 400m back from the front. Howell (1924) explains that the field hospital was opened three days after the battle. The strain and pressure surgeons were put under was even more so than these figures present because, surgeons from different nations were present under the same hospital roof which meant patients that were present, were also hailed from different nations. Immediately, the number of patients, therefore, being treated increased from around 7000 British to approximately, 100,000 in total (over a four-day campaign at Ligny, Quatre Bras, Wavre and Waterloo), 2000 of whom needed amputations and the hospitals in the region and the number of surgeon present, found these numbers a struggle to deal with (Crumplin, 2014: 72). Statistics from Waterloo, show that there was a mortality rate of 30% for primary amputation, rising to 45% for secondary, particularly in the lower limb (Cantlie, 1974).

Those experiencing traumatic amputations 200 years ago rarely survived, in fact, the average life expectancy during this time was around 40 (although social class impacted this), so the experience of amputation which was likely to occur during military conflict, most likely occurred in men in their 20s. We know some people did survive amputation due to the existence of artificial appliances, meaning they potentially wore their prosthesis for around 20-plus years, the possible consequences of this form the basis of this research investigation. The blasts experienced in battles such as Waterloo, because of cannonball explosions, did not stop immediately after the initial impact, instead, they could continue to bounce and roll with evidence suggesting an advancing cannon could pass straight through up to forty men (Watt, 1975). The cannon did not have to have direct contact with a person for it to cause fatal damage, the term ‘wind of the ball’ (Watt, 1975) refers to internal damage such as concussion and lung collapse resulting from a near miss. A cannonball could create a blast wave that causes a ‘brisance’ effect on the bone which shatters it, the direct impact would rip the limb off, and environmental fragments, as well as any shrapnel, causes damage to the soft tissue, including muscles, tendons and nerves, putting further stress on the already shattered bone (Clasper and Ramasamy, 2013). In theory, amputation internally had already occurred and so the only solution for a surgeon was to amputate the rest of the affected area. The trend of war-related amputations continued to increase in number throughout the century, which in turn increased the need for prosthetic devices to be developed and manufactured.

Recent archaeological discoveries at the battlefield in Mont-St-Jean by the charity Waterloo Uncovered demonstrate the magnitude of battlefront amputation that occurred at Waterloo. Several leg bones were found in what is considered to be a pit for the limbs to be discarded, located close to the field hospital (Waterloo uncovered, 2015, 2016, 2017, 2022). They are identifiable as amputated limbs not only due to the level of trauma that they display, such as numerous fractures and breaks consistent with wounds from cannon fire or gunshot, but they also show evidence of surgeon saw marks (Waterloo uncovered, 2015, 2016, 2017, 2022).

Frontline injuries which resulted in amputation could be caused by fractures, infections and blast wounds. The healing of these varied as well, with traumatic amputations being a catalyst for several other health concerns. Research by Clasper and Ramasamy (2013) details the type of complications that can occur after a traumatic amputation. They remark upon the considerable mental effects such trauma can cause, but also the chronic pain from nerve injury, tissue damage and potential functional loss of the limb over time. In the nineteenth century, amputation was mostly connected to traumatic events and consequently, the post-trauma healing of such amputations was likely to have resembled the experiences of those under investigation by Clasper and Ramasamy (2013).

The Vietnam War is the only modern conflict from which data regarding the long-term prognosis for traumatic amputation has been developed. Therefore it is the only modern conflict from which we can make comparisons between the post-military experiences of those involved in Vietnam to those involved in a conflict in the nineteenth century. Dougherty (2001: 383-389) noted that twenty-eight years after sustaining their injuries, those who had undergone transtibial amputation were living ‘normal lives’ with 99% employed, 96% married and 83% with children, wearing their prostheses for around 16 hours a day. Comparatively, those who had undergone transfemoral amputations had integrated less into society and although most were still leading ‘relatively functional lives’, there was still an increased level of disability associated with transfemoral amputation. Whilst life expectancy was equivalent for transtibial and transfemoral, mobility was reduced for the latter, which saw an impact on the markers for a ‘normal life’, 91% had married, and 87% had children, but only 70% had been employed and they only wore their prostheses for an average of 7 hours a day. Despite this neither group saw a major impact on their mental health (Clasper and Ramasamy, 2013: 72). This data, whilst representing individuals and their experiences of war and post-war in the twentieth century, they do share the commonality of a traumatic amputation with men who suffered the same at Waterloo. The data suggests the lived experiences for both transfemoral and transtibial amputees changed, but much more so for transfemoral amputees. It is probable that this was also the case post-Waterloo, with men possibly struggling to reintegrate fully into society after suffering (and surviving) a transfemoral amputation.

2.3 Social Divides of Amputation

Whilst amputation and the medical techniques involved in this process are not the focus of this thesis, appreciating there were various types of amputation and the use of specific variations in the method of amputation which were often targeted at members of different social groups is important to understand another reason why certain artificial appliances were more prominent in wealthier or poorer circles. Similarly, traumatic amputations made up most of the amputations during the nineteenth century, often a result of railroad, mining and agricultural accidents, the clientele was therefore largely labouring classes (Galland, 2003). When at war, these traumatic amputations came in more frequency and due to the nature of the battle, spanned social classes more frequently.

There is limited evidence to suggest there was much, if any discussion, between an artificial limb maker and a surgeon before a patient, undergoes their amputation, particularly during battles like at Waterloo. There are several possible reasons for this. Firstly, amputations were rarely planned. People could be mutilated whilst working on the railroad or in an agricultural or industrial setting and therefore, it was likely such an operation took place unexpectedly, with no time for a patient or a surgeon to contact the relevant artificial limb manufacturers, to discuss what type of limbs would be most suitable for the specific individual. Secondly, another reason for this lack of communication was simply that still at this stage artificial limbs and their makers were separated from the science of medicine. Physicians, doctors and in the latter stages of the nineteenth century, surgeons, were all at the forefront of science, however, artificial limb construction rarely saw people primarily trained in this application – people learned the skills involved after having learnt another craft and then combined the two. However, by 1877, O'Flanagan argued that the distinction between the two branches of medicine should end and that instead, a surgeon should also be a trained physician before practising surgery.

Both Henry Bigg (1885: 103) and Frederick Gray (1857) suggested that how an amputation is performed, such as the length of the stump, has an overall effect on the way the stump heals and therefore the level of pain a patient might have to endure whilst wearing a prosthesis. Both conclude communication between surgeon and prosthetist was crucial therefore before amputation. Surgeons, according to Smith (1865: 490) acted on '…the belief that the poor man will either have no artificial appliance to his stump, or one of the rudest character, while the rich man will avail himself of the highest degree of art to compensate his loss.'. Henry Bigg's description of amputation in the military presents an interesting comparison, in which he states in a footnote that his chapter entitled 'Military Amputation and Government Appliances', also applies to 'pauper surgery'. Bigg notes; 'Apart from their pension they are supplied with such artificial appliances as are deemed likely to be most useful to them in the everyday life of their class, and further they are granted fresh ones to the end of their life at such intervals as reasonable wear and tear may justify.' (1885: 102). Overall, the contrast in what was available for wearers of different social statuses demonstrates the relationship between class and disability, it could be said that certain artificial limbs act as markers of economic privilege.

Both Bigg and Gray's examples also demonstrate that during the second half of the nineteenth century there were growing concerns about the comfort of the amputee whilst they wear their prostheses and also that there was growing discomfort surrounding the lack of synchronicity between surgeons and appliance makers. However, the battlefield frontline was hardly the location for in-depth conversations surrounding possible appliances and so the goal was just amputating the leg and then dealing with the consequences. For example, Cantlie (1974) provides the example of Charles Bell who performed numerous amputations after the battle as a way of evidencing the multitudinous number of pending amputees. Bell states ‘All decencies of performing surgical operations were soon neglected. While I amputated one man's thigh there lay, at one time, thirteen all beseeching to be taken next. It was strange to feel my clothes stiff with blood and my arms powerless with the exertion of using my knife.’ (Cantlie, 1974). It is partly for this reason that we see evidence of double amputations, such as the Marquis of Anglesey, whose initial front-line operation once healed was not considered sufficient for the Anglesey leg and so he voluntarily underwent another amputation to ensure the stump would be appropriate. Importantly, this was not an option for most individuals because firstly, the medical care received was what the individual could afford, so it was unlikely people would spend money on an operation if they were fortunate enough to survive the initial one. Secondly, undergoing another amputation would keep a man out of work for another extended period and this was just not feasible for most people who needed to earn money to survive. The result was that they were likely to have poor experiences with the artificial appliances they could afford and their stump probably didn’t fit appropriately.

Henry Bigg (1885: 101) explained after the larger campaigns such as Peninsular or Crimea, that the number of maimed men had enormously increased. The volume of those in need of artificial appliances always increased after conflicts. When government provisions of limbs were introduced in the 1840s, it was seen as a ‘national debt’ to ensure wounded soldiers were able to ‘re-enter the civil class from which they were drawn’ (Bigg, 1885: 100). As such, the government supplied artificial appliances deemed ‘likely to be useful to them in everyday life of their class...’ (Bigg, 1885: 102). Bigg however writes that whilst these were made out to be for the benefit of the veteran, the government was using it as a façade to firstly give the appearance they were looking after their loyal soldiers and secondly, to ensure these soldiers could return to some form of work and continue contributing to society (1885:100).

Consequently, little regard was paid to the types of artificial appliances that were being provided and instead, their quality and efficiency were based primarily on the intended recipient. Bigg (1885: 102) states the more '...perfect the artificial appliance with which a government supplies its pensioners, the more faithfully will its obligation be carried out and the better chance will the man have of getting tolerably lucrative living…' after his army service and of becoming again useful to his country as tradesman or employee. From the 1840s for over 30 years, the same appliances had been churned out by contractors connected to the Commissioners Chelsea Hospital with no modernising or alterations. The result was that many soldiers were provided with 'deficient or useless' appliances, primarily because of the misunderstanding that existed amongst government officials surrounding the precise relationship between amputations and subsequent appliances (Bigg, 1885: 102).

Bigg (1885) dedicates an entire chapter of his book to military amputation and government prostheses in which he argues the lack of synchronicity between manufacturers and surgeons is the root cause of long-term health conditions observed in military amputees. Bigg (1885) suggests that the object of amputation should be to 'remove what is useless and replace it with what is useful' which can only be achieved if thought is put into the subsequent appliance by the surgeon before the amputation and this can only be the case if the surgeons are familiar with the requisitioned government appliances.

The general rule of amputation that had been long accepted was regardless of where the injury was on the patient, always amputate immediately at or below the knee – even if the injury was on the foot. Surgeons such as Mr Erichseu (Bigg, 1885: 104) began to argue that this was more inconvenient and damaging to the patient and instead the amputation should occur slightly above the initial injury. However, as Bigg makes clear to the reader, this change in amputation technique was only effective if the surgeon could take time over the amputation with real consideration for the type of prostheses the patient was potentially to wear. Instead, during times of war, such as the Crimean, where over 10,000 amputations took place (Connor, 1998), time pressure was too demanding and there was no provision by the government for the constructor to personally fit the patient's substitute leg. Adapting a stump therefore to fit a specific appliance would firstly not have been the surgeon's priority and secondly, may have prevented the wearer from being able to utilise the most appropriate appliance later on.

2.3.1 Physical Consequences of Amputation

Knüsel's (1995) archaeological evidence from York demonstrates the impact of amputation on individuals, evidenced by secondary joint disease and a variation in muscle responses, demonstrated by muscle markers. During analysis of the skeletal population at Fishergate in York, the skeletal remains of an individual suspected to be over the age of 45, demonstrated evidence of chronic septic arthritis, secondary to a right knee twist fracture and bone adaptation as a result of altered biomechanical loading (Knüsel, 1995). The individual had been treated with copper-alloy plates making this individual the sole example of lower limbs being cared for in this manner, which leads Knüsel to suggest that those associated with Cistercian monastic houses had superior and preferential medical care during the 13th and 14th centuries. The pathological evidence from this example demonstrates the right tibia and femur, laterally rotating about 30^{o} out of normal anatomical alignment (Knüsel, 1995: 370-371). A large osteophyte protruding anteriorly from the tibia as well as the femoral condyles having a porous, lytic appearance is also present. Exostosis is present on the right femur and periosteal bone has formed in the area of the soleal line of the right proximal tibia, encompassing the distal femur and proximal fibula. The distal third of the right femoral shaft is swollen and two thumbprint-shaped depressions are present on the lateral aspects of the femur and tibia, as well as deposits of new bone (Knüsel, 1995: 370-371). The right femur and tibia dimensions are asymmetrical compared to the left side. Conclusions by Knüsel (1995) note that the joints have expanded more mediolaterally rather than anteroposteriorly.

Radiographs on the individual's right tibia highlight a '...comminuted fracture of the lateral condyle of the tibial plateau with dislocation and twisting of the tibia posteriorly and laterally (i.e. a rotary fracture dislocation).' (Knüsel, 1995: 371). This type of injury results from forced abduction of the flexed knee and simultaneous rotation of the tibia (Knüsel, 1995). The type of injury suspected of occurring was as a result of significant force also causing major soft tissue damage, with modern medical prognosis suggesting it would only be resolvable through surgical procedures, something unavailable during medieval times and therefore leaving the patient with a chronic knee injury. Knüsel, (1995: 372) proposes that the alteration to the right knee joint space and the '...presence of joint surface destruction, eburnation and osteophyte formation are commensurate with a diagnosis of secondary osteoarthritis.'. Risk of gangrene increases with this type of injury, particularly as a result of the likelihood of persistent ulceration and open wounds, all of which would often have resulted in amputation or today a skin graft (Kennedy, 1963; Taylor, Arden & Rainey, 1972). There is evidence of knee-joint deterioration which would suggest loss of mechanical function in the limb and would therefore mean that the individual would have carried noticeable signs of a physical injury, from chronic ulcerations, evidence of infection of surrounding tissues (septic arthritis) and therefore likely alterations in biomechanics.

There is evidence of a tendency to adopt a squatting position, likely to alter stress trans missions and lead to the expansion of the right femur. Osteophytes are evident within the area of muscles responsible for the flexion of the foot and leg, adduction, extension and medial rotation of the thigh at the hip joint, suggesting that these muscles were stressed beyond '...normal capacity through exposure to abnormal forces…' (Knüsel, 1995: 372). Evidence of adaptive alterations such as osteoarthritis of the vertebrae, lower limbs, arm and forearm, demonstrate long-standing alteration in the way in which body weight has adapted and subsequently been transmitted through these elements during kinesis. Osteochondritis is evident in the spine, as is scoliosis which has been described by Knüsel, Chundun and Cardwell, (1992) and Knüsel and Göggel (1993) as being interconnected to individuals with lower limb pathologies which ultimately affect gait. Likewise, there is evidence of spondylolysis separation of the first sacral vertebra as well as osseous alterations which again lead to conclusions of mechanical stresses in the lower back (Farfan, Osteria & Lamy, 1976). The left lower limb demonstrates osseous response resulting from muscle hypertrophy, whereas the right limb demonstrates evidence of partial disuse atrophy and thus the changes in cross-sectional areas of the femurs relate to the changes observed in the mechanical loadings (Knüsel, 1995) and therefore an affected gait. Knüsel also discusses pelvic tilt caused by reduced weight-bearing in the incapacitated limb, with scoliosis evident to support this theory.

There is also evidence of crutch usage, apparent due to the asymmetries observed in the upper body. Crutches were more affordable than artificial limbs so it's possible poorer amputees would have just utilised a crutch for aided mobility, likewise, some stumps were not always suitable for an artificial leg and a crutch may have been the only option. People did utilise both however, skeletal evidence that demonstrates alterations in the size of one arm, does suggest the use of a crutch on this side. Knüsel's (1995) research showed evidence of the right humerus increasing in diameter compared to the left. These external alterations result from hypertrophied musculature in the right arm. Osseous alterations such as this have been noted previously in a crippled leper from Chichester, West Sussex, U.K. (Knüsel & Göggel, 1993). In support of this assessment, Wing & Tredwell (1983) found greater bone density, which corresponds to greater external robusticity, in the radii of modern crutches using patients (Knüsel, 1995: 373). The importance of this example concerning this research is that it provides evidence of physiological alterations that can occur in the body over some time after an injury that affects the biomechanical gait of an individual. The osseous alterations that have been described above, act as proof of skeletal responses to changes in load, the skeleton will reflect osteological indicators to changes in load history over time, which the individual has had to adapt to maintain functional integrity. The research within this thesis takes these ideas further and provides a visual representation of the possible biomechanical alterations that may have been utilised by an individual, providing evidence to support why specific pathologies occur and which pathologies may specifically be related to prostheses.

2.4 National Glory or National Disaster of Waterloo

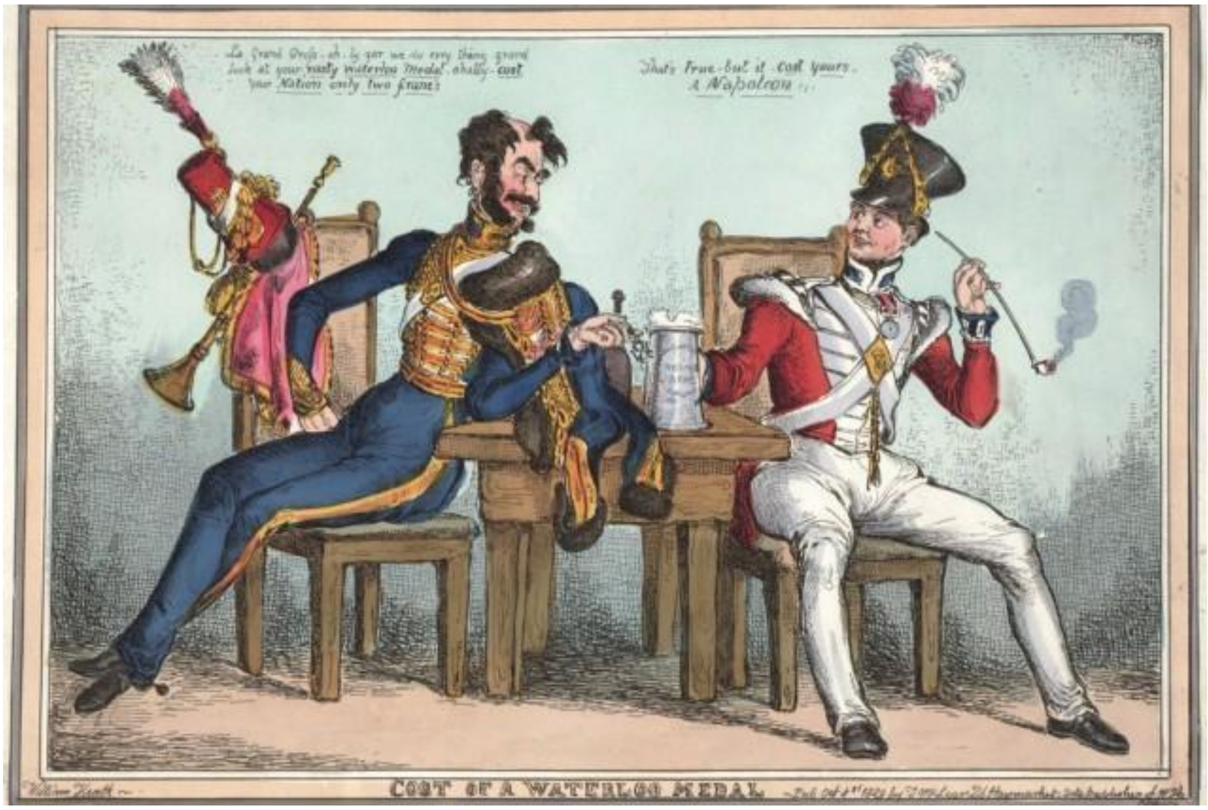
(Fig. 2.8 depiction of the battle, Waterloo Association, 2018)

Whilst Waterloo was celebrated as a victory for Britain and Britain's dominance, the response to the returning soldiers was impacted by the social status they held both before joining up and after demobilisation. Those soldiers who experienced glory upon return were largely officers and like in previous conflicts, it was these individuals who would be immortalised in memorials - such as the Battle of Trafalgar's statue celebrating Lord Nelson's victory. The assistance of the thousands of lower-ranked soldiers was largely ignored. Like Trafalgar, Waterloo had the allure of national glory. The reputation Lord Wellington held as a great tactician and soldier were cemented for years, for example, we are led to believe from articles such as the initial dispatch publication in The London Gazette (22nd June 1815) that Waterloo had been an overwhelming success for the British. A consequence of publishing celebratory articles caused the nation to celebrate; according to Hicks (2015) there were reports of street celebrations, bells being rung and cannons being fired. But even forty years after the battle, Wellington still epitomised a national hero evidenced by the national outpouring of grief that marked his death (Reynolds, 2019).

A Waterloo hysteria engulfed the nation, the nation appeared proud of their soldiers and proud of Britain. there seemed to be a real sense of national identity and patriotism following the immediate success of Waterloo. Many visited the battlefield as tourists. For those that couldn’t visit the battlefield in person, ‘infotainment’ opportunities (Hicks, 2015) such as plays and panoramas, would demonstrate to audiences the various roles and decisions each major military leader played in the battle.

(Fig. 2.9 Soldier Relating his Exploits in a Tavern, John Cawse, Forrest, 2015)

The extent to which Waterloo was the resounding success contemporary media had nineteenth-century people believe it was, is questionable. The perspective we are provided with from the original narrative differs from the reality and instead it was not the resounding success story, rather demobilised men found life hard to readapt to, particularly those who had been physically injured. Widespread feelings of patriotism and national pride were hard for the working-class masses to experience, due to the expense that the twenty years at war had accrued. Dissatisfaction over national living/working conditions, the economy and pay were rife. As Davidson et al (2016) note, many of the challenges of terminating war emerged such as the reincorporation of millions of demilitarised soldiers into society. Populations had changed, governments and economies were decimated and thousands of soldiers were still occupying France. These challenges were exacerbated by revolutionary movements such as republicanism, nationalism and abolitionism (Davidson et al. 2016).



(Fig. 2.10 Heath's cartoon about the cost of the commemorative medal, 1815, Hicks, 2015)

2.5 Status and Demobilisation

Status played a role in the aftermath of war and the demobilisation of thousands of soldiers reintegrating back into civilian life demonstrates the different challenges that were faced by lower classes. Officers at Waterloo were most often gentrified men from the upper echelons of society, they had to be literate and 'gentlemanly' (Reynolds, 2019) which is why upon their return we saw them move into the realms of politics and literature - with many writing autobiographies of their Waterloo experiences. Comparatively, the infantry was largely made up of the lower class groups, who had been lured into the military on false promises of life-long pensions, compensation for disabilities/impairments and also beer allowance bribes (Nielson, 2014 in Linch and McCormack, 2014: 183). The Duke of Wellington stated that many of the men '…enlist from having bastard children, some minor offences – some for drink…' they were '…the scum of the earth; it is wonderful that we should have made them into the fine fellows they are.' (Haythornewaite, 1996: 30-31). Soldiers would have joined for life in exchange for a sum of £23 17s 6d, however, the majority of these funds were reabsorbed by the cost of outfitting necessities (Haythornewaite, 1996: 30-31).

Unfortunately, the labouring masses that made up the regular infantry would have largely been illiterate and upon their demobilisation found themselves returned to a Britain with crippling debt, a weakened economy and a lack of jobs. Reintegrating into society and fulfilling the expected masculine role of provider was therefore challenging if there were no jobs for them to return to. 300,000 soldiers returned to Britain in 1816 and 32,000 in 1817 (Gash, 1978: 147), today that would be the equivalent of 1.2 million displaced soldiers; around 2% of the country's population. As discussed by Clapham (1920: 427), many of these dismissed soldiers were 'simply thrown onto the labour market; the vast majority of whom were ex-wage earners or potential wage earners, industrial, mercantile or agricultural'. The 1821 census shows that 21% of the population lived in cities of 20,000 inhabitants and upwards, and 27% lived in places of 102,000 and upwards (Clapham, 1920: 427). As industries such as coal-mining, spinning and weaving during the beginning of the nineteenth century were still largely 'cottage-based' and rural, Clapham suggests that around one demobilised man in every three was a probable wage earner within industry or commerce. The addition of a physical impairment such as an amputation made this reintegration even more difficult. The surplus of newly demobilised soldiers swamped the employment market, affected the likelihood of securing employment and had a direct impact on the review of the corn laws in 1822. The government attempted to decrease expenditure on ex-personnel by filling civilian administrative roles with them. For instance, many were sent to the colonies with wages set off against their pensions, likewise, Gash proposes that Peel's Irish and eventual Metropolitan Police forces could not have been established '…without the ability of the authorities to recruit large numbers of ex-servicemen' (1978: 150). Clapham concludes that the years 1815 to 1820 were 'both economically and politically**,** probably the most wretched, difficult, and dangerous in modern English history' (Clapham, 1920: 426-427).

The inequality shown to regular privates and infantry as opposed to officers and captains such as Anglesey was stark. Compensatory prizes, for example, for a Private who fought at Waterloo amounted to £2 11s 4d compared to Captains and Generals who received £90 7s 4d and £1275 10s and 11d respectively. However, the commander-in-chief received an astounding £61,000 from the British Army (Reagen, 1992: 34). Officers who returned maimed, we are told from contemporaries such as Beckwith, were provided with lifetime annuity at a level which was suitable for their rank and status (Beckwith, 1816 in Kelly, 1820: 156). Reynolds (2019) discusses literature in his research into ownership of Waterloo and draws from William Makepeace Thackeray's '*The Book of Snobs*', to demonstrate the open and honest criticism of British elites evident in literature at this time. Like Dickens, Thackeray criticises the 'institutionalised unfairness and prejudices' (Reynolds, 2019) within institutes. For instance, its representation of Waterloo and veterans are treated sympathetically or harshly depending on their social status (Reynolds, 2019). If we consider the cost and affordability of the artificial limbs under investigation here concerning Reynolds (2019) comments, it would suggest the prejudices that existed within society, bled into all aspects of life and perhaps this is why we observe certain appliances being out of reach for those occupying lower social groups. The inequality shown within pensions, surgery and artificial appliances for different veterans of differing social statuses demonstrates the heroic perceptions surrounding wealthier veterans. However, those who occupied lower classes were treated less favourably, suggesting perceptions of impairment regardless of how it was caused, did not affect the overall views of impairment rather status remained the authority of treatment and what options were available.

For instance, work undertaken by individuals with impairments was often paid less than those considered able-bodied and robust (Turner and Blackie, 2018), likewise they were often tasked with jobs that were considered less prestigious. There was a hierarchy of status related to able bodiedness and age and the work undertaken by disabled individuals was often considered 'lowly' by outsiders. This was not necessarily the attitude of those who completed these jobs, for instance a disabled individual known as Rymer stated that for people like himself, work was part of his 'hard fight to live' to support himself and avoid dependency as well as being a source of pride (Turner and Blackie, 2018). As discussed in section 2, people who were reliant on parish support were considered a burden and so the employment of individuals with impairments was consistent with cultural values that demanded that people with disabilities remain productive where possible (Turner and Blackie, 2018).

Further unequal treatment is evident in the pensions paid to families of the dead or the wounded. By 1819, this 'Waterloo fund' had dispensed over £192,000 to wounded servicemen and their families (Forrest, 2015). The variations in amounts distributed to soldiers were enormous, prizes ranged in value from £2 11s 4d for privates to £61,000 for Wellington himself (who was even bought a Hampshire estate by the government). Not only does this demonstrate the elitist attitude that was prevalent within the military and wider society, but it also explains why artificial appliances varied between social classes. There was no specific provision made by the government to supply artificial limbs until after the Crimean War in the 1850s. It is reasonable to argue that if an officer returned an amputee, their pension would cover the cost of artificial limbs they may require; as opposed to the lower ranks who were at the mercy of a potential employer to pay them enough in addition to their limited pension pay, to help them afford a device. The experiences post-Waterloo of the Marquis of Anglesey for instance demonstrates the ease at which a wealthier impaired individual could reintegrate into society. Perhaps the lack of employment opportunities and poor wages in the roles that were available to these ranks contributed to the likelihood that a lower-ranked soldier would not be able to afford an artificial limb and instead would resort to constructing one themselves, from materials such as table and chair legs.

Syeda (2019) argues that the amended Vagrancy Act of 1824 is ultimately what caused the most damage to these mutilated soldiers. Many roles were no longer available and it became a common sight to see ex-soldiers begging on the streets. Destitution was rife in London with Jarrett (2012) claiming that people were warned about frequenting certain areas at night as they risk being 'knocked down with the crutches of beggars' (25). Although the act did prove to have opponents such as anti-slavery campaigner William Wilberforce who condemned the legislation for not considering individual circumstances surrounding the ex-soldier homelessness, it is a damning piece of evidence that sheds light on the discrimination the poor faced within an overwhelmingly elitist society. The homelessness of many wounded ex-soldiers seems to have been perceived as collateral damage of war, with limited attempts to find a feasible solution to the growing problem.

By considering how lower-ranked soldiers were treated upon their return we begin to understand the perceptions that people had of them, particularly impaired individuals. On the face of it, the media was discussing the overriding topic of national pride yet examples such as protests, lack of employment and poor standards of living as discussed above portray a different story. Whilst advertisements promising to enable an easy return to work for those who were impaired, via the use of prostheses, suggest an acknowledgement that people desired and needed to work. The lack of jobs as well as an increased number of impaired homeless people ending up in poor houses (Jarrett, 2012), tells a different story to the romanticised version nineteenth-century media presents. The peak year for workhouse inmates was recorded in 1818 by Henriques (1968: 370) - the same year remaining soldiers in France made their way back to Britain. There was also a rise in crime and inmate numbers at workhouses, during the immediate aftermath of Waterloo, which demonstrates the dissatisfaction and displacement within society that many felt in Britain at this time. Soldiers of certain classes may have been perceived as heroes but there existed an inequality which left some less likely to find employment.

However, it would be wrong to suggest that society at this time was not used to impairments and physical differences. In fact, the wide spectrum of impairments that did exist would have been a lot more common in everyday life, in part because the medical understanding and treatment was not available to treat individuals and so illnesses such as the contagious polio, could progress to cause further more serious ailments, such as paralysis. Likewise, particularly during the industrial age, mutilating injuries during employment, such as in the mining industry were also increasingly common amongst certain societal groups. There is evidence to suggest that injuries that created physical impairment was a relatively common incident, that it couldn't be as sensationalised in the media as a workplace death for instance. For example, the geologist Henry de la Beche for instance, told a House of Lords committee discussing coal mining accidents in 1849, that the number of fatal accidents was ‘very considerable’, however, the number that involved the maiming of men was much larger and that as they did not ‘excite the notice which is occasioned by explosions in the larger collieries...a great many men are disabled who are never heard of... subsequently forced into dependency on poor relief.’(Turner and Blackie, 2018).

Turner and Blackie (2018) note that a miner was statistically likely to be involved in an accident that left them maimed every two hours, which would suggest that within some communities such as the lower classes, maimed and disabled men would have been visible and accepted as daily occurrences. If every man who was maimed was written off by employers as unemployable and this happened every two hours, there would soon have been a shortage of staff. Military-based injuries therefore that caused physical impairment, whilst possibly rendering the individual no longer fit for military service, would not have necessarily prevented a civilian line of employment, particularly during a period of mass industrial expansion which undoubtedly necessitated more staff. It is therefore likely that those who felt able to work, would have pursued employment for as long as they were capable. It is also interesting that with industrialisation and the increase in employees this necessitated, there came an increase in hazardous roles and subsequent accidents which would eventually lead to policy innovations such as health and safety regulations, age restrictions and medical institutions catering for specific populations (Turner and Blackie, 2018). It is suggested therefore, that the increasing visibility of disability during the nineteenth actually began to highlight social divisions and develop class consciousness. Therefore those that experienced disability within the lower classes, may not have been as prejudiced against by their own communities, as those who were more inclined to conceal their disabilities in wealthier groups.

2.6 Constructing Physical Wholeness as a Norm During Nineteenth Century Britain

During Victorian Britain, medical retailing played on notions of physical wholeness as an ideal and a norm. Conversations surrounding what physical normalcy looked like also entered the realms of both academic and also fictional literature. *Enforcing Normalcy* (1995) by Lennard Davis, illustrates the construction of ‘normal’ as a concept, by demarcating disability as a ‘negative’ in comparison to the ‘positive’ of an able-body. This notion was constructed during Britain’s industrial age, a time when ‘bodily statistics’ were used to describe the optimum man (Sweet, 2016). Lambert Adolphe Quetelet for example, came up with the concept of 'l’homme moyen', or the average man, in his influential 1835 text, *A Treatise on Man and the Development of His Faculties* (Sweet, 2016: 53).

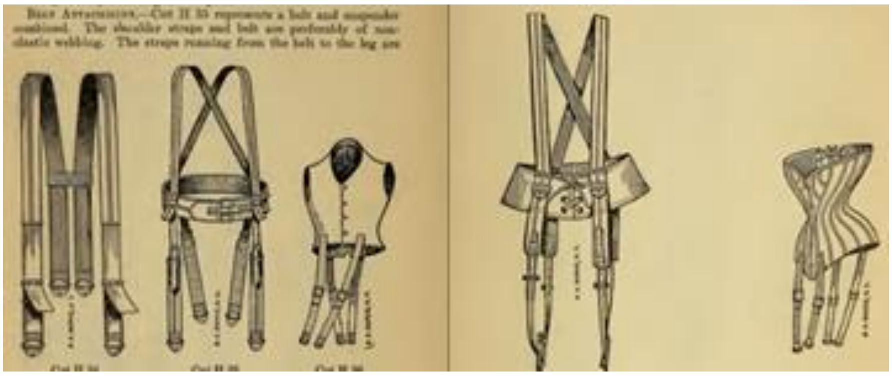
The words describing ideas of the ‘normate’, ‘normal’, ‘normalcy’, ‘normality’, ‘abnormal’ and ‘average’ all only entered European languages in the mid-1800s (Kelly, 2019: 6-7). Understanding the difference in beliefs surrounding concepts of the ‘norm’ versus the ‘ideal’ body during the nineteenth century helps to understand the origins of the conceptualisation of a ‘norm’ body. Unlike that of an ideal, the norm implies that the majority of people should somehow meet this and those not doing so highlight undesirable deviations. This deviation from the norm is where physical differences are highlighted and therefore where people with impairments are situated. Contrastingly, the ideal as a concept is therefore unachievable and no one has this status, many ideal bodies represented in the art are often fragments of a variety of women or men combined to create this perfect, almost ‘divine’ creation, a fiction.

Prostheses narratives have offered other perspectives by presenting prosthetic body parts as 'faulty' devices unable to provide a convincing impression of wholeness. Sweet (2016) suggests that prostheses narratives whilst exposing the need for 'wholeness', simultaneously highlight physical completeness as an idealistic fallacy, 'unattainable for many and unsustainable for the majority' (2016: 51). Much like today, popular opinions and beliefs in the nineteenth- century were often driven by the media, including local or national papers, poetry, songs and literature. Literature in the form of academic and fictional publications provides comparisons of the values and beliefs of a society and the people within it (Eagleton, 1983). Academic literature reflects the cultural and contemporary scientific beliefs, providing descriptions, images and symbols that convey cultural messages in a way which we understand today (Eagleton, 1983). Contrastingly, works of fiction communicate the ideas and values of everyday culture, beliefs and traditions with myths and legends, acting as methods that pass on moral lessons, and understandings of rights and wrongs (McCollum, 1998). According to Rankin (2009: 5), the most common depictions of disability in literature are stereotypical and dehumanising.

Representations of prostheses in historical literature do not depict them as successful medical cures to physical differences, rather that they encourage the reader to question the logic of prostheticising as a solution to physical loss. Those writing about or illustrating prosthetics did not have to mock the failings of those who were physically 'different', but rather simply remark on the accepted standards of a 'normal' physique. For example, Charles Darwin completed a study on the ideals of fitness (Evolutionary Fitness in Origins of Species, 1859), which acted as a method of highlighting what was physically normal, and in doing so added to the anxieties that being abnormal presented. At a time when physical impairments within society caused panic, to be deformed or considered as deviating from accepted norms was justification for ridicule (Falk, 2012). This was a result of a belief which portrayed physical impairments as a result of the laws of God and moral failings. If a person – particularly those of lower social standing – didn't fall into the ideals of normalcy they were considered the 'other' and being an 'other' automatically led to conclusions of unproductiveness, infertility, and idleness of the individual within society.

Consigning those with disabilities, both physical and mental, to subordinate positions in society during the nineteenth century, by illuminating their differences in cartoons and songs, led those occupying the 'physical norm' in society to have an elevated belief in their dominance as they were able to separate themselves physically from the 'other' (Falk, 2012). Being in any way associated with the 'other' was cause for concern and anxiety, and explains why amputees would have attempted to remain anonymous and why we see prostheses manufacturers at the time exploiting the marketing tool of anonymity.

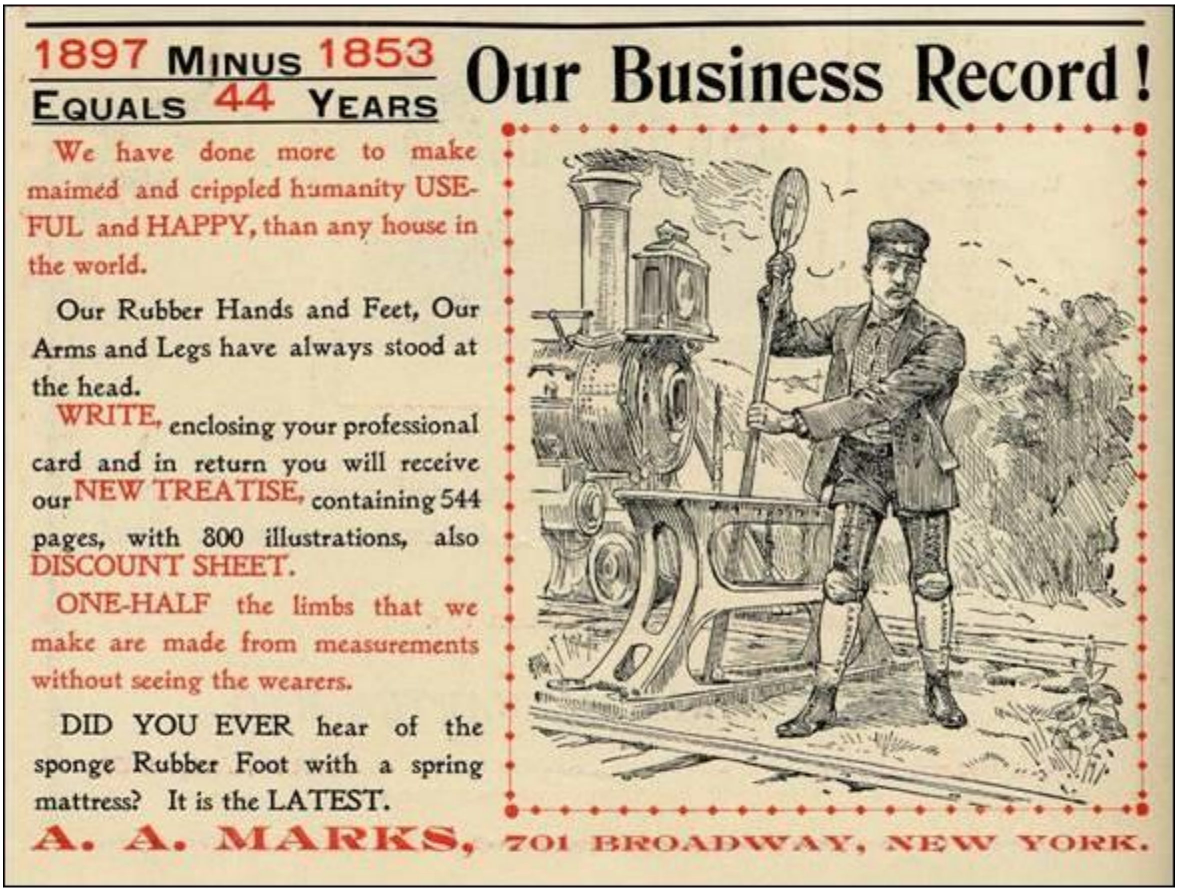
Anonymity benefited those with impairments because it provided them with a mask to present to society showing that they upheld the Victorian ideals of health. Amputation and prosthesis opened up cultural tensions about what bodies can and should look like and designs changed frequently to accommodate appearance preferences. For example, whilst section 3.2-3.4 discusses lower-limb designs and how they are attached to the body in more detail, figure 2.11 displays how some artificial leg designs secured to the body and how these changed from the typical peg leg thigh strap attachment to suspender, corset and vest methods (fig 2.11) all being trialled for the more sophisticated appliances. There was a growth in disparity during the nineteenth century between the appliances available to the wealthy and poor, what was attainable to both, and the achievability of concealment increasing with the wealth of the client. In terms of perceptions, this suggests that the higher up the social ladder you were, the more possible it was to conceal a disability due to the increased availability of appliances.



(Fig. 2.11. Various attachments for artificial legs that had been available during the latter nineteenth century as described by Marks, 1907: 97)

Academic essays from the nineteenth-century comment on physical wholeness and the prejudices that accompany physical loss, ideologies that often became strengthened through their similarity to biblical principles of God’s creations being perfect. For instance '…a beast with one eye…we should without enquiry, decide it to be a monster and turn from it with abhorrence…' (Payne Knight, 1805 in Sweet, 2016). People who deviated from the physical norm of a whole body created by God must have harboured invisible impairments or have family histories of sin which manifested as physical aberrations. Sweet (2012) explains that psychiatrist Henry Maudsley (1874: 43) agreed there was a link between the body and the mind, claiming that those with physical differences were more likely to be mentally abnormal and display unusual behaviours. An example of negative perceptions toward disability is highlighted in the late nineteenth-century begging laws which were supposedly introduced to protect women from having to witness the physically different, often dismembered, beggars. Women were considered incapable of being able to cope with witnessing the physically disabled and could have seizures or hysterical outbursts as a result (Schweik, 2009: 153).

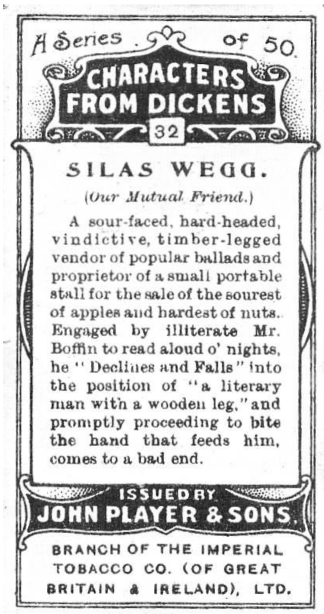
Likewise, under the 1834 Poor Law, fears of people, particularly men, seeking relief that did not fully ‘deserve’ it (Stoddart Holmes, 2004), made it extremely challenging to access aid and generated further questions about what an ‘able-bodied person was, with many being sent to workhouses instead. The threshold for what was considered physically able was changeable and vague, therefore inability would often be ascribed to idleness.



(Fig. 2.12 A. A Marks advertisement for their new rubber foot with springs 1897 demonstrating the ability to work on the railroads with their limbs aimed at the working classes, stock image from google)

(Fig. 2.13 Advertisement with a wealthy individual being sold a sophisticated Anglesey style leg and ultimately regaining sophistication and respectability, image courtesy of Mary Evans Online Picture Gallery, https://www.maryevans.com/ accessed 12/06/2017)

Lower limb prostheses are the most common prostheses depictions found within contemporary fictional writings. Dickens, Melville and Conan Doyle all developed characters who wore artificial legs, and they are often portrayed in a manner which demonstrates the failure of their appliance in some way. Legs that fall apart or cause great difficulty for the wearer to walk, due to the heaviness of the material used to make them, demonstrate to the reader an acknowledgement of artificial leg usage, with a negative perspective surrounding their efficiency and opinions of those wearing them. Comparatively, there was a romantic fashion of escapism (Eagleton, 1983) apparent in the literature of the Industrial Revolution era. For instance, Dickens presents characters with disabilities such as innocent Tiny Tim in *A Christmas Carol* (1843) whose personality epitomises the antithesis of his experiences of a challenging industrial life. Dickens used physical abnormality to emphasise a character's immorality, such as the one-legged Silas Wegg in *Our Mutual Friend*. Wegg is portrayed by Dickens as a villain and social parasite, who wants to buy back his artificial leg to complete himself and be seen as respectable (fig. 2.14) (Ihara, 1998). Representations such as these, reflect existing societal fears as well as propagate fears of physical loss, detailing transgressions and prejudices that coincided with limb loss – limb loss and criminality, for instance, discussed below. Observations of nineteenth-century representations of limb loss and disability, demonstrate the tension between the positive and negative depictions of impairment. Amputees or those with other impairments are often linked to criminal or negative behaviour in fictional writing from the time and reflect existing societal tensions surrounding the connection between physical impairments and criminality for instance. Observations of nineteenth-century representations of limb loss and disability demonstrate the tension between the positive and negative depictions of impairment. It is argued here that how artificial limbs were represented and stories about their wearers were communicated to audiences, contributed to the societal perceptions that were formed during this time.



(Fig. 2.14 *Silas Wegg*, J. Clayton Clarke ('Kyd') 1910, Watercolour reproduced on John Player cigarette card no. 32, Scanned image and text by Philip V. Allingham, online at https://victorianweb.org/art/illustration/kyd/47.html last accessed 29/03/21)

The fear of the disabled, as evidenced above, could be said to have been partly driven by the increased mechanisation during the nineteenth century as a consequence of the Industrial Revolution. Not only did these new machines create more risk of physical injury within employment but also more competition to prove an individual's employability. A combination of the fear of the physical consequences of mechanisation (such as injury) with the physically impaired, who resulted from and came to represent this growth in technology crept into fictional literature, disguised within stories with discussions of fear and resistance to mechanisation. This 'technophobia' prevalent with the Luddites (1812-1817), saw the rise of the machine as the cause of physical and social injustices inflicted upon society, as a result of machines taking the place of people in factories. Whilst this technophobia was relatively short-lived and primarily focussed on factory machines, a concern for the growing meshing of humanity and technology endured. This was evident in nineteenth-century writings.

Edgar Allen Poe's 1839 story of *The Man That Was Used Up*, is an example of the anxieties surrounding the dehumanising effect of man, merging with a machine, causing people at the time. One of the characters is described as a maimed man, reassembled almost entirely of prosthetics, many of which not only conceal his physical losses but improve upon the natural ones. The narrator describes the character in amazement, before the knowledge of this prosthetic nature, acknowledging posture, perfect teeth, hair, eyes and arms all in a positive light, only later to discover these are artificial. However, Sweet (2012) explains that despite the impressiveness of the prostheses, the story is more concerned with the relationship between the human and machine, questioning when a man becomes more machine than human, how this affects personhood and who is in control, the person or the devices? The terminology of the title of the story is important because words have changed their meaning throughout time and so where today, we may interpret this title in one way, the notion that someone was 'used up' during the early nineteenth century had a different connotation which could mean 'to debunk' or 'critique' (Berkeley, 2004: 372). The title, therefore, describes a man who is both physically reduced and whose personhood is put into question; the 'passive verb construction implies the man is not a user but an object of use by something' (Sweet, 2016: 109). Vanessa Warne (2009: 104) adds that stories such as Poe's, '…anticipates the developments in design, manufacture and marketing of prosthetic body parts, accurately envisioning the commercialism, technological character and normalising…' of post-war veterans. The publication of literary sources portraying the negatives of physical difference runs parallel to the growth in industrial manufacture and artificial limb manufacture and demonstrates anxieties surrounding the physical merging of machine and person. The goal of these popular media pieces was to challenge the dominance of the prostheses wearer by making it clear that the use of these artificial parts does not conceal physical loss, rather they act as a mechanism from which perceptions about the individual wearing them are generated.

Evidence of people engaging in criminal acts, vagrancy and unemployment rates all saw huge increases after the Napoleonic Wars, and those with physical disabilities were the first casualties of the impending economic crash that occurred after 1815 (James Marten, 2012). This suggests that whilst popular media and fictional writings helped to fuel concerns amongst society, they were also commenting on current affairs. With this trend, it is possible to argue that the mass demobilisation of soldiers after conflicts contributed to mass unemployment rates, and with this an increase in crime rates, which also explains why both the academic and fictional literature of this time tends to draw links between criminal behaviour and impairment.

Manufacturers made outlandish claims that their limbs would ‘rebuild’ maimed amputees. For instance, Gray (1857) discusses the proficiency of his appliances by referencing famous wearers such as the Marquis of Anglesey and providing their affidavits of his substitutes. The promise of a more normalised working life, social security and social mobility was played upon by artificial limb manufacturers. For instance, the claims that manufacturers made have examples where potential wearers coming from places like Milan to acquire a limb that was '…so perfect…that by it he was enabled very readily to button the wristband of his shirt with his right hand, draw on his boots, carve his food, ride and drive, and perform a great variety of things…' (Gray, 1857: 98). Likewise, Gillingham’s (1888: 35) artificial limb manuscript acts as a sales catalogue, describing exactly how excellent his appliances are, who has worn them and their successes with them. The promise of a more normalised working life, social security and social mobility was played upon by artificial limb manufacturers. O’ Connor contends, 'The discourse of prostheses is . . . infused with class consciousness, suggesting that man cannot occupy a meaningful social position unless he is physically complete' (2000: 130). Manufacturers regularly insisted upon the social disadvantages of amputation as a way of bolstering the capacities of their devices. According to Sweet (2012: 160-161), many claimed they '…could mask the appearance of impairment (thus alleviating the stigma and social degradation) while allowing a wearer to maintain the same job and standard of living that s/he enjoyed before their injury.'. Warne (2008) has argued that the unwillingness to be identified as an artificial limb user was extremely common. As LaCom concurs; 'Those unable to meet industrial workplace standards because of a disability or deformity were increasingly exiled from the capitalist norm, which demanded 'useful' bodies, able to perform predictable and repeated movements' (2005: 548).

Sound limbs became the main part of a working man's capital, so to protect and conceal them as much as possible was in their best interest to reduce the 'risk of irrevocable diminution' (Reeve, 1971: 186, in Sweet, 2016: 155). Jamie L. Bronstein writes, 'For workers, injury lasted as long as it kept one from returning to the same or a similar job at the same pay rate' (2008: 96). The social model of disability has identified that stigma and exclusion within a typically 'ableist' society, impacted on the social opportunities of the impaired (Sweet, 2016).

It is almost certain that the fictional portrayals observed in contemporary literature were informed by the social and cultural views of artificial limbs, which is why we see their depictions throughout the century change in various ways. It cannot be concluded that these portrayals impacted designs produced, but literature discussing the prosthetic body to render it complete, impacted how artificial limbs were marketed to wearers. One distinguishing characteristic that manufacturers of specialised artificial limbs promoted, was the concept that their artificial limbs would not render the wearer socially immobile or ostracised by their specific class, on the basis that their limbs were discreet and unidentifiable when worn. The social model of disability has identified that stigma and exclusion within a typically 'ableist' society, impacted the social opportunities of the impaired (Sweet, 2012).

Gray (1857) claimed the more sophisticated manufacturing techniques involved in the production of the Anglesey Leg variations, however, meant the resulting cost of the item left them out of reach for working-class men. Gray explained (1857: 107) '…I will state my regret that, from the expense entailed by their elaborate construction, they are not within the reach of the poorer class of sufferers. This is the more to be regretted because in the case of the affluent the loss of a limb does not reduce the sufferer to a state in which his relative position in life is rendered worse, whereas, when a poor man becomes crippled, he is reduced to a state of almost perfect destitution and misery…'. Consequently, their use was confined militarily to the wealthier commissioned officers, rather than privates.

Despite there being no real accepted method of production, nor monitoring of production, there existed some form of expectation and respect for what was being produced. The men cared for at Netley Hospital, set up by Queen Victoria in 1856, ranged in social status but those who received Anglesey Legs at the queen's expense were often Privates and Non-Commissioned Officers. Presumably, this was because men of this rank were less likely to afford their own Anglesey Leg and the Queen was engaging in a charitable act. For instance, the queen commanded Henry Bigg to produce an Anglesey Leg variation for Private R. F. Cooke of the Army Medical Corps (fig. 2.15) who had been shot in the foot following an ambush by the '…Arabs…four miles south of Tamai.' (Bigg, 1885: 51). He was provided with an Anglesey leg by Bigg after which he was described by Bigg as being able to '…walk most admirably, and is following his trade of paper-hanger, to which he was apprenticed before entering the service…' (Bigg, 1885: 51). This example by Bigg is not unique, in his book, he writes of other men who received his help at the queen's expense, however, it must be noted that these were relatively rare and exceptional outcomes for most men of this standing. In reality, most soldiers who started life in lower classes or poorly paid jobs would have been issued with mass-made government-supplied military appliances such as the box, socket or bucket legs (chapter 3).

(Fig. 2.15 Private R. F. Cook in Henry Bigg 1885: 50)

Warne (2008) makes note of an 1863 essay written by Oliver Wendell Holmes Sr who offers insight into how amputees in different social groups bought artificial limbs. 'A plain working man, who has outlived his courting days and need not sacrifice too much to personal appearance, may find an honest, old-fashioned wooden leg, cheap, long-lasting, requiring no repairs, the best thing for his purpose. In higher social positions, it becomes important to provide the cripple with a limb that is presentable in polite society, where misfortunes of a certain obtrusiveness may be pitied, but never tolerated under the chandeliers.' (1863:574).

The term 'artificial limb' during the nineteenth century was only associated with prostheses that could imitate both the appearance and movement of a natural leg and were not inclusive of rudimentary style peg legs. Marketed as more comfortable, safer and more aesthetic, these limbs often included articulated joints to emulate natural gait. They were also made to measure and therefore costly; around £26 5s 0d (the equivalent of around £3100 today) for an Anglesey whereas a peg-leg is recorded as costing £1 10s 0d (£100 today) (Gillingham, 1888: 10).

2.7 Social Divides of Walking

Another important factor that would have challenged the reintegration into society and employment for an amputee wearing an artificial limb, would have been the use of their limb over specific terrains and in different weather conditions. Laporte (2000) discusses the history of sanitation suggesting that Victorian London was infamous for its pollution and disease-ridden streets. The growth in industrialisation saw cities saw population booms and therefore diseases became more easily spread. Jackson (2014) describes London during the nineteenth century as ‘swamped with mud, composed principally of horse dung, forming a tenacious, glutinous paste; air peppered with soot, flakes of filth tumbling to the ground…the distinctive smell was equally unappealing…stale fruit and vegetables, rotten eggs, foul tobacco, spilt beer, cart grease…damp straw.’ (1). Despite London’s financial and mercantile superiority, it was infamously filthy and although the Victorians had been proactive in their approach to sanitation – investing millions into a modern network of sewers - considering cleanliness as the ‘hallmark of civilisation’ (Jackson, 2014), their response to the state of London was ‘apathetic’ (Krout, 1897).

Riello, (2006: 49) quotes records from the time which suggest street debris, at times, could be over a foot deep. Horses were left to defecate in the streets, Louis Boilly in 1804 best captured the state of the streets in his L’averse painting (fig. 2.16). The picture depicts a middle-class family paying to cross a muddy street by walking on a plank of wood laid down by a ‘ruffian’ (Turim, 1993). It was not just contaminated streets that were a problem, but the polluted air that also made moving around the streets of inner cities such as London, unpleasant and undesirable.

Streets were thick with fog because of noxious factory gases and domestic coal fires, Corton (2015) discusses the thick fog of the 1880s and 1890s. Wallace (1993), in her study of walking as portrayed in English literature and mimicked by Riello (2006: 46), suggested that walking was not considered healthy and those who could afford to be transported via carriage would be. Walking was for the ‘poor, criminal, young and above all, ignorant’ (Jarvis, 1997: 23). Unsurprisingly, due not only to the conditions of the streets but also the crime rates, walking was considered unhealthy and unsafe (Riello, 2006). Walking became associated with certain people, according to Riello (2006) the ‘populace and plebeian classes’ and consequently, walking developed class and social connotations. The concerns that arise for this research, are the challenges that walking in urbanised spaces could pose and therefore the added issues that an artificial leg could cause. Wooden feet or pegs, as with both limbs under investigation here, would have created a potentially slippery surface with little grip.

Likewise, the mud and grime from the street would have hastened the decomposition of the wood, increasing its chances of breakages and ultimately shortening its lifespan. Whilst both the Anglesey leg and box-leg designs were wooden at their bases, the poorer classes who were likely to wear the box-leg designs, were also likely to walk more than wealthier classes at this time, who would have opted for carriages. Consequences of this may have been a faster degradation of appliances for the working classes, who were less likely to be able to afford new ones frequently. This may explain why we see evidence of working-class individuals repairing their appliances over several years as opposed to discarding them if they became damaged. Contrastingly, wealthier individuals were less likely to walk on their appliances for extended periods, particularly avoiding areas of cities which were dirty, meaning their appliances - which were probably better quality initially, due to their materials, mechanisms and costs - would last longer despite these owners being able to afford to purchase appliances more easily and frequently.

(Fig.2.16 L'averse, 1804, Louis Boilly, Turim, 1993)

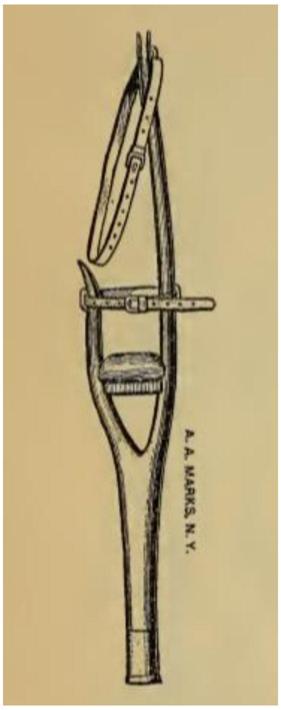
Key to this research are class and social divisions, which influenced the need to walk as part of daily life and the length of time the appliance would have been in daily use, would have affected the lifespan of the artificial appliance and therefore the reintegration of individuals of different social classes into society. Despite the health benefits that were associated with walking, the wealthy only did so in what was considered safe and hygienic environments such as public parks (Clark, 1973) which were created to bring the benefits of the country into towns. Of course, long working hours that were associated with industrialisation and factory jobs would have prevented many poorer members of society from enjoying the benefits of these parks, largely built in wealthier areas of towns and cities.

Chapter 3: Peg-leg

3.1 The Origin of the 'Peg-leg'

Little information is available on the origins of peg legs. Cantos (2005: 17), in an examination into the history of amputation and prostheses, claims peg legs were first seen in antiquity along with crutches. However, it is not until 1669 that we first see the term peg-leg connected to medicine and used as a way of describing a 'pin of wood' to aid walking (Whitelaw, 2005 Warne, 2008). The term peg has sixteenth-century Dutch origins 'pegge' or 'pegel' meaning watermark or rod, it is thought these originate from the term 'peil' or 'pie' which refer to a 'staff being used for support'. The term peg-leg itself is a broad, colloquial noun often placed in connection with criminals and pirates, particularly within nineteenth-century fictional literature. The nineteenth century is when we begin to observe negative connections between those who were physically different and those who were perceived as 'normal'. As demonstrated in chapter 2, novels such as Our Mutual Friend, propelled and promoted an unrealistic paradigm which saw peg-legged amputees portrayed as greedy, ignorant and intemperate (Warne, 2008). One contemporary amputee singles out authors Thackeray and Dickens, arguing that the magnates of literature went out of their way to fling stones at the ideal wooden-legged man (Warne, 2008: 32). Much like the ancient myths, peg-legs and prostheses in nineteenth-century literature are a topic of fascination, however, these stories are riddled with missing pieces and fabrications that leave the reader uninformed and biassed.

A. A Marks (1905) describes various types of peg-leg variations available during the nineteenth- century, including their materials (Fig. 3.1) ‘the simplest and least expensive form… consists of two wooden branches, one running up on the outside of the thigh, well up on the body, the other on the inner side reaching nearly to the crotch. These branches unite below the point of bearing and continue to the ground, terminating in a rubber tip. A padded shelf is placed between the branches on which the knee rests when in a flexed position. The leg is held in place by leather straps passing around the thigh and body.’ (Marks, 1905: 70). Marks also discusses how often they should be used and any problems that can occur through overuse; ‘We disparage the use of peg-legs, as we are keenly alive to the fact that they are inadequate to meet the demands that must be put upon them. Any form of peg-leg that will keep the knee joint in a flexed position is liable to weaken the tendons of the knee, impair the knee movement, and limit its range of motion. They should, therefore, be used only as expedient.’ (Marks, 1905: 71). As with Bigg’s claims, the concerns raised by Marks will also be under investigation during the biomechanical analysis in chapter 5.



(Fig. 3.1., A. A Marks 1905 Peg-Leg variation)

This chapter will discuss and describe the three government-approved legs that were available to soldiers after amputation, as mentioned by Bigg (1885). All three take the form of peg-leg and mirror styles that were created by manufacturers for private civilian sales and designs by individuals who constructed their own from household materials. Their designs are simple, lack sophisticated engineering and are not aesthetically similar to a natural leg shape. Based on Bigg's claims above, that artificial limbs were allocated to soldiers based on social status, the designs illustrated below suggest the intended recipients were those of a lower social class. The three government-supplied military legs that have been chosen, also demonstrate the various levels of understanding those charged with producing these items understood about amputation (particularly as a result of military trauma).

3.2 Bucket Leg

The Bucket Leg was a government leg used with amputation at or above the knee and according to Bigg (1885: 103) 'known to nearly everyone'. It consists of a wooden bucket (hence its name, fig. 3.2) which receives the remnant of the thigh and into the lower end of this, there is a wooden peg on which the patient walks, or, as Bigg describes the movement 'stumps along' (Bigg, 1885: 103). The majority of the weight of the user is taken by the bucket into which the remainder of the thigh stump is placed, meaning no direct weight is placed on the remaining ischial tuberosity or sitting bone at the end of the stump. Interestingly, Bigg identifies the external shape of the bucket as a real turning point in prostheses and claims that it allowed the weight to be taken entirely from the stump to the wooden support. He also notes that the internal shape of the circular wooden bucket should be carved into a triangle to fit around the thigh stump and not circular as 'one would have originally presumed' (Bigg, 1885: 106). The bucket was held to the body by a leather body strap which passed through a loop at the top of the outside aspect of the bucket, if the stump was particularly short, a leather strap that attached like a belt around the waist was also used.

(Fig.. 3.2 Amputee soldier wearing a peg-leg in the 'bucket leg' design, Bigg, 1885: 108)

The peg of the bucket leg is fixed directly into the lower end of the bucket. Records suggest the wood used was likely to be oak or ash, both are hardwoods and would have been widely accessible during the nineteenth century. Bigg (1885) explains that the angle or pitch of the peg on the bucket was most efficient for the wearer during their gait stride if it was angled a little outwards rather than straight down. The axis of the joint is identical to the axis of the natural hip joint which means that the bucket is held, whether in sitting or standing, close up to the stump and unfortunately due to a lack of knee and ankle joints and the rigidity of the wood, it was likely to protrude forward rather uncontrollably. 'The whole limb from hip-joint to the end of the pin being rigid and straight. The inconvenience of this in travelling by omnibus or railway, where passengers have to pass one another, can't be easily imagined, and this convenience is to a greater or less extent felt whenever the person is seated.' (Bigg, 1885:107). One way of improving this issue was discussed by several prominent manufacturers during the nineteenth century, including Bigg (1885), Palmer (1880), Marks (1907) and Gray (1857) who all suggested adding a knee-joint with a spring catch to it. It was hoped that when the patient sat down the spring in the knee would shorten causing the knee joint to flex/bend. Similarly when the knee was in use for walking the knee was extended and firmly notched by the knee catch. Bigg argued that all soldiers be fitted with a prosthetic of this style because of the benefit it would provide to their health and potential future employment. The style described, has many similarities to the Anglesey leg, suggesting there was a belief that this style was superior and had fewer complications for the wearer. These assumptions will be tested and form part of the investigation in chapter 11.

Many prosthetists of the day would comment on the number of patients who would suffer ulcers, blisters and infections on their skin as a result of constant pressure and rubbing as a result of the contact between the amputee's stump and the prostheses socket ('bucket' in this case). On December 29th 1854 one amputee wrote to prosthetist Frederick Gray of the troubles experienced through the use of a peg-leg; '…in the peg-leg, pressure in my case was taken on the knee; this always caused pain and excitement to the parts, and I believe to be dangerous, in as much as blisters and broken skin were a continual annoyance.' (Gray, 1907: 205). One attempt at combating ulceration was to pad the stump with cloth and linen, another was to construct the bucket from leather instead of wood, the leather was lighter and more flexible, Bigg (1885) even suggests that it would cling to the fleshy surface of the stump more efficiently without causing friction burns. It is important to note that prosthetists still struggle with skin problems as a result of ill-fitting sockets and have developed ways of securing the prosthetic directly to the residual bone instead, although this has concerns of its own (Ott et al, 2007).

There were four key measurements required to manufacture the bucket leg; firstly, the circumference of the thigh as ischium – giving the size of the top edge of the bucket circle. Secondly, the circumference of the end of the stump. The stump is presumed to taper downwards, however, it is noted that if an abnormal shape of the stump occurred it would have to be noted and the size and situation of any swelling given. Thirdly, the length of the residual stump so that the bucket may be made long enough. Finally, the length of the inner thigh stumps to the ground so that the artificial leg would correspond in length to the sound limb. It would also be recorded which leg was sound and which needed an appliance. Bigg concludes his list of requirements by adding that a trace of both legs (sound and amputated) may also have been beneficial to the manufacturer but not imperative.

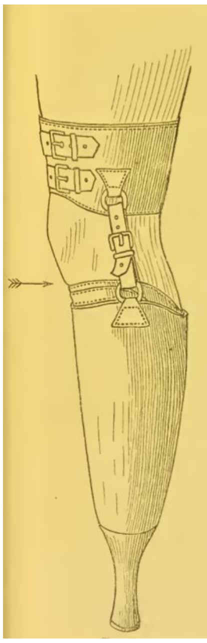
This bucket type of leg was considered a strong and durable prosthetic, most suited to men who had been amputated at the femur or knee joint and who sat socially within the working class, 'for those who are compelled to be careful of their pockets and careless of appearance' (Bigg 1885: 108). It could be argued therefore that the purpose of this leg was not one of aesthetics but one of function, albeit a basic, minimal function of getting from A to B. Records that survive suggest the wearer had a gait which did not mirror that of a natural bipedal stride, instead, they would 'stump along, as with all peg-legs, in great pain' (Gray, 1857:135, 195).

The problem that this form of peg had, according to Bigg, was that it did not clear the ground when the wearer took a step forward, it consequently swung away from the wearer and thus created a habit of sweeping the leg around which was 'difficult to break' (1885: 106). It was suggested in the early 1800s that when a patient required prostheses after an amputation, they should initially learn to walk again with the aid of a peg leg (Warne, 2011).

If Bigg's suggestion that the use of a bucket leg altered the wearer's gait is correct, this suggestion of learning to walk again through the use of a peg leg was potentially a damaging one, that may have affected the long-term aftercare of a large number of military amputees. For instance, some poorer soldiers were provided with peg legs - like the bucket leg - immediately after their amputation, and they became accustomed to how it affected their stride and naturally began to compensate for their movement to make it less painful. As they had learnt to walk with a peg-leg variation, they would often swing their leg around (Bigg, 1885) in what today is identified as a 'transverse rotation' (Twiste and Rithalia, 2003). Because of this, Bigg argued that supplying amputees with peg legs was a mistake (1885:107). Transverse rotation is now known today to cause complications such as osteoarthritis. Examples like this allow a picture to be built of the detrimental effect some of these prostheses caused, but also evidence for the understanding of the anatomical effects of prostheses during the nineteenth century. For instance, at no point in Biggs description of the altered gait does he identify and label this leg swing nor does he suggest why it is detrimental to the wearer, he notes that it is different to what is expected during gait, identifying it as non-optimized prosthetic gait, but he does not go into great detail as to how this might then affect the wearer.

3.3 Socket Leg

The socket leg and bucket leg are very similar, with the socket leg being a smaller version of the bucket leg and primarily used for trans-tibial rather than trans-femoral amputees. It is composed of a wooden bucket socket where the tibial stump below the knee-joint is placed, the thigh is secured in position with a leather strap (fig. 3.3). Whilst this limb is very simple to construct, problems arise for the wearer because its form prohibits much weight bearing. Bigg elucidates that as weight cannot be placed on the stump, the wearer naturally attempts to bear weight on the tibia 'just below its tuberosities, where it swells out and is wider above than below, becoming wedge-like' (1885: 108). As a consequence, the tibia is wedged into the circumference of the socket, constantly compressed by the weight of the body and this resulted in the wearer’s skin generating nipped and pulled, creating friction burns, blisters and sores in ‘nearly every case’ – despite attempts to pad these areas with a cloth.

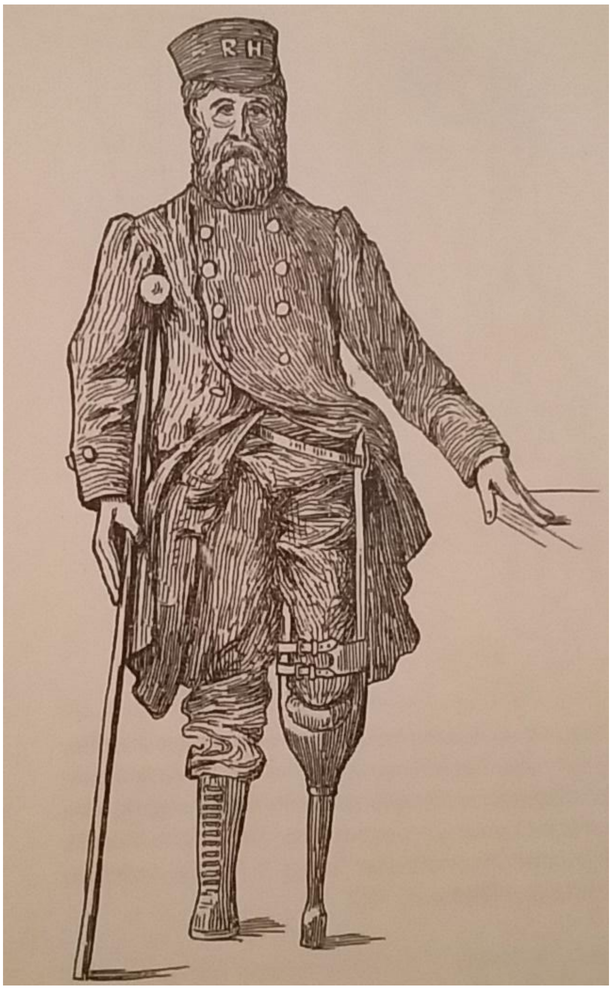


(Fig..3.3 Socket leg, Henry Bigg 1885: 108)

Hence, as a rule, the socket leg, even if carefully made, was often a failure and was consequently advised against as government-supplied appliances by prosthetic practitioners such as Bigg, Marks and Gray. After the Crimean War finished in 1856 Bigg’s father (also Henry Bigg) was commissioned by the Queen to construct a small number of socket leg prostheses for wounded soldiers which she inspected and expressed satisfaction over the final products (Bigg, 1885). However, proportionately ‘very few’ are recorded as having been constructed for the soldiers, meaning potential complications with their use such as discomfort and pain, could be rectified more easily by the manufacturer as each prosthetic was ‘personally and carefully fitted by the constructor’ (Bigg, 1885: 114). The socket leg, according to Bigg (1885) would only be of use to military patients if they could have the personal attention that civilian patients seemed to attain and this was just not possible. Bigg argues that required individual focus and personalisation on wounded soldiers was just not possible due to time constraints and the volume of prostheses required, therefore soldiers would often receive limbs which caused physical pain and long-term damage (1885: 115). Consequently, As such, Bigg ‘condemns’ the socket leg and any operations (military) that accompany it (1885:108).

3.4 Box-leg

Primarily used for amputations below the knee-joint, examples of Box-leg style peg-legs also saw use for trans-femoral amputees (fig. 3.4), In fact, the longer the stump, the more 'inconvenient' for the wearer (Bigg, 1885). The leg is described as similar in shape to that of a 'tuning fork' with the wearer kneeling between the two side supports placing weight on the peg (fig.3.4) (Bigg, 1885). The outer thigh support is about two feet long and extends up beyond the hip joint, while the inner thigh support is half the length of the outer support. The peg has the same construction as that of the bucket leg described above (section 3.2). The wearer places their bearing, as they kneel, on the lower end of the femur, the patella, or the remnant of the tibia. This leg was regarded as initially painful and taxing on the wearer but after persistent use 'quite tolerable' (Bigg, 1885: 101). One major concern for the Box-leg and how it 'attaches' to the patient, is that when a wearer has a stump that extends lower than the knee, requiring the hamstring to be permanently contracted in the kneeling position - through long-term use - the wearer would observe the leg 'stuck' in the flexed position even whilst not using the peg-leg. Not only would this be uncomfortable for the patient, but the contraction of the stump also meant that if they were eventually able to afford a different/better prosthetic, it is unlikely another design would fit as the patient wouldn't be able to adapt their new posture to it.



(Fig..3.4 Military soldier wearing 2 peg-leg variations, the one on his left leg is a ‘Box-leg’ notable due to its thigh straps, waist straps and thigh support, Henry Bigg, 1885: 101)

The thigh support which secured to the inside of the thigh was made of wrought iron, which is virtually pure iron with low carbon content (0.1-0.25%), it is therefore tough, malleable, ductile and easily forge welded – important during the nineteenth-century because the welding torch had not yet been invented (Nauman, 2004). Wrought iron was used for items like artificial limbs because although refining steel was possible from the 1600s onwards, it was expensive as the iron used for steel was imported from Sweden as it was of a higher quality than British iron. Wrought iron was strong, particularly under tensile strength, and could be easily worked but primarily, it was cheap (Nauman, 2004).

The Box-leg was secured to the body with two leather straps, one attached to the outer thigh support for extension and securing around the hips (the body strap), and the other a broad strap, passing round the thigh supports to secure the residual thigh. The leather straps were attached to the wooden peg with copper-alloy pins and nails. Many sources describe homemade peg legs using easily sourced items. For instance, Lazenby, (1993: 23) who researched ectoprostheses belonging to a nineteenth-century criminal called Maddie Brown showed ‘much evidence to suggest that the prostheses were ’homemade’, albeit with some expertise’. Warne (2008: 3) expands upon this by suggesting that the ‘lower classes would produce their peg-legs from table or chair legs and belts due to the expense involved in purchasing one’. The knee rest should have been padded by the wearer with linen and cloth otherwise it would cause a tender stump with the possibility of ulcerating the skin, therefore making it difficult for the wearer to transmit the weight of the body to the artificial appliance. This was particularly important for transfemoral amputees to generate not only more comfort but an increase in a secure fit. The addition of the leg rest for the wearer was a modification which separates it from other peg legs and one which highlights the awareness of the manufacturer’s anatomical understanding because its addition would have alleviated some of the weight of the stump from the knee. The main problem with reconstructing this type of artificial leg, along with other forms of peg-leg, is that there is limited information regarding the actual reconstruction process and specific materials being used. This is due to several reasons, primarily that many peg legs were, as previously noted, homemade with household materials. Also, they were considered to be lacking in sophistication, so records that detail the construction processes and materials used to secure sections together are largely non-existent, as such we rely on analysing surviving artefacts for unrecorded information. Unlike the more sophisticated limbs such as the Anglesey, which were patented and their materials advertised to help sell them, peg legs were not marketed in the same competitive way and therefore we have limited information regarding their manufacturing processes and specific materials used. The reconstruction in appendix B, therefore, aims to offer insight into the manufacturing process, likely materials used and in what ways they were used.

The measurements required to make this form of the artificial leg were as follows: (1) the breadth of the knee to give the distance between the two arms of the appliance; (2) the length from knee to ground when the patient is standing on the sound leg and the knee of the injured one is flexed. Interestingly, Bigg notes that in times of mass production or urgency whilst a trace of the stump can be ‘of great service’ measurement is not necessary or time appropriate (1885: 104). The Box-leg with knee rest proved to be a good cheap substitute for lower limb amputations. This appliance was most commonly used for military personnel due to its ease and speed of production, despite the better judgement of some manufacturers who suggested that the bucket leg was best suited for transfemoral amputees. Eventually supplied by the government, this design was provided to amputated soldiers for free and so despite it not being regarded by prosthetists as most effective for below or at-the-knee amputations, it was used for a variety of lower limb amputations. It is the Box-leg which will undergo a full reconstruction, detailed in appendix A which will explain the methods and materials employed in the first stage of the experiment, that of the reconstruction.

Chapter 4: Anglesey Leg

But when it came to fitting the stump

With a proxy limb – then flatly and plump

She spoke in the spirit olden;

She couldn't, she shouldn't, she wouldn't

Have wood

Nor a leg of cork, if she never stood,

And swore an oath, or something as good,

The proxy limb should be golden

—Thomas Hood, 'Miss Kilmansegg and her Precious Leg' 1840

4.1 The Origin of the Anglesey leg

The leg is also known as a 'Clapper' after the noise it makes when the toes, ankle and knee are flexed (Science Museum, 2022). The Marquis of Anglesey had gained public notoriety and fame after losing his leg in one of the last battle rounds of the day at Waterloo, with anecdotes of his masculine bravery and stoicism being popular themes of conversation at the time. After being hit in the leg with a cannon it was reported that he exclaimed to Lord Wellington, 'By God Sir, I've Lost my Leg!', at which Wellington rather calmly replied 'By God Sir, So you have!', and then both continued fighting (Warne, 2008: 34). After subsequently undergoing an amputation of his damaged leg the artificial leg he chose to wear as a prosthesis was designed by James Potts in 1800 and as a consequence of this decision and the notoriety the Marquis held, the limbs gained its own fame and became known as the Anglesey leg.

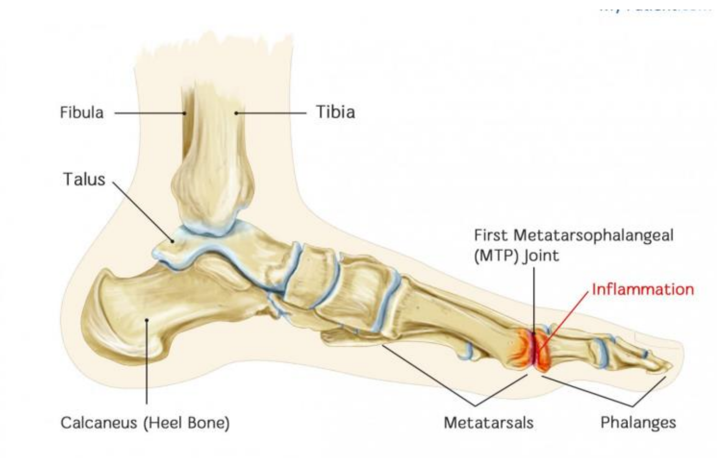
The main reference point for the research presented in this chapter was James Potts' original 1800 artificial leg patent (later colloquially known as the Anglesey leg). It provides information regarding certain materials and some processes, however, it is lacking in specific detail – not unusual for patents as inventors wanted to protect their products. Fortunately, other literature is available, including Gray's (1857) and Biggs' (1885) accounts, as well as the archaeological examples from museums which have been assessed which will help to fill in some key information which may be lacking in Potts' original description. Firstly, Gray and Biggs both identify key materials used, secondly, there is mention of some tools used for manufacture, thirdly, the way in which both sources are written illustrate an order of methodology and, whilst this may not be detailed, it does help to understand what processes came first – this in part, is aided by the use of some published diagrams. Where information cannot be ascertained directly relating to Anglesey leg manufacture, other contemporary sources have been used to offer suggestions relating to woodworking at the time, as well as the physical analysis of museum pieces.

What is clear from the accounts of Biggs and Gray is that they both identify that the Anglesey leg required a more personalised approach to manufacture than the peg leg and consequently, whilst many of the materials used are known due to their survival in museums, exact processes of production do not appear to be set in stone and instead it seems that each manufacturer had favourable ways in which they completed certain tasks. Gray (1857: 66) suggests artificial limbs should be a good and efficient substitute for missing limbs; Anglesey Legs are referred to as '…perfection…we saw...beautifully exemplified in an artificial leg made for the Marquis of Anglesey'. Whilst this account does precede a description of the manufacturing process, many details are omitted, such as how certain elements of the limb fitted together, or in what order the limb was constructed, although these omissions may have been intentionally absent in order to maintain 'trade secrets'. The Anglesey leg, cannot be analysed and understood in isolation, intricacies involving its use, manufacturers and 'celebrity status' all had to be assessed in order for a more complete picture of its place in nineteenth-century society to be ascertained.

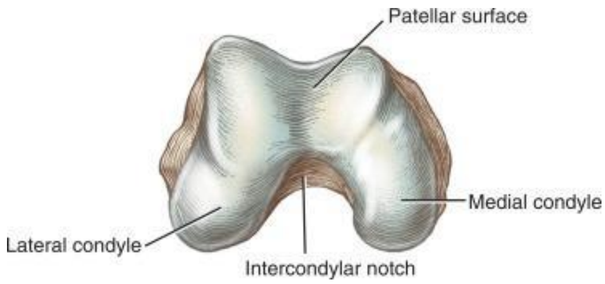
Sample catalogues from a range of manufacturers survive in libraries and archives. They focus on the Anglesey Leg, and other English patterns made upon it for a century until the First World War, which transformed it from a cottage industry to an international business. James Gillingham's (1888) 'Artificial Limbs and Surgical Appliances etc', mentioned in chapter 2, is an example of the type of catalogues that were circulating at this time. It features photographs of real amputees wearing his artificial appliances, with the contraptions not just isolated to lower limb prostheses, he also demonstrates upper limb appliances as well as orthotic equipment. Gillingham's book was created in such a way that it acted as a photographic and artistic catalogue aimed at wealthier clientèle. This catalogue was of use for this reconstruction because it presents close-up, detailed images of artificial legs including articulated variations such as Anglesey legs being worn. This provided useful information about how these limbs were secured to the wearer which is rarely discussed in the original literature, and it also confirmed the key materials used in production; wood, metal and leather.

4.2 Materials and Construction

The Anglesey Leg consisted of a wooden socket and shank, a steel knee joint, and after the Marquess' 1815 requested personalised adaptations, Potts' wooden leg became the first artificial leg to provide articulation in the toes (metatarsophalangeal joints fig. 4.1). This adaptation, in turn, permitted the wearer during their gait cycles pre-swing phase, to push off from their toes which causes ankle-dorsiflexion leading to dorsiflexion of the femoral condyles (Fong et al, 2011) (knee bending to allow the foot to raise upwards towards the shin fig. 4.2), facilitating the swing phase of the leg (Fleigel and Fleuer, 1966). This addition shows an understanding of anatomical features, their processes and functions, it also demonstrates greater care to replicate natural human gait processes for those who could afford it. Whilst the details of the reconstruction are discussed in Appendix B, the justification behind certain material choices and methods will be detailed here, based on the descriptions of Anglesey variations, noting the specific wood and metal, to the tools utilised in production.



(Fig..4.1 Metatarsophalangeal joint in the human foot and James Potts' artificial version of this in his Anglesey Leg https://www.rehabmypatient.com/toe/first-metatarsophalangeal-joint-sprain and Household Cavalry Museum [last accessed 14/04/21])



(Fig.. 4.2 Inferior aspect of the distal end of the femur, Neumann 2010, 88)

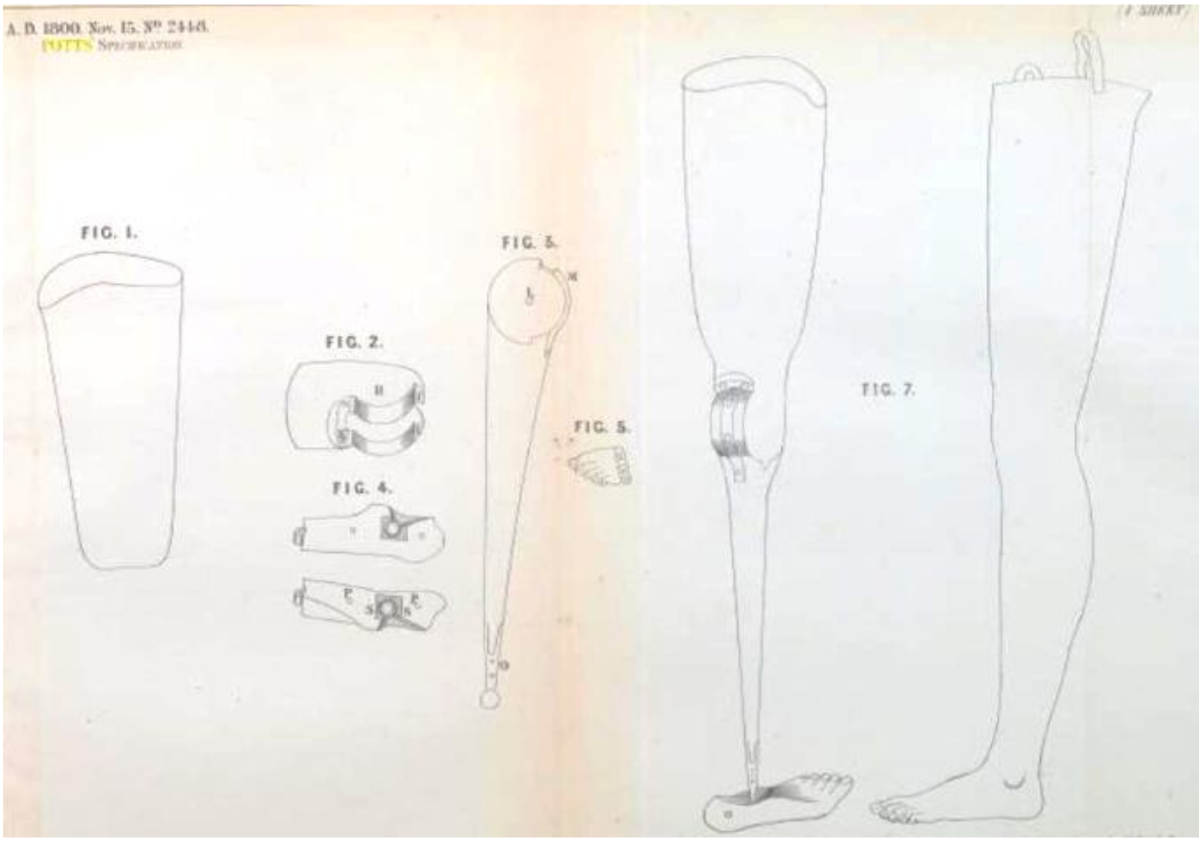
The main structure of the appliance was created from wood, this included the thigh socket, calf, ankle and foot sections. The type of wood chosen varied for different legs but in the case of the Anglesey variation the most frequently mentioned wood for manufacture was willow. It would have been a familiar material, used throughout history for manufacturing different items such as wattle and daub houses, clogs and shoes, fishing nets, baskets, cricket bats and boats (Hageneder, 2001), willow is pliable and unlikely to split. Willow was also used to make cricket bats, a popular sport during the nineteenth-century, with the likes of W. G. Grace, promoting sports masculinity and affectation. Bats were made from English white willow because it has a favourable grain density, strength and structure. At a time when willow was being used for an elitist sport and when bat manufacturers would have known and understood the material attributes of working with willow, it is unsurprising that it was adopted for the manufacture of other items such as artificial limbs. According to Gray, the willow is a good choice because it is 'both light and tough' (1857: 76) and Marks (1907: 87) also acknowledges the 'tough, light' attributes of the willow, it was easy to work and also grows quickly. It is likely that for many carpenters and furniture makers, willow would have a material familiarity that would have made adapting its use to artificial limbs uncomplicated. It could be proposed that in combination with its physical properties and attributes, the status of the willow tree and its portrayal in popular culture had an effect on its adoption by manufacturers for wealthy clients. It became a fashionable wood with attributes marrying well with the desired properties for artificial limbs, hence its widespread utilisation in the manufacturing of Anglesey legs.

However, willow is susceptible to wood ants and wasps, similarly, it contains a large quantity of bark sap which can make it watery and soft. In order to combat the likelihood these issues would cause detrimental effects long term, certain activities were done in advance. Firstly, the willow would be dried in hot chambers because this process secures it from '…warping, or from, getting out of shape when formed. The last contraction would...render it useless' (Gray, 1857: 76-77). Secondly, the weight-bearing elements would be reinforced with another strong hardwood, the aesthetic differences are clearly visible. Images of the Anglesey leg suggest the wood that surrounds the knee joint mechanism and also the thigh socket is some sort of dark wood which resembles mahogany. Mahogany seems an unusual choice of wood to produce artificial limbs in Britain during the nineteenth-century, owing to the fact it is not indigenous to Britain and grows best in warm climates, such as the Caribbean. Likewise, during the late eighteenth century, there was a shortage of real mahogany due to farming and as a consequence, to keep up with high demand and its association with the wealthy, various other dark hardwoods began being marketed as mahogany, for instance, sapele. Without microscopic analysis, identifying wood species is not completely accurate however to date, no evidence of English furniture made with real mahogany predating the eighteenth-century exists.

On closer investigation through handling the original objects and researching historical literature, it seems more likely that the wood used was a mahogany substitute such as sapele, made to look like authentic mahogany. Sapele, like mahogany, has a natural worm resistance and as a hardwood, was often used for shipbuilding in the nineteenth-century. The 'new' mahogany adopted by the nineteenth century had a different composition to original mahogany and could be worked in different ways, for instance, the legs and rails of furniture made after the 1750s could be more slender and the Chippendale-style of furniture would not have been possible without access to the wood of such strength (Gray, 1857). This may explain why there are examples of these 'new' mahoganies such as sapele being used in artificial limbs during this period, specifically Anglesey legs. Likewise, it demonstrates the problems that can arise in archaeology in identifying materials without more in-depth investigation, such as via microscopic analysis. For instance, on merely handling the artefact at the Household Cavalry Museum and then reading supporting documentation, conclusions were drawn by the author that Anglesey legs were made from willow and mahogany, however on further investigation it is likely that instead, Anglesey legs were more probably made from a mahogany substitute such as Sapele and for this reason, the reconstruction in this research will therefore utilise a mahogany substitute that holds the attributes noted above.

4.2 James Potts' 1800 Patent

James Potts' patent for his articulated artificial leg which was later known as the Anglesey, was achieved on 11th December 1800 (Potts, 1800: 2, in Eyre and Spottiswoode, 1856: 338). Potts' patent application is the closest we have to a construction manual for the Anglesey leg that is available. It begins by requesting that a stump socket be made of ‘bent leather’ (presented as fig. 1 in fig. 4.3), this then fits fig. 2 (in fig. 4.3) which is a wooden joint he suggests be about three inches thick. There are wooden stoppers (denoted by the letter I) on the wooden joints (fig. 2), with the letters K and H depicting another lock and joint pin hole respectively. Figure 3 (4.3) is a piece of wood from the joint of the knee which is created to imitate the bone of the leg, with M being the under the lock of the knee, L the joint pin hole and O the ball (representing the ankle). The illustration in figure 4 (of fig. 4.3) depicts the ankle and heel region of the foot. Here, Potts states the foot should be made of wood and have room for ‘stuffing’. The sockets to enclose the ankle ball were to be made of brass, P represents holes for the screw nails and nuts and R is the toe joint. fig. 5 (of fig. 4.3) is a piece of wood made to the shape of human toes which is to be joined to fig. 4 (of fig. 4.3) via a pin ‘…to have motions of the forefoot.’ (Potts, 1800: 2). fig. 6 (of fig. 4.3) is the ‘skeleton of the leg without stuffing’, although there is no description as to what is meant by the term stuffing. fig. 7 (of fig. 4.3) is the finished left leg with all the pieces described neatly concealed. The leg is described by Potts as being for an above-the-knee amputation and it is to be attached to the body via a strap which is fastened at the back of the leg and with a strap around the body. Potts suggests that the inside of the ‘tube’ – presumably the calf section of the leg – is to be stuffed for the ‘...ease of the wearer as to prevent the leather from rotting with the sweat of the body; the outside must be stuffed to prevent the breeches from wearing; the whole leg must be stuffed to bring it up to the natural shape and give it the appearance of a flesh…’ (Potts, 1800: 2). Along with this stuffing, the knee joint must be stuffed to prevent noise whilst walking, but Potts' notes not to stuff it too much to inhibit the flexibility of the leg falling ‘impelled by its own gravity’, nor to affect the role of the pinholes which ‘…is made long on purpose to let the locks pass each other when the weight of the body is off the leg, so that it may follow naturally as the person walks…’ (Potts, 1800: 2). Comparatively, the ankle must be stuffed well in order to retain its shape but not affect the various directions of motion nor affect the strength of the step. Finally, the leg must be covered in leather and quilted to keep it in its correct shape, springs can be added to just the ankle section or the whole leg to make the stocking create ‘natural wrinkles’ (Potts, 1800: 3).

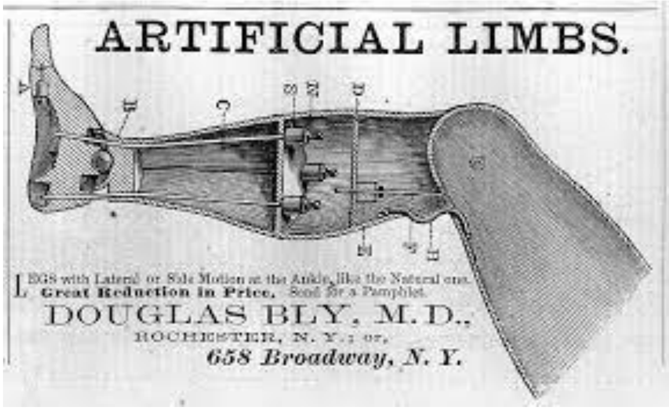


(Fig.. 4.3 James Potts Artificial leg patent, 11th Dec 1800, English Patents of Inventions, 1856)

Firstly, Potts' patent lacks a description for the order of manufacture, instead, the patent provides a report of the required parts. It feels very much like an ingredients list with no accompanying recipe. Whilst this is not an entirely unusual occurrence in patents – often lacking in detail to protect certain manufacturing processes – it does however leave the modern reader filling in the gaps. However, the way in which the stuffing is being utilised is different from just protecting the wearer's stump, it appears to be being used as a way in which to form the limb's basic shape. It is also evidenced in Potts' patent application that his design of leg is different from that eventually produced for the Marquis of Anglesey, sixteen years later. This is also where we observe the first major difference between what Potts has described in his patent application and what can be observed when handling Anglesey leg specimens. The legs we see in museums are made from wood, they have hollowed wooden calf, thigh and foot sections, they do not appear to have been stuffed with any material, instead, the only other material found inside the legs is the internal metal mechanisms. The legs can be covered in a thick stocking at times and some of them have shearling (discussed below) used as cushioning material around the socket, as fig. 4.3 demonstrates, however, that neither of these is evident in all Anglesey examples.

Another striking difference between the description given by Potts and the Anglesey leg assessed in the Household Cavalry Museum is the suggested use of 'bent leather' for the manufacture of the socket. The existing Anglesey leg used as a model for analysis for this research in the Household Cavalry Museum - worn by the Marquis himself - had a wooden socket. Warne (2008: 29) refers to the use of 'lace-up leather sleeves' in some artificial legs, although she does not specifically suggest this about Potts' design. There are examples from Gillingham's 1888 publication which show amputees wearing leather thigh sockets, but these appear to be on transtibial amputees (1888: 2, 3 and 13). Gray (1857: 67) refers to the use of willow for Anglesey legs, this is supported further by Warne (2008: 29) who corrects the nineteenth-century suggestion that cork was used – a misconception based on the colloquial terminology for artificial legs made in Cork, Ireland – claiming it would be too 'friable' and that wood was used instead. Perhaps the change from a leather socket to wood was one of the alterations requested by the Marquis referenced by Guyatt (2001: 308).

The next difference in the description and accompanying illustrations provided by Potts, compared to what is observed in exhibits, is the description of a piece of wood to imitate the leg bone and the use of a ball for the ankle joint. There is evidence, about fifty years after Potts' patent application, of a ball and socket being used in artificial legs; fig. 4.4 shows an advertisement for Dr Douglas Bly's artificial leg invention. The limb was marketed as the first with a ball in the ankle socket giving it a full range of natural limb movement, the design was patented in 1858 (Bachmann, 2014). However, Potts' famous design worn by the Marquis of Anglesey utilised no such mechanics. Warne suggests these ankle balls could be made of ivory for smooth manoeuvrability (2008: 30). However, based on the 1800 patent of Potts, it would suggest that the idea of a ball in the ankle socket had already been invented 58 years earlier. Yet it appears that this design was swiftly changed to incorporate an ankle joint similar to that evidenced in the knee (knuckle joint) with the utilisation of catgut or leather to represent tendons, as observed in the 1816 version created specifically for Henry Paget (the Marquis). Likewise, the wood referred to in Potts' patent as mimicking the leg bone, is also not present in the 1816 limbs, where instead the hollowed section is filled with the spring mechanisms to establish a functioning gait cycle.



(Fig.. 4.4. Dr Douglas Bly's advertisement showing his ball socket patent https://blogs.harvard.edu/preserving/2014/01/13/dr-blys-artificial-leg/)

4.3 Potential Construction Process

4.3.1 Creation of the Socket, Wooden Elements and the Tools Used

Because Potts' patent lacks any detail as to the production methods, establishing an understanding of this process is where the experimental reconstruction in appendix B, plays a vital role. However, we can also learn some of the processes and the order they occurred from some later nineteenth-century literature. For instance, the first phase of production that took place according to Gray (1857: 67), was to take a wax mould of the wearer's stump and some critical measurements of the stump itself. Once the mould had been created and the correct measurements are taken, the manufacturer '… makes a cast in wax upon the stump, and then, by a peculiar method, transfers, as it were, this impression to tight and tough desiccated willow, in such a manner that every swelling and hollow is represented in the socket. Thus, the machine can be worn without the risk of undue pressure; or if any part be more than commonly tender, the pressure can be easily regulated or removed.' (Gray, 1857: 67). This is a further example of the socket being referenced as being made from wood, not leather. It was the purpose of the mould and measurements to ensure the specific pressure points and potentially painful areas of the stump were noted so that the wood could be carved to create a socket which would eradicate as much undue pain as possible. Gray claimed that discussions with surgeons clarified that attention to each case was vital, due to the '…evil that would result from the indiscriminate use of one form of substitute for every amputated limb.' (1857: 16). Biggs' (1885) makes a point of describing exactly how the level of the knee joint was to be established for the specific wearer, noting a mathematical equation to be used during manufacture. Biggs (1885: 26) states 'The axis of the knee-joint of the artificial limb must truly correspond with the axis of the knee of the natural limb, so that the artificial one may be identical in motion with its natural fellow of the other side (since usually only one leg is lost at a time). The sound limb and the artificial one must be alike both in appearance and in movements, 'both in outline and in axis.’ He goes on, ‘…now, the axis of the natural knee joint may be accurately taken to be a line drawn through the condyloid eminences…’ – the joint itself. In the case of amputation through the knee joint, an artificial limb cannot be created so its hinge is carried straight across the leg at the point of the axis due to the bone from the femur that is still present. To combat this issue and still create an artificial joint, Bigg recommends putting ‘…two lateral rods along the sides of the limb with rule joints in the true axis of the knee (that is at the line through the condyloid eminences).’ (1885: 26). It is here Bigg shares his equation for reaching the optimum location for the knee joint on the artificial leg, he states that the rule-joints work on rivets which are around an inch in diameter and an inch wide, the hinge joint works on a bolt around four inches in diameter and an inch wide. He concludes; ‘…and as the areas of cylinders are as the squares of their diameters the proportion of surface which bears the weight of the body and withstands the influence of wear and tear is in the one case as compared with the other represented by the following 4 x (3/8)2 : ½ x (3/16)2 : : 4 : 173 or as about 1 to 43…’ (Bigg, 1885: 26).

There is no mention by Potts in his patent of where wood for limb construction was sourced from. Investigating contemporary literature, about the origins of wood used for artificial limbs, there is a suggestion from an 1888 newspaper article discussing the manufacture of ‘cork-legs’ in which it states ‘When a leg is ordered it is cut out of the solid block and gradually planed down till it becomes quite thin.’ (The Saint Paul Daily Globe, March 25th 1888: 12). Whilst this informs us that the leg was created from a solid block of wood, it does not demonstrate where the wood is originally acquired from. Walter Rose’s (1936) memoir records life for a nineteenth-century carpenter and the acquisition of wood it describes that carpenters would utilise their local landscape and fell the trees themselves, store them and use the bark for tanning leather and dry the wood for carpentry. Rose’s (1936: 60-70) memoirs suggest the acquisition of timber for the manufacturing of artificial limbs was probably done in a largely similar manner, in which carpenters would purchase the wood at auctions or from private property, or even purchase woodland themselves and fell the trees in situ before waiting for the trees to dry for at least a year in log form before being cut into boards because they would be liable to warp.

(Fig.. 4.5, Walter Rose's memoirs, drying cut timber 1936: 80)

A general understanding at this time by artificial limb makers was that pressure points existed on amputee's stumps so poorly fitting artificial limbs would prove painful and uncomfortable for the wearer, hence the importance of the wax casting to highlight these potential pressure points so the socket can be adjusted accordingly. The second point to highlight is that whilst there is an understanding that these potentially painful locations exist, how to address and then resolve these efficiently, remains fairly secretive. For instance, there is no clarification on how the impression is transferred into the willow stump, instead, Gray (1857) just says 'by a peculiar method'. Whilst more care was taken to fit the Anglesey leg to the specific wearer, it is increasingly evident that production methods were not monitored, nor was there a principal accepted method of production from which every manufacturer followed (discussed below, also see chapter 2 and appendix B).

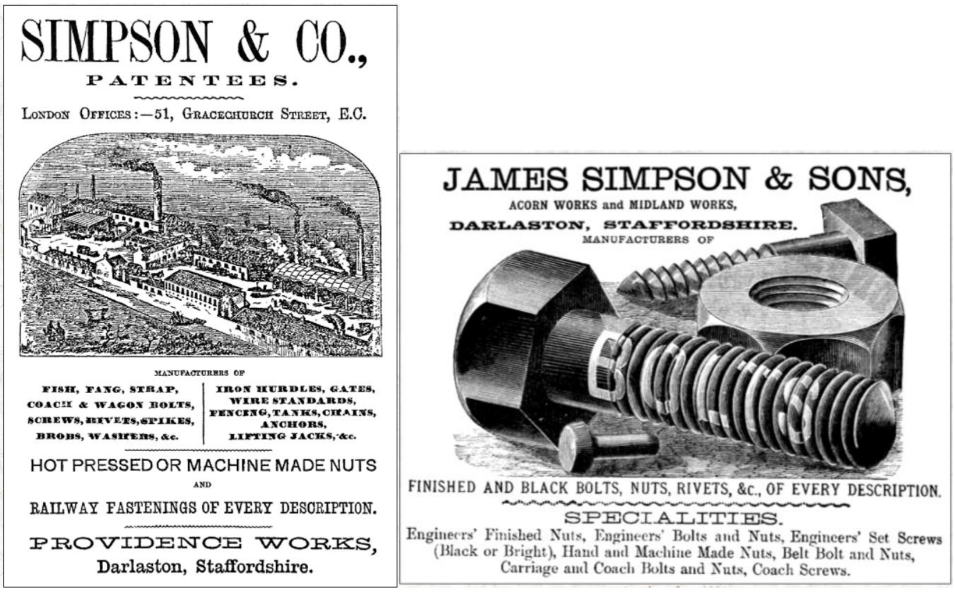
An example of the lack of a standardised production method for the Anglesey leg is the fact that the manufacture of the internal socket was created in various ways during this time. Bigg (1885: 84) discusses his use of a pointing machine during the 1850s to form the internal socket cavity, an instrument originally used by sculptors to accurately copy clay, plaster or wax models into wood or stone. Only being introduced to Britain by John Bacon in the late eighteenth century, it is likely that when the original Anglesey legs were being created by James Potts, he did not utilise this machine whilst constructing the internal socket. Instead, he probably used just his eyes and hands, leading Biggs to suggest that whilst the accuracy may to the eye look excellent, in reality, the minutest differences in the stump will be missed causing '…a discrepancy between the remains of the natural limb and the cavity formed in its artificial continuation, and a much greater degree of annoyance and pain than can be imagined by those unacquainted with my art.' (1885: 85). Bigg did not acquire a pointing machine until the mid-

1850s and consequently, to that date he had utilised the same methods as artificial limb makers had before, that of taking a casting and copying the imprints by eye into the socket cavity.

Although there is no mention by Potts in his patent about the various stages of production, its possible wooden sections were all created synchronously. This would have ensured they could repeatedly be checked against each other for size and to ensure they fitted together correctly. There is no mention of how the wood was shaped by Potts; however, Biggs (1885: 76) makes note of 'carving wood' in his description of how to create the 'phalanges' for an artificial hand. Holmes (1860: 577 in Warne 2008: 85) previously discussed in section 2.2.3 remarked upon his surprise at seeing manufacturers shaping limbs by hand rather than a lathe, 60 years after the Anglesey was first invented. It could be argued therefore that hand-carving was a technique preferred for Anglesey production at the beginning of the nineteenth-century as well.

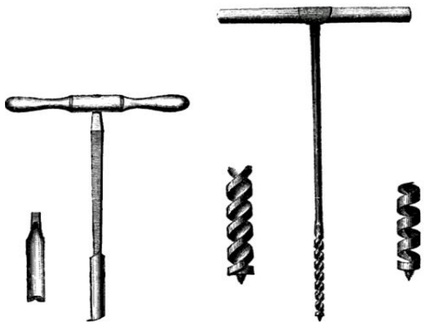
4.3.2 Securing the Wooden Sections with Metal Pins and Screws

Once all the wood was carved to shape and size for the patient, the pieces needed to be secured together and this was done with the use of metallic nails and pins. For the Anglesey leg specifically, there is evidence of a variety of metals such as gunmetal, brass, iron or steel and mild steel being used for the pins and screws (Marks 1907: 90). Potts' patent also calls for the use of brass pins (Potts, 1800: 2) and as these are accessible today, these will also be used in the reconstruction. Pott's patent also calls for screw nails (Potts, 1800: 2) for the construction of his artificial device which, as nuts and bolts had been utilised in construction for some time and had achieved an increase in popularity as a result of the Industrial Revolution, their use in artificial devices like the Anglesey is unsurprising. Before 1841, each screw, nut and bolt manufacturer – usually a backyard workshop – had its thread size which caused challenges for machinery manufacturers (fig. 4.6). Graves suggests that the standardisation of the thread size meant manufacturers could make nuts and bolts nationwide which would all fit each other (Whitworth in Graves, 1984: 136-145).



(Fig. 4.6 nut and bolt manufacturers Simpson & Co. 1865 showing growth in factory size and 1884 showing nut and bolt style)

As Potts does not detail exactly how the holes for the nuts, nails and pins were created in the Anglesey leg wood, advice was sought from Welsh's (1966: 55) research on the nineteenth-century woodworker's toolbox. In this, various methods for creating holes in the wood are suggested, for instance, a drill press and auger. An auger is a mechanical instrument widely used in the nineteenth century, often made of wood, iron or steel by a blacksmith, it worked in a similar way to a modern screwdriver in that a hole was created by manually driving the screw down into the wood by turning it by hand. It required considerable effort and a repeated turning movement but often the varying depth and diameters of the hole could be controlled based on the interchangeable nature of the screws (fig. 4.7).

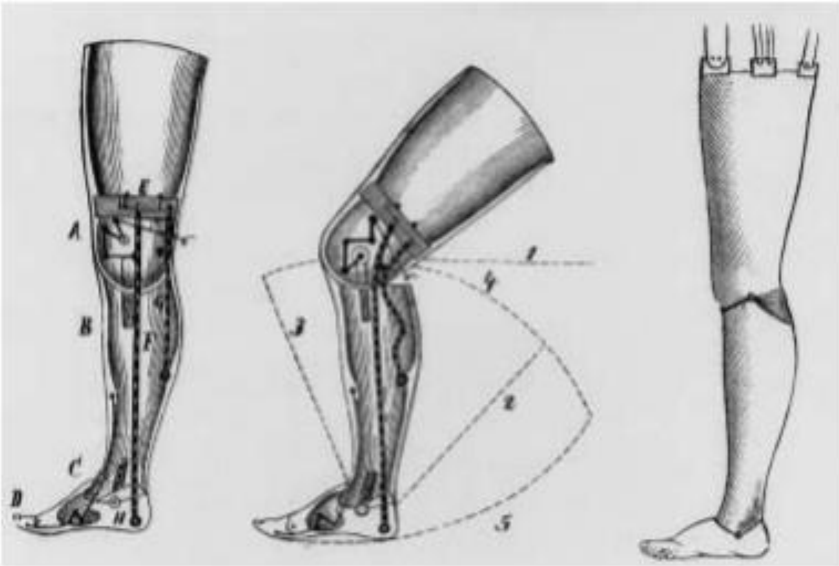

(Fig. 4.7 shows two nineteenth-century augers, a shell auger and a screw auger)

A drill press or hand drill was also available during the nineteenth century with the drill press (fig. 4.8) being a popular option for creating holes in industrial manufacturing. Nineteenth-century drill presses were mainly powered by line shafts and pulleys, sometimes using steam and then, as the 20th century neared, crude electrical energy (Cole et al, 2003: 105).

(Fig.. 4.8 nineteenth-century drill press, turned by hand to drill hole)

4.3.3 Internal Mechanics

Once the carved pieces of wood had been secured together with the brass pins and nails, the leg was ready to be fitted with its internal mechanisms (fig. 4.9). James Potts' 1800 artificial appliance patent makes no mention at all of the catgut tendons, it briefly states that springs can be added to the ankle and that springs are not required in the whole leg (Potts, 1800: 3). However, the artificial limb appliances accessible in archives such as the Science Museum, London, all have internal mechanisms which include springs, catgut, wire rope or leather. The limb worn by the Marquis of Anglesey at the Science Museum as well as the limb worn by him stored at the Household Cavalry Museum, London, are both variations with some form of internal mechanism which allows the ankle and knee to bend in unison (fig. 4.10). It is claimed by Warne (2008) that the Marquis of Anglesey requested some personalisation and alterations to James Potts' artificial leg, it may be that he requested the tendons were used throughout the leg instead of just the ankle or not at all. Likewise, Biggs (1863) and Gray (1857) both note the use of some form of the tendon such as catgut within Anglesey devices.



(Fig.. 4.10. Internal workings of the Anglesey leg including the type of joints used and range of movement as a result of springs, Potts, 1800: 4)

Catgut tendons (tightly wound dried and treated sheep or cow intestines fig. 4.11) and leather were both familiar materials in the nineteenth century because they were also used in carpentry, toy, instrument and clock making, manufacturers of which often also were involved in the production of artificial limbs. They were used inside the calf and ankle section of the appliance to emulate the tendons in a human calf that contribute to the switch between the stance and swing phases during the gait cycle. The use of metallic springs may have been a way of combating the relatively short lifespan of both the leather and catgut, for instance, in music, the frequent friction caused by moving a bow over violin strings (made from catgut), they become brittle and snap, similarly if you tighten the strings too much whilst tuning a violin, they can snap. The use of catgut tendons within the Anglesey would have seen repeated stress and friction placed around the knee joint during the bending motion of the knee during the swing phase of gait. A similar move from catgut to metal wire was also observed at the end of the nineteenth century in guitar making suggesting that the growing use of steel wires, in technology such as artificial legs, provided an effective but longer-lasting material. Warne (2008: 29) explains that the Anglesey leg '…mechanisms…were metal and were designed to lock automatically and then to release, allowing the leg to imitate the striding motion of a natural leg'. Wire ropes have a tensile strength which means they are dynamically effective for lifting, hoisting and for transmission of mechanical power.

(Fig..4.11 Catgut tendons, author's own)

4.3.4 Leather

Another example of technological innovations being made to the Anglesey leg is apparent in the leather straps which secure the limb to the wearer. The use of leather in Potts' appliance forms an important area of discussion for the Anglesey Leg because firstly, Pott makes no reference to where the leather should be sourced from, nor does he suggest a guide amount that may be needed and finally he also gives no clue as to how the leather is to be secured to the wooden elements. The accompanying drawing to the patent description (fig. 4.3) shows the use of screws at the back of the knee cap where his leather socket is supposedly joint to the rest of the leg, which may suggest screws were his intended method of attaching the leather to the limb. In Potts' patent, leather was intended to be used in three main ways, firstly as the whole socket for the stump, secondly as a means of attaching the leg to the wearer in the form of a strap and thirdly, as a way of covering the leg completely in the form of a sock which is to be stuffed within to '…the natural shape and give it the appearance of flesh…' whilst also allowing '…some stuffing, to prevent noise whilst walking…' (Potts, 1800: 3). It could be presumed that for his original design, which incorporates a leather socket, the amount of leather required would relate to the initial measurements of the wearer and it also would be a lot more than eventually required by a leg which had the leather replaced by a wooden socket. He does suggest that the leather could rot as a result of being close to the wearer and so one way to combat this was through stuffing the socket as well. However, the change from the leather socket in Potts' patent to the wooden socket worn by Anglesey occurred within 16 years, and one of the reasons for this may have been the realisation that wood did not rot and degrade as quickly as leather meaning the wearer gained a longer lifespan from their appliance.

There are limited descriptions of how the leg should attach to the wearer, Pott's original patent refers to straps around the thigh and body (1800: 2). Photographs and original artificial limbs show a wide variety of leather straps, suggesting no standardised option and possible personal preference for the wearer (fig. 4.12); 'Short stumps necessitated the addition of straps worn around the waist, suspenders worn over the shoulders, or straps that attached to a corset' (Warne, 2008: 29). It seems possible that leather straps could be produced at any stage of production, however, when and how to attach them to the structure seems dependent on how much involvement the wearer had with the manufacturer during production. The decision to add the straps for a secure attachment before the wearer would collect the leg would suggest a less bespoke manufacturing process. However, attaching it and making relevant adjustments throughout the manufacturing process seems more likely and in keeping with the tailored outcome.

(Fig.4.12 shows three different thigh socket attachments of the Anglesey Leg with the drawing showing a later variation of the leg and a possible method of attachment from Henry Bigg 1885: 58)

4.3.5 Shearling or Woollen Sock

One of the final elements of the leg manufacturing process was probably the addition of some form of comfort enhancer or padding because it is something that would have been highly personal to the wearer that they may have added or adjusted to suit their comfort levels. The use of shearling or stump socks of cloth is evidenced by the physical remains of material in museum assemblages that would have been used to protect the sensitive area of the stump against pressure and frequent rubbing against the wooden socket (fig. 4.13). Whilst Pott does not directly suggest the use of shearling in his patent, he does suggest stuffing the socket so the leather does not rot in frequent close contact with the skin. . Shearling is a skin from a shorn sheep, it had a suede surface on one side and a clipped fur surface on the other, it makes a perfect material for protecting a stump because it is flexible, has waterproof attributes, provides some cushioning and also allows skin to breathe as it is not synthetic. The use of shearling is not evident in every Anglesey leg, instead as Warne (2008) details, some variations of leg functioned as a miniature crutch, '…supporting the weight of the body via the sleeve and thereby avoiding direct contact between the prostheses and the potentially sensitive and injury prone tip of the amputated limb…' (29).

(Fig. 4.13 Anglesey leg and accompanying stump sock made from shearling, note it is suede smooth outer appearance, image courtesy of Plass Newydd, National Trust)

4.4 Concentration on Mechanical Intricacies

Bigg (1885) argued that aesthetics and anatomical accuracy did not drive the advancement of artificial appliances, instead, a concentration on simple mechanisms to substitute specific movements such as the swing phase of gait led to the most change observed in artificial limbs. The Anglesey leg, for instance, did not aim to replicate all the muscles that aid movement in a natural leg, but rather emulate the movement of a swing phase and utilised materials which allowed for these mechanical movements. Bigg suggested it was a waste of time to attempt to reconstruct the anatomical nature of the natural human leg, instead suggesting '...in giving man the power of walking…it is not anatomical imitation that is to be aimed at, but mechanical.' (Bigg, 1885: 30). A distinction must be drawn therefore between the anatomical and mechanical elements of the leg – that is, there is no need to artificially reproduce substitutes for every muscle, ligament and bone – instead mechanical elements such as structure and integrity of the limb must be the primary focus for manufacturers. According to Bigg;

'…it has taken continued progressive efforts on the part of mechanicians to reach the present point. I have in my possession a series of limbs constructed at different times during this century, and it is curious to note how very crude the artificial limbs were only fifty years or so since, and how step by step they have approached nearer and nearer truth to nature. The fact is that the mechanician of the past was not an anatomist, and did not pick as it were the body to pieces in order to be guided in his efforts at artificially reconstructing portions that might be lost. He only copied vaguely by the light of external structure and through his own instinctive intelligence…' (1885: 30).

Marks (1907) supports Biggs's original claims years later when he discusses the form of the Anglesey leg's wooden foot and its ankle joint. He claims that the wooden foot with its articulated joints is antiquated, arguing that the effort that was placed on attempts to generate as wide-a-range of motion as a natural ankle through the close study of ankle anatomy, was fruitless and instead the simple mechanics of a straight forward front and back (up and down) motion was as effective as enabling side articulation. Marks states; 'Being convinced by most careful study and experimentation...we dissuade all from using the side motion…One method has little advantage over the other.' (1907: 25). Bigg adds that the principal concern in artificial limb production is that the surgeon and mechanician do not work together and consequently, there is no unison to the final product because it is impossible for the surgeon to fully prepare the patient for their artificial limb if they do not know what sort they are going to receive and whilst some patients may be expected to receive better quality ones such as the Anglesey leg unless the stump heals appropriately this is not certain.

Chapter 5: Gait Analysis

The appendices below (pages 188-277) detail the construction process involved in the manufacturing of both the Anglesey leg and the box leg under investigation here. They discuss the materials and tools involved, the processes and decisions that were made throughout construction and evidence this information with images. It is from these reconstructions that information about the manufacturing process could be deduced and the lab-based gait analysis completed, the methodology and results of which are presented below.

5.1 Bipedal Gaits

Gait involves a combination of open and close chain activities. A detailed classification of gait recognises six phases: Heel Strike, Foot Flat, Mid-Stance, Heel-Off, Toe-Off and Mid Swing. According to Schultz (2005 in Moevus, 2015); 'The gait cycle is a repetitive pattern involving steps and strides. A step is one single step, a stride is a whole gait cycle. The step time is the time between heel strike of one leg and heel strike of the contra-lateral leg. Step width can be described as the mediolateral space between the two feet.'. At the end of the single support phase, the walker's centre of mass (COM) is directed downward towards the ground. In the step-to-step transition phase of gait, the leading leg strikes the ground and performs negative work on the walker's COM. The negative work done by the leading leg and the positive work done by the trailing leg redirect the COM from a downward trajectory into the upward trajectory needed to complete the next step (Matthis and Fajen, 2013). Musculoskeletal systems have evolved over time to be efficient for bipedal locomotion and as Matthis and Fajen (2013) explain, the visual control of walking is tied to the basic biomechanical features of this structure.

Abnormal or asymmetric gait can be caused by a variety of factors such as bone malformations, hip injuries or even stroke (Moevus et al, 2015), which thus makes gait analysis an accurate indicator for a wide range of pathologies. This theory relies on the assumption that a healthy person has a symmetrical gait, which is why for these experiments a person who has no known conditions nor has undergone an amputation will wear the prosthetic reconstructions. By assuming an asymmetrical gait may be an indicator of certain pathologies, analysing the effect of historical artificial limbs on a symmetrical gait will identify potential pathologies that could result through long term use. Gait analysis is an effective, non-invasive tool for detecting joint deficiencies during rehabilitation, however, it was not a tool that was widely used until more recently and so patients who underwent amputation and rudimentary rehabilitative processes during the nineteenth century, would never had their personal gait pattern analysed and used in the fitting of a prosthesis. Specifically, the goal of this photo-based gait analysis tool is to generate a perceptual map of asymmetries of an individual wearing historical artificial limbs.

The joints within the lower limbs produce various ranges of motion and muscle responses to ensure propulsion forward. Although the centre of gravity moves both up and down and side to side during gait, the degree to which the individuals centre of gravity changes during gait cycles, defines the efficiency of the walk (Schultz, 2005 in Moevus, 2015) and can be used to identify underlying physical weaknesses and physiological conditions. For instance, it is assumed that there is an anterior-posterior displacement of the hips of around 4-5°in healthy gait (Moevus et al, 2015) during this experiment. Should a greater deviation in angles be observed whilst in the use of artificial appliances, it can be said that these limbs do not recreate a healthy, normal gait pattern. Whilst this type of analysis is common today in the study of modern prosthesis efficiency, an analysis of the efficiency of historical limbs has never been attempted and therefore this data is unique.

The efficiency of human walking is evidenced each time a step is taken, with walkers harnessing the inertia of their moving bodies to propel them forward at a minimum energy cost. When something affects this fine-tuned model, there are consequences for the walker. For instance, moving from a flat, obstacle-free terrain, to a complex, rocky terrain, the walkers instinctively adapt their dynamics to maintain stability and energy efficiency. Similarly, complexities arise with the consequences of lower limb loss and the use of a prosthesis, as the individual may not be able to attain a comfortable or safe foothold as easily and instinctively as individuals with both natural limbs. The main hypothesis tested in the experiment below is that when walking whilst utilising the Anglesey leg and box-leg, to what extent are the anticipated gaits altered and what implications would that potentially have caused for the individual.

5.2 Experimental Background

Gait patterns demonstrate the fine-tuned collaborative interactions that take place between the ‘neurological, articular and musculoskeletal systems’ (Moevus et al 2015). Gait analysis is an increasingly used method for diagnosing various types of diseases that are connected to neurological, muscular and orthopaedic systems. It is also key to paleoanthropological reconstructions of bipedalism as well as other locomotory forms. This chapter is focused on the methodology of gait analysis for both the peg-leg and Anglesey leg reconstructions, with the focus being on the overall effect on walking and how this changed upon wearing artificial limbs. Due to the impact of Covid-19 and the inability to access the biomechanical gait lab for what at the time, was an unknown period (eventually 8 months), a preliminary experiment was conducted at home using basic methods such as loci plotting and a treadmill. The processes and results of this experiment are described in appendix C. Whilst the preliminary experiment was useful for gauging possible findings, under the circumstances that the labs may not be available before the conclusion of this research, it is crude data. However, in combination with the controlled lab data, they do provide a foundational set of results which act as a basis from which gait changes could be predicted.

Research into the effects of modern prostheses on kinetic gait, suggests various ill effects that can result from a variety of potential causes. Ill-fitting prosthesis, excessive coronal plane movement of the trunk and leg length discrepancy, to name a few, can all lead to detrimental effects for the wearer through long-term usage. For example, coronal plane movement can lead to a weakness of the hip abductors (Heitzmann et al, 2020), these muscles include the gluteus medius and gluteus minimus which are all involved in moving the leg away from the body, rotating the leg at the hip joint and maintaining stability (Heitzmann et al, 2020). Weakness of these muscles can lead to a lack of stability and therefore increased risk of falls (see section 5.5).

However, this information and understanding of the effects of prostheses on the human body have never been applied to the research of historical prostheses. Generating data using the same techniques used for modern prosthetic assessments will investigate whether historically accurate artificial limbs posed physiological risks to the wearer. This is the first data of its kind and so offers not only an exploratory insight into the efficacy, functionality and comfort of these appliances but also a novel approach from which further investigation into historical orthopaedic and prosthetic devices can be based, where we can also see a collaboration between biomechanics, engineering, history, literature and archaeology.

5.2.1 Aims of Experiment

The aim of the experiment here is to demonstrate physically, how artificial limbs changed how their users moved, providing for the first time a digitised visual dataset from which physical changes in gait are generated. Likewise, whilst doing so, the functionality of the individual legs will be ascertained. Finally, if the legs can be identified as changing natural gait, it will be possible to determine the type of long-term damage that may have been at the root of the chronic pain, discussed by both Bigg (1885) and Gray (1857) because of wearing limbs that did not fit properly.

5.2.2 Lab-Based Methods

The biomechanical gait lab experiment involved a state-of-the-art marker-based approach, the Vicon motion-tracking system which offers millimetre resolution of 3D spatial displacements. Using markers at regular intervals on the body, the optical motion camera monitors the slightest degree of gait displacement. Its accuracy means it is widely used in medical applications, however, consequently, it comes at a high financial cost.

5.2.3 Subject/Participant

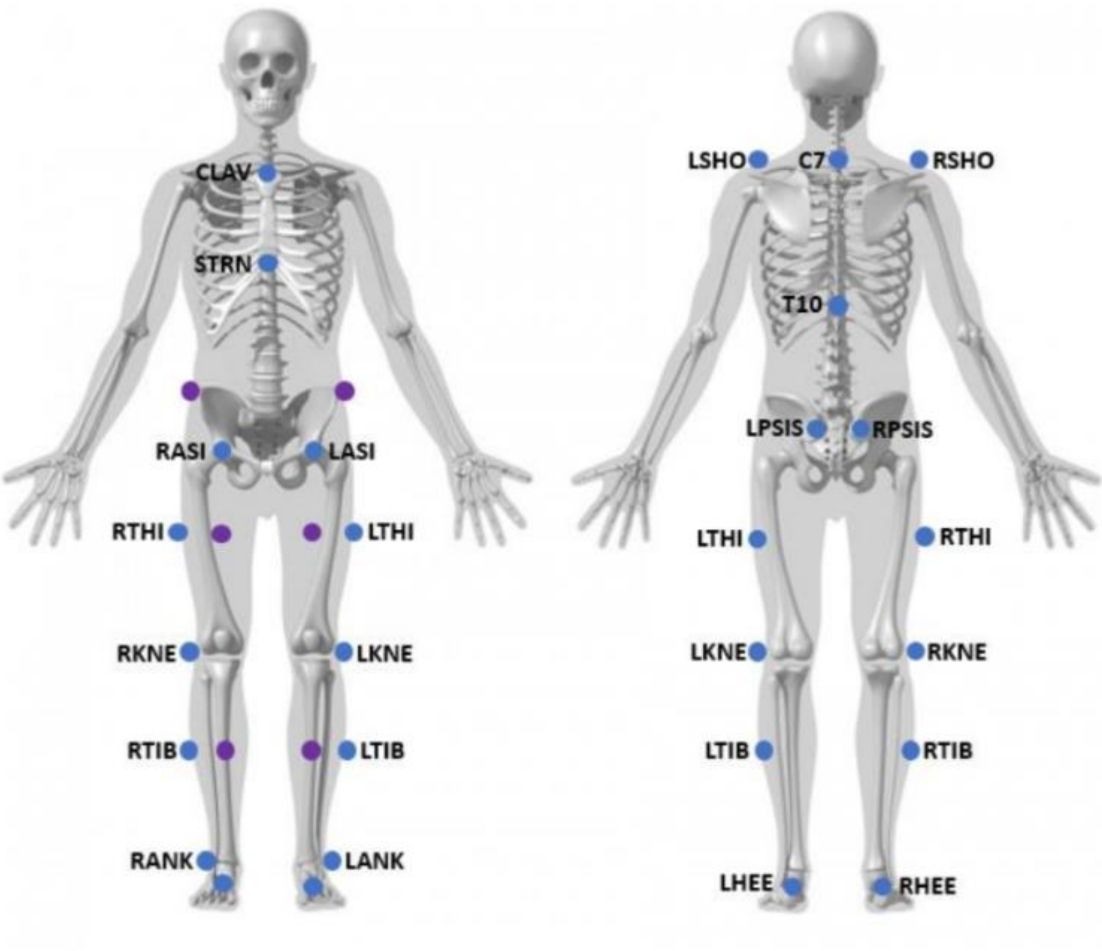
The reconstructed artificial limbs were made using original patents, drawings, literature and original artefacts (see Chapter 2). As they would not be used by anyone other than the author of this thesis, ethical approval was not required, however, the correct health and safety forms were completed and submitted. There had been a discussion with the mechanical engineering department about gaining ethical approval for amputee volunteers to become involved in the experiments. There was the possibility of a winch support system that was due to be installed in the lab during the period of this research. However this did not happen in time and therefore, with health and safety a priority, external volunteers were not used. The participant who underwent the walking experiments was the author of this thesis and not an amputee. She is 5ft 6in tall and weighs 140 lbs, further information on construction methods for each appliance is presented in Appendices A and B. Despite not being an amputee, the participant had the artificial limbs constructed to their dimensions, particularly important for the Anglesey leg which held a more personalised construction process. Likewise, it is noted throughout the findings of this research exactly where any differences in findings may be apparent as a direct result of the fact the wearer was not an amputee. Specifically, the extra weight that would have existed on the side where the appliance was attached, because usually, the wearer would have been missing part or most of their leg reducing the overall weight on that side.

The appliances were constructed in 2017 and 2018 respectively and the participant, therefore, had just over two years to gain familiarity with the appliances, how they secured to the body, as well as occasional practice in wearing them to walk. Due to the fact the wearer was not an amputee, each artificial appliance would be worn as if a transtibial amputation had occurred, by bending the knee and using it to take the weight of the body. The wearer had become familiar with walking in the limbs so that simple tasks were now possible, these included, standing statically for 10 seconds or more, being able to walk in a straight line with the use of one or two crutches and being able to stand on the sound side with no assistance for five seconds. The use of an unimpaired wearer for these experiments meant that the control data collected showed accurate before and after effects of wearing these artificial limbs. Where crutches for stability were used, this was noted and taken into consideration in the findings, each experiment was repeated several times and the standard deviation of results was included in these findings. The data presented has not been manipulated in any way, so fair conclusions can be drawn.

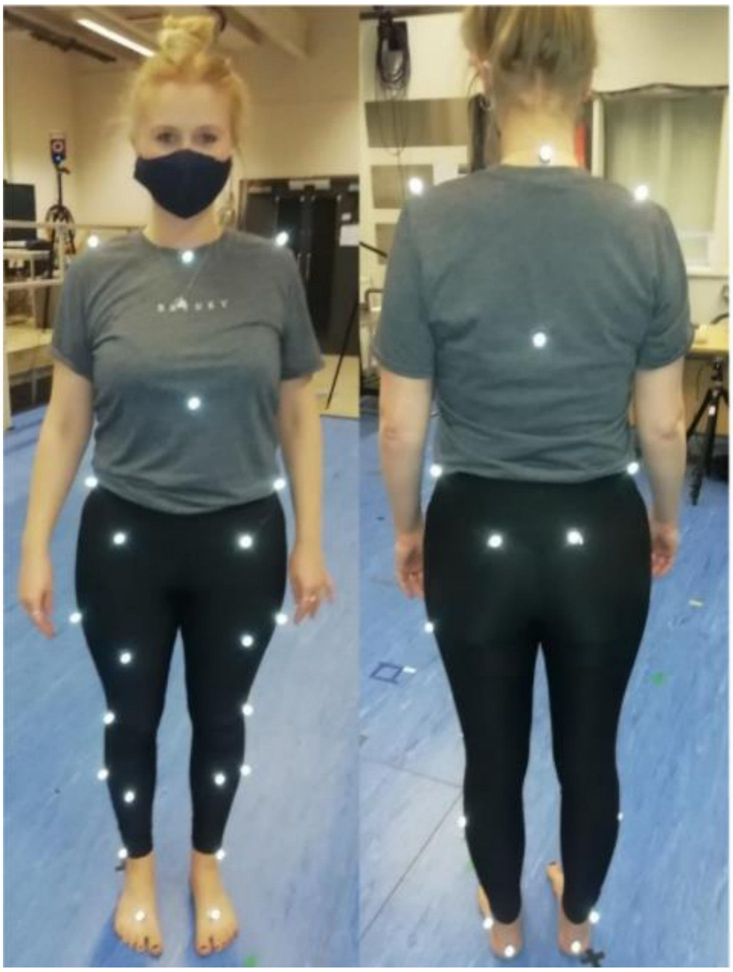
It is also worth noting weight differences between artificial limbs and natural limbs to see how this may have affected overall gait changes. The percentage of total body weight that the whole leg possesses is around 18% for a female and 17% for a male (Plagenhoef et al, 1983). If we consider that during the nineteenth- century the average height and weight of a male was approximately 165 cm and 60 kg, for a woman; 155cm and 50kg (Bell et al, 2011), it suggests that on average the weight of their legs would have been around 12lbs (5.4kg each) for men and 9.9lb (4.5kg each) for women. The Science Museum suggests that the average Anglesey leg weighed around 9lbs (4.1kg) and the peg legs weighed around 5lbs (2.3kg). It is expected that artificial limbs are overall lighter than biological legs, which is what is observed in this experiment, with the reconstructed Anglesey leg weighing 6.6lbs (3kg) and the peg-leg weighing 4.4lbs (2kg). The wearer weighs 140 lbs (60kg) which means their biological leg weight is around 12lbs (5.4kg) Therefore on average artificial limbs created a weight deficit for the wearer of approximately 2-3 kg. However, on wearing the artificial limbs, it was observed and noted that heaviness was felt on the prosthetic side. Despite the artificial limbs weighing less than the biological leg, in this experiment, two fully functioning legs were still attached to the body and so the artificial leg was an additional weight on one side as opposed to slightly less weight than normal. When wearing the limb, there was an additional 2-3kg (depending on the appliance) added to the right side of the body, bringing with it complex alterations in gait and efficiency of muscles. Similarly, it is well documented with modern prostheses, that due to the time lapse between amputation and prosthesis fitting being at least 6 weeks, many people find their prostheses extremely heavy as they have grown used to the lack of weight in that area. Consequently, the belief is that the lighter the prostheses the better, due to the understanding that energy spent during walking is concentrated on the limbs. Thus, the heavier the prostheses, the more energy is used while walking or running (Brookmeyer et al, 2008).

5.2.4 Subject Preparation

The participant was required to be barefoot and wear tight-fitted clothing during testing. The participant's height, weight, bilateral knee and ankle widths and leg length were measured. Twenty-seven reflective markers were placed on the participant’s skin to create an adapted Plug-in Gait model (fig. 5.1 and 5.2).



(Fig. 5.1 Representation of the marker set used. The markers in blue are using the Plug-in Gait model and the purple are reference markers favoured by the gait lab specialist to improve data processing, see http://www.idmil.org/mocap/Plug-in Gait+Marker+Placement.pdf)



(Fig. 5.2 Reflective markers placed on the body in positions mimicking Plug in Gait model)

5.2.5 Equipment

Marker and ground reaction force data were captured using a 10-camera optical motion capture (100Hz; Bonita B10, Vicon Motion Systems Ltd, Oxford, UK) and force plate (1000Hz; AMTI, MA, USA) system. The biomechanical gait lab experiment involved a state-of-the-art marker-based approach, the Vicon motion-tracking system which offers millimetre resolution of 3D spatial displacements. Using markers at regular intervals on the body, the optical motion camera monitors the gait displacement. Its accuracy means it is widely used in medical applications, however, consequently, it comes at a high financial cost.

5.3 Gait Analysis and Data Collection

Using a 5m walkway the participant was instructed to walk forward at a comfortable speed, over the force plate. The initial trials required the participant to make full contact with the force plate using their right foot, with subsequent trials following the same protocol but for the left foot. The participant was allowed to become familiar with the two tasks, ensuring that the correct foot contacted the plate without altering the participant's pattern of gait. A total of 3 successful trials were completed for each side. A trial was deemed successful if the participant made full contact with the platform using the correct foot and at least four steps were captured by the camera system, in the form of a heel strike to heel strike pattern of both limbs. This setup was completed for all three conditions: normal gait, with the peg prosthetic and with the Anglesey prosthetic.

5.3.1 Balance

The participant was asked to stand on the force plate and maintain balance on both limbs for 30 seconds. This was completed twice for each condition. Once with eyes open and once with eyes closed.

5.3.2 Gait Analysis and Balance

Gait events were identified, and kinematic and kinetic data were extracted to the stance phase captured on the force plate by identifying the start and end of the ground reaction force (>20N). Kinematic and kinetic data were then time normalised for all trials to convention 100 frames. The Centre of pressure in the frontal and sagittal direction was extracted via the use of force plates.

5.3.3 Data Processing and Analysis

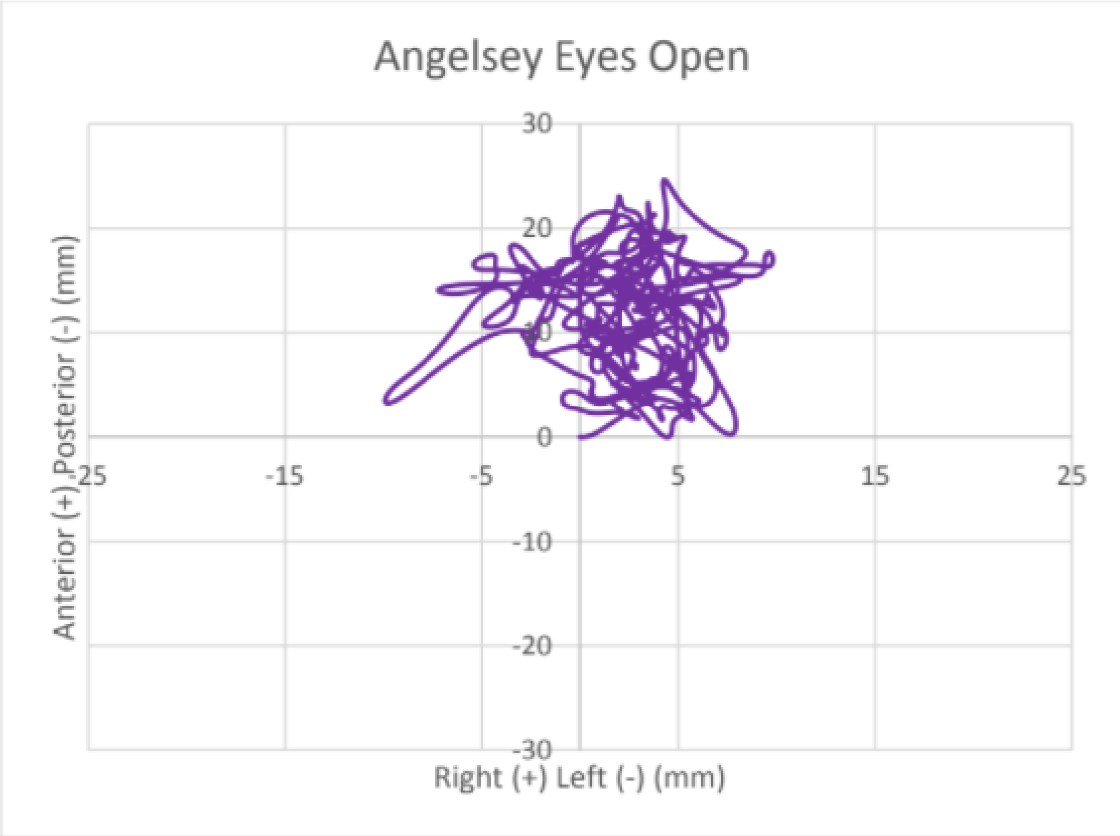
Data was initially processed in Vicon software (Nexus 2.8.2, Vicon Motion Systems Ltd, Oxford, UK). This included gap filling and screening of the marker trajectories and application of a low-pass filter using a zero-lag, fourth-order Butterworth filter (cut-off frequency of 6 Hz) on both the marker and force data. The Plug-in Gait model was implemented using the Vicon software. After the implementation of the biomechanical model, the kinematic and kinetic outputs and force data were exported to MATLAB (MATLAB 2020a, The MathWorks Inc., MA, USA) for the final stages of processing and analysis. This included extracting the quantitative data into MATLAB and using it to generate graphs depicting the three different gait cycles; normal, Anglesey and box-leg.

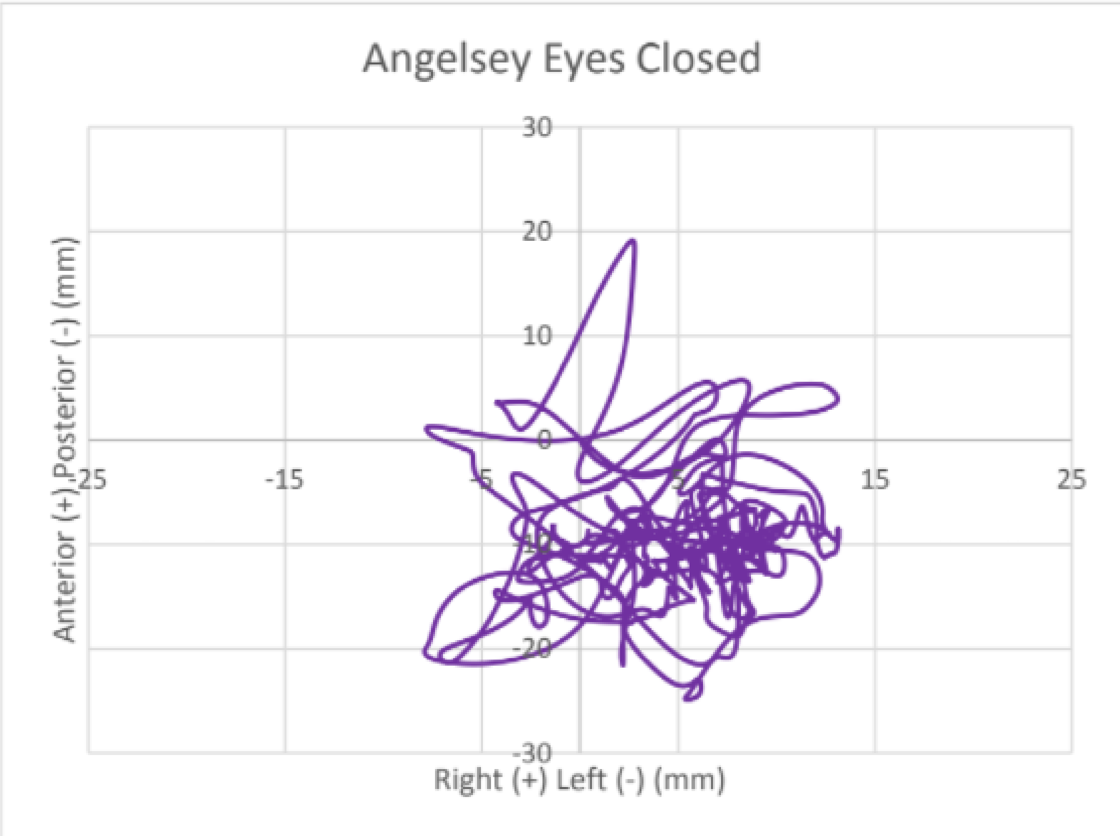
Chapter 6: Results

The various experiments on gait analysis produced data that showed a difference between the control (normal, unimpaired gait) and prosthetic gait. The data collected has been divided up into sections below which will explain the importance of this type of data and what the data is showing.

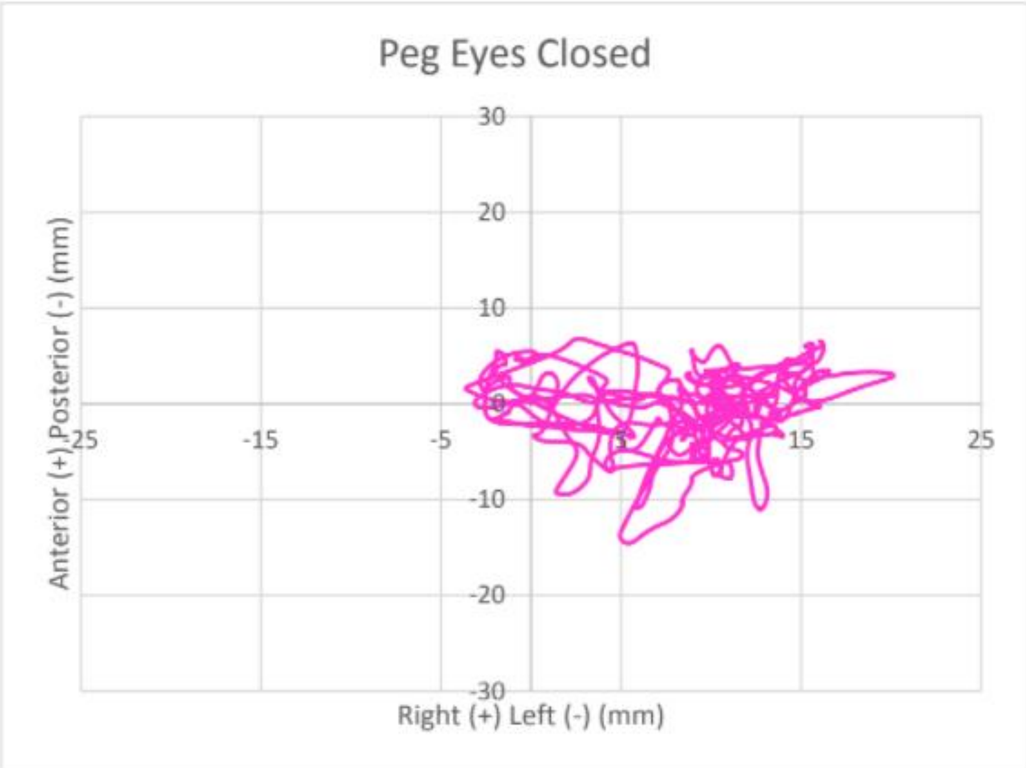
6.1 Balance/Centre of Mass

The first set of data is that of the balanced experiment, which presents the results of each 30-second stationary balance, eyes open and closed for Anglesey (fig. 6.1, purple), peg (fig. 6.2, pink) and normal (fig. 6.3, grey).

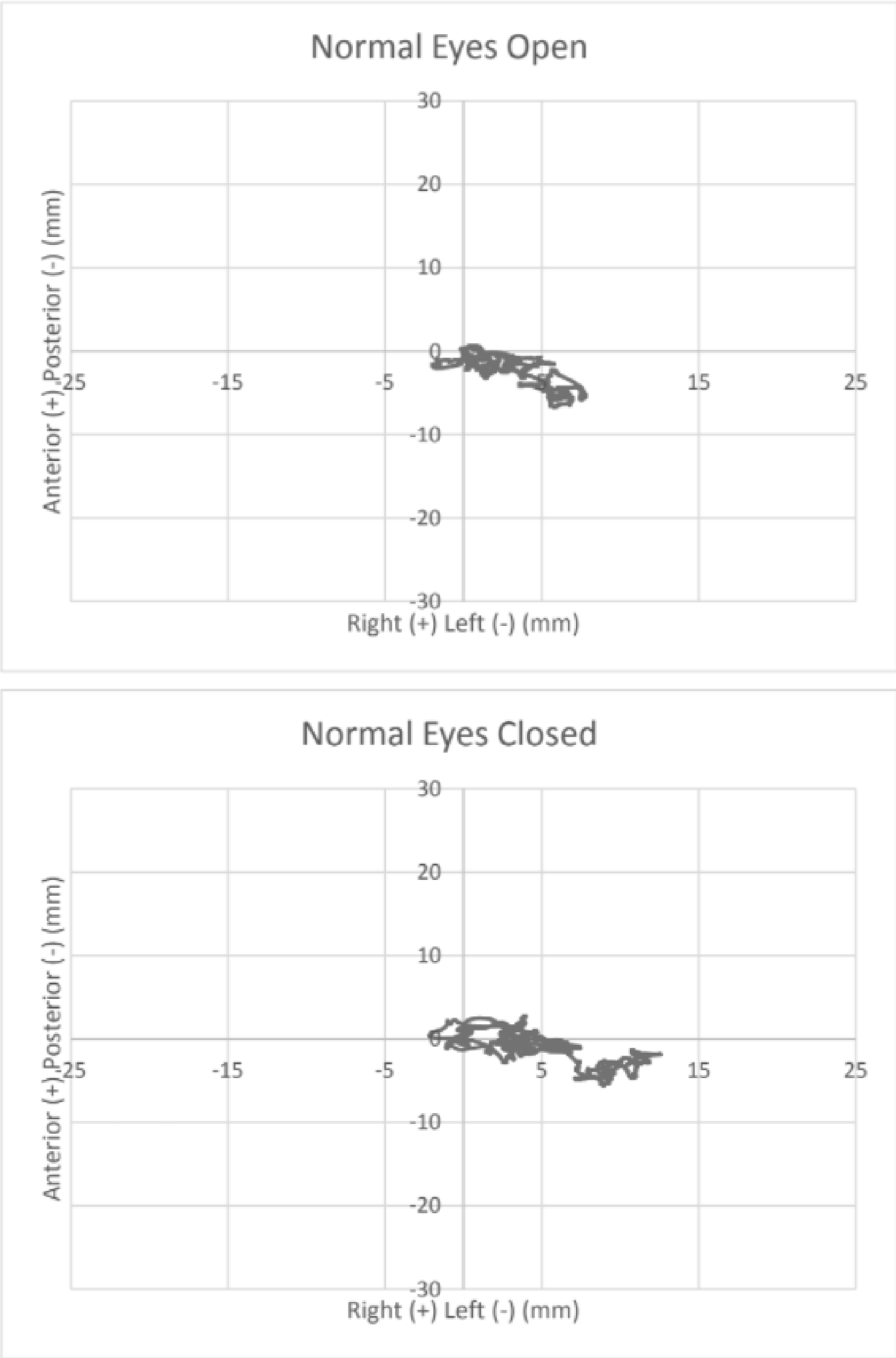




(Fig. 6.1 Force place generated balance results for Anglesey leg, eyes open and eyes closed for 30 seconds each). (-5, -15, -25) represents more pressure being placed on the left side of the body compared to (+5, +15, +25) which represents more pressure on the right side of the body. Anterior (+) and Posterior (-) represent how far the body is leaning forwards or backwards.)



(Fig. 6.2 Force plate generated balance results for peg-leg, eyes open, eyes closed for 30 seconds each.) (-5, -15, -25) represents more pressure being placed on the left side of the body compared to (+5, +15, +25) which represents more pressure on the right side of the body. Anterior (+) and Posterior (-) represent how far the body is leaning forwards or backward.))

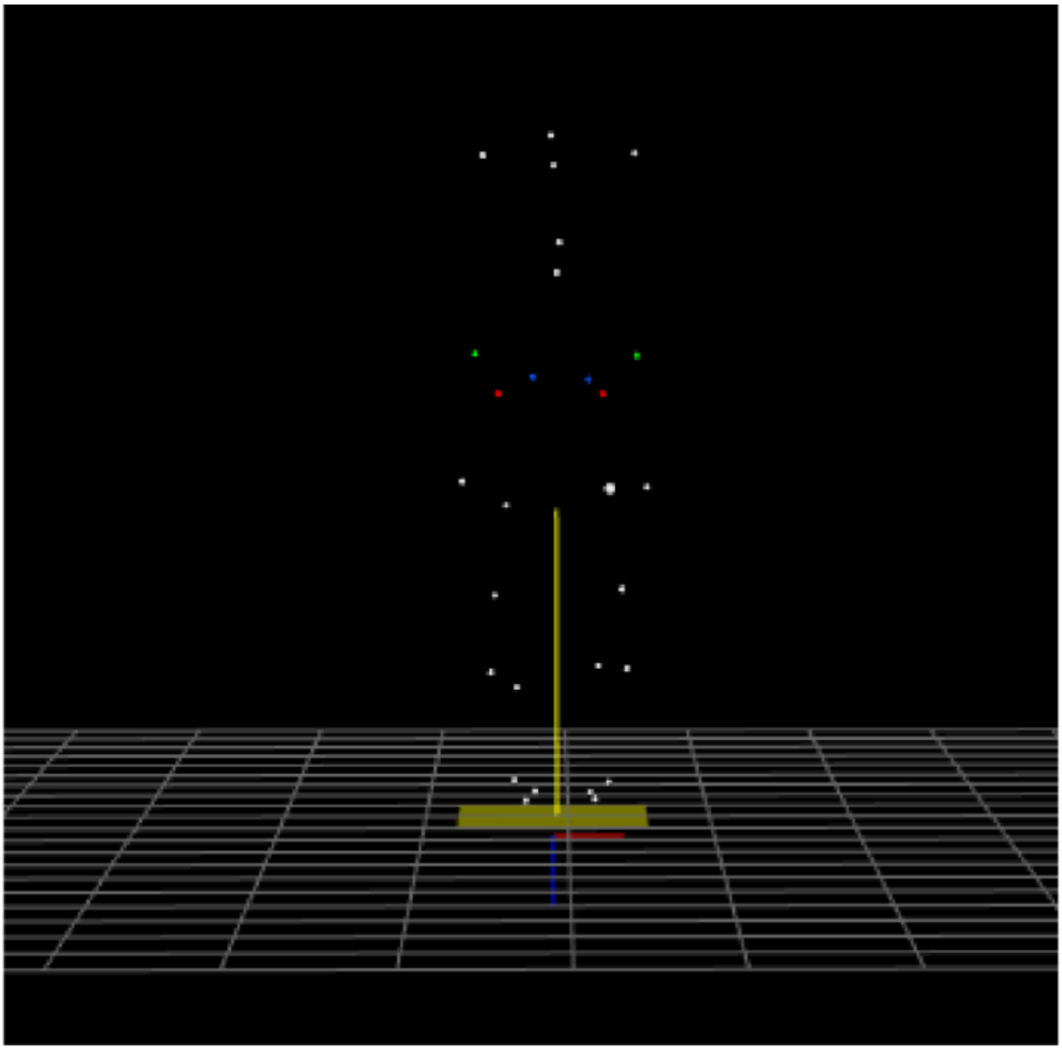


(Fig. 6.3 Force plate generated balance for no artificial limbs, eyes open eyes closed for 30 seconds each) (-5, -15, -25) represents more pressure being placed on the left side of the body compared to (+5, +15, +25) which represents more pressure on the right side of the body. Anterior (+) and Posterior (-) represent how far the body is leaning forwards or backwards.)

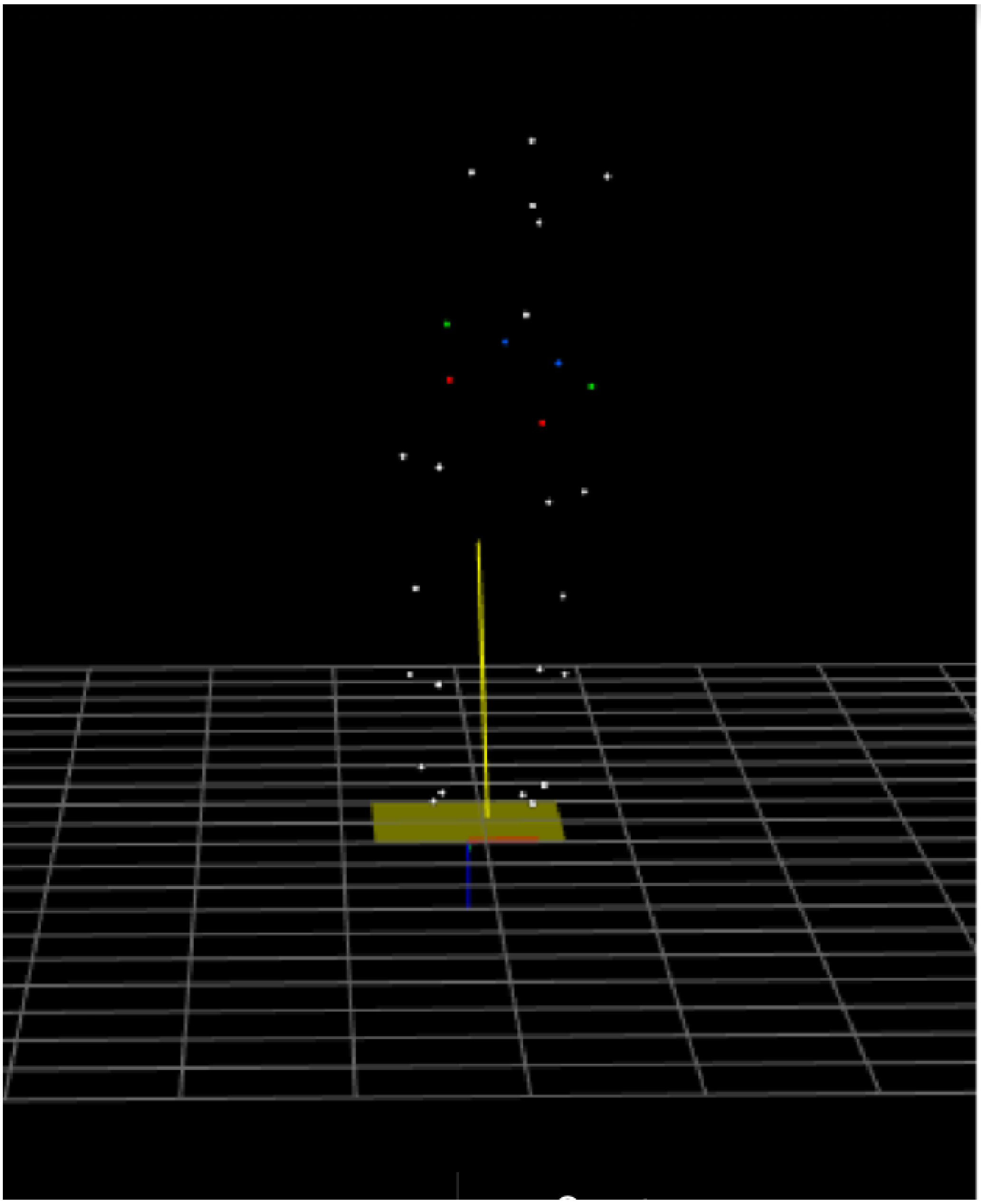
The three graphs above (figures 6.1-6.3) demonstrate the normal, box-leg and Anglesey leg's effect on balance and spatial awareness. The numbers -5, -15, and -25, represent more pressure being placed on the left side of the body compared to +5, +15, and +25, which represent more pressure on the right side of the body. Anterior (+) and posterior (-) represent how far the body is leaning forwards or backward. It would be expected that for a gait unaffected by a prosthesis, the balance would remain fairly controlled and stable, whilst it is natural for one side of the body to be more dominant than the other, which is evidenced in the control test with no prosthesis (fig. 6.3) with a slight lean to the right side, the balance is mostly controlled and unchanging throughout the 30 seconds both with eyes open and closed. Comparatively, in figures 6.1 and 6.2 there is a decrease in stability that occurs when both artificial limbs are worn in comparison to the stability that is apparent in figure 6.3 with no artificial limbs. The Anglesey leg which also had a crutch available for periods of greater instability shows the biggest fluctuation in stability, balance and centre of gravity (fig. 6.3) than the box leg.

Figures 6.1, 6.2 and 6.3 show that the results are consistent with the expectation that balance decreases when eyes are closed due to the impact on the senses and spatial awareness. Additionally, the decrease in stability whilst wearing artificial limbs is expected due to the body's interaction with a foreign appliance which has no nerve receptors and so no sense of touch and therefore no connection to the proprioception system. Unexpectedly, the figures show that although minimal (as the graph is in mm) there is slightly more stability observed in the peg-leg (fig. 6.2) as opposed to the Anglesey (fig. 6.1).

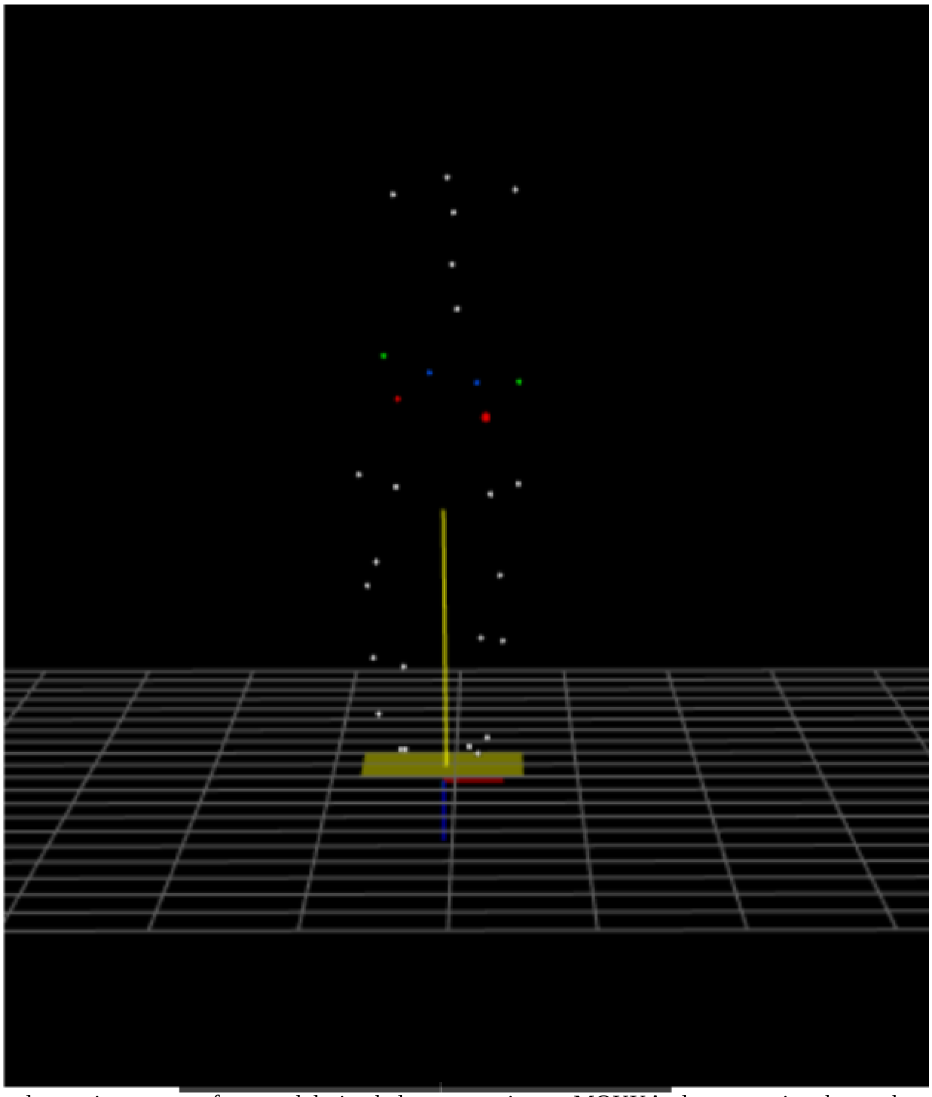
The MOKKA visual data (see fig. 6.4, 6.5 and 6.6) shows an uneven pelvic and hip postural change whilst wearing the artificial limbs. The blue dots represent the LPSI and RPSI and the red dots represent the LASI and RASI, the green dots represent the RPEL and LPEL. They have been specifically highlighted in figures 6.4-6.6 to demonstrate the tilt that takes place in a stationary position with each of the prosthetics compared to the normal gait. The hip is raised on the right side (side of the prostheses) with an increased lean toward the sound supporting leg. This would cause the trunk to tilt and alter the natural CoM, explaining why the balance in figures 6.1 and 6.2 becomes erratic.



(Fig. 6.4 Normal static stance on force pads during balance experiment, MOKKA. The blue dots represent the LPSI and RPSI and the red dots represent the LASI and RASI, the green dots represent the RPEL and LPEL)



(Fig. 6.5 Anglesey leg static stance on force pads during balance experiment, MOKKA, demonstrating the trunk and pelvic tilt observed in the balance data which create more pressure on areas of the body not accustomed to it - compared to Fig 6.4 above. The blue dots represent the LPSI and RPSI and the red dots represent the LASI and RASI, the green dots represent the RPEL and LPEL)



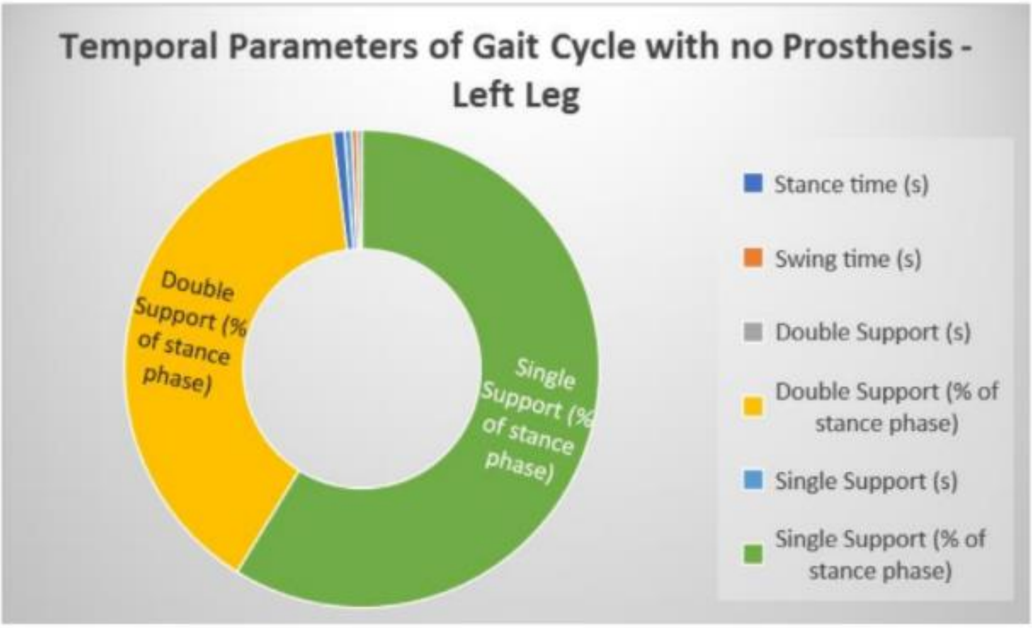
(Fig. 6.6 Box-leg static stance on force pad during balance experiment, MOKKA. demonstrating the trunk and pelvic tilt observed in the balance data which create more pressure on areas of the body not accustomed to it - compare to Fig 6.4 above. The blue dots represent the LPSI and RPSI and the red dots represent the LASI and RASI, the green dots represent the RPEL and LPEL)

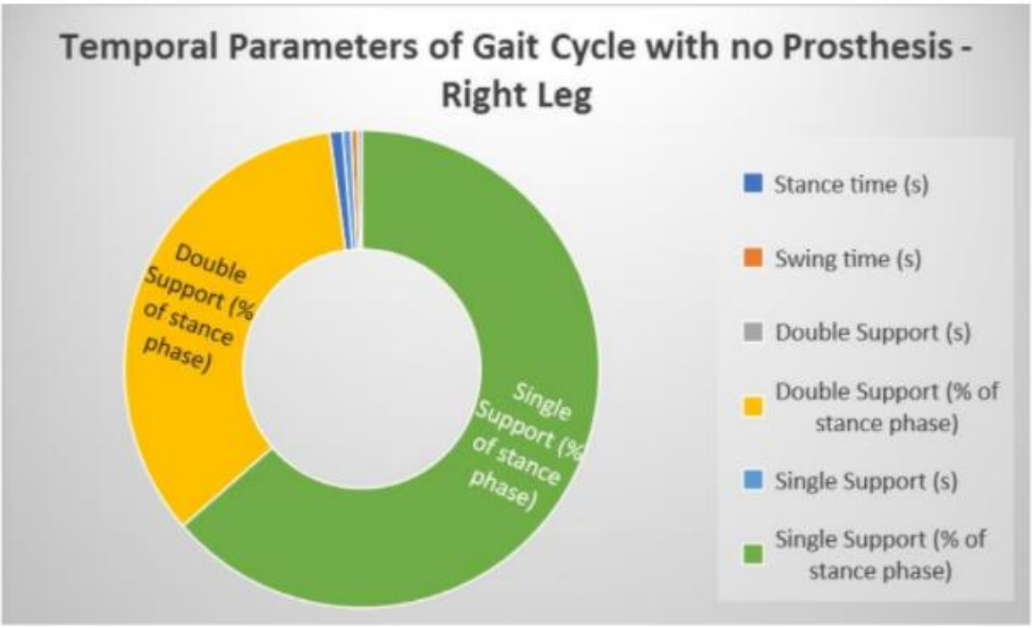
6.1.2 Temporal Parameters

Temporal parameters allow the experimenter to assess the overall quality of the person's gait. By walking over a pressure-sensitive pad, the experimenter can collect data on the spatial and temporal characteristics of a person's gait, for instance, stride length, velocity, cadence and in the case of this experiment, length of time spent in double and single support phases, figures 6.7-6.9 display the collected data.

Left	Trial One	Trial Two	Trial Three	Mean	Standard Deviation
Stance time (s)	0.82	0.76	0.77	0.78	0.03
Swing time (s)	0.38	0.43	0.38	0.4	0.03
Double Support (s)	0.33	0.27	0.29	0.3	0.03
Double Support (% of stance phase)	40	36	38	38	2
Single Support (s)	0.49	0.49	0.48	0.49	0.01
Single Support (% of stance phase)	60	64	62	62	2

Right	Trial One	Trial Two	Trial Three	Mean	Standard Deviation
Stance time (s)	0.9	0.86	0.82	0.86	0.04
Swing time (s)	0.44	0.45	0.45	0.45	0.01
Double Support (s)	0.31	0.33	0.28	0.31	0.03
Double Support (% of stance phase)	35	38	34	36	2.08
Single Support (s)	0.59	0.53	0.54	0.55	0.03
Single Support (% of stance phase)	65	62	66	64	2.08

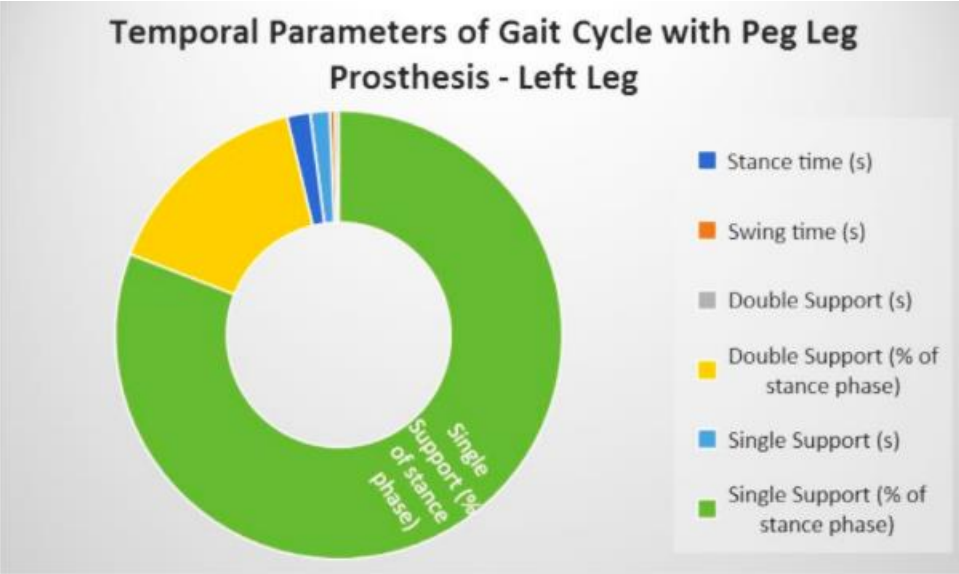


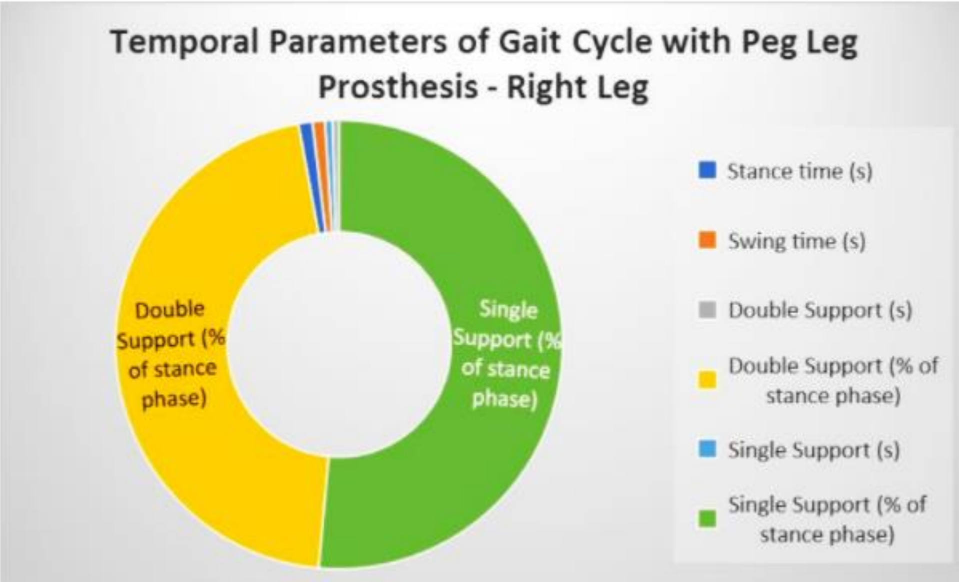


(Fig. 6.7 Temporal parameters of gait cycle without artificial leg – 'normal gait', table and graph. Stance time refers to the time spent with one leg in front of the other, and the swing phase refers to the period of gait where you are on one leg and the other is moving forward. Single support is time spent on one leg during the gait cycle and double support is time spent on both legs during the gait cycle. Time spent in single support on the left leg was 0.49s and on the right leg, 0.55s. This is identified in the graphs in green. Comparatively, the yellow identifies the time spent on both legs during gait, which was 0.3s for both right and left experiments.)

Left	Trial One	Trial Two	Trial Three	Mean	Standard Deviation
Stance time (s)	1.75	1.62	1.64	1.67	0.07
Swing time (s)	0.39	0.4	0.35	0.38	0.03
Double Support (s)	0.28	0.28	0.6	0.38	0.18
Double Support (% of stance phase)	16	17	36	23	11.27
Single Support (s)	1.47	1.34	1.04	1.28	0.22
Single Support (% of stance phase)	84	83	64	77	11.27

Right	Trial One	Trial Two	Trial Three	Mean	Standard Deviation
Stance time (s)	1.04	0.91	0.94	0.96	0.07
Swing time (s)	0.93	1.11	1.25	1.1	0.16
Double Support (s)	0.49	0.32	0.25	0.35	0.12
Double Support (% of stance phase)	47	35	27	37	10
Single Support (s)	0.55	0.59	0.69	0.61	0.07
Single Support (% of stance phase)	53	65	73	63	10

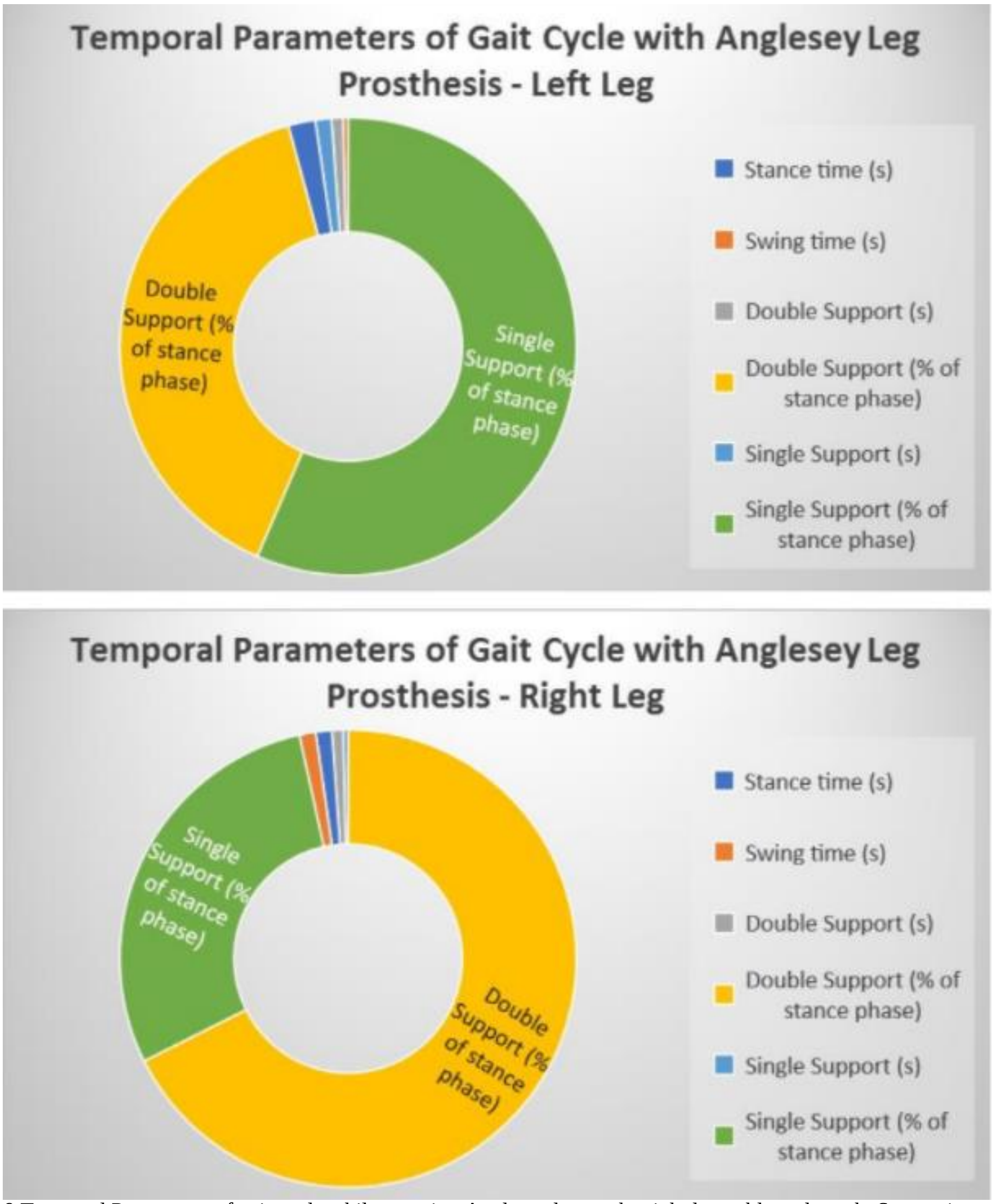




(Fig. 6.8 Temporal parameters of the gait cycle which are wearing peg-leg on the right leg table and graph. Stance time refers to the time spent with one leg in front of the other, and the swing phase refers to the period of gait where you are on one leg and the other is moving forward. Single support is time spent on one leg during the gait cycle and double support is time spent on both legs during the gait cycle. Time spent in single support on the left leg was 1.28s and on the right leg, 0.61s. This is identified in the graphs in green. Comparatively, the yellow identifies the time spent on both legs during gait, which was 0.38s for left and 0.35 for right leg experiments)

	Left				
	Trial One	Trial Two	Trial Three	Mean	Standard Deviation
Stance time (s)	2	2.25	2.19	2.16	0.11
Swing time (s)	0.38	0.34	0.22	0.31	0.08
Double Support (s)	0.84	0.49	0.73	0.69	0.18
Double Support (% of stance phase)	41	22	33	32	9.5
Single Support (s)	1.19	1.76	1.46	1.47	0.28
Single Support (% of stance phase)	59	78	67	68	9.5

	Right				
	Trial One	Trial Two	Trial Three	Mean	Standard Deviation
Stance time (s)	1.18	1.43	1.69	1.43	0.25
Swing time (s)	1.2	1.17	1.06	1.14	0.07
Double Support (s)	0.82	1.13	1.24	1.6	0.22
Double Support (% of stance phase)	70	79	73	74	4.58
Single Support (s)	0.36	0.3	0.45	0.37	0.07
Single Support (% of stance phase)	30	21	27	26	4.59



(Fig. 6.9 Temporal Parameters of gait cycle whilst wearing Anglesey leg on the right leg, table and graph. Stance time refers to the time spent with one leg in front of the other, and the swing phase refers to the period of gait where you are on one leg and the other is moving forward. Single support is time spent on one leg during the gait cycle and double support is time spent on both legs during the gait cycle. Time spent in single support on the left leg was 1.47s and on the right leg, 0.37s. This is identified in the graphs in green. Comparatively, the yellow identifies the time spent on both legs during gait, which was 0.69s for the left leg and 1.6s for the right leg experiments)

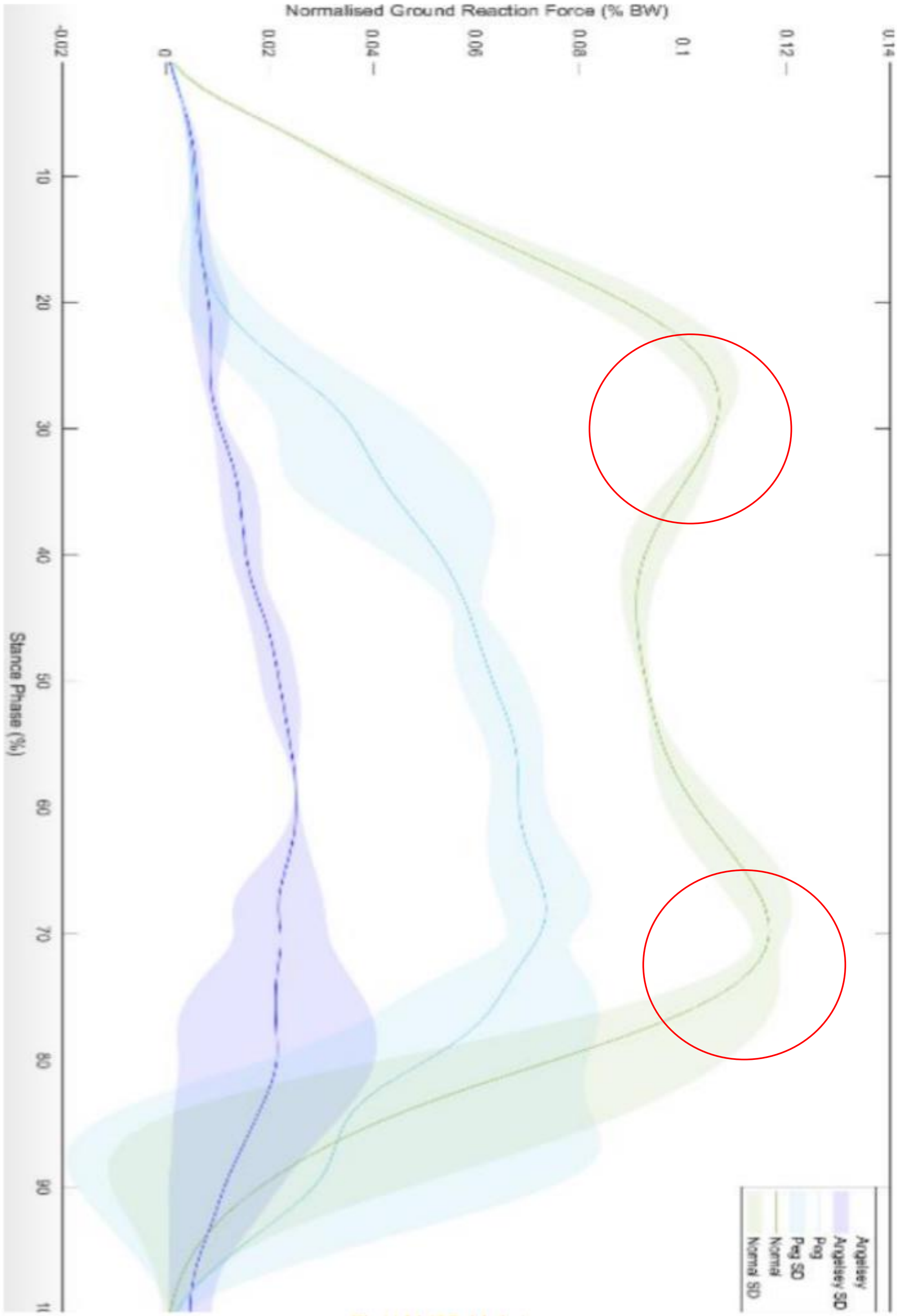
Immediately apparent in figures 6.7-6.9 is a decrease in balance and reliance on the prosthetic side and increase in the length of time spent in the double support phase of stance (as indicated by the yellow sections) as well as an increase in reliance on the single support phase of the healthy uninhibited limb (indicated in green). The data within these charts corresponds with the lack of balance and instability whilst using the prostheses, which was observed initially during the static balance tests above in figures 6.1-6.3. During the normal gait (without prostheses in figure 6.7) the double and single support phases, stay true to the expected percentages of roughly 40% double (yellow) and 60% single (green) support for both limbs during the stance phase of gait (Umberger, 2010). What is apparent in the box-leg gait (fig. 6.8), is that although both legs stay on the correct pattern longer on single (green) than double (yellow) support, there is a lot more reliance on the sound limb (left leg). The length of time spent on the single support of the sound leg increases from 60% to 84% of the single support stance phase of the left leg (fig. 6.8 left leg, compared to fig. 6.7 sound left leg), meaning the peg-leg spends more time in its swing phase, making its way back round to the front and what would be the beginning of the peg's stance phase. The single stance phase of the right limb (peg) decreases from 65% to 53%, confirming that there is less confidence in the stability and efficiency of the peg to support the weight. The biggest change that occurs is when the Anglesey leg is worn (figure 6.9), although the single phase of the left leg (sound limb) maintains the correct 60/40% when the weight is loaded to the right limb (Anglesey), confidence is lost in the prosthetics capabilities and the double support time increases from 35% (normal right leg) to 70%, and from 41% (left leg) during the same gait cycle, as seen in yellow. The MAT Lab data discussed below will determine if and what changes were observed using artificial limbs, with chapter 13 taking this data and applying it to clinical indicators for what type of damaging effects these changes could have caused an individual long term.

6.2 MAT Lab Results of Gait Biomechanical Deviations

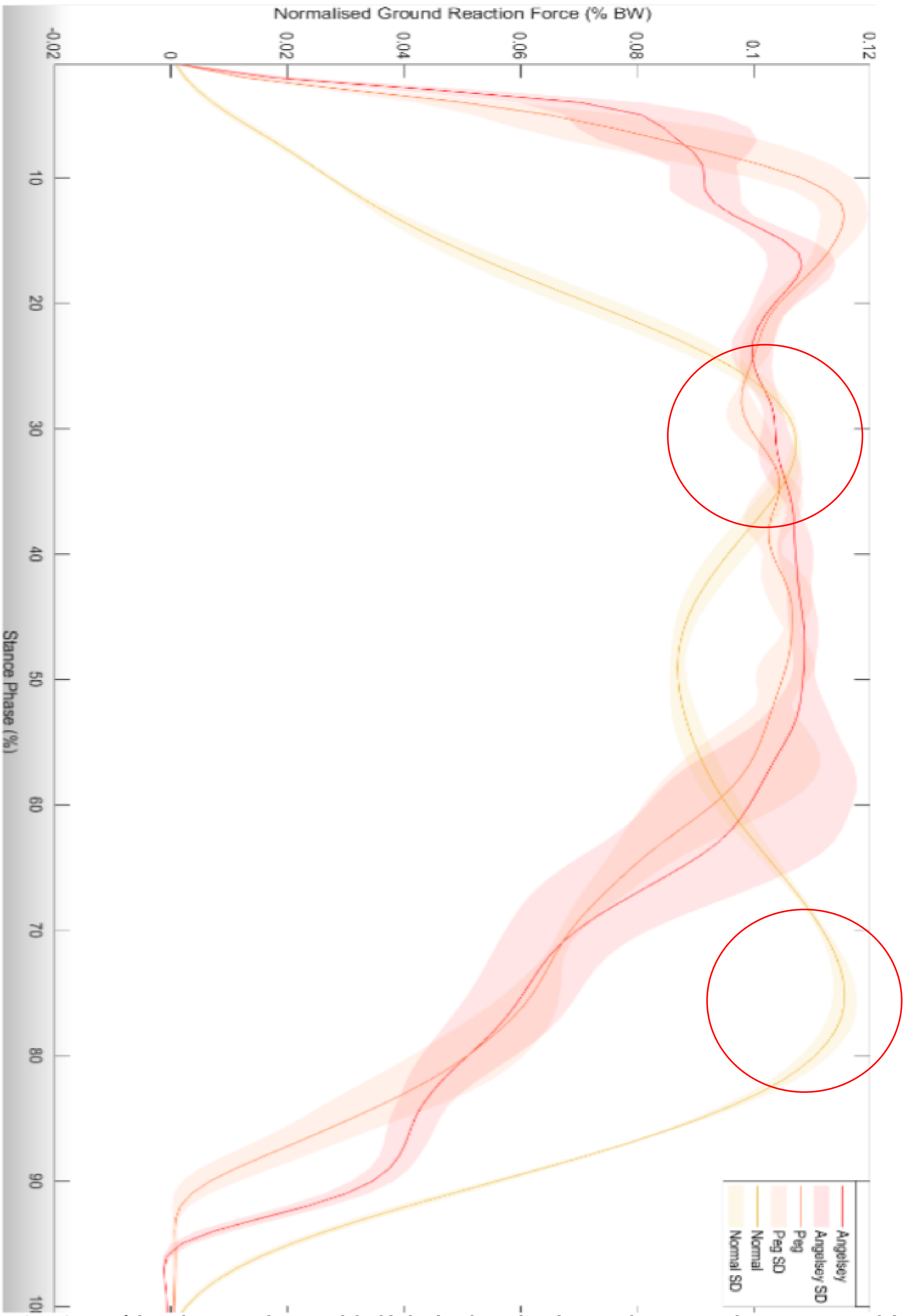
This section focuses on changes in energy expenditure during gait cycles, starting with an assessment of the ground reaction forces to see what impact the artificial limbs are having on how forces and stresses move through the body's joints and therefore identify what detrimental effects these alterations could lead to. Following Saunders et al (2004), the main determinants impacting energy expenditure during gait have been identified as pelvic rotation, pelvic tilt, pelvic obliquity, hip abduction/adduction, hip extension, hip rotation, knee extension, knee rotation and knee abduction/adduction. These determinants have been analysed and presented below in graph formation to demonstrate any changes that have been caused as a consequence of wearing the historical artificial limbs. Because velocity affects many parameters of walking, the understanding of a normal gait is one with a self-selected, comfortable velocity, it is here the individual naturally chooses energy-efficient movements and speeds (Steif et al, 2014). When pathologies or external factors affect this energy efficiency, we begin to see changes in gait which in turn can cause detrimental effects of their own.

6.2.1 Ground Reaction Force

The ground reaction force (GRF) is useful in clinical movement analysis as it reveals small changes in gait or a shift in the centre of gravity/CoM. The GRF occurs when there is contact with a support surface, such as the foot on the floor, it is equalling and opposing the force due to body mass passing through the foot to the ground surface (Ball et al, 2010). GRF is distributed across the whole area of contact between the feet and the floor (Mathieson, 2009), it is a three-component vector representing the forces in the vertical, anterior-posterior and medial-lateral planes (Durwood et al, 1999). Each component measures a different characteristic of the movement, the vertical is primarily generated by the vertical acceleration of the body and is of the highest magnitude (Headon and Curwen, 2001). GRF tells us the point of application (of force), its magnitude and its line of action through each gait cycle. It has magnitude as well as directional qualities. The spatial relation between this line and a given joint centre influences the direction of its rotation. The rotational potential of the forces that act on a joint is called torque or moment (Craig et al, 2016). In normal gait, during the early and late stance, it is expected that the magnitude of GRF is greater than the body weight but in midstance, it is less than the body weight because of the downward and upward accelerations of the body CoM (Meadows, 2019). In normal gait, it is expected that the magnitude of the two peaks (circled in red) is approximately equal (Meadows, 2019). In prosthetic gait, this is likely to change because prosthetic alignment affects gait by manipulating the positioning of the lower extremity and prosthetic joints concerning GRF (Ball et al, 2010). The two graphs in figures 6.10 and 6.11 depict the normalised (percentage of the body weight GRF = GRF/bodyweight) ground reaction forces (GRF) during a gait cycle for all three of the circumstances, normal, peg-leg and Anglesey gait. The first peak is the initial impact peak with the line leading up to this showing us the vertical loading rate, the second peak is the active peak which is observed as the gait cycle continues.



(Fig. 6.10 GRF Right leg. The two red circles demonstrate the two expected peaks in normal gait with the Anglesey (dark blue line) and box legs (light blue line) struggling to follow the expected trajectory of forces whilst being worn on this leg)



(Fig. 6.11 GRF Left leg. The expected max peak highlighted within red circles is not being met in the same manner whilst the artificial appliances are in use on the right leg, showing that the effects of the limbs aren't concentrated on that specific limb but their use affects the forces and pressures on different areas of the body, in this case, the left leg which does not meet the same peak trajectory as is expected with a normal gait. Anglesey leg is shown in dark red and peg-leg in orange.)

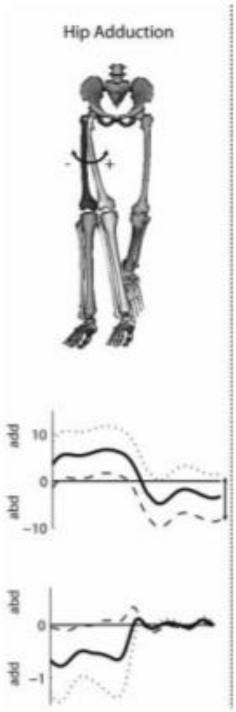
Figures 6.10 and 6.11 show that the normal gait in both the left and the right leg follows the expected trend of two equal peaks of force during early and late stance, seen circled in red in both figures 6.10 (light green line) and 6.11 (yellow line). This suggests the CoM and overall stability are as expected. Figure 6.10 shows the Anglesey leg in (dark blue) displaying a drastic drop in overall GRF being placed through the right ankle, knee and hip with neither the Anglesey (dark blue line) nor peg (light blue line) peaking at the same intensity as a normal gait. The GRF for both does not have its initial peak until the latter stance phase although this is minimal, instead, the overall GRF is maintained for longer with no peak or decrease throughout the gait cycle.

Comparatively in figure 6.11 (left leg) whilst the box-leg which is being worn on the right leg alters (orange line) the GRF for the left leg, it begins its gait with a GRF initial peak only marginally greater than with no artificial limb. However, the peak is earlier and unstable, the force plateaus with no second peak before it eventually decreases at the latter stage of the stance. In figure 6.11 the GRF being maintained in what would be the posterior Achilles tendon region has no way of creating anterior GRF to balance out the forces, consequently generating more pressure up through the body and residual limb which is observed as occurring in fig. 6.10.

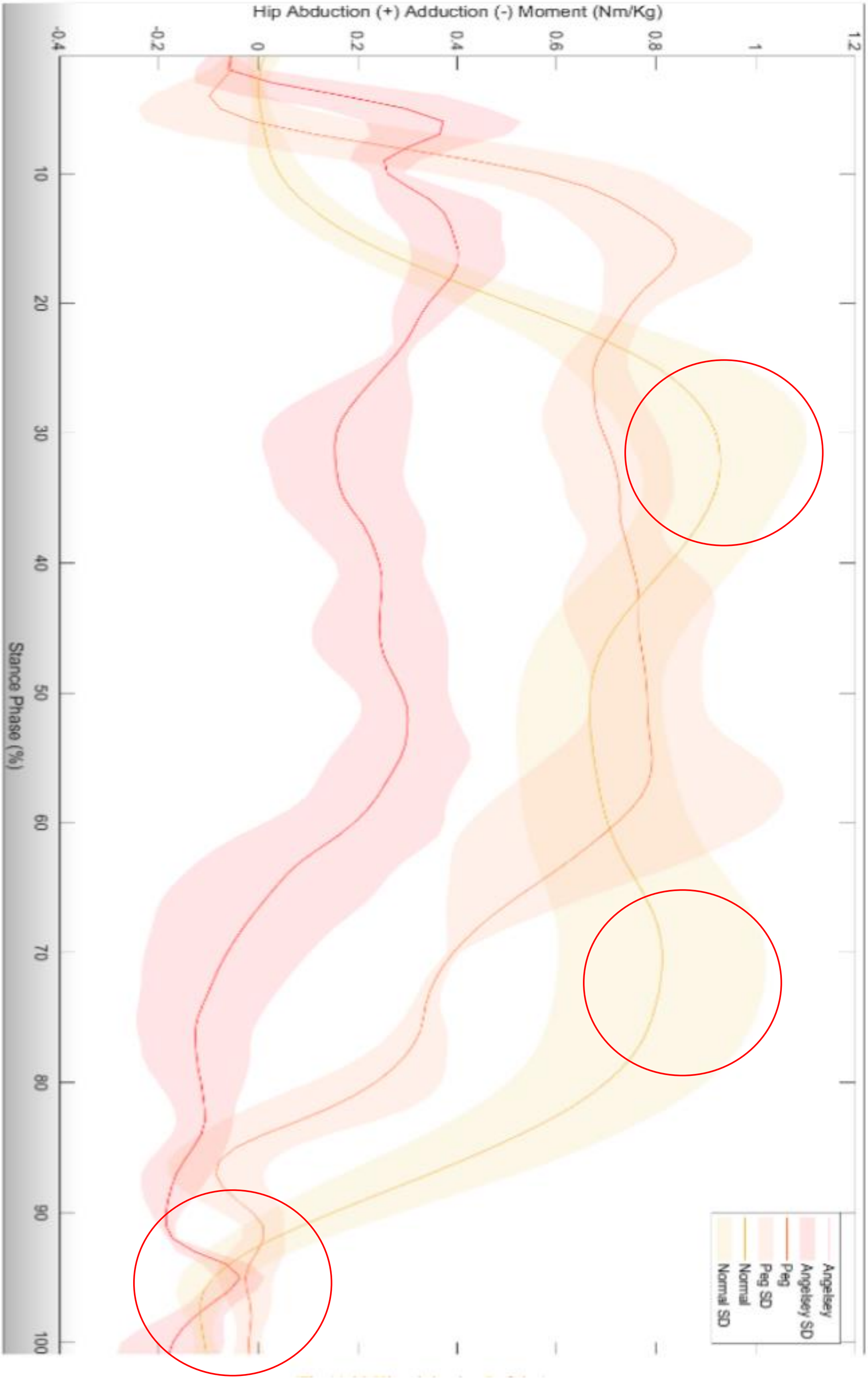
Whilst the Anglesey leg is being worn on the right leg (dark red line in figure 6.11), the left leg follows a similar trajectory with a very weak first peak and little evidence of a second peak, interestingly, it follows the same decrease in force as the peg-leg. However, both the peg (orange line) and the Anglesey (red line) affect the overall GRF going through the sound left leg, as both show higher peaks in the force that are sustained for longer, suggesting more long-term pressure is being sent up through the left ankle, knee and hip.

6.2.2 Hip Abduction/Adduction

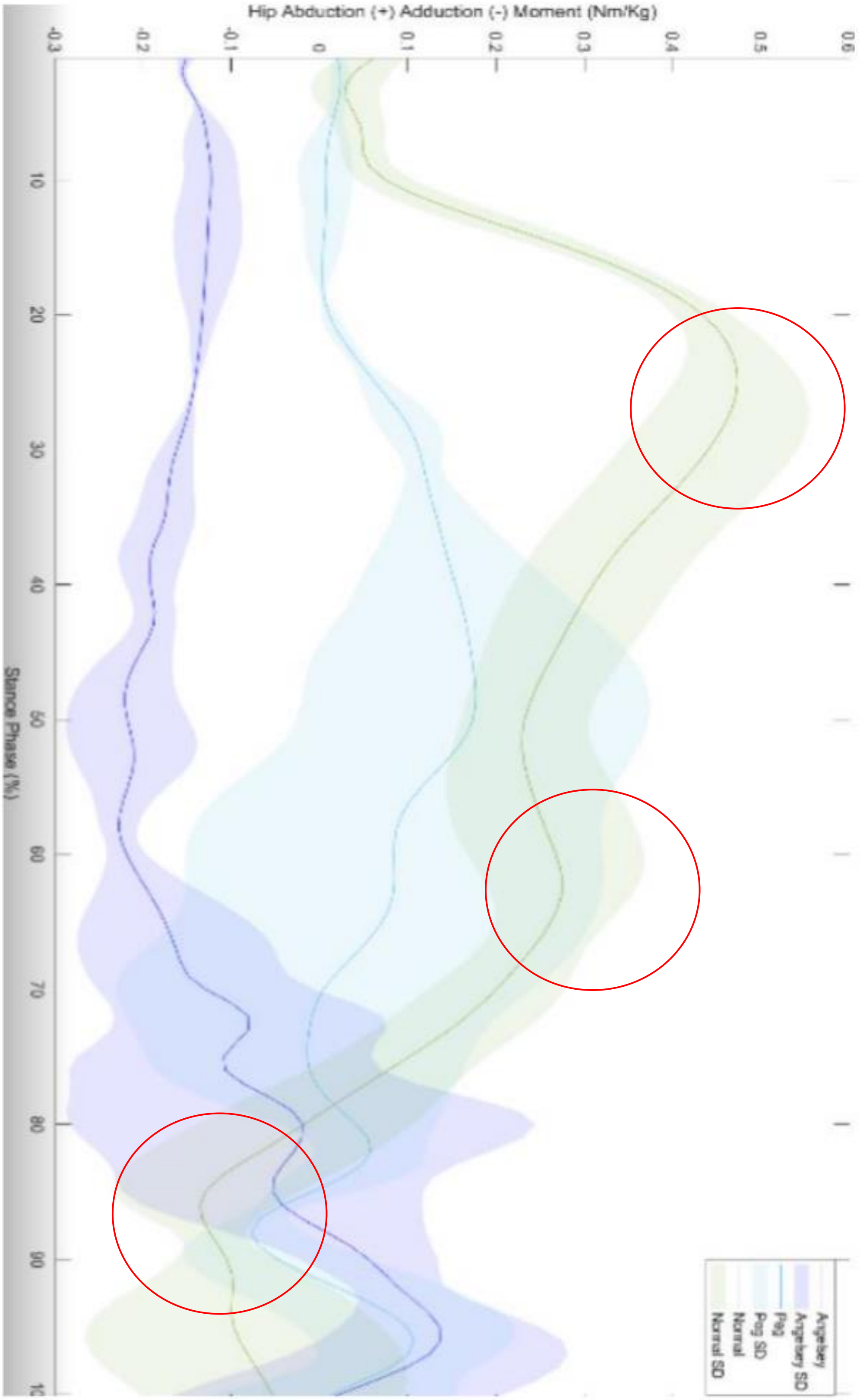
Hip abduction as depicted in the graphs in figures 6.13 and 6.14 below, is the movement of the leg away from the midline of the body. Hip abductor muscles contribute to our ability to walk, stand and rotate our legs with ease. Hip adduction is the opposite of abduction and is the movement towards the midline which squeezes the legs together, in the frontal plane, it occurs during early stance, reaching a maximum just before toe-off. It is expected in normal gait that hip abduction of 5-8^{o} occurs in the early swing phase (Krebs et al, 1998) with Perry (1992) noting that total transverse plane motion is 8^{o}, this is demonstrated in figure 6.12.



(Fig. 6.12 Wesseling et al (2015: 1096) depiction of average hip abduction/adduction variations during normal gait with the graph showing kinematics (degrees) and kinetics (NM/kg). Adduction is the movement of the limb towards the midline of the body whereas abduction is the movement away from the midline. The graphs demonstrate adduction as the negative line whilst abduction is depicted in positive numbers. The different perturbations by ±5° in hip and pelvis kinematics The kinematic graphs show the average nominal joint angles (solid line) and the perturbations by +5° (dotted line) and −5° (dashed line). The kinetic graphs show the average nominal joint moments (solid line) and the moments when perturbing the kinematics by +5° (dotted line) and −5° (dashed line)).



(Fig. 6.13 Hip Abduction left leg with artificial appliances on the right leg. The normal unaided gait depicted in orange demonstrates the peaks at the expected +8° and expected troughs at -1.5° (circled in red). Comparatively, we see both the Anglesey and box leg kinetic perturbations struggling to reach the same degree of abduction as unaided gait with the box leg remaining at the same level of abduction throughout the gait cycle with minimal and unstable peaks and limited levels of adduction. Demonstrating that whilst the artificial appliances are being worn on the right leg, they are still affecting the overall function of bodily movement and causing noticeable changes in the natural gait pattern on so-called 'unaffected' limbs.)

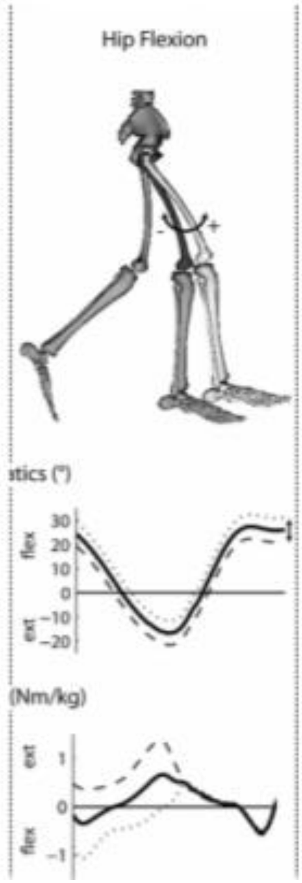


(Fig. 6.14 Hip Abduction of the right leg with appliances on the right leg. For the unaided gait, we see the expected peaks at the expected +5° and expected troughs at -1.5° (circled in red). Comparatively, we see both the Anglesey and box leg kinetic perturbations struggling to reach the same degree of abduction and adduction as unaided gait with the box leg remaining largely adducted throughout the gait cycle with minimal and unstable peaks and never reaching abduction. Likewise, the Anglesey leg, whilst reaching abduction and adduction during the gait cycle, is in both circumstances greatly minimised. Demonstrating that whilst the artificial appliances are being worn on the right leg, they are affecting the overall function of bodily movement and causing noticeable changes in the natural gait pattern).

As the body moves forward from the initial heel strike to the terminal stance, the ground reaction force vector (quantity with both direction and magnitude) changes from anterior (forward) to the hip joint before migrating posteriorly when the GRF is posterior (back) to the hip (Perry, 1992). The peak flexion torque (a force to rotate a body around an axis) occurs at initial contact before declining and changing to an extension torque at midstance, remaining as an extension torque until late stance (Perry, 1992). In the coronal plane, adduction torque is maintained through the stance phase (Perry, 1992). This translates in the graphs above to an initial peak in moments (the line going above zero for abduction) before decreasing to negative moments for adduction, depicted above in red circles and similar to what is observed in figure 6.13.

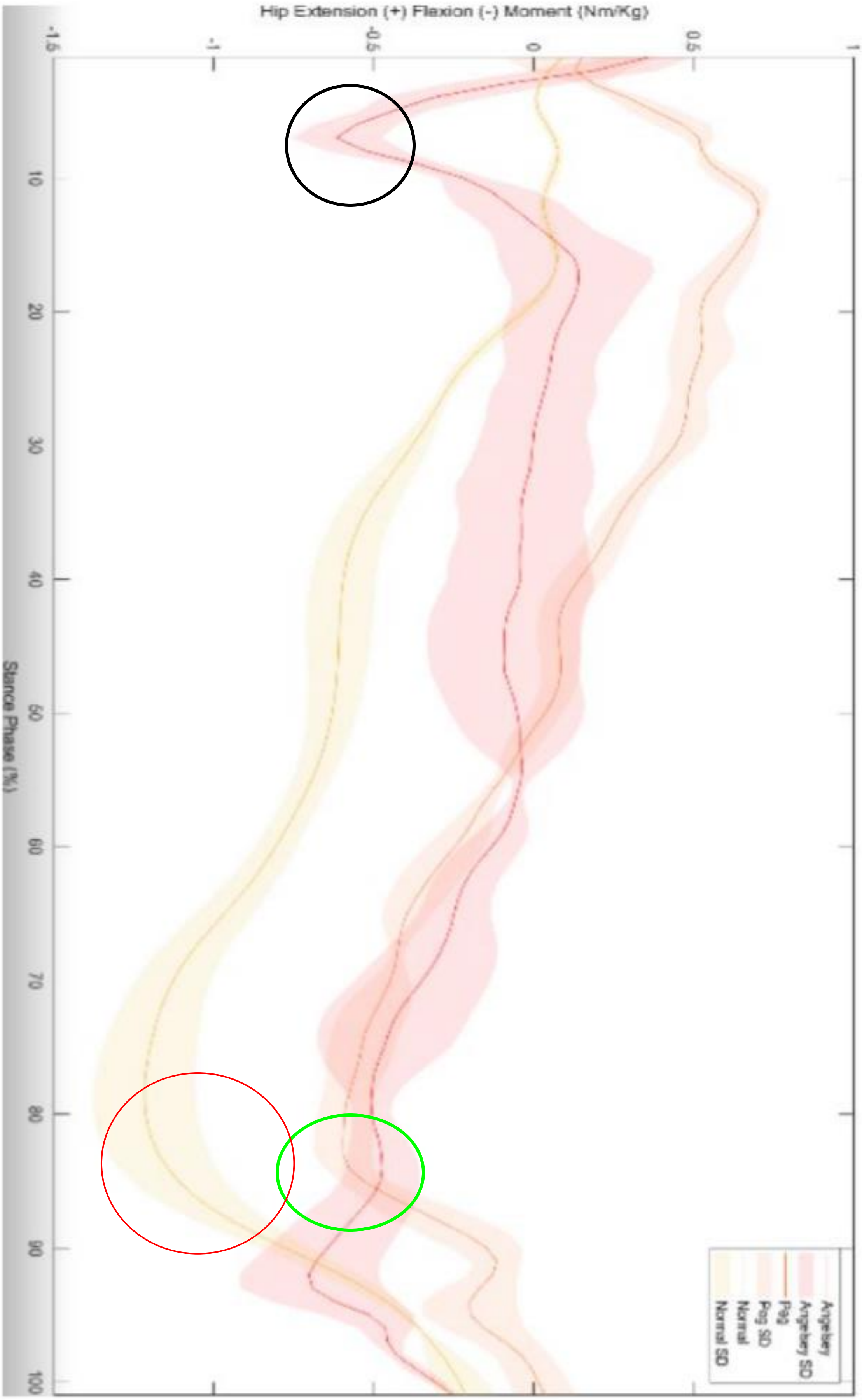
The graphs above show the alterations in hip abduction of the left (fig. 6.13) and right leg (fig. 6.14) during a gait cycle, whilst wearing no artificial limb (yellow line in figure 6.13 and green line 6.14), whilst wearing the Anglesey leg (orange line 6.13 and light blue line figure 6.14) and whilst wearing the peg-leg (red line figure 6.13 and dark blue line figure 6.14). It can be seen in figures 6.13 and 6.14 that the unimpaired gait on both the left (yellow line) and the right leg (green line) follows the expected trajectory, with abduction peaking before then rapidly entering adduction before the swing phase. Contrastingly, neither the peg (red line fig. 6.13) nor the Anglesey leg (orange line fig. 6.13) allows the left leg abduction moment to peak at the same rate as in the unaided gait seen in the yellow line in figure 6.13, although the peg affects the natural range of motion slightly less. Similarly, the hip abduction observed in fig. 6.14 for the Anglesey (light blue line) and peg-leg (dark blue line), show a markedly lower range of motion, with adduction being a permanent state of motion for the Anglesey, with it struggling to reach abduction. The peg-leg too struggles to maintain abduction moments, only slightly peaking at the same time as observed in normal gait albeit with less intensity, before decreasing into a more stable adduction moment. This tells us that the hip remains more adducted through the gait cycle than the unaided gait.

6.2.3 Hip Extension/Flexion



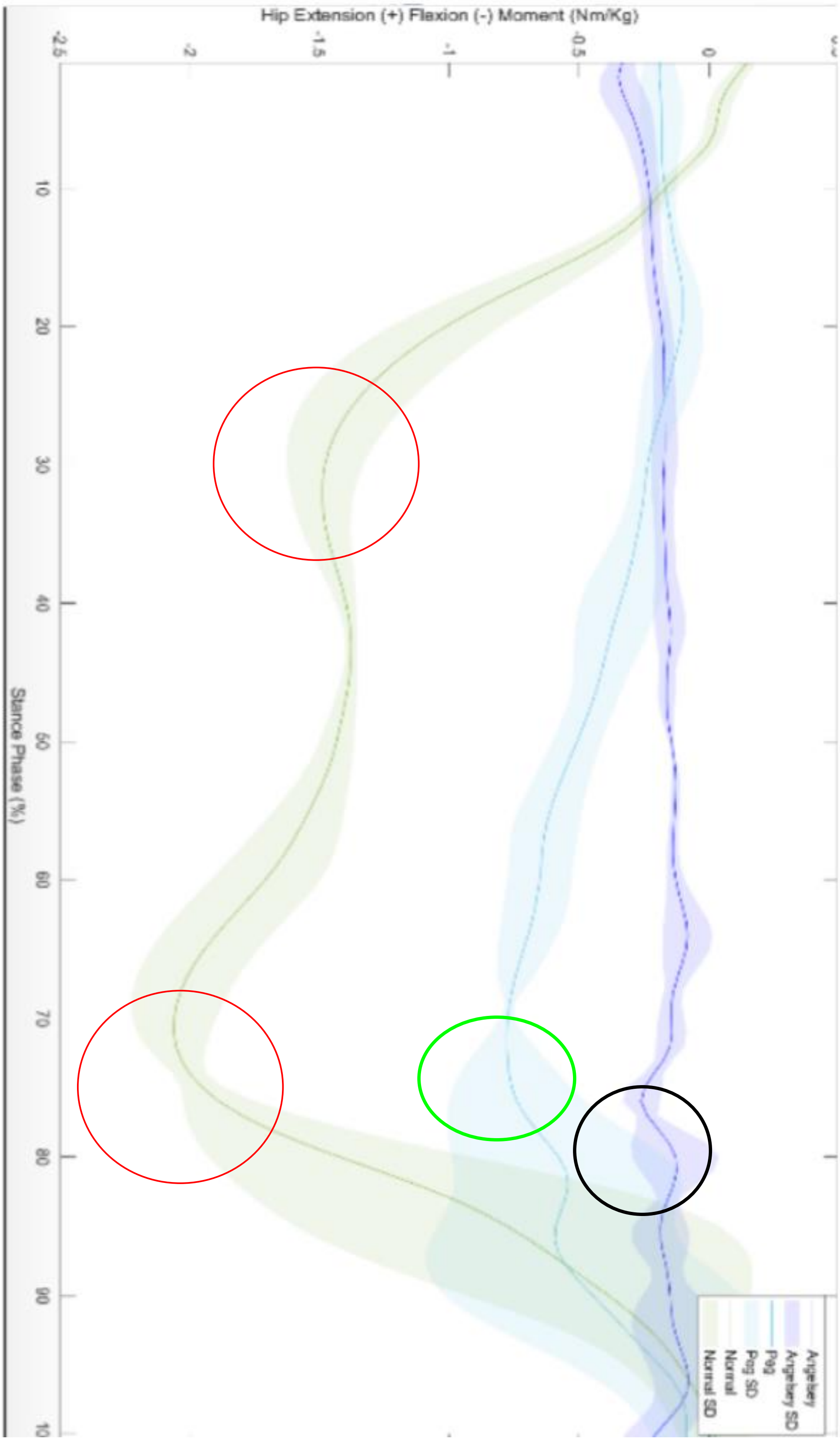
(Fig. 6.15 Wesseling et al (2015: 1096) depiction of average hip extension/flexion variations with graphs showing kinematics (degrees) and kinetics (NM/kg). The different perturbations by ±5° in hip and pelvis kinematics The kinematic graphs show the average nominal joint angles (solid line) and the perturbations by +5° (dotted line) and −5° (dashed line). The kinetic graphs show the average nominal joint moments (solid line) and the moments when perturbing the kinematics by +5° (dotted line) and −5° (dashed line)).

During the expected normal gait cycle the maximum hip flexion of 30-35^o occurs in the late swing phase (raising leg towards the front), with a maximum extension of around 10^o being reached at toe-off around mid-cycle (extending leg behind) (Krebs et al, 1998) as seen in figure 6.15 above from Wesseling et al (2015: 1096). It is expected during normal gait that there would be an obvious dip at initial contact, then a peak loading response before a further dip at terminal extension before moving through the terminal stance and swing phase. Figures 6.16 and 6.17 display the changes observed between unaided gait (yellow line fig. 6.16 and green line 6.17) and the two prosthetic gaits (Anglesey depicted in fig. 6.16 as an orange line and 6.17 as a dark blue line, with the peg-leg in fig. 6.16 as a red line and in 6.17 as a light blue line). During normal gait with no artificial appliances, the trajectory of hip extension and flexion moments of both the left and right legs in figures 6.16 and 6.17 follow the expected format with a dip, slight peak, and further dip before a swift increase, highlighted with a red circle. This differs for the moments observed in the peg and Anglesey gaits which not only affected the left leg so its range of motion decreased, but as fig. 6.17 displays, there is limited if any alteration in hip extension and flexion through the stance phase of the cycle whilst wearing both artificial limbs (shown via the dark blue and light blue lines). If we take the maximum hip flexion of the normal gait to be the participant's 100% extension/flexion (circled in red in both figures 6.16 and 6.17), then it is evident during the gait cycles for each context that the peg and Anglesey are affecting the wearer's gait, so they do not reach their full flexion/extension potential. For instance, for the right leg in figure 6.17, the normal, unaided maximum NM/kg is -2.227 (we will take this as our 100%), and the use of the Anglesey on this limb causes the right leg to have an output of -0.3189 NM/kg (black circle), with the use of the peg-leg reducing its flexion capacity -0.785 NM/kg (green circle), the wearing of the artificial limbs means that respectively, the right leg is only reaching 14.32% and 35.25% of its maximum potential shown in the normal gait. Likewise, the readings for the left leg in figure 6.16 give us a reading of -1.379 NM/kg as our maximum flexion/extension during normal gait, with this changing to -0.9155 NM/kg for the Anglesey and -0.6886 NM/kg (black circle) for the peg-leg (green circle), which suggests that the leg is only reaching 66.39% and 50% respectively of its maximum potential.



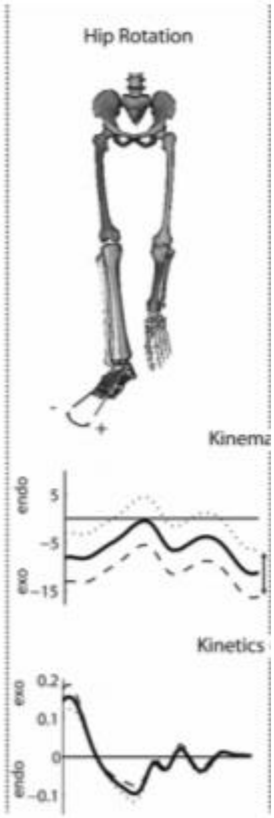
Hip Extension (+) Flexion (-) Moment (Nm/Kg)
-1.5
-1
-0.5
0
0.5
1
Stance Phase (%)
10
20
30
40
50
60
70
80
90
100
Angelsey
Angelsey SD
Peg
Peg SD
Normal
Normal SD

(Fig. 6.16 Hip extension and flexion of the left leg, whilst the artificial leg is worn, is done so on the right leg. This graph depicts the stance phase of the gait cycle and therefore shows the unaided gait (orange) following the expected trajectory of a dip during heel strike and toe-off before entering the swing phase. With the toe-off dip circled in red. Comparatively, the Anglesey and box-leg both affect the functioning of the sound limb because whilst they are worn, the left leg struggles to complete a gait cycle with the expected forces and pressures of both heel strike and toe, with the hip maintaining a prolonged period of extension than is expected with a natural gait.)



(Fig. 6.17 Hip extension right leg, whilst the artificial leg is worn, is done so on the right leg. This graph depicts the stance phase of the gait cycle and therefore shows the unaided gait (green) following the expected trajectory of a dip during heel strike and toe-off before entering the swing phase. The heel strike and toe-off dips are both circled in red. Comparatively, the Anglesey and box-leg both affect the functioning of the right because whilst they are worn, the right leg struggles to complete a gait cycle with the expected forces and pressures of both heel strike and toe. The hip maintains a prolonged period of greater extension forces than is expected with a natural gait for both artificial limbs, with the Anglesey affecting flexion more than the box-leg.)

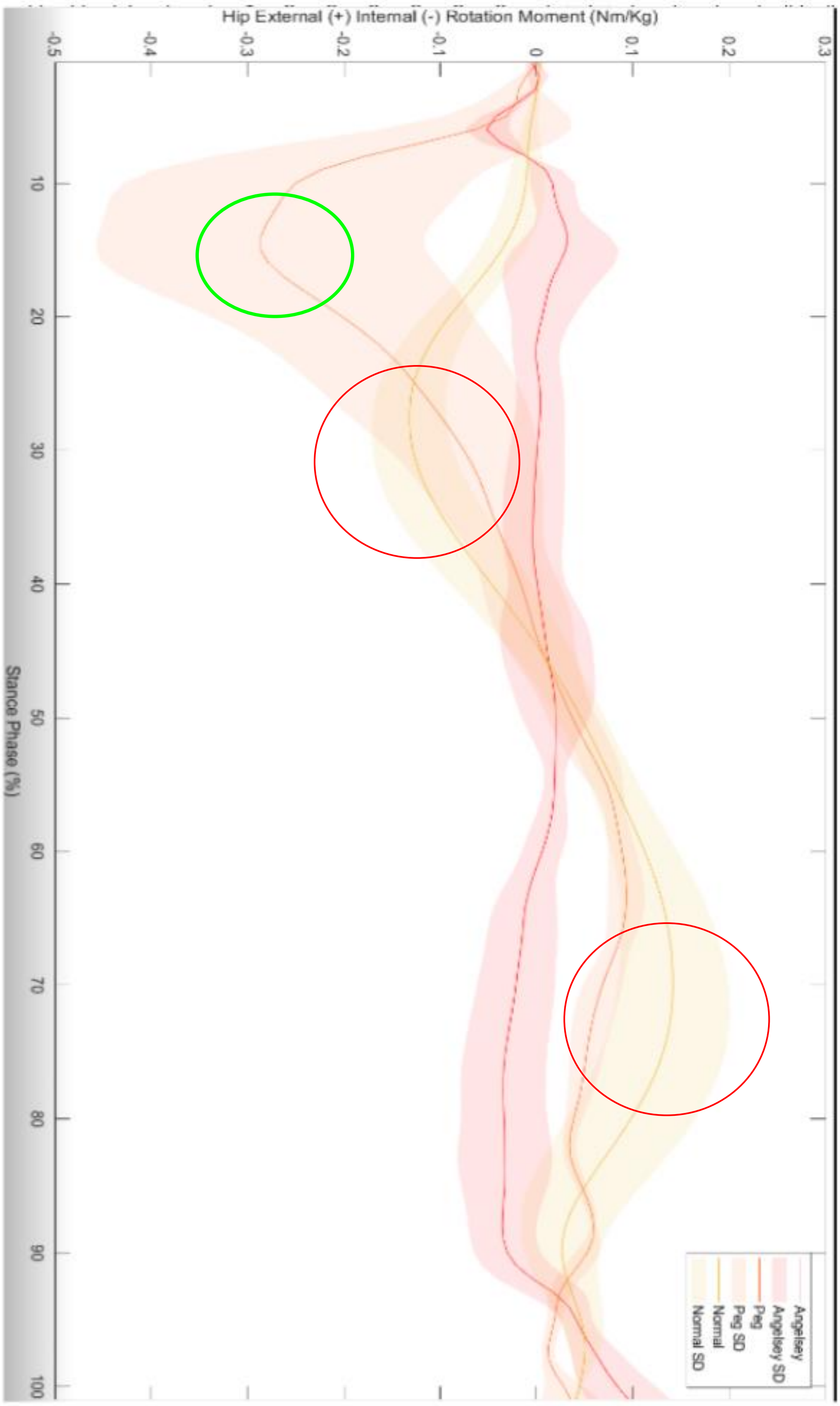
6.2.4 Hip Rotation



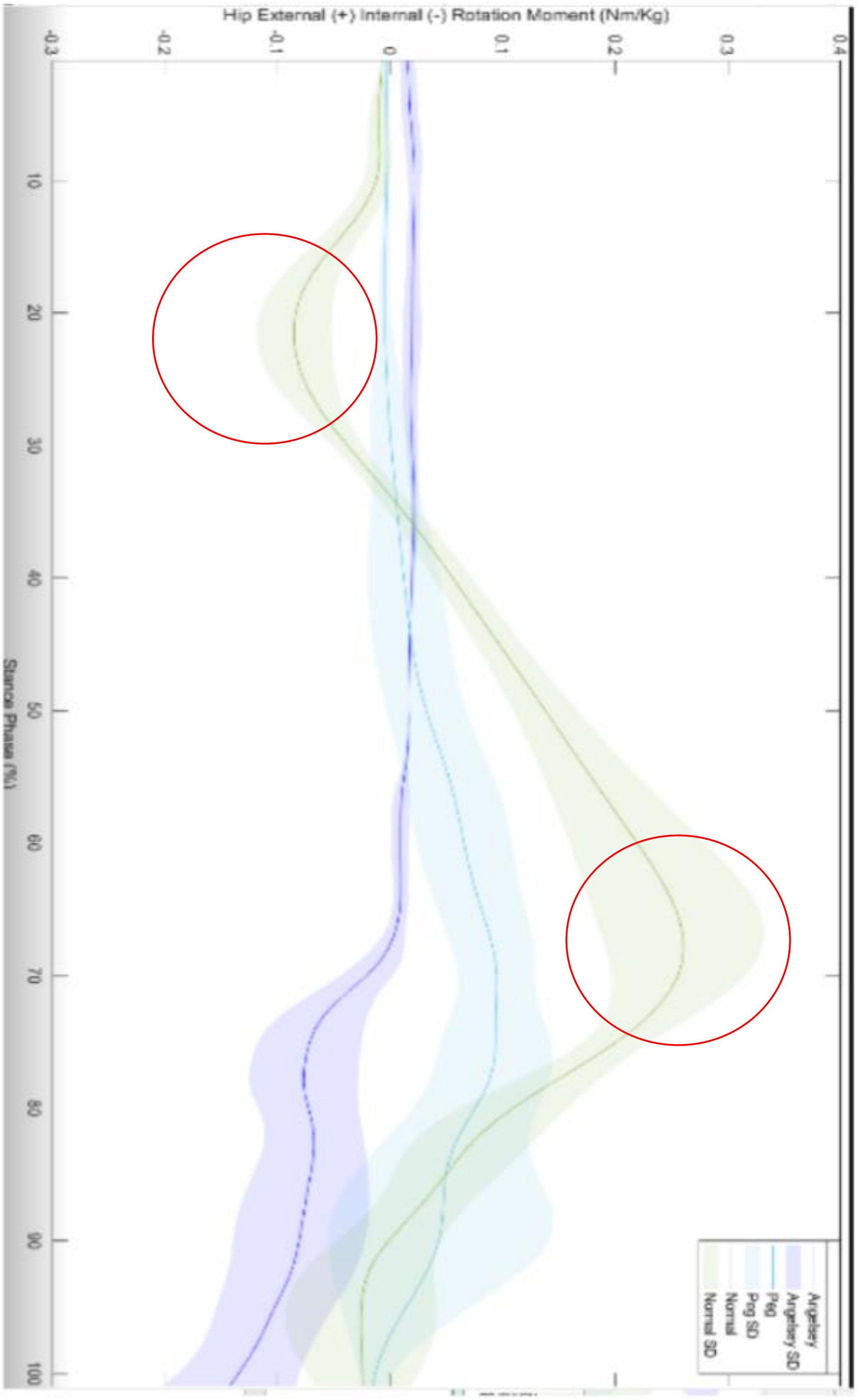
(Fig. 6.18 Wesseling et al (2015: 1096) depiction of average hip rotation variations with graphs showing kinematics (degrees) and kinetics (NM/kg). Endo represents internal rotation and exo as external rotation. The expectation being that throughout a gait cycle the hip will remain largely externally rotating but with a fluctuation which observes two peaks throughout the gait cycle with stance phase seeing an initial increase in internal rotation evidenced by the large peak at heel strike, before going into another peak for toe off. The different perturbations by ±5° in hip and pelvis kinematics The kinematic graphs show the average nominal joint angles (solid line) and the perturbations by +5° (dotted line) and −5° (dashed line). The kinetic graphs show the average nominal joint moments (solid line) and the moments when perturbing the kinematics by +5° (dotted line) and −5° (dashed line)).

Krebs et al (1998) discusses kinematics, noting that the hip rotates around 40^{o} in the sagittal plane (longitudinal central division of the body) during a normal gait stride. Maximum internal rotation is reached near midstance, with the hip externally rotating during the swing phase (Krebs, 1998). The primary factor affecting the rotation of the prostheses in the swing phase, according to Hekmatfard et al (2012: 78), is the moment of inertia which is related to the mass and squared distance from the CoM to the axis of rotation. Figures 6.19 and 6.20 demonstrate a normal hip rotation during the gait without prostheses, shown via the yellow (6.19) and green lines (6.20), both of which mimic the example provided by Wesseling et al (2015: 1096) in figure 6.18. The red circles depict the maximum and minimum rotational hip moments during the normal unimpaired gait cycle. Figures 6.19 and 6.20 also demonstrate the changes that have occurred in hip rotation as a result of wearing the Anglesey leg (orange and light blue lines in figures 6.19 and 6.20 respectively) and peg-leg (red and dark blue lines in figs 6.19 and 6.20 respectively). A notable change for both artificial limbs, particularly in figure 6.20 for the right leg, is a reduced level of rotation, maintaining a relatively stable but low NM/kg for the leg which is wearing the artificial limb. Contrastingly in figure 6.19, the peg-leg causes an over-rotation in the left leg (circled in green).

Due to the decrease in adduction and abduction that the hips are displaying during the prosthetic gait, it is unsurprising to observe evidence of hip circumduction which is where there is a semicircle movement of the limb which is also affected by the movements of hip flexion, abduction and forward rotation of the pelvis. We most noticeably see the rotation in the peg-leg gait (MOKKA visual data fig. 5.6-5.8), which is where there is no knee joint to flex, so the limb is rotated around the outside of the body to the front. We have already seen the control of the hip is altered by the wearing of the prostheses, below will identify knee alterations.

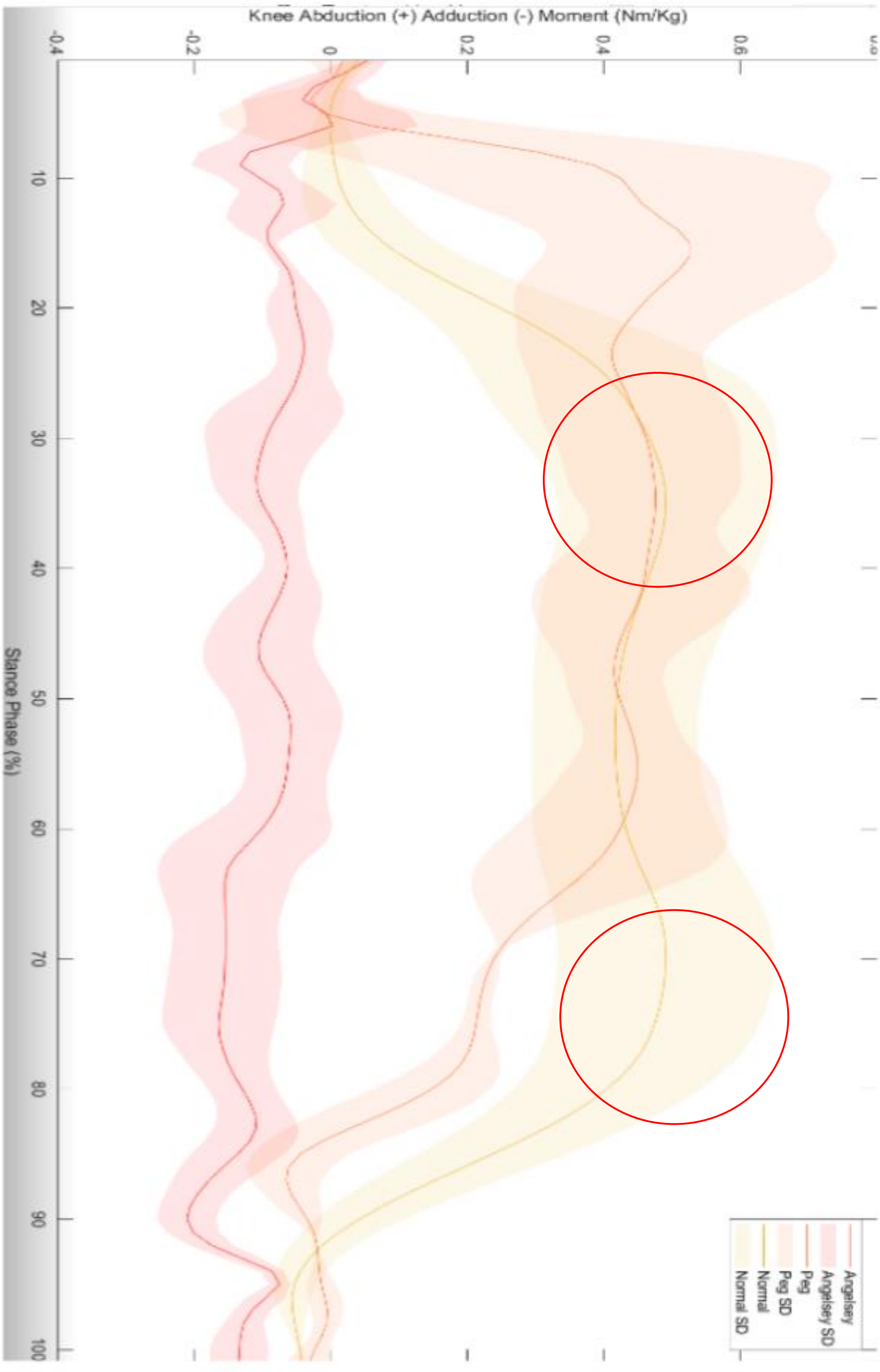


(Fig. 6.19 Hip rotation left leg. The initial dip (circled in red) followed by a peak (Circled in red) for heel strike and toe-off during the unaided gait is as expected and follows the trajectory proposed by Wesseling et al 2015. Circled in green is the over-internal rotation that occurs during the use of the Anglesey leg, whereas the box leg causes the hip to reduce both its internal and external rotation on the left-hand side.)

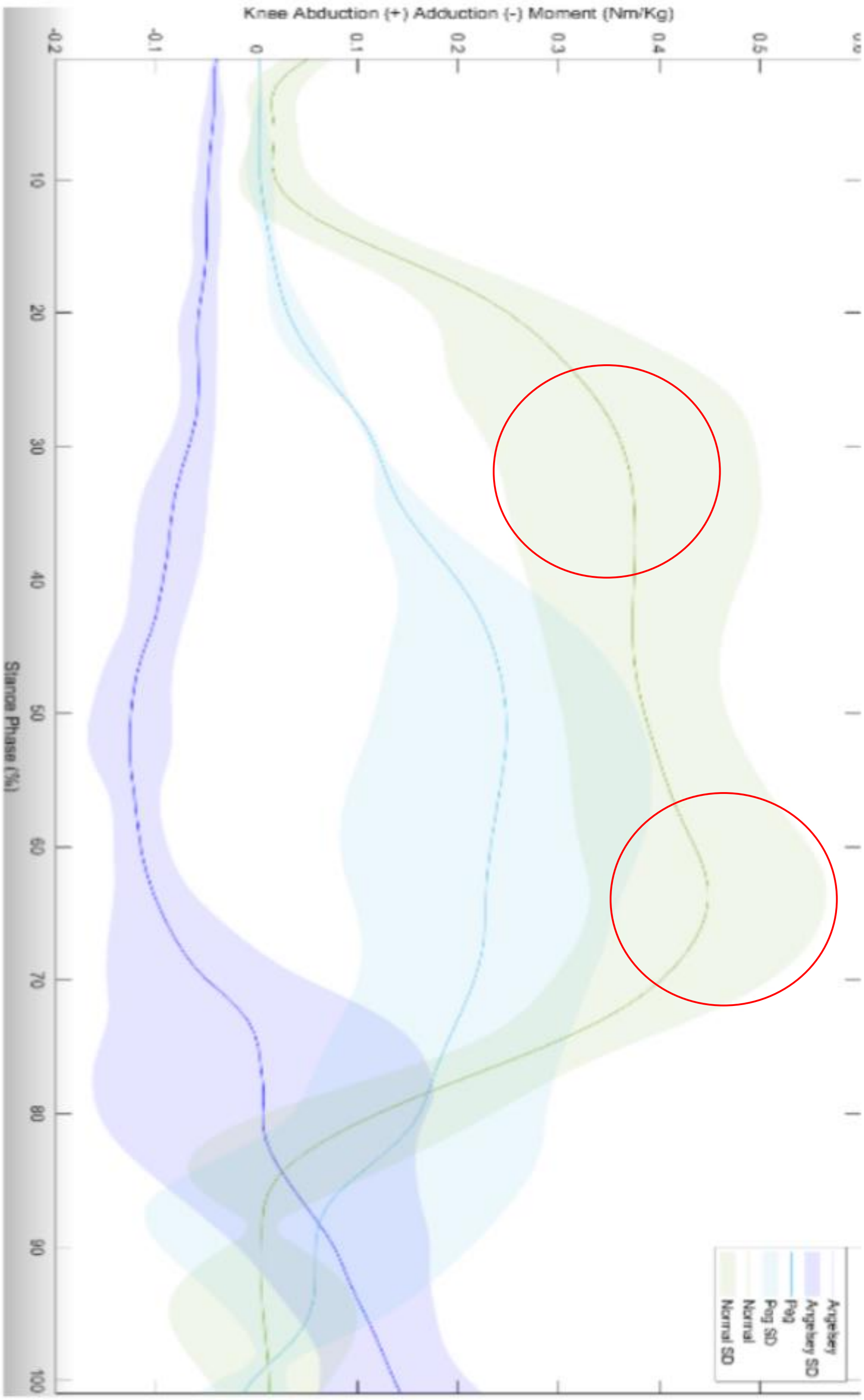


(Fig. 6.20 Hip rotation on right leg. The initial dip (circled in red) followed by a peak (Circled in red) for heel strike and toe-off during the unaided gait is as expected and follows the trajectory proposed by Wesseling et al 2015. Both the Anglesey and box leg impact the efficiency of the hip rotation of the right leg which is clearly inhibited by the lack of rotation that occurs during the stance phase.)

6.2.5 Knee Abduction\Adduction



(Fig. 6.21 Knee Abduction left leg. Expected is the two peaks circled in red, with moments around 0.5 NM/kg. The functionality of the left leg is impacted by the use of both artificial legs and impacts its ability to reach the expected level of forces during stance phase, meaning these forces are being propelled elsewhere through the body. The left leg is placed into prolonged abduction during the use of box leg and a prolonged period of adduction during the use of the Anglesey leg)



(Fig. 6.22 Knee Abduction right leg. The right leg prior to attachment of the artificial limbs functions as expected with the two peaks circled in red. However, the use of both artificial appliances prevent the level of abduction and leave the leg in prolonged adduction, particularly evident for the Anglesey. Whilst the box leg allows some abduction of the knee it is much lower than expected meaning these forces are being diverted elsewhere in the body.)

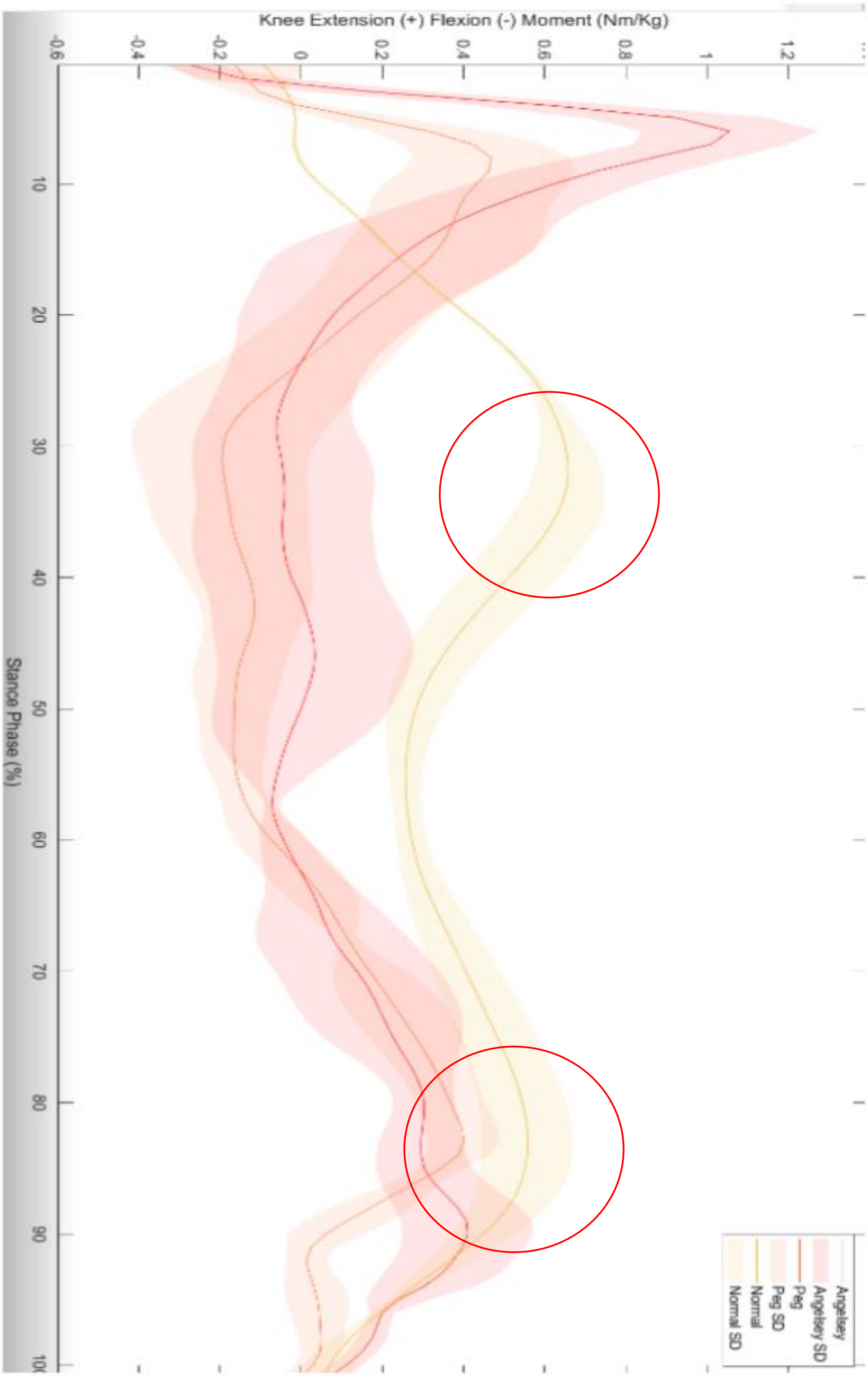
The expected knee adduction for normal gait, is seen in figures 6.21 and 6.22 as the yellow and green lines respectively, both of which depict a two-peak flow during the stance phase highlighted with the red circles. The first peak is the early stance phase and the second is the late stance phase, this knee adduction moment is thrusting the knee into the varus and consequently increasing the load across the tibia and femur (Khalaj, 2014: 190). As can be seen in figures 6.21 and 6.22, the peg (red line fig. 6.21 and dark blue line figure 6.22) and Anglesey (orange line fig. 6.21 and light blue line figure 6.22) demonstrate much lower forces being placed into the knee abduction moments. This may be a result of less time spent on single support during the stance phase as has been identified in figures 6.1-6.6. This explains why in figure 6.21, there is more variation and overall greater peaks in adduction moments. Similarly, the use of crutches to increase stability, alleviates forces on other joints, including the knees and consequently this may lead to the reduction of movement causing the drop in NM/kg moments observed in the above graphs for both the peg and Anglesey. The changes that are observed in the Anglesey and peg-leg data, resemble the data often produced in biomechanical research of patients with osteoarthritis of the knee. For instance, Khalaj et al (2014), suggest the clinical symptoms of knee stiffness, pain and muscle weakness all contribute to decreased range in motion which inevitably affects the person’s ability to perform certain daily tasks and can increase the likelihood of trips and falls.

6.2.6 Knee Extension/Flexion

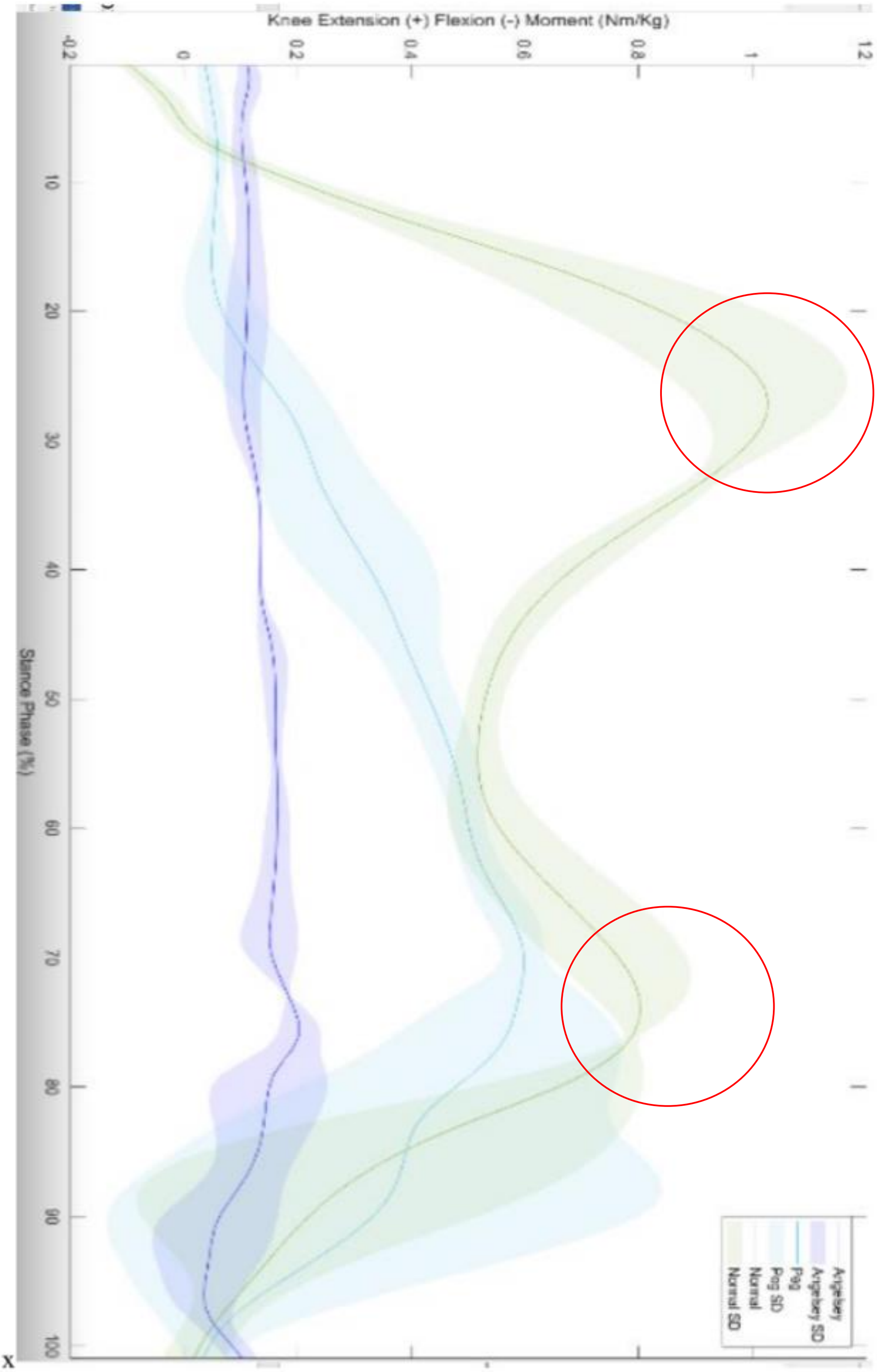
In normal gait, the knee goes through two phases of extension and flexion during each gait cycle, it begins in full extension (5^{o} of flexion) and then increases its flexion to 15^{o} (Perry, 2002) before extending to neutral. It begins to flex again, with the beginning of double stance, which continues in swing to reach 60^{o} before the extension is returned to (Perry, 2002). The flexion of the knee to 15^{o} requires the quadriceps to retrain knee flexion, whilst the hamstrings relax as they no longer need to prevent over-extension. Knee flexion initiated during loading response increases to 18^{o} as single limb support begins, the knee then reverses its motion to a progressive extension so the femur can advance, and an extensor moment begins. Quadricep action is at its maximum at midstance before declining to late stance, this leads to the body weight extending the knee passively between 0-5^{o}. At terminal stance, the knee begins to flex with the body weight falling toward the opposite limb before the swing phase causes passive flexion to 40^{o}

(Perry, 2002). Figures 6.23 (yellow line) and 6.24 (green line), demonstrate a normal gait that follows these expected rules, which is depicted in two peaks (circled in red), the first (greater than the second) showing the peak loading response after heel strike, the second is the peak occurring just after toe-off as the leg begins to enter pre-swing.

These graphs also demonstrate the alteration observed in the prosthetic gait, the Anglesey leg identifiable via the orange (fig. 6.23) and light blue lines (fig. 6.24) and the peg-leg identifiable via the dark red (6.23) and dark blue lines (fig. 6.24). The artificial limbs both affect the function of the sound left limb, which although still demonstrating knee flexion and extension, the peaks are much smaller forces than in the sound gait cycle and more unstable, likewise, the heel strike is earlier for both prosthetics. This instability at the knee joint generates an early heel strike which increases flexion at the ankle, which creates difficulty for the tibia to move forward and stabilise the knee joint. The consequence is less single support time and increased reliance on the sound limb, with the pelvic and trunk tilting toward the sound limb to move CoM in that direction. Likewise, a step length decrease is noted. Again, the use of crutches may also have contributed to the decrease in NM/kg moments, due to the body weight being dispersed over these objects for stability.



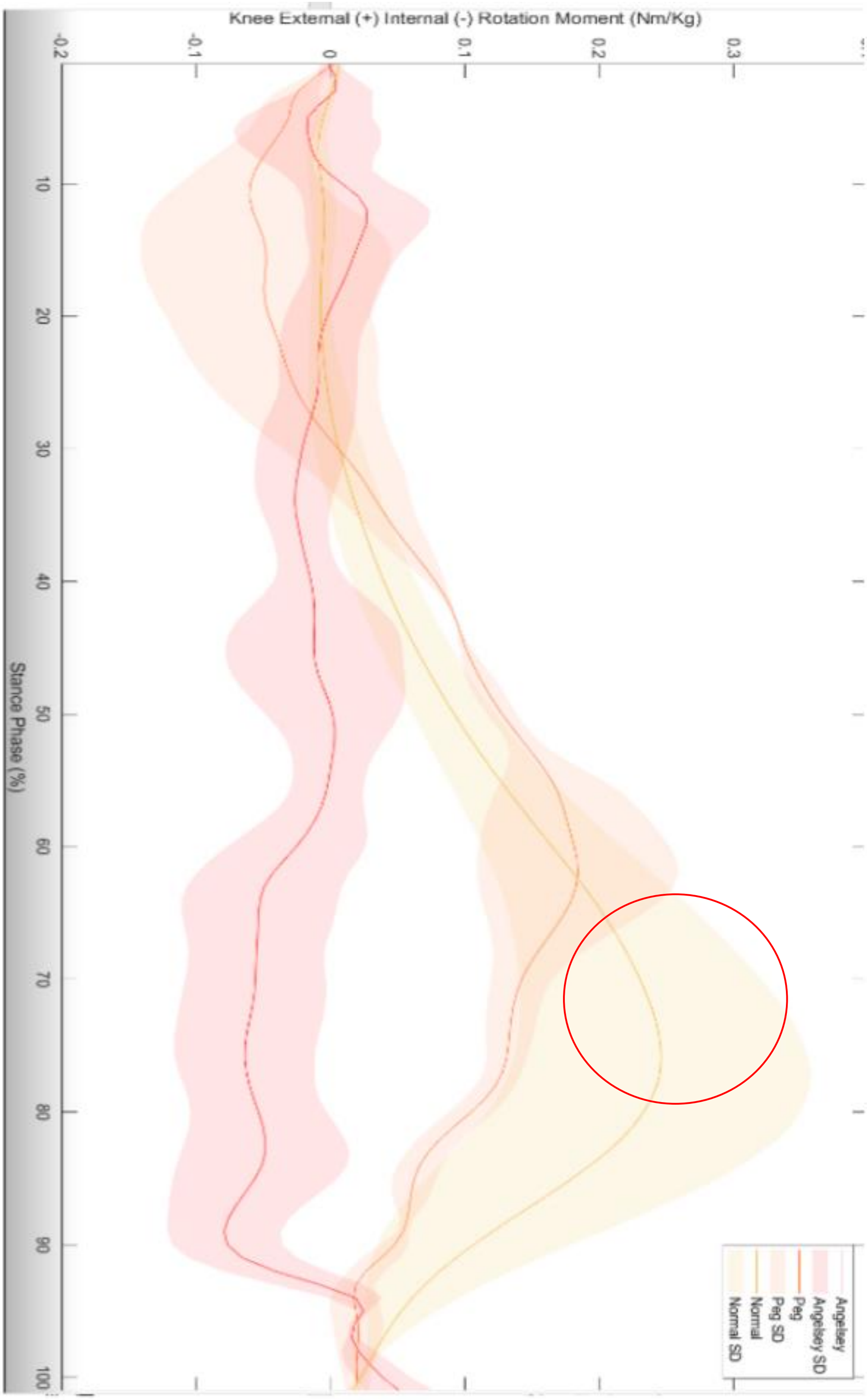
(Fig. 6.23 Knee extension left leg. Circled in red are the expected peaks for the normal gait with an extension of the knee peaking around 0.6 NM/kg and flexion dropping to approximately 0.3 NM/kg. Comparatively we see the effect the Anglesey leg (orange line) (whilst worn on the right leg) has on the left leg, with it preventing the left leg from reaching full extension and peaking around 0.4 NM/kg both at heel strike and toe off. Likewise, the box-leg (red line) also inhibits the left leg from reaching full extension at toe off, peaking at 0.4 NM/kg, however it causes a high over extension during heel strike which also happens much earlier, with the peak occurring at 1.2 NM/kg.)



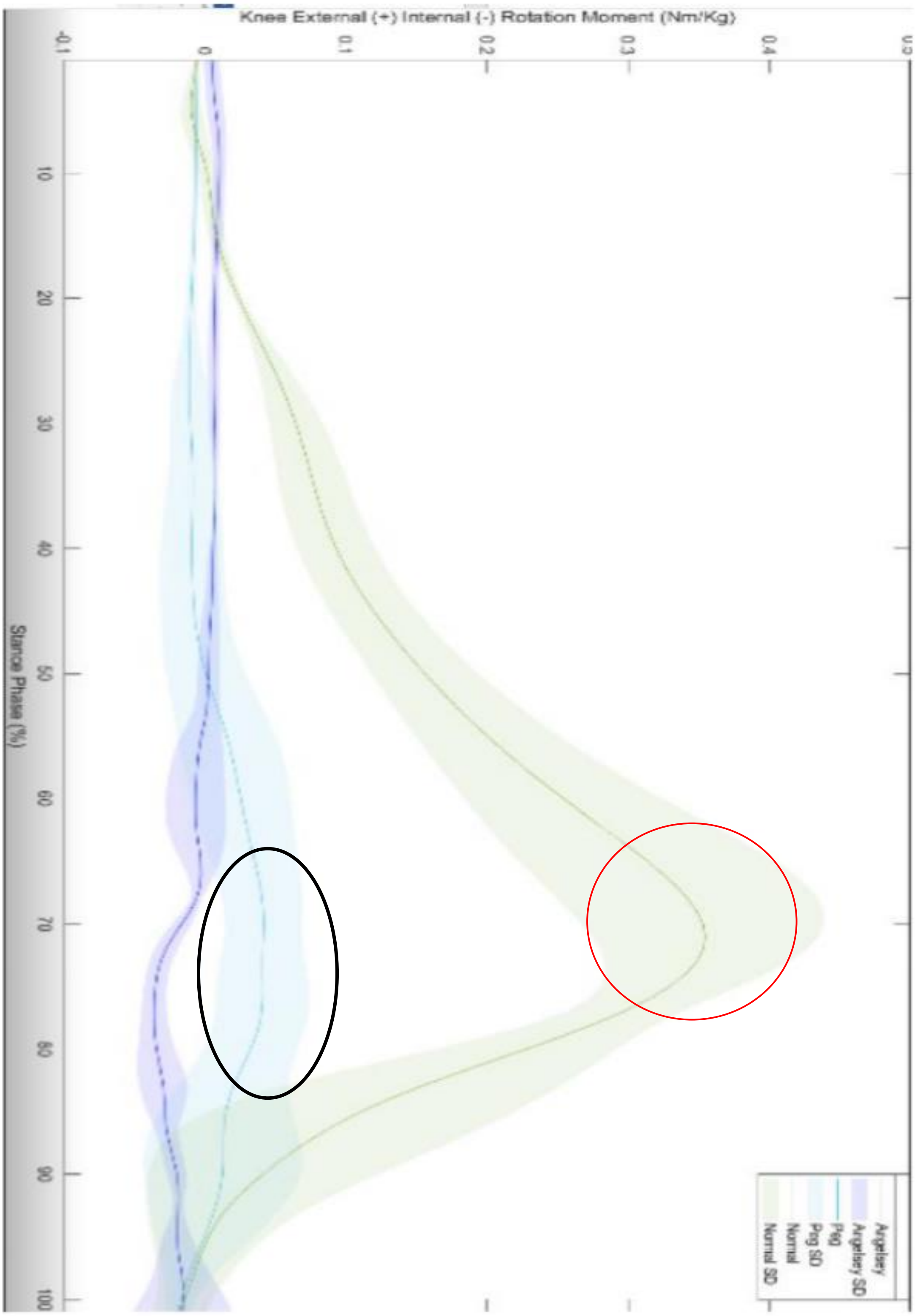
(Fig. 6.24 Knee extension of right leg. Both artificial appliances affect the anticipated trajectory of extension and flexion that the normal gait (green line) demonstrates, with the peaks circles in red showing extension at 1 NM/kg and flexion at around 0.4 NM/kg. Instead, the Anglesey leg (light blue) demonstrates one peak at toe-off at 0.6 NM/kg, and the box-leg (dark blue) shows no signs of knee extension of flexion throughout the stance phase instead remaining at a constant 0.1 NM/kg.)

6.2.7 Knee Rotation

The increase in hip adduction observed above, increases the forces at the knee (Wesseling et al, 2015: 1100), these changes in loads affect the motion of the joint and so it is observed that there is a decrease in knee rotation during the gait cycle. The graphs in figures 6.25 and 6.26 demonstrate these force changes at the knee, through the decrease in the rotation that occurred because of wearing the artificial limbs. The yellow line in figure 6.25 and the green line in figure 6.26 shows the normal and expected trajectory of the knee rotation moments, with its peak toward the later stages of the stance phase (circled in red). Comparatively, the use of the Anglesey leg (orange line figure 6.25) affected the left knee in a way that maintained the expected trajectory, albeit with less intensity at its peak and with greater instability. Whereas the peg-leg (red line fig. 6.25) prevented the left leg from rotating at all during the stance phase. Figure 6.26 shows the level of knee rotation for the artificial limbs (Anglesey in light blue and peg-leg in dark blue). It is important to note that the use of crutches whilst wearing the artificial limbs are likely to be affecting not only the load but also the amount of rotation.

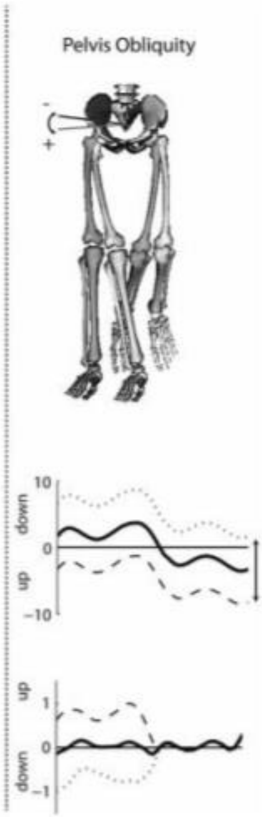


(Fig. 6.25 knee rotation left leg. As anticipated the unaided leg (yellow line) begins neutral and the rotation occurs at toe-off prior to swing phase beginning, peaking (red circle) at between 0.2 and 0.3 NM/kg. Comparatively, when the artificial legs are worn on the right leg, this impacts the functionality of the sound left leg and inhibits the level of knee rotation observed. The Anglesey (orange line) still demonstrates a peak in knee rotation but slightly sooner than unaided gait and at a shallower rate of under 0.2 NM/kg. The box-leg (dark red line) inhibits knee rotation completely for the left leg with it remaining neutral throughout the stance phase.)



(Fig. 6.26 Knee rotation right leg. Normal gait with the peak circled in red, shows the expected trajectory of right knee rotation with the peak at 0.3 NM/kg, however there is no peak for either the Anglesey (light blue) and box leg (dark blue) which both remain neutral throughout the stance phase.)

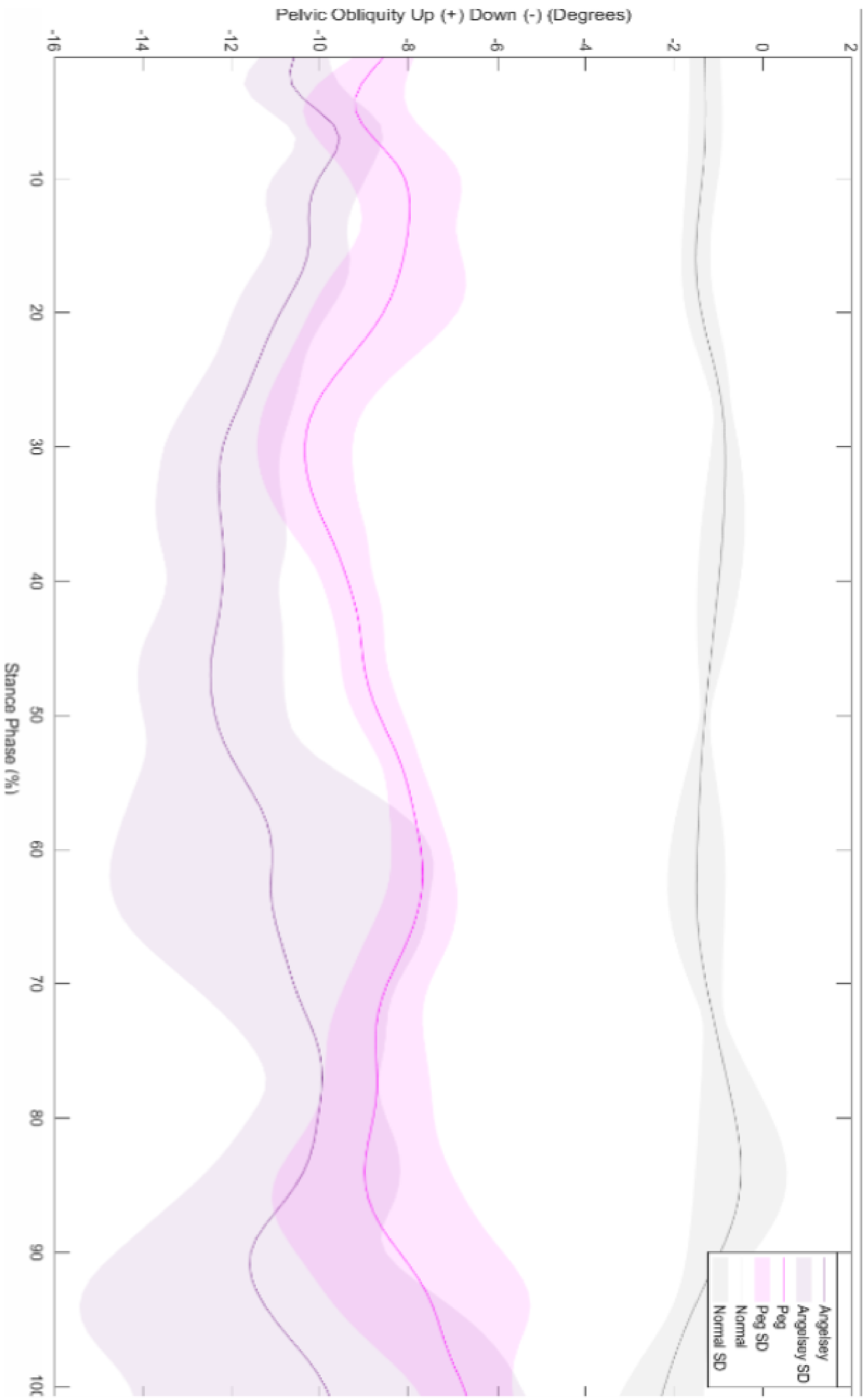
6.2.8 Pelvic Obliquity



(Fig. 6.27 Wesseling et al (2015: 1096 depiction of average pelvic obliquity variations with graphs showing kinematics (degrees) and kinetics (NM/kg) The different perturbations by ±5° in hip and pelvis kinematics The kinematic graphs show the average nominal joint angles (solid line) and the perturbations by +5° (dotted line) and −5° (dashed line). The kinetic graphs show the average nominal joint moments (solid line) and the moments when perturbing the kinematics by +5° (dotted line) and −5° (dashed line)).

Pelvic obliquity is the 'coronal-plane rotation on the pelvis' (fig. 6.27) (Michaud et al, 2000). It is where an individual presents an asymmetrical pelvis falling to one side. It is suggested by some researchers that pelvic obliquity acts as a shock absorbing function during load response (Perry, 1992). In unassisted normal gait, it is expected that the pelvic obliquity curve will be periodic with one cycle per stride, with the pelvis being neutral as the heel of the leading limb contacts the ground. The hip of the trailing leg begins to drop during loading response, which increases the amount of pelvic obliquity, with its maximum being reached immediately after toe-off. This motion then reverses with the swing phase, reaching neutral at midstance again before decreasing slightly before heel contact. The peak occurs just after toe-off with smaller fluctuations at the end of the single-support phase (Saunders et al, 1953). The magnitude of obliquity has been observed by researchers to increase 'linearly' with walking speed (Childress and Gard, 1997).

The results of this experiment are evident in figures 6.28, which shows an obliquity difference between the three experimental conditions in a static standing position. Secondly, it is evident there are overall, greater intensities of pelvic obliquity associated with prosthetic gait. The pelvic drop during the prosthetic loading response was significantly less than during the sound-side loading response. Whilst the normal gait has a slight variation in obliquity, it is stable throughout, suggesting there are no signs of pathological gait. The decreased downward obliquity in combination with the increased hip adduction (above) suggested another reason as to why in figure 6.28 we see an increase in hip contact forces, the results support those of Lenaerts et al (2009). Both prosthetic gaits in figure 6.28 show the hip dropping on the left side, instead of the expected neutral obliquity during normal gait observed with the grey line, the pelvic obliquity that occurs whilst wearing the Anglesey leg (purple line) and peg-leg (pink line) mirrors the gait of someone who is hip hiking or lateral trunk leaning, discussed in section 6.3.4.

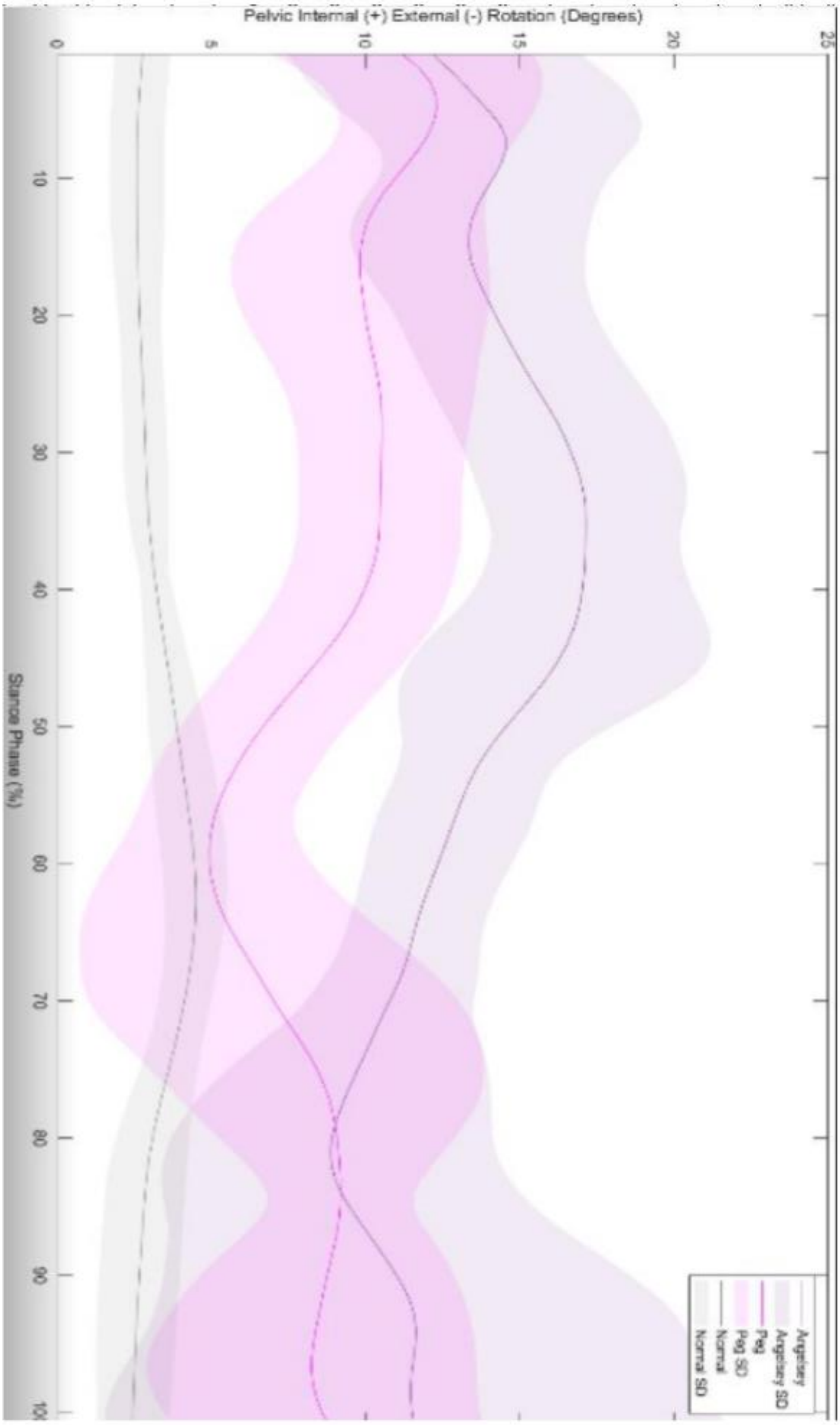


(fig. 6.28 Pelvic Obliquity)

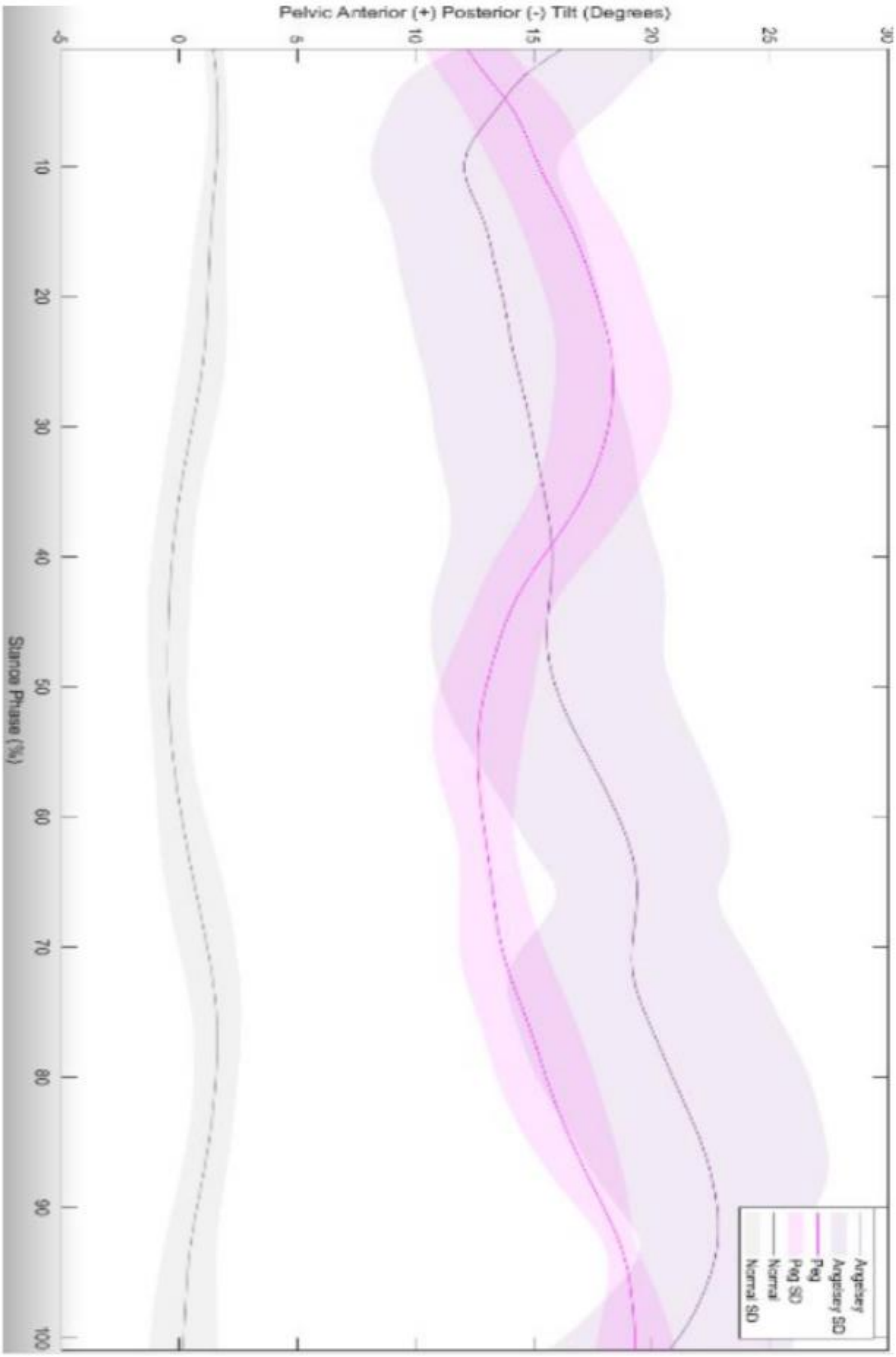
6.2.9 Pelvic Rotation/Tilt

Pelvic rotation is when an individual presents one hip further forward than the other, it is often associated with pelvic obliquity, spinal rotation and leg length discrepancy. The pelvis rotates forward on the swing side and rotates backwards on the stance side, with this rotation being relative to the swing side. During the gait cycle, the '…entire lower segment, consisting of the pelvis, femur, tibia and fibula, undergoes rotation in the transverse plane…' (Mann, 1975: 257), the rotational degree increases gradually in magnitude from proximal segments to distal ones (Mann, 1975), normal walking on level ground is likely to see around a 6^{o} pelvis rotation (Mann, 1975). The results in figure 6.29 show the normal rotation (grey line) is around 3-5^{o} during the stance phase and maintains an expected stability.

Contrastingly, the Anglesey leg (purple line) gait in figure 6.29 observes a much greater level of rotation of 13-16^{o} and around 6-12^{o} for the peg-leg (pink line). Rotation at the 'mediolateral axis' produces motion within the sagittal plane', often referred to as pelvic tilt (Lewis et al, 2017: 7) (figure 6.30) can be either anterior or posterior. The posterior pelvic tilt is when the anterior superior iliac spines sit higher than the posterior. Anterior pelvic tilt is when an individual's pelvis tilts forwards, with the anterior superior iliac spine lower than the posterior (Childress et al, 2000). When standing with weight evenly distributed between both lower limbs, the pelvis is usually level or in 'neutral' (Levangie and Norton, 2011). Fig. 6.30 shows both prosthetic gaits displaying a greater degree of anterior tilt than the regular gait cycle.



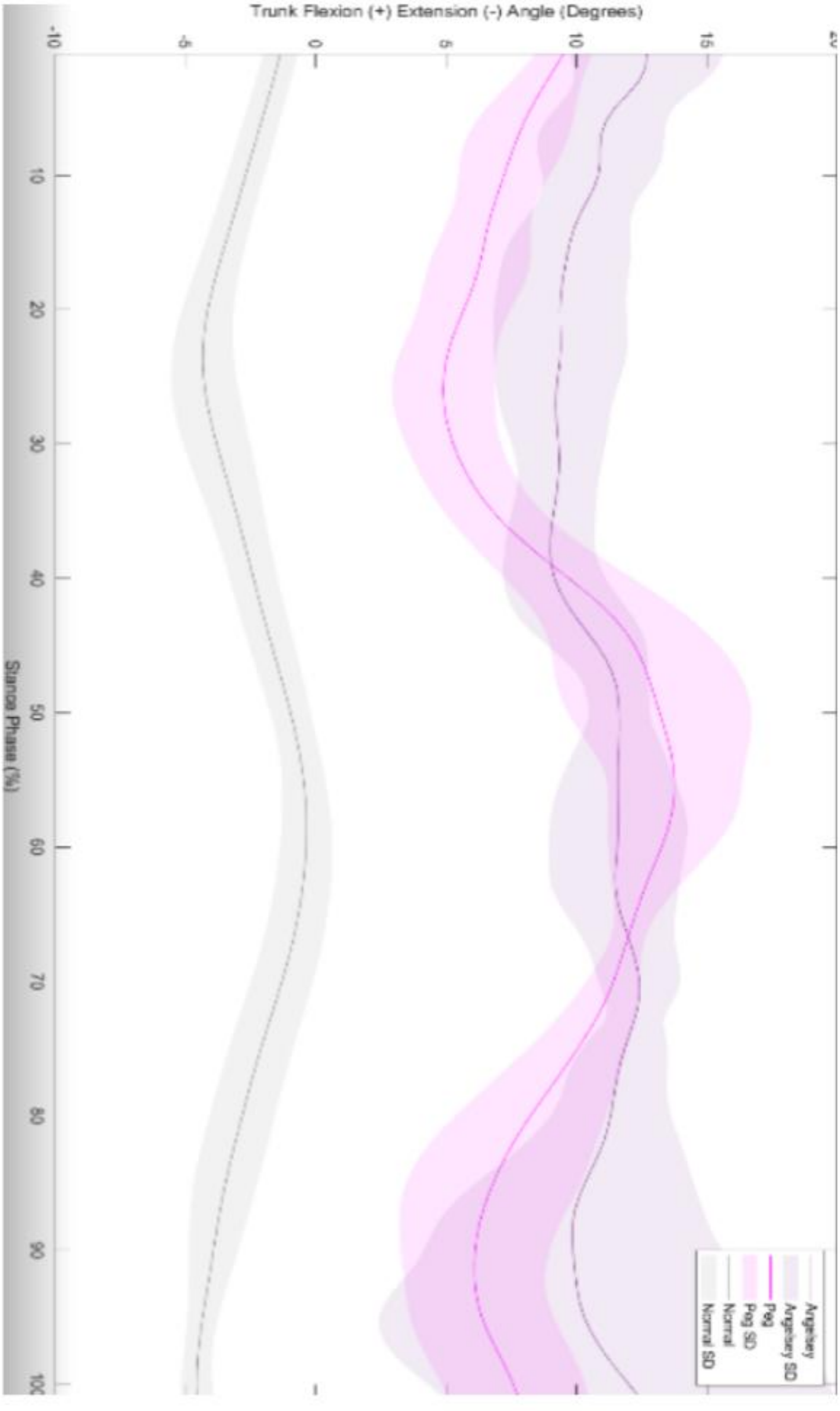
(Fig. 6.29 Pelvic rotation, the grey line depicts the stable expected trajectory of pelvic rotation through the stance phase, around 3-5°, with the purple line representing the Anglesey leg and demonstrating a much higher level of rotation at 13-16° and 6-12° for the peg -leg which is represented in pink.)



(Fig. 6.30 pelvic tilt. The purple line is the Anglesey leg which demonstrates a much higher level of tilt than the grey line which is the expected neutral pelvic positioning during the stance phase. The pink line represents the peg-leg and the greater level of pelvic tilt that it causes, both the peg and Anglesey legs show fluctuations around 15-18^{o}).

6.2.10 Trunk Tilt

Lateral trunk tilt occurs when the hip abductors fail to perform during loading response or midstance. The lean is used to compensate for the weakness and/or painful hip. Leaning the trunk toward the affected side, as has been observed in figures 6.4-6.6, inclines the ground reaction force laterally from its point of application at the foot (Tateuchi et al, 2020). Because the vector then passes closer to the hip joints' anteroposterior axis, its moment arm is shorter, and it produces a smaller hip abductor moment (Tateuchi et al, 2020). It is also associated with a weakness in the gluteus medius muscle. It is expected in normal gait, for a minimal lean to occur during the cycle, particularly toward the swinging leg, which is observed in figure 6.31 (grey line). Trunk lean as seen in the Anglesey leg (purple line) and peg-leg (pink line) gaits in figure 6.31, is much greater. Compensatory adjustment to gait such as a trunk lean, changes the GRF vector to closer to the hip joint by displacing the CoM of the body to the stance limb.



(Fig. 6.31 Trunk tilt. The grey line depicts the expected level of tilt through the stance phase, remaining neutral. The peg-leg in pink and Anglesey leg in purple are both demonstrating a much greater degree of flexion, with the peg leg peaking slightly higher than the Anglesey.)

6.3 Summary

Overall, the results presented above offer some surprising suggestions which contradict initial assumptions and primary source assertions (chapter 3, section 3.4) surrounding the functionality and comfort levels of both artificial appliances. Firstly, the Anglesey leg, despite being the more sophisticated and realistic in design and manufacture (appendix B) in comparison to the box-leg, does not perform biomechanically as efficiently as expected. There is evidence that balance is affected more severely by the use of the Anglesey leg and with this instability, greater alterations in trunk posture, hip obliquity and knee rotation amongst other concerns. It is evident in the data that in all cases (sections 6.1 and 6.2), the box-leg provides a greater level of stability to the wearer and offers less biomechanical alterations than the Anglesey leg. Finally, neither leg performs particularly efficiently compared to natural gait, but this is possibly due to a number of reasons such as weight and long-term versus short-term usage, all of which are directly addressed in chapter 7. However, the data also proves that both legs were functional and act as mobility aids, which ultimately was their purpose. Chapter 7 takes the data and discusses it in more detail, with regard to detrimental effects as well as positive findings, comparing the results to modern medical understanding and also the primary literature presented in the background chapter 2.

Chapter 7: Discussion

7.1 Introduction

Investigations into human locomotion and bipedal gait, have largely focussed on early humans, such as Ruff et al's (2016) investigation into the bone structure proportions and likely locomotive behaviour of 'Lucy' (Australopithecus afarensis A.L. 288–1), whilst modern medical research focuses on the bipedal gait of individuals suffering with specific illnesses such as Parkinson's disease and Cerebral Palsy. The study of the effect of prosthetics on gait and the conclusions drawn from this data regarding detrimental effects, can tell us a lot about the physical experience of an individual as they go about their daily life. The implementation of this research model into a historical framework, can add to the missing data within the archaeological record surrounding disability and most importantly the experiences of the disabled in past societies. An ethnoarchaeological approach to walking and the material culture that is associated with this task, provides a human agency to this action, by acknowledging and appreciating the ways in which past people interacted and manipulated their world around them. For an amputee, confronting a future where walking was unlikely, and the everyday tasks where walking was a major component, would have been terrifying in the past, where employment and proving their capability of working were vitally important to the survival of themselves and their dependents. Therefore, the invention, continued innovation and use of artificial legs tell us two things; firstly, people recognised a need for these items and then developed something to replace the missing limb. Secondly, regardless of how rudimentary these early prosthetic legs may look, people wore them suggesting they must have fulfilled specific roles they were intended for to some extent. Whether this was to ease and aid mobility or to promote a more normalised aesthetic is what this research has investigated, whilst contextualising disability and prostheses within the nineteenth century.

One of the main aims of this research was to assess prostheses and the social agency they possess as well as investigate the complex meanings individuals had developed with regard to prostheses in their daily lives. The research began with an in-depth investigation into the history and innovation of artificial limbs, amputation and disability, specifically in the nineteenth century. Its concentration on military appliances and connection to warfare gave the research focus that allowed the research to delve deeper into a previously under-researched topic in order to understand the wider impact of returning from warfare, and how these ex-servicemen reclaimed their position within their communities. The experimental research has been a way to reanimate artificial appliances that were at one stage, incredibly personal effects. The current method of museum display, or literary research, is one-dimensional in that these items, whose original function was to aid mobility, are now frequently displayed in glass cabinets without a wearer or as photographs in books. This research has created an environment in which we have seen the mechanisms utilised in these appliances, working in the manner initially intended.

The second phase of this research aimed to take these items and better understand their social importance by creating an increased understanding of their production and use, skill, material knowledge and efficacy for the wearer. As the most frequently used mode of transport for a human is bipedal walking, it seemed a good place to explore the functionality of these artificial limbs. Transferring the attention away from the object itself, its material form and aesthetics, the relationship between the artificial legs, their manufacturers and their wearers is explored. In doing so, an understanding of the physicality of the object is ascertained, as well as the bodily relations that each artificial limb facilitates. These investigations do not come without various challenges, yet central to this approach is the acknowledgement that as Ingold (200: 157-171) argued, '...the use of the body in similar ways to those who inhabited a different time and place, is to gain an insight into the experiences and attitudes of these people'. As this research has shown, the use of the body in experimental research generates a new means of understanding cultural awareness and experiences.

Of all categories of material culture, objects connected to the human body such as dress, adornment and artificial appliances, hold the closest relationship with a person, due to how they facilitate daily experiences and what these items outwardly portray. The analysis therefore of two reconstructed artificial limbs, can provide insight into the disabled body during the nineteenth century. Understanding the relationship between individuals, society and prostheses, helps us to understand how those who wore them presented themselves in daily life. Understanding how these artificial legs facilitate and constrain movement, both figuratively and literally - socially and physically - helps our understanding of the social, political and national attitudes of and toward disabled veterans. The first section of this discussion chapter, will discuss what the data obtained in the chapter 5 experiments can tell us about the gait pattern associated with the box-leg and Anglesey leg and expand upon possible consequences of the resulting pathologies, drawing comparisons between the two before discussions around archaeological examples are introduced in section 6.6. The final section will discuss what this research has shown, placing its findings within the context of available literature that has been discussed in chapter 2.

7.2 The Experimental Investigation

The lab-based exploration first evaluated whether the peg-leg and Anglesey leg were usable as prosthetic limbs. Secondly, it investigated to what extent these appliances affected mobility, natural posture and gait. This information, whilst exploratory, can inform us about the long-term effects of these items on the body, as well as the physical feelings and movements people wearing them may have experienced. For example, the use of nineteenth-century artificial limbs can aid mobility for an individual who has undergone either transtibial or transfemoral amputation, however, both artificial limbs explored here caused a dramatic change in the natural gait of the individual and created gait patterns that mimic pathological gait concerns. This included a lateral trunk tilt (section 6.2.10), exaggerated hip hiking (section 6.2.4) and increased ground reaction force (section 6.2.1), which would contribute to specific pain as well as to long-term damage to the body, such as osteoarthritis and scoliosis. Thus, the use of these artificial limbs may create an environment where the wearer is uncomfortable and uses their body to move in compensatory ways to increase comfort levels. Identifying these changes, and producing data which demonstrates these alterations for the first time, means we can compare the findings of the effect of these historical appliances on biomechanics with modern appliances to suggest what physical complications may have arisen as a consequence of these two appliances. The following discussion will be divided into two sections, the first will be focused on the box-style peg-leg and the second will concentrate on the Anglesey leg. Each section will discuss the findings from chapter 5 and what these mean for the wearer of each limb, before concluding the most efficient, comfortable and least invasive to natural gait.

7.2.1 Physical Effects of the Prosthetic Devices

As noted in chapter 2 the focus of this research has been military prostheses during the nineteenth-century. These were most probably men in their early twenties (Snow and Snow, 2015) and whilst the average life expectancy was around 40 (although social class impacted this) this meant some of these disabled soldiers could have utilised an Anglesey or peg-leg for around 20 years or more. As Gailey (2008) suggests, amputations were likely to be carried out on individuals in their twenties if they were service-connected injuries. This length of time would ultimately have caused the individual not only vocational, body image and socialisation concerns but also altered gait, reduced activity and unusual stresses to different parts of the body (Gailey, 2008).

The men likely to utilise an Anglesey leg were wealthy. They were expensive limbs and as such, despite their fame at the time, their expense may have contributed to why they were very rarely used. Those using the box-leg were poorer, more common and driven by maintaining a form of income. The findings of this experiment are therefore critical for illuminating the efficiency of both prostheses and for acquiring an understanding of the lived experiences these individuals had. Likewise, differences between the effects of both artificial limbs will be identified, which will prove vital in establishing the authenticity of claims made during the nineteenth century in documentation such as Henry Bigg's (1885) and Frederick Gray’s (1857) manuals (see chapters 3 and 4).

7.2.2 Balance

Firstly, the wearer's stationary balance decreased whilst wearing the peg-leg and there was a clear shift in the centre of mass (COM) compared to the normal gait (see section 6.2.1). Likewise, figures 6.1, 6.2 and 6.3 (in section 6.3.1) show that the results are consistent with the expectation that balance decreases when eyes are closed due to the impact on the senses and spatial awareness. Additionally, the decrease in stability whilst wearing artificial limbs is expected due to the body's interaction with a foreign appliance which has no nerve receptors and so no sense of touch and therefore no connection to the proprioception system. Unexpectedly, the figures show that although minimal (as the graph is in mm) there is slightly more stability observed in the peg-leg (fig. 6.2) as opposed to the Anglesey (fig 6.1). This is an unexpected outcome firstly because the Anglesey offers more surface area due to the incorporation of a foot, allowing a larger area to balance on and maintain stability. Secondly, the incorporation of joints and ligaments, in the form of articulated mechanisms and springs, could be assumed to offer the wearer a more realistic and familiar rebalancing experience during the 30 seconds of standing. However, this was not the case. One of the possible explanations behind the increased instability is the raising of the hip and pelvis which is observed in the MOKKA visual data (see fig. 5.6, 5.7 and 5.8).

These changes are most pronounced in the Anglesey limb as opposed to the box leg. This data mimics that of the preliminary experiment which identifies an angle change in the hips for each limb, as evidenced in Appendix C. To assess the quality of an individual's gait pattern, before ascertaining the ground reaction forces working through their bodies, assessing the temporal parameters such as cadence and stride length can help us understand how long an individual spends on each limb during the stance phase and therefore what degree of reliance is placed on a specific limb and if this changes with the use of artificial appliances.

The importance of these stationary experiments, relates to the importance of balance and postural control in everyday life, for instance; spatial awareness, stability, and the ability to navigate obstacles such as curbs and uneven road surfaces. This data provides the opportunity to see how the COM shifts when stationary to maintain balance, whether this is anteriorly/posteriorly (forward or back) or medially/laterally (side to side). When a person loses a leg or both legs, due to the loss of some mass, the COM of the person changes automatically, to maintain balance and stability. Existing literature suggests that balance has a close relationship with fall risk and fall prevention (Carpenter et al, 2001). Reduced balance also affects confidence, which is also known to affect overall mobility, this addition of balance data COM illustrates the confidence levels of the person wearing the prosthetic, indicating how they would perform in their daily life. The addition of balance data also provides potential explanations as to why a person may have adapted their gait, whereas the gait analysis alone just identifies an adapted gait. Balance offers a justification for some of the alterations that may become apparent in the gait data, for instance, the graphs in figures 6.2 and 6.3 (section 6.2) show poor stability whilst wearing the Anglesey, which justifies why when walking there was a decrease in reliance on the single support phase of the gait cycle with the Anglesey – as will be shown in the temporal parameter data below. The closing of the eyes provides a greater reliance on the vestibular and proprioception sensory systems (inner ear and kinaesthesia – a sense of self-movement and position) which portrays a more realistic representation of balance ability. Consistent relationships between poor balance and falls undoubtedly generate an increased risk of fractures (Carpenter et al, 2001).

The data produced in the balance experiments, mirrors that of research into hip abductor weakness (See Hwang et al, 2016) which suggests that hip abductors have a vital role to play in preventing pelvic drop on one side, which in turn causes the ipsilateral trunk to lean for compensation, this lean can cause femoroacetabular impingement, patellofemoral pain, low back pain and as Friel et al (2006) has noted, ankle sprains (Hwang et al, 2016: 34). Steif et al (2014) claim that the ipsilateral trunk lean toward the affected limb acts as a compensatory mechanism to unload the hip joint, however, this lean changes the natural gait pattern and in doing so increases loads and stresses elsewhere around the body. The best way to see this in action is through the analysis of ground reaction forces and how these are affected throughout the body (section 6.2.1). However as these forces were seen to have increased or changed their direction, these changes in loads on areas previously conditioned for different load levels could have initiated degenerative changes in the individual. It is understood in research on modern gait patterns and compensatory changes that increased joint loading in certain areas such as the hip and knee, as a result of trunk leaning will ultimately lead to ill effects, it is therefore reasonable to apply this understanding to the gait change that occurs as a result of historical artificial legs (see section 6.1). Trunk lean is used as a way of reducing knee abduction moments in patients with osteoarthritis, and hip osteoarthritis patients also increase trunk tilt likely due to weak hip abductor muscles (Tateuchi et al, 2020). The trunk tilt reduces hip loading and pain by decreasing the hip abductor muscle moments on the affected side (Tateuchi et al, 2020). It appears the use of the artificial limbs is creating a situation for the wearer where the hip abductor muscles feel weaker or restricted, their balance is affected due to the pelvic tilt, rotation and obliquity and the trunk is being leaned to the sound left side as a compensatory measure to increase stability and relieve pressure from the artificial side.

The balance data suggests that whilst the wearer's eyes were open, weight was shifted toward the left side of the body, suggesting a conscious decision to place more support on the sound leg, however, when the eyes were closed the balance returned to the natural position of more weight being placed on the right-hand side of the body, which was also the side with the artificial limb. It may be that with the eyes closed and the subsequent inhibited spatial awareness, the body was attempting to return to its natural posture, but with the eyes open there was a lack of confidence in the appliance. It is also notable in the results that whilst balance does gravitate back towards the right side with the eyes open, there is a lot more movement and instability involved in maintaining the balance compared to the normal balance (section 6.1). Peg-leg wearers during the nineteenth century, would have been more likely to engage in physical employment in factories with machines, for instance, therefore confidence in the appliance and its efficiency to maintain stability, would have been important for safety. Maintaining balance is vital to preventing falls, concerningly, if an individual experiences a lack of stability as a result of wearing their artificial limb, they compensate for this by altering their COM as evidenced here. Resulting muscle weakness on the affected side will also contribute to a lack of balance and increase the likelihood of falls and trips. Those who therefore wore a peg-leg would have been at greater risk of falling than an able-bodied person, and so compensating their balance would have been necessary to ensure a more normalised lived experience, particularly one which enabled earning an income. For those working in harsh and potentially dangerous environments such as in factories, this space would have become increasingly hazardous if stability was not easily ascertained or maintained and it is, therefore, possible that the individual would have been at greater risk of being involved in an accident, or employers would have been hesitant to employ someone who would have been at greater risk of injury and would have discriminated against these individuals in favour of able-bodied men.

As a consequence of postural changes to maintain stability whilst in the peg-leg, an ipsilateral trunk lean was also identified as a rise in the hips as the body leaned towards the sound left leg (see sections 6.1, 6.2.9 and 6.2.10). It is highly likely that this level of imbalance would have required the use of a crutch to aid mobility. Whilst it is arguable that over time, the individual may have grown more confident in their artificial limb so they may no longer have required a crutch, it is also argued that the repetitive strain placed on the hip and back muscles whilst the individual was maintaining their balance would have likely contributed to lower risk of developing back pain and over time, increasing the chances of developing osteoarthritis of the hip and spine. A combination of instability, use of additional support such as a crutch and the pain they were likely in, were all possible reasons that could have caused the individual to lose the ability to work. As discussed in Chapter 2 the possible inability to work could have left them destitute and it is possible that one of the reasons we see a large increase in vagrancy in the immediate years after Waterloo is because of the challenges faced physically by the returned soldiers who had suffered disabling injuries that as identified here, led to complications physically and therefore rendered them unemployable.

Similarly, for those wearing the peg-leg, ideas of social acceptance would have been further inhibited by the identified hip hike that this data suggests was possible (sections 6.2.2, 6.2.3, 6.2.4, and 6.2.9). The Victorian body was idealised as a whole, strong and beautiful, those who wore peg-legs, as discussed, were lower-class citizens and the addition of a noticeable injury such as a raised hip and trunk lean would have caused further societal judgements due to existing beliefs that physical abnormality was the consequence of immorality (see chapter 3). The balance data presented in section 6.1.1 suggests that whilst the peg-leg offers the wearer a slightly increased feeling of stability whilst stationary compared to the Anglesey leg (see section 6.1.1), the altered posture identified in this data would have possibly left the individual at risk of stigmatisation, even if the peg-leg was unnoticeable under clothing, further supporting the suggestion above that employers may have been discriminatory against disabled individuals.

7.2.3 Temporal Parameters

Measuring the temporal parameters of gait cycles means any changes that become apparent in velocity, cadence, stride length and amount of time spent in single or double limb support can be discussed. The data presented in chapter 6, section 6.1, demonstrates a decrease in time spent in single support on the side of both the Anglesey and box-leg. The unaffected gait cycle has a mean average time percentage of between 38% (left leg) and 36% (right leg) double support and 62% (left leg) and 64% (right leg) single support. When compared to the peg-leg gait cycle, these averages change to between 23% (left leg) and 37% (right leg) for double support and 77% (left leg) and 63% (right leg) for single support. The Anglesey leg sees changes of between 32% (left leg) and 74% (right leg) double support and 68% (left leg) and 26% (right leg) single support.

This data demonstrates a decrease in double support time and an increase in single support time for the peg-leg, with the biggest changes occurring on the left (non-prosthetic leg). Due to the lack of stability that was apparent in the balance data, it was assumed that more time would be spent in double support during the peg-leg gait, to decrease the length of time maximum weight was placed on either limb. However what is clear from the data produced here is that instead, the velocity of the gait decreased from 0.71m/s for normal gait compared to 0.41m/s for peg-leg gait, suggesting that this extra time was used to create a slower, more considered gait to ensure balance was maintained. Importantly for this experiment was the change in time spent on the peg-leg itself during the single leg support phase, a decrease in time spent on the peg-leg was observed whilst a large increase in single support on the left side was noted. This data ties in with the suggestion that overall the gait was slower and overall avoidance of spending exaggerated time on the affected limb was evident.

The data in chapter 5 demonstrates that many of the changes in gait and posture noted for the box-leg were accentuated with the Anglesey leg. For instance, the biggest change observed is the amount of time spent in single support on the right leg whilst wearing the Anglesey leg. Decreasing from 64% (normal gait), 63% (box-leg) to 26% (Anglesey) there is an obvious shift toward the sound limb during the gait cycle whilst wearing the Anglesey leg. Firstly, there was a lack of confidence in the limb whilst in use that it would successfully replicate the bending of the knee and swing phases, as a result, there was a conscious decision by the wearer to place more weight on the sound leg to maintain balance and stability. Secondly, the limb felt heavy and challenging to manoeuvre, as such, it is probable that extra time was spent on the sound limb whilst the Anglesey leg was being brought forward. This is supported by the slower velocity observed for this gait.

The data in section 6.1.2 showed a decrease in cadence and velocity for the Anglesey leg, compared with not only normal gait but also the box-leg. A decrease in velocity of 49% was observed for the Anglesey leg, which is even slower than that observed for the box-leg (39% slower than normal gait) immediately contradicting the contemporary claims that those who wore Anglesey variations were not noticeably (positively) different in their movement to those without limb loss. Similarly, claims that people were able to walk for miles and dance as before (see Chapter 2), seem questionable particularly as an initial decrease in speed of almost 50% is evident. The leg length discrepancy, reduced range of motion and instability observed in the box-leg, would have posed challenges for the individual walking down the street. A decrease in velocity of 35% in our experiment on solid even ground was recorded however this was likely to be more when navigating the streets of urbanised cities such as London in the nineteenth- century. As discussed in Chapter 2, the roads were busy with people, horses and coaches, they were cobbled, uneven, unsanitary and muddy; navigating an uneven and possibly slippy surface with a box-leg would have proven challenging for the individual wearing it, particularly when floor clearance and balance were both concerns. Whilst trips and falls would have been at greater risk, energy consumption also would have increased as well.

If people were more easily tired or much slower with their movements, working within labour-intensive roles would have been challenging. Industrialisation and lack of legislation meant the average working day for a factory working during the nineteenth century was around 16 hours a day. The data identified here suggest a much slower rate of movement and therefore the likelihood that individuals would have been considered undesirable employees at the time if they could not keep up. Depending on the reason for amputation, either vascular (diabetes, gangrene, infection) or traumatic (crushed, irreparably damaged) there is between a 68% and a 100% increased energy consumption required by the individual to merely walk at a regular pace. Therefore adding a heavy artificial appliance to the patient, addresses why a slower velocity with the box-leg as well as a decreased range of motion is observed. It is suggested by Harandi et al (2020) that even with modern prosthetics, a transfemoral amputee will walk around 30%

slower than someone without amputation. Whilst this data represents the initial stages of learning to walk in artificial limbs, with speed likely to increase over time as confidence grows, it is doubtful that the speed would have ever returned to the normal pace, particularly as it is noted today there is still the anticipation that upper thigh amputees will remain 35% slower in their movements those without artificial limbs.

A decrease in speed is indicative of a gait change, which consequently leads to an increased time spent in double support on the right leg and single support on the left leg as evidenced in section 6.1.2 for both the Anglesey and box-leg. The lack of stability evidenced in the static balance data for the Anglesey leg (section 6.1.1) is dramatically different to that observed not only in the normal leg, but in the box-leg as well. Where there was a tendency to place more weight towards the front (with eyes open), this weight was naturally transferred to the back when eyes were closed, meaning the balance was difficult to ascertain and maintain also, there is the possibility that the individual would suffer hip and back pain as a result of these changes. A decreased range of motion, higher energy consumption and greater instability led to a slower velocity and this would have caused increased challenges regarding the capabilities of an individual to appear 'normal' within society, disguise their disability and maintain work productivity as contemporary literature suggests they did (see chapter 2). Social implications would have depended on status but it is likely that a slower cadence and velocity for a peg-leg wearer, would mean a slower working pace which may have impacted their work success. Likewise, a slower walking pace, may not have impacted Anglesey wearers work rate, but it would have suggested a disability to onlookers, however neither paces would have prevented the individuals from functioning in society regardless of where they sat socially.

As discussed for the box-leg the decreased support on the prosthetic limb, leads to an antalgic gait to reduce pain and increase stability. However, the amount that the Anglesey leg has affected the gait compared to the Box-leg would suggest that those who wore the Anglesey leg, were not only slower but also more unstable and as such relied on the sound limb more. The extra pressure placed on the sound limb over a prolonged period increases the likelihood of developing a lateral lean and therefore pain in the back and neck. Osteoarthritis, scoliosis and severe pain can all be consequences of this sort of postural change (Lemaire and Fisher, 1994: 1094-1099), as observed with the box-leg data.

A consequence of speed change and importance to the conclusions of this research is that this change would have ultimately resulted in an altered gait pattern, an overall slower velocity and limp which would not have been easily disguised by the affected individual for both the Anglesey and box-legs. This slowing of movement would have impacted the speed at which an individual could have completed a task that required walking, which within employment would have reduced the individual's productivity and made them less desirable to employers. The gait associated with a decreased single support is called an antalgic gait and it is utilised by individuals who aim at reducing pain whilst walking (Walter, 2011). If pain arises when weight is placed onto a foot, knee or hip when walking, an individual is likely to avoid putting pressure on that area, which results in a limp (Frothingham, 2018). Often a result of injury, arthritis, gout, osteoarthritis, malalignment after fracture healing, rickets, sciatica and osteomyelitis of the spine (Frothingham, 2018), this pain avoidance gait places more stress onto the support (or healthy side - in this case the left side) which is evident with a lateral lean (as discussed above) and therefore a change of the person COM towards the healthy side. This type of lean was observed in both the preliminary experiment's stationary images in chapter 6 (figures 6.4-6.6) and also the balanced experiment in section 6.1.1.

7.2.4 Ground Reaction Forces (GRF)

During the analysis of the temporal parameters it is unsurprising to observe more time being spent relying on the support of the sound leg and consequently observing an increase in GRF, through the sound leg compared to with no prostheses or the box-leg (section 6.2.1). The Anglesey leg in figure 6.10 (dark blue line) displays a decrease in GRF being placed through the right ankle, knee and hip with neither the Anglesey (dark blue line) nor box-leg (light blue line) peaking at the same intensity as a normal gait. Comparatively, figure 6.11 (left leg) highlights the GRF as only marginally increased whilst the box-leg is being worn on the right leg (orange line). However, the peak is earlier and unstable. The results presented in section 6.2.1, tell us that less force is being placed through the artificial leg and instead when the two graphs are analysed together, we see an increase in this GRF being placed through the sound leg whilst appliances are being worn.

Both the box-leg (orange line) and the Anglesey leg (red line) affect the overall GRF going through the sound left leg, as both show higher peaks in the force that are sustained for longer, suggesting more long-term pressure is being sent up through the left ankle, knee and hip. Forces of the body are usually transmitted through the skeletal system to the ground through the base of support, which includes structures within the feet and toes. For a lower limb amputee, this structure is missing and so must rely on the prostheses to offer the same support as a natural limb would have. One of the main roles of lower limb prostheses is to provide the wearer a vertical force transmission along the axis of the body – in other words, it must hold up body weight whilst standing (Levine et al, 2012). The forces produced by body weight push down on the prostheses, through the prostheses and onto the ground, therefore the prostheses must be strong enough to maintain this weight. A good understanding of pressure tolerant areas of the stump must be taken into consideration when designing the socket because the GRF has a parallel and equal force of person to the ground, that puts pressure on the skin and therefore if the axial load is incorrect, this can cause detrimental effects to the wearer such as pain and imbalance. Likely, the wearer would therefore attempt to alleviate the pain and compensate for the imbalance by placing less pressure on the axial load (if it is incorrect) and placing more faith and support into the sound residual limb, which the data in both 5.12 and 5.13 suggest is likely happening.

A decrease in GRF was observed through the right leg whilst wearing the Anglesey leg, meaning the forces are being redirected through the sound limb resulting in an increase in forces through the ankle, knee and hip of the sound leg. The more intense changes are observed in the left leg whilst wearing the Anglesey leg suggesting that over time, the sound left leg would suffer more damaging effects than an individual wearing a peg-leg style (figure 6.11). A drop in ground reaction force through the right leg (the artificial leg side) was potentially a consequence of the fact that crutches were being utilised to increase stability. Like most artificial limb wearers of the nineteenth- century, crutches, either one or two, were used to maintain balance and stability whilst walking, meaning that some of the force that would have been sent through the ankle, knee and hips of a bipedal walker, is split between the artificial limb and the crutches sending some of the force directly to the wrists, elbows, shoulders and neck. The use of crutches to increase stability, whilst alleviating forces and stresses on joints in the lower body, increases them in the upper body and as Khalaj et al (2014) discuss, this can lead to stiffness and pain in the joints (arthralgia) and muscles (myalgia).

Complications resulting from a drop in ground reaction force through the right leg is osteoporosis. Osteoporosis is a term referring to low bone mass, which can lead to an increase in the risk of bone fractures. Comparatively, increased forces on the sound limb and increased use due to lack of confidence and performance of the artificial leg would have created the conditions for osteoarthritis of the ankle, knee and hip to occur. Consequences of these changes on the lived experience of the individual would have seen changes in mobility and challenges to gain and maintain physical employment in labour-intensive roles.

Frost's (1990) Mechanostat theory of bone cellular biodynamics suggests that increased mechanical loading beyond a given level inhibits remodelling and promotes modelling, specifically at the periosteal surface (Lazenby, 1993: 27). This response adapts the size and shape of the bone toward a larger dimension which in turn can resist the increased load, on the sound side. This explains why over time, more changes would be observed skeletally on the remains of an individual who had experienced amputation and survived for longer. The opposite would be observed when a reduction in loading has occurred, for instance on the amputated side there would be a reduction in bone mass and volume. It is proposed therefore, in conjunction with the data in section 5.5, that unilateral amputees would have experienced compensatory gait changes that would have caused the sound limb to change shape and size due to an increase in stresses and loads placed on it, compared to the remaining stump which would have decreased in size as a consequence of lack of use. The consequences of these changes for an individual during the nineteenth century would have seen them struggling to perform certain tasks such as staying mobile for long periods of time, interfering with their ability to work long hours, stay agile and stable and of course perform tasks with the same speed and intensity due to lower energy levels.

The produced data leads to assumptions that media and business advertisements during the nineteenth century discussed in chapter 2, which represented artificial limbs as fail-safes to restoring a normal undisabled lived experience, were largely exaggerated. The evidenced decrease in stability and slower gait cycle for both artificial limbs, suggests that the wearer would have had difficulty hiding these changes, even if their clothing physically covered the artificial leg. It is likely a crutch would have been necessary to increase stability and balance. In section 6.21 we see the Anglesey leg in (dark blue line) (fig. 6.10 displaying a drop in overall GRF placed through the right ankle, knee and hip with neither the Anglesey (dark blue line) nor peg (light blue line) peaking at the same intensity as a normal gait. Comparatively in figure 6.11 (left leg) whilst the box-leg is being worn on the right leg alters (orange line) the GRF for the left leg, it begins its gait with a GRF initial peak only marginally greater than with no artificial limb. One likelihood of this initial sharp peak, greater than both the Anglesey and normal, is the smaller surface area through which the force travelled upwards. The peg-leg has no foot, just a stump like that of a stiletto or a heel, the smaller the surface area the greater the pressure

(P=F/A). Similarly, because an amputee is missing body parts, there are instances where the muscle action does not exist to counter the GRF because the muscles and joints do not exist anymore.

These changes in GRF would have ultimately resulted in slower walking velocity and greater instability which would have made maintaining an efficient workload challenging for the working classes and been impactful amongst wealthier circles by proving difficult to conceal these gait changes, even if clothing hid the artificial limbs. The use of a crutch, or two crutches during the nineteenth century would have been an obvious indicator that the individual was physically ‘imperfect’. The casualties that ensued after the various military conflicts of the nineteenth century, resulted in an increase in demand which in turn disallowed the luxury of the intricate hand-whittled, custom-designed devices and saw the birth of crutch mills toward the 20th century. The use of a walking device such as a crutch and even the fashionable walking cane would have become associated with certain members of society and its association with the disabled may have been a contributing factor in the demise of walking aids as a fashion accessory amongst the wealthy middle class toward the end of the nineteenth century. However, it is at this time that medicine, pain relief and prostheses were improving and so the necessity for crutches and canes to aid stability was also in demise.

The results of the hip investigations presented above, demonstrate that the changing hip kinematics and consequential adaptations in the ground reaction forces introduced inconsistencies between kinematics and external forces. The use of the artificial appliances caused changes in not only the side of the body where the limbs were worn (right leg) but also the left, suggesting that their use impacted posture over the whole body and therefore manipulated the expected forces and stresses that we are used to seeing in specific areas during normal gait. Two main assumptions can be garnered from this data; firstly, GRF direction and magnitude do not alter with changing hip kinematics however the point of force application moves with the foot. This means the GRFs are travelling through the body in places that aren't used to experiencing these levels of force. So when we see the forces seemingly decrease whilst the artificial limbs are in use (5.12 and 5.13), these forces are not decreasing, rather their direction has been changed as a result of the limbs and therefore elsewhere on the body is experiencing these forces. Which can cause detrimental problems as discussed below.

Secondly, trunk kinematics is adapted to obtain a dynamically feasible gait pattern, which can be modelled by applying external torques on the hip and pelvis. The postural changes that were observed in sections 6.2.8-6.2.10 illustrate the effects most clearly on the hips, pelvis and back, with an obvious lean occurring. The gait pattern that resulted from these changes and presented in figures 6.30 and 6.31 demonstrates the alterations in forces and also the increasing stresses that are being placed on specific areas of the body that are not used to it and which ultimately alters the gait pattern that is presented.

7.3 Physical Appearance and Gait Changes

Physical appearance drove public perception of an individual and the changed gait identified here, along with the possible use of a crutch would have undoubtedly led to societal judgements that would have impacted the lived experiences of the individual. Additionally, although it is likely that with practice, confidence in the appliances would grow and some gait changes decrease in intensity, the contrasting lives of the groups synonymous with each limb experienced would have had an impact on not only the public perception of disability but also the ease by which these men returned to the expected normality of their social status. On returning from war, the lower social classes were still expected to find employment and provide for their families and not become a burden relying on poor relief (chapter 2). Comparatively, wealthier men who had served in the military most often as officers and commanders, who were often members of the gentry, returned from war to a hero's welcome, rarely having to seek employment. The data accumulated here determines that despite the Anglesey leg being sophisticated in technology and considered during the time as an elite prosthesis, manoeuvrability differences between this and the box-leg are minimal and would have made little difference to the efficiency with which people moved in them. The differences are mainly observed when we look at people's varying perceptions within these groups upon their return. The wealthy who lost a limb were considered heroes who had sacrificed for their country and monarchy, the fact these people rarely needed to work meant that the artificial limb they used was for show as much as it was for function. Whereas, the lower classes who also lost a limb in battle, were immediately judged on their ability to still manage to contribute to society by securing work, despite the prejudices that they were confronted with by not longer conforming to what was considered physically elite, masculine and strong (chapter 2). This is not to say that they could not and did not work as disabled individuals, but their success in securing and maintaining work would have been based on their physical appearance and as we have seen in the data, the functionality of the box-leg would not have offered the same physical strength, stability and agility that employers would have been keen for their workers to possess. The data in chapter 5 tells us that the Anglesey leg caused more pronounced gait changes in the wearer than the peg-leg, suggesting that through long-term use, the wearer would possibly suffer more detrimental effects than an individual in a less sophisticated peg. This might imply that the wealthy were not purchasing a more functionally elite limb as was expected before this research, but merely a more aesthetic one. The gait changes observed were like the peg-leg, with trunk leaning, less knee flexion and rotation in the sound leg, less hip flexion and rotation, decreased pelvic obliquity and greater pelvic rotation for the affected limbs. The long-term social implications both artificial limbs had on the individuals who wore them differed, therefore, due to the social class within which they respectively belonged.

Whilst the reproduction of the Anglesey in Appendix B demonstrates a more sophisticated build to the peg-leg, with a greater anatomical understanding as well as an appreciation of biomechanics, its superiority in producing a more natural gait has not been validated here. Despite the addition of a foot section which should offer a greater surface area for the wearer than the peg-leg and offer a more natural feeling of heel-strike and toe-off, instead, it created a greater area that felt slippery and needed greater clearance to avoid trips. It was very noisy, ringing true to the nineteenth-century colloquial term of clapper leg because the wooden joints gliding over each other could be heard, the springs becoming torte with tension and then the wood clapping back together as the hip reached full flexion and prepared for swinging the leg back round for heel-strike.

Frederick Gray (1887: 71) offers up a suggestion which relates well to the findings of the lab-based assessment, as he discusses manoeuvrability, comfort and peg-legs. He suggests that the reason the Anglesey leg is uncomfortable for the wearer is because it only allows movement in one direction '…having only one axis of motion, and the result of this is there is no adaptability of the artificial foot to any irregularities of the ground.' (see chapters 3 and 4). His statement comes almost 90 years after the original invention of the Anglesey leg, by which time, many adaptations to its original design had been made, the most notable being the addition of a ball-and-socket joint which according to Gray considered ground irregularities by allowing the '…foot to tilt, just as the natural one does, without any way tending to disturb the balance of the leg that rests on it.' (Gray, 1887: 71). Interestingly, Gray notes the importance of the ankle rotation during natural gait that a single-hinged artificial limb like the Anglesey cannot replicate, claiming the '…hinge joint has no 'give' in it when subjected to the weight of the body…' leaving the wearer likely to find their limb jars when stepping, he also mentions the word ‘concussion’. What Gray may also be identifying here, which the data in chapter 5 (5.5) produced is the increased level of GRF and stress that would be affecting the residual limb and hip, as well as the sound limb and hip which as noted can leave the wearer compensating with a trunk tilt and circumducted gait.

The instability evidenced by the data within this research, for both artificial appliances, correlates with modern research on the effects of ill-fitting prostheses on amputees today. Modern research suggests those who wear appliances which cause instability may suffer in other ways such as the previously noted increased risk of falls or increased likelihood of developing osteoarthritis symptoms. The box-leg wearer in this research spent more time in the single support phase (section 6.1) on the left leg, the GRF data in (section 6.2.1) mirroring this by demonstrating a decrease in the forces placed on the right leg whilst in the stance phase for the box-leg. The forces were then redirected through the left leg for longer (figure 6.9 and 6.10) which is when issues such as osteoarthritis can begin to develop if these gait alterations are allowed to continue long term. On a more superficial level, this extra time spent on the sound left leg, would have created a noticeable limp in the wearer. Similar results are observed in the wearing of the Anglesey leg and the instability this caused, (5.11 and 5.12) demonstrates a more pronounced avoidance of single support on the artificial appliance, with more time instead spent on the sound leg. Again, not only would a limp have been noticeable but, this increased reliance on the sound leg generated more intense and long term GRFs where the body was not used to these (see figures 6.9 and 6.10). Whilst osteoarthritis can take time to progress, the long-term effects of osteoarthritis if left untreated, can include swelling, bone growth, debilitating pain and the inability to move joints easily. It is likely that the physical appearance of someone suffering the effects of this during the nineteenth century would have been noticeable to onlookers, particularly through gait deviations and therefore it is probable that employers would have been unlikely to invest in an individual less capable of the demanding physical roles.

The biomechanical gait changes observed as a result of wearing the box-leg identify a change in hip abduction and adduction. For instance, the gait whilst wearing the box-leg displays a significantly lower value for hip abduction and adduction than compared to the unimpaired gait (see chapter 6 section 6.2.2 yellow line in figure 6.13 and the green line in figure 6.14). This supports results presented in more modern literature that hip joint muscle strength insufficiency is more pronounced in those with impaired gait and it generally affects the implicated side. Presented as a dropping of the hip toward the side of the swinging leg, also known as Trendelenburg gait (Pirker et al, 2017), this muscle weakness is mimicked when wearing the box-leg and Anglesey. The compensatory efforts made by the wearer to reduce hip pain and place less reliance on the weakened abductor muscles are observed by a shift in the trunk to the unaffected lower leg to reduce the demand of the hip abductors. The peg-leg creates a gait which keeps the hip in more adduction than the unaided gait – like the data produced by Krebs et al (1998: 58) who consider cane-aided walking compared to unaided gait. The decrease in hip abductor muscle force during the prosthetic gaits, relates to the shifting of the trunk to the unaffected side to reduce demand on the hip abductors and reduce pain. This causes lateral trunk bending (Trendelenburg gait) and over time even further weakness of the hip abductor muscles and glute muscles.

Referring back to Lazenby's (1993) research into Peg-Leg Brown (section 1.2) that the enthesopathy evident on Brown's femur is likely a result of elevated levels of habitual strain, which occurred after amputation causing increased functional obligation of the hip adductors and impairment of thigh flexors (Lazenby, 1993: 22). The data produced in section 6.2.2 for the box-leg, concurs with these suggestions, as it shows evidence of greater strain on the hip adductors during swing phase for the affected limb. This is the first-time biomechanical gait analysis has been used to identify and confirm the type of pathologies that we may find skeletally on an amputee, where no prosthetic device is remaining. Consequently, we can use the data to offer a hypothesis around the physical movements of the individual wearing specific appliances, as well as conclude due to Lazenby's research, how quickly these painful conditions such as enthesitis can occur because of wearing artificial appliances that change gait and create repeated strains.

7.3.1 Trendelenburg Gait

A gait pattern that today is identified as a Trendelenburg gait, is also apparent within the results for the use of both the Anglesey and box-leg. It has the appearance of a limp or missing every other step and is demonstrated most notably in figures 6.1-5.5 which depict hip abduction. The wearer may lean back or to the side slightly as they walk to maintain their balance. They may lift their foot higher off the ground with each step to avoid losing their balance or tripping over their feet as the pelvis shifts unevenly (Madormo, 2018). If left untreated, which was likely during the nineteenth century, moderate to severe cases of Trendelenburg gait would be debilitating and lead to serious complications including pinched nerves, walking with pain, stiffness or a grinding in the hips, losing range of motion, losing the ability to walk and therefore requiring the use of a wheelchair, becoming paralysed in the lower body or having death of bone tissue (osteonecrosis) (Madormo, 2018). Whilst these may seem extreme and unlikely today due to the level of care and physiotherapy that is available, during the nineteenth century this type of condition was more likely to have arisen. The complications that can arise as a result of an untreated Trendelenburg gait, could have left an individual unable to work and the addition of an amputated limb would have posed further employment challenges.

7.3.2 Circumduction

Another gait that there is evidence in the data of, is circumduction gait, which is recognised as a swing phase deviation in which the hip abduction is combined with a wide arc of pelvic rotation (figure 6.28).Circumduction is most likely to occur when there is limited motion affecting the knee (limited knee flexion), hip flexion or a leg length discrepancy. The muscles most affected by this are the knee and hip flexors. This gait is often observed in individuals who have experienced a stroke and therefore presents itself as a noticeable gait deviation. Beliefs during the nineteenth century surrounding morality and physical health would have been challenged by the appearance of an individual who was displaying a gait, which suggested ill health. This gait would therefore not only have caused physical mobility issues but also social challenges, particularly within employment, leaving many working class men less likely to secure a job and possibly why we see a rise in workhouse inmates during this period. It may also offer a justification as to why wealthy individuals were keen for anonymity and disguised the artificial leg.

A decrease in hip flexion and extension moments evident within the data during the use of the Box-leg (section 6.2.3), is concerning because weak extension and flexion of the hips result in people taking smaller steps which are usually observed in individuals with hip extensor muscle weakness. Whilst a weak muscle is not present here, the artificial limbs are changing the natural alignment of the hips to a position which mimics that of a weak muscle. Again, a slower gait results and there is likely to be a decreased floor clearance and potential dragging of the toes on the affected side, increasing the chance of trips and falls. The hip circumduction that is observed in the MOKKA visual dataset (sections 5.3.1 and 5.3.2) for the box-leg, is also mimicking the signs of weak hip flexors, this presents itself in the data as hip circumduction, which involves the semi-circular movement combining hip flexion, abduction and forward rotation (Krebs et al, 1998). These results are comparable to the data collected by Heitzman et al (2020) who acknowledge that a decrease in hip flexion and extension moments are what is expected from people with gait deviations due to amputations and will likely lead to joint degeneration and susceptibility to hip osteoarthritis. Similarly, an overotation observed in the hip would also have contributed to the increased likelihood of hip osteoarthritis. Rotation observed in the box-leg gait is likely a consequence of the fact the box offers no knee joint to flex and so the limb rotates around the body to the front. As noted above, limb length discrepancy would also have contributed to this gait change, so the leg has clearance above the ground during swing phase. To compensate for leg length discrepancy, vaulting may occur which is where the sound leg exaggerates its heel elevation during stance in order to assist with clearance of the swing of the opposite leg. This exaggeration within the sound leg's hip, would contribute to the increased likelihood of osteoarthritis developing as well as pinched nerves within the spine causing pain.

Should these complications have arisen for individuals during the nineteenth century, which the data produced in chapter 5 proves was likely, it is probable therefore that mobility would have decreased. According to Poinier et al (2020) complications of hip osteoarthritis, if left untreated can be complex and devastating to an individual's life. Amongst other symptoms, complications can include; rapid breakdown of cartilage resulting in loose tissue at the joints, osteonecrosis, stress fractures, bleeding or infection within the joint, deterioration of the tendons and ligaments around the joints and finally pinched nerves, all of which can lead to instability. In combination with physical pain caused by these complications, weight gain is also a common concern with osteoarthritis because the instability and pain can lead to immobility and therefore weight gain - which has its own risks such as heart disease and diabetes.

The findings of this research concur with Gailey's (2008) research into modern prosthetic apparatus, in that there is evidence of the prosthetic gait causing an increase in hip adduction moments in conjunction with an increase in pelvic obliquity (figure 6.29). Both prosthetic limbs under investigation created a pelvic drop that was significantly less on the prosthetic side than that on the sound side. The Anglesey leg, however, affects the natural range of motion more significantly than the box-leg. In fact, during the Anglesey gait, it does not reach the abduction phase at all. Concerningly, what this data identifies is a lack of abduction and therefore a weakness in the abduction muscles which can cause pain and create issues with walking, standing, sitting and rotating. The correlation between lack of abduction and femoral bone mass density by Hurwitz (1998), is noteworthy for suggesting that those wearing Anglesey legs, displaying signs of a lack of abduction during gait, were predisposed to hip pain, osteoarthritis and also a decrease in bone density on the sound side, which suggests osteoporosis. Kulkarni et al (1998: 348) concluded that osteoporosis was frequent amongst those with amputation because of the disuse that led to a decrease in muscle mass, immobilisation of the amputated limb in the socket and lack of muscular contraction during activity (Kulkarni, 2005: 81-86).

Pain medication during the nineteenth century was unregulated and could lead to addiction in patients, whilst not the focus of this research, it is important to note that self-medicating to relieve ailments brought with it potential complications that could have caused further harm to an individual who was suffering due to their impairment and artificial appliance. Cocaine was advertised as a muscle and nerve tonic - perfect for individuals suffering the long-term pain and discomfort associated with the identified postural changes of amputation within this research. The findings of this research which suggest long-term pain, the development of conditions such as ulcers and osteoarthritis and difficulty in making a living (to afford advice from a doctor), make it plausible that individuals who underwent amputation were at an increased risk of needing pain relief and therefore were more susceptible to the potential addictions that could arise through the overuse of accessible opioids such as morphine.

Referring back to chapter 2 discussing the experiences of individuals returning from war who had been disabled, the increase in workhouse numbers and increasing numbers of vagrants is unsurprising when the biomechanical data is assessed, which demonstrates a significant change in physical movement and likely detrimental effects of this. Ultimately, the changes identified within this research, suggest that at least in the immediate months after amputation and the use of a box-leg, the individual would have seen radical alterations to the way they physically walked due to the hip rotation and adduction that was occurring as compensatory pain relief methods and as a further consequence of this, would have taken time to adjust to regain stability levels that would have enabled them to possess workplace productivity.

7.3.3 Knee Rotation

Of particular interest within this research is the gait alterations that become evident whilst monitoring the knee rotation, flexion and abduction moments during the Anglesey gait. The interest lies with the fact that the Anglesey leg had an articulated knee aimed at replicating the natural gait movements and based on this more similarities between the natural gait movements and the Anglesey movements may be evident. As anticipated, there is a greater similarity between the natural knee movement and that observed in the knee during the use of the Anglesey device. The difference lies with the intensity of forces being maintained on the sound limb for a longer period of time (section 6.2.7). However, this data demonstrates that the Anglesey leg, with its articulated joints, is functioning in the same manner as a natural leg, with the mechanisms allowing for abduction to occur more closely to what is expected in natural gait. This is important because it means that the individual wearing the device is more closely mimicking natural movements (albeit slower, as identified above) and therefore in theory is more likely to conceal their disability, as well as reduce the risk of more complications arising due to gait changes. Similar results are observed when we look at knee flexion and extension.

The reason we are seeing these findings at the knee for the Anglesey, is because of the knee joint that is manufactured into the artificial limb to replicate these exact movements. We are seeing a functionality to this mechanism, which may partly explain why there are descriptions from the time, which say the individual's movements were very natural. Although, despite the efficiency of the knee joint, the identified concerns at the hip, suggest biomechanical changes that would have been noticeable and physically challenging over long periods of time. Furthermore, as a consequence of wearing the Anglesey leg, the biomechanics of gait are changed in such a way that the hip hiking evident for the box-leg and an exaggerated rotation of the pelvis is also evident here. Likewise, a pelvic obliquity is apparent with the drop during the loading response as is a trunk tilt.

These alterations are similar to those of the box-leg, suggesting that both prosthetic appliances are impacting gait and posture and regardless of social status, complications with biomechanics were likely. It is also likely with the data produced that the wearer would not have been able to conceal their disability in a way which would have led to full social acceptance, mobility and employability. Although the physical complications that are apparent with the Anglesey leg would have certainly impacted the livelihood of those wearing them less than those wearing the box-leg. From a social perspective, the wealthy who didn't need to secure employment were less physically restrained by their limb loss, because of the less labour-intensive roles they could occupy compared to lower-status members of society. The heroic roles these individuals played in battle were well documented and portrayed in plays, art, literature and memorials (see Chapter 2 (section 2.6)) and therefore limb loss under such circumstances was considered a noble honour, concealment to a great extent was less important compared to those who may have been born with congenital impairment, or those who needed to conceal their loss to secure employment.

7.3.4 Hip Hiking

The pelvic obliquity data shows the box-leg affecting the natural hip movement in such a way that causes the left side of the hip to drop as opposed to maintaining a neutral level. This is identified as hip-hiking toward the sound side and it reduces the coronal plane hip moment, by avoiding reliance on the abductor of the amputated side for stability and to ensure swing-side foot clearance. Likewise, this compensatory action would decrease the overall obliquity of the pelvis because hip hiking requires the hip of the swing leg to be raised, therefore reducing the normal amount of pelvic drop during the loading response (Michaud et al, 2000).

Evidence of hip hiking also evident within the Anglesey leg data (section 6.2.4) confirms similarities between modern prostheses research by Lenaerts et al (2009). Hip hiking compensation decreases the overall pelvic obliquity and helps to maintain a steady COM however, it produces a scenario where the individual may become susceptible to scoliosis and pain in the back and lower limb. This data suggests the individual would have displayed obvious gait difficulty and therefore struggled to conceal this, despite both prostheses being marketed as assisting with gait difficulties caused by amputation. The inability to hide this gait pathology would have highlighted to outsiders a physical difference and as discussed in chapter 2.3.1, led to concerns about ability to work (lower classes) as well as masculinity for the upper classes. Social acceptance as previously discussed in chapter 2 was driven by appearance, both physical (the body) and by how you dressed it.

Wealthier individuals, upon leaving the military were treated in heroic ways, often finding themselves sharing their battlefield tales with an adoring audience. Wealthier individuals were fortunate that they rarely had to prove to potential employers that they were physically fit enough to work, because the very rich simply did not partake in physically demanding jobs, instead as chapter 5 notes, they became MPs or authors if they worked at all. They also had the ability to afford clothing that would more efficiently hide their artificial limbs. Their mobility in terms of changes in gait, however as this research has identified would have been less easily disguised, regardless of the expense paid on more sophisticated limbs, particularly immediately after being fitted for the leg. The discomfort, instability and heaviness that the Anglesey leg causes whilst being worn, as well as the erratic biomechanics identified in the analysis in chapter 5, provide evidence which suggests that the wearer of this type of limb would have struggled to completely conceal their disability. Whilst literature discussed in chapter 2, noted how well these individuals could dance and move, almost as well as before they lost their leg, the data produced here suggests this was unlikely to be the case, specifically immediately after being fitted with an Anglesey leg - contrary to their advertisements. As personalised rehabilitative care did not exist at this time, the findings here suggest that it would have taken months before the individual wearing the leg would have become more used to moving in the appliance, let alone dancing in it. However, whilst the literature from the time may have idealised perfection and bodily wholeness, this was just not the norm and instead varieties of disability were very present in the public view. Largely due to the mass industrialisation and mechanisation which caused numerous injuries to the workforce. This meant disability was not an uncommon sight and instead, the utilisation of the artificial limbs under discussion within this thesis would also not have been an unusual sight. It may have been much more accepted as the norm within lower classes due to the dangerous nature of the work they were likely to be involved in and instead, the wealthier classes may have struggled more so to accept the visibility of disability within their circles. This was probably a result of the literary readings they had more access to, which expressed physical norms, as well as the value placed upon physical appearance for the purposes of securing good marriages. The importance of concealment of artificial appliances, therefore, was greater amongst the middle and upper classes, in part due to the increased rarity of individuals utilising these appliances and also because of the desire to appear physically 'perfect'.

7.3.5 Pelvic Rotation

The data demonstrates the box-leg increasing the pelvic rotation to a greater intensity than the natural gait which in turn, leads to pelvic tilt anteriorly or posteriorly (section 6.2.8) An increase in pelvic rotation can be connected to lumbar lordosis (inward curvature of the spine). The gait changes identified with the box-leg demonstrate a pathology which mirrors a curvature of the spine which could suggest the individual would experience physical complications we associate with lumbar lordosis today, such as pain, fatigue and, crucially, instability. Compared to modern studies, the concerns that have been highlighted with the biomechanical assessment lead to the determination that if the individual maintained these gait changes, left pain untreated and osteoarthritis set in, eventually they could become immobile and certainly not capable of functioning in society as a non-disabled individual who could work.

7.4 Summary

As noted above and discussed in chapter 3, box-legs were more frequently worn by lower-ranking soldiers, likely to have undergone poorly performed amputations. With this in mind, their living conditions were probably poor, healthcare minimal, and their jobs in factories, in agriculture or on the railroads were labour-intensive and physically demanding. When we consider the physical challenges that these peg-legs posed, not only the gait changes and pain but the extra physical exertion required to move after an amputation, life would have been challenging. The rise in unemployment immediately after Waterloo, the increase in vagrancy numbers and workhouse inmates could, in part, be justified by the challenges faced by newly disabled veterans. Similarly, these gait changes would have been challenging to disguise. There was no physiotherapy available at this time and so healing and adjusting to the box-leg would have been a long process that essentially involved learning to walk again. Combined with the slower gait velocity identified here, the physical changes such as a trunk tilt, hip hike and circumduction gait are all noticeable and would have been difficult, if not impossible to conceal from potential employers.

Public perception of perfection as ideal, was unachievable particularly for an individual who was wearing a box-leg, because the individual with such an impairment did not even meet the criteria for a body which constituted the ‘norm’. A walk that, as identified here, could cause more challenges, such as osteoarthritis and in turn lead to even more significant physical gait changes for the individual and even possible immobility. Lack of work, combined with poor nutrition as a consequence of low income, physical challenges such as pain, weight gain, immobility, osteonecrosis, would all have contributed to poorer lived experiences. Whilst these are extremes today, the nineteenth century saw a simultaneous population and industrial boom that would have created new challenges for those who were unable to keep up with the mechanised pace of life. The poor medical care and lack of aftercare would have left amputation wounds poorly healed and susceptible to infections. These factors when combined, create a picture synonymous with poor lived experiences and little opportunity to mitigate these circumstances. Unfortunately, this style of artificial leg was the most common for injured soldiers and so those fortunate enough to survive their injury and subsequent amputation, were undoubtedly faced with innumerable challenges that made an already challenging existence during the nineteenth century, even more difficult, although not impossible as discussed below.

The Anglesey leg was much more prolific in causing the gait changes such as pelvic rotation than the box-leg. The data presented in chapter 5 demonstrates results which match the hypothesis laid out at the start of this research and match expectations and findings from modern literature. The findings suggest that whilst both artificial limbs reconstructed for this experiment do provide the wearer with the ability to look more physically complete (discussed in chapter 3), the weight, materials and design of both the Anglesey leg and box-leg impact the ease with which the individual maintains stability and walks. Identifying a change in the biomechanics of an individual's gait as a consequence of wearing these appliances, provides data for the first time, which suggests wearer's were likely to experience other concerns such as pain, discomfort and other osteological pathologies.

The above data has demonstrated the potential problematic gait pathologies that individuals who utilised these artificial appliances could have experienced. The important point to note is the different ways in which these problems affected individuals of different social statuses. Firstly, the Anglesey leg identifies gait traits that are more extreme and intense than the box-leg, however, the use of crutches which was a fashionable statement amongst the wealthier classes who were more likely to wear the Anglesey leg, may have acted as a mechanism of concealment as well as a tool for stability. Similarly, crutches or walking sticks may have mitigated some of the damaging effects of the artificial appliance, such as hip hiking. Whatever the opinion of amputation amongst upper class circles was (discussed in chapter 3), the act of concealment within these groups was undoubtedly easier because of the lives they lived, which seldom required the physical necessity of labour intensive employment.

Comparatively, the individuals who were likely to wear box-leg appliances may not have had concealment as the most important driving force behind wearing a prosthetic limb. As noted, disability amongst working class groups became increasingly more common throughout the nineteenth century as a consequence of industrialisation and mechanisation and therefore a growth in tolerance for individuals who had suffered physical injuries. Whilst the box-leg data shows gait changes, they are less extreme than those identified for the Anglesey leg and although posed its own problems long term, individuals would have been keen to secure work and maintain a wage. Despite there being evidence of increased numbers of individuals out of work and on the streets, growing numbers in workhouses, we do know disabled individuals represented some of the workforce through their impact on employment based legislation (see chapter 2) that occurred towards the end of the nineteenth century. Suggesting that disability was visible in the workplace and these people were trusted by their employers to do an efficient job, also, some of these individuals were likely to be the wearer's of artificial limbs such as the box-leg due to the number of working age men that returned from the Napoleonic Wars in search of a living.

As discussed in chapter 2, Martha Stoddart Holmes (2004) suggests that despite Victorian literature representing disabled individuals as having an inability to work, in reality, this was not the case and as the data here has proven, even those with missing limbs would have been able to walk and remain mobile with the use of the artificial limbs here. Although the data suggests concerns over speed, pain and instability, the legs themselves are functional and with practice would have possibly become more comfortable for the wearer. In fact, there are examples recorded by Turner and Blackie (2018) that give descriptions of individuals who weren't amputees but whose gaits were affected by the injuries that they had encountered at work and these mirror those observed in the data here. For instance, instability, slowness and pain (2018: 50) if this was the case amongst working class groups, those with artificial limbs may not have been as noticeable as initially assumed due to the high number of injuries that occurred in these sorts of jobs.

7.5 Comparisons of Findings with Modern Appliance Gait Analysis and their Long-Term Health Implications

7.5.1 Osteoarthritis

Research conducted by Plomp et al (2015) into the morphological characteristics of healthy and osteoarthritic joint surfaces in archaeological skeletons from several sites and eras, including the nineteenth century, found high incidences of osteoarthritis in male joints. One explanation could be the labour-intensive jobs that men usually participated in such as in mines, they were farmers, worked on railroads and served in the military. Not only were these jobs physical, resulting in repeated stress on joints but they were high risk and increased the chances of an individual requiring an amputation. As noted in chapter 2, individuals of lower social status experienced nutritional deficiencies, which in combination with high-intensity jobs would have predisposed them to conditions such as osteoarthritis. The loss of a limb and the biomechanical changes identified in chapter 5 and discussed here which would have further exacerbated osteoarthritis, could have therefore contributed to the likelihood that an individual may have experienced long term issues.

Studies on modern prostheses, suggests that one of the main compensations observed during prosthetic gait, is an increase in the external rotation of the residual amputated limb. It is believed by medics, that this may be a compensatory effort to place more reliance on the sound limb, increased stance time on the sound limb and therefore protect the soft tissues of the amputated limb which can struggle to support weight after amputation, possibly causing the individual pain (Silverthorne et al, 1996). Not only this but this compensation would also improve medial/lateral stability (Silverthorne et al, 1996). Data has shown that the load placed on the intact limb would therefore increase, and the vertical GRF too would increase on the sound limb side and decrease on the amputated side (Breakey, 1976). The data produced within this study, has identified that there is an over-rotation of the residual amputated leg as a possible compensatory mechanism to aid movement and alleviate new forces and pressures. Therefore it is possible to utilise the medical understandings of the complications these compensations have for modern patients and apply this understanding to the nineteenth century variations discussed within this research. For example, whilst suggesting that this compensation may increase stability, Hurwitz et al (2001) adds that this gait change with modern prostheses could lead to a degeneration of weight-bearing joints which in turn could lead to osteoarthritis and pain. It is probable therefore, that the same complications could arise for an individual during the nineteenth century, where joint moments in the knee, ankle and hip (Murray, 1983) of the sound limb were evidenced as increasing in both the box and Anglesey leg. Hurley et al (1990: 33-42) adds that these compensatory mechanisms throughout a lifetime, if left untreated, would lead to an increase in stress on the sound limb and therefore more likelihood that the individual would develop degenerative arthritis.

The influence of mechanical loading on bone structure has been noted for over a century, initially by Julius Wolff in 1892 (Frost, 2004). However, according to Frost (2004) load bearing bones are not limited to weight bearing bones and therefore these loads, rather than weight, most influence bone strength post birth, for instance loads associated with the muscle actions of walking (Kaptoge et al, 2007). Bone remodelling can occur at the whole bone level or at specific places along the bone. The whole bone level would observe, according to Gowland, (2013) bone migrating to accommodate stresses and strains, in comparison to the remodelling which occurs consequently to microscopic fatigue damage which then gets repaired. It is these sorts of changes that are likely to cause damage to an individual wearing prostheses that repeatedly change their natural gait, adding loads where there previously was none or significantly less. The data in section 6.2.1 provides evidence of a change in mechanical loading which in conjunction with Frost’s (2004) research, would lead to the assumption that the sound leg would experience more loading stresses and therefore over time, remodelling. The consequences of such on an individual's life during the nineteenth century would be fatigue when walking and pain both of which would have possibly led the individual to seek addictive pain relief options and also caused problems in employment.

According to Gailey et al (2008: 17), three of the most common complaints observed in lower-limb amputation today are osteoarthritis - usually of the sound leg, undermining its integrity (Hansen and Childress, 2000: 205-215), causing osteoporosis and lower back pain. As this research has identified, the gait changes that are evident would have also led individuals during the nineteenth century to experience the same complaints as noted by Gailey et al (2008: 17). Hungerford and Cockin (1975) found that veterans of World War Two who had evidence of osteoarthritis of the knee, was significantly higher in those who had undergone amputation; 22% with no amputation, 41% with transtibial amputation and 63% with transfemoral amputation (Cockin, 1975). With knee pain in the sound limb being the most common complaint for the veterans under investigation, gait asymmetry and intense loads on the sound limb was attributed as the cause of the higher levels of osteoarthritis in long term prostheses wearer's (Burke et al, 1978). Conclusions by Norvell et al (2005) suggest that those with transfemoral and transtibial amputations are 5 and 3 times respectively, more likely to suffer knee pain and other concerns than those with no amputation, due to the increased forces placed on the sound limb during gait.

The data in chapter 6 section 6.2.1 compliments Cockin’s (1975) findings, as it demonstrates an increase in the load placed on the sound limb (for both artificial appliances), not only in terms of increased stance phase on the sound limb but also a shift of load to the sound side, observed via an increase in double support time during the prosthetic limb’s stance phase. Likewise, a decrease in knee abduction moments observed in the box and Anglesey limb data, demonstrate a reduction in motion and increased load being placed on the sound limb, due to an increase in single support time on this limb. The findings here are comparable to Hungerford and Cockin’s (1975) due to their connection with military patients who had undergone amputation due to trauma, much like individuals during the nineteenth century under investigation here. The data points to more intense loads through the sound leg, which according to Cockin (1975) correlates with a greater chance of developing osteoarthritis.

7.5.2 Gait Speed and Energy Consumption

Gait speed is slower and more asymmetric in amputated gait as opposed to regular bipedal gait (Hurley et al, 1990). A decrease in both cadence and velocity was also identified in the findings of this research. Cook et al (1997), suggest that one way of countering the increases in mechanical stress that result from artificial limbs, which restrict natural movements such as knee flexion, is to decrease walking speed. This is a common gait alteration that appears to naturally occur in prosthetic gait to maintain stability, however, it may also be helping to reduce unwanted pathological risks such as osteoarthritis.

Many amputees are recorded during the nineteenth century as noting that physical rehabilitation was exhausting and long. It was assumed - due to prominent advertisements such as those seen in chapter 2 - that the amputee would be easily strapped into their new leg and immediately walk as before. However, this experiment has provided evidence which suggests the contrary and supports the first-hand accounts of individuals such as Napoleon Perkins (1863), who needed to re-learn how to walk again with their new prosthetic leg. He was expecting to be able to walk immediately but was disappointed that he 'could hardly walk with the aid of my crutches.'. It took numerous attempts to gain more confidence in the appliance before he began to be able to move around more freely, initially with the support of crutches and eventually unaided. The same was experienced by the wearer in this experiment. The artificial legs were worn a number of times prior to the biomechanical analysis, in order to gain familiarity with the appliances and increased confidence. However, despite having 6 months in order to do this, crutches for stability were still used during the analysis, suggesting that the rehabilitation for an amputee learning to walk in these artificial limbs during the nineteenth century was an incredibly long and slow process and not immediate as the advertisements suggested (chapter 2).

7.5.3 Spinal Concerns

Those who have lower limb amputations are also at risk of increased spinal issues, including pain and scoliosis. Burke et al in 1978, reported after radiographic findings that the rates of scoliosis in lower limb amputees were around 43% and degenerative changes were evident in 76% of those involved in the study. Severe and chronic back pain can be so debilitating that daily life is inevitably impeded (Ehde et al, 2000 and Kulkarni et al, 2005). The result of coping with back pain, causes many amputees to change their gait to reduce discomfort and place more dependence on the sound limb, as seen in the data in section 10.5 where we see an increase in double support for both the Anglesey and box-leg, with an increase in GRF's for both as well. As noted in the data in chapter 6 (sections 6.1.1 and 6.2.10), scoliosis was a possible effect of lateral trunk bending toward the sound leg as a compensatory effort to transfer load away from the affected limb generating a Trendelenburg gait. Hubert (2001) discusses the socio-economic effects of scoliosis, proposing that those who exhibited the condition were not only self-conscious and embarrassed (Fowles et al, 1978) by it but were more likely to be unemployed and descend into vagrancy if they received no support from their communities. His conclusions are drawn just on discussions of scoliosis, and so it would be plausible for those who developed this condition because of the use of artificial limbs, to experience the same sort of plight. It is proposed here that one reason why we may not find a large amount of archaeological evidence of amputations, is because many of those who did befall this fate, found themselves unable to financially support themselves and therefore had to move to the poorest areas such as inner cities. This aligns with the increase in vagrancy and workhouse inmates that is discussed in chapter 2. These people may then have died and been buried in unmarked graves, or as happened to many unclaimed cadavers at this time, become the topic of anatomical study at hospitals, leaving only fragmentary evidence which disguises original pathologies suffered by the individual. Meaning that finding amputees with evidence of amputation and prosthesis use, is challenging.

This study has demonstrated an asymmetrical gait pattern as a result of placing more dependence on the sound leg whilst wearing both the Anglesey and box-leg. And whilst the data produced here can only be applied to the initial stages after amputation due to the length of time taken to practise walking in them, the changes that are observed in gait, if allowed to persist, would lead to back pain and osteoarthritis as discussed in more modern findings. Again, affecting the lived experiences of people by affecting their employment opportunities, long-term employment, ability to conceal their disability and overall physical mobility.

7.5.4 Socket Fit

Socket fit is vital to comfort and prostheses efficiency, correct alignment can also affect stability and stress on the sound limb. The alignment affects comfort, function and aesthetics and if alignment is incorrect, it is likely, socket fit will also be detrimentally affected which may cause pressure in places that cannot withstand pressure, such as the residual limb and socket interface, which causes pain and tissue damage (Yang et al, 1991). For example, of 78 people who underwent traumatic amputations, only 43% were happy with their prostheses within Dillingham et al's research (2001: 569), with skin irritation and wounds reported as frequent issues. The socket fit of both the box and Anglesey limbs was poor, firstly the box has no socket, it is just something to kneel on and whilst most evidence suggests people would place cloth to pad their knee or stump on the stump support, as this research data has identified, it still offered minimal support and stability. Similarly, the Anglesey whilst it does offer more of a socket of which there is evidence of being carved more intricately to adapt to the wearer's pressure points, is still produced from solid wood and therefore does not completely mould to the expansion and shrinkage of the ever-changing stumps (section 2.3.1). Whilst this limb did have limited padding and there is evidence of sock supports being utilised as well, the data collected within this research suggests the comfort levels would have been minimal, and it is unlikely the wearer would have been able to maintain their use for hours all whilst placing heavy loads on the limb. Certainly from the experience of wearing each limb for this investigation, the Anglesey leg was found to feel less secure around the wearer than the box had been. This was probably due to the lack of waist attachment which there is evidence of some of these limbs having. As a result, the limb during the swing phase felt like it was slipping down which resulted in the reluctance to lift the leg far off the ground. Similarly, both limbs felt heavy, with the Anglesey leg's socket feeling like it would cause bruising around the thigh if worn for long periods. For both legs to feel secure, they had to be very tight so the leather straps dug into the thigh and reduced the risk of slipping down or twisting.

Gailey (2008) accepts that not enough research into the effects of alignment of the gait of people with amputation has been conducted to produce solid conclusions, but the flexion of the prosthetic limb has been found by Yang et al, (1991: 985) to affect GRF through joint moments on the prosthetic limb and this may suggest a correlation between prosthetic misalignment and back pain. The knee flexion observed in the data here (in section 6.2.6) demonstrates a decrease in flexion of the sound limb during both prosthetic cycles, as well as an earlier heel strike (decreased single support) and an unstable CoM. This suggests a pelvic tilt and a trunk tilt, moving the COM to the sound side, and increasing the load on this limb. The consequences of these changes would increase the wearer's instability and therefore chances of trips and falls, as well as generate more intense discomfort, due to the change in manoeuvrability of both the prosthetic limb and also the sound side.

It is proposed by Schindler (2007) that repeated trauma, particularly of the knee, can lead to increased likelihood of developing osteochondritis dissecans (OD). This is where the subchondral bone and surface cartilage are affected in such a way that it can result in the total separation of the osteochondral fragment, creating a loose body. If left untreated, the individual would suffer pain and discomfort, due to it jeopardising the integrity of the joint, potentially leading to the development of osteoarthritis (Schindler, 2007: 47). Whilst not isolated to the knee joint, it occurs here more frequently than the ankle, hip and other diarthrodial joints. Mann et al (1991) conclude, after researching three early twentieth-century skeletons, all with examples of prolonged knee flexion, that the damage that this pathology can cause to the bone, is a consequence of consistent contact pressure and increased quadriceps forces. They suggest that whilst the knee is in a static, permanently flexed position - such as that observed when kneeling on a peg-leg – long-term static forces can result in bone adaptations.

Crucially, this data demonstrates the overall impact both artificial appliances have on the rest of the body, because as expected in the knee flexion data (6.2.6) both the Anglesey and box-leg impact the level of flexion on the right leg whilst being worn. However, the data also demonstrates the impact they have on the sound leg during their use, with the left leg unable to match its level of flexion achieved whilst no appliance was being worn. This is the general theme of the data findings throughout the gait analysis, that the appliances interfere with the natural ability of the sound leg and consequently their use is not just impacting the leg they have lost but also the rest of the body. Including postural changes that occur as a consequence of the compensatory movements, these appliances are causing.

7.5.5 Posture and Leg Length Discrepancy

Finally, the posture and leg length discrepancy of an amputee can have a detrimental effect on the individual. The findings of this research concur with Cockin (1975) who identifies that those with lower limb amputations, demonstrate a greater sway toward the sound limb to maintain stability as well as hip-hiking as also observed in the data produced in this research. Those who have a prosthetic that is the same length as their sound limb, display fewer pain symptoms than those with obvious asymmetry. Friberg (1984: 125) found that of 113 traumatic war related amputations, only 15% of the individuals had the correct length prosthetic limb and 30% had a length difference of 20 mm which resulted in lateral trunk bending and back pain. Over time, scoliosis would possibly develop as well as hip and knee pain in the sound limb (Gailey 2008: 24). A discrepancy in leg length can also affect the positioning of the pelvis

(Young, et al 2000 in Gailey 2008) and a lateral pelvis tilt toward the shorter leg would occur, which would again contribute to postural changes and back pain. The increase in hip rotation for the box and Anglesey was between 5-16^{o} which is much greater than desired and would be associated with lumbar lordosis, which can cause pain, fatigue and instability. Likewise, if during the 1980s, with custom construction, only 13% of amputees had the correct length artificial appliance, it is highly probably that during the early nineteenth century, even fewer men were likely to receive the correct limb length due to the lack of customisation that existed within construction at the time - particularly for box-legs.

What is most notable from the literature, is that many of the findings observed in individuals utilising modern artificial appliances, which at the time of use were likely top of the range and manufactured using the latest technology and anatomical as well as biomechanical understanding, show findings on biomechanics incredibly like those produced for the nineteenth century variations in this study. That is not to say the intensity of the asymmetry and compensations was the same, but rather, the same changes are observed in both. What this means is that we can for the first time begin to build a scientific basis for potential skeletal markers observed on archaeological remains, that may have previously been misdiagnosed or missed in general, that relate to the use of artificial appliances such as those under investigation here.

In combination with the background research in chapter 2, the importance of these lab-based findings comes as a contradiction to the written statements of success that particularly the Anglesey leg harboured at the time. Biggs (1887) and Gray (1857) both talk about the success and efficiency that an articulated knee and ankle, on an artificial leg can have in helping a person regain a gait that mimics their natural one (Chapter 6). However, this data shows that whilst these limbs do offer the wearer a regained bipedal mobility, they also bring with them potential damaging consequences which have both short-term and long-term health effects, as well as a gait which seems unlikely would trick an onlooker into believing nothing was wrong.

7.6 Use and Disuse of Appliances

As discussed in chapter 2 (section 2.2), Clasper and Ramasamy (2013) note the long-term effects physically and mentally of traumatic amputations on soldiers. When the ethnographic data from Vietnam veterans is compared to the data produced in chapter 5, a picture of the lived experiences for amputated soldiers utilising the box-leg or Anglesey leg becomes clearer. If the twentieth-century transfemoral prostheses designs - with their padding and custom fit - were only wearable for around 7 hours a day (section 2.2), the early nineteenth-century styles under investigation here, with the gait concerns that have been identified in this research (chapter 5), it is arguable, would have left individuals struggling to wear their appliances for even 7 hours. If so, doing a full day's work (around 16 hours) would have been incredibly exhausting and probably painful.

A comparable study by Cooper et al (2010: 349-360), considered when veterans abandoned prostheses and why. Their findings included pain (25%), residual limb too short (33.3%), too heavy (16.7%) and too much fuss (16.7%), with them being abandoned after around 6.7 years. What is interesting here is that the amputations these individuals would have undergone would have been far more efficient to those who experienced battle-side amputations at Waterloo as discussed in chapter 2 (section 2.2), similarly, these recent examples would have benefitted from rehabilitation and extensive physiotherapy to regain efficient mobility, again something that was not available 200 years ago. Yet, a large proportion of these people still abandoned their artificial appliances for varying reasons, including the discomfort. Ethnographic data such as this does not exist for those who underwent amputation during the nineteenth century due to traumatic amputation, however, the reactions of these individuals can inform us of how men in similar situations may have responded to their injuries in the past. This is particularly important when we combine the data presented in chapter 5 which details the challenges that the Anglesey and box-leg appliances could create, with the experiences of men who suffered similar outcomes as a result of military conflict. Sargent and Johnson (1996) suggest that ethnographic data has a large part to play in the reconstruction of disease and disability in the past, therefore, paralleling this data with experiences during the nineteenth century, can offer an image of possible experiences for these individuals at the time.

Therefore, what it does possibly identify, is that without the benefit of rehabilitation, efficient amputations (some performed better than others depending on social status – see chapter 2), and completely customised artificial limbs, many amputees during the nineteenth century may have struggled to reintegrate into society after the loss of their limb in battle due to the discomfort the limbs being used caused. Their mental health may have been affected (difficult to identify archaeologically) but evidence of mental health concerns after Vietnam (Clasper and Ramasamy, 2013) acts as an example of the potential experiences of those post-Waterloo. Likewise, a growth in addiction to opiates (Crane, 2011) amongst the labouring classes acts as an indicator of the physical responses to the labour intensive roles these individuals were involved with compared to the wealthy. Similarly, the expense of seeking medical advice from doctors by the wealthier middle and upper-classes compared to self-medicating of the poorer working classes, which all demonstrate the wider class tensions that existed during the time.

Another concern that ties in with this discussion on use of the appliances, is their durability whilst in use. The durability of both limbs under investigation would depend on the wearer's usage; the organic nature of the main material, wood, suggests that over time, it would wear down, become weathered, damaged and therefore weakened. This seems particularly likely when as noted above, hours were long and conditions were gruelling. The reliance on walking for working class citizens meant that people were in crowded, dirty, polluted streets whilst getting to and from work (see chapter 2) and consequently their artificial limbs were subjected to the damp and muddy streets that would inevitably undermine the integrity of the wood, making the wood more vulnerable to splitting also also the wearer at increased risk of slips and falls. It would have been likely therefore that the wearer's would need to be able to mend their own appliances or have access to someone who could mend them, although this would have cost money which is probably why we see discussions around homemade and mended peg-legs in the literature (section 2.6).

Gray, notes that the one hinged variation (Anglesey) was relatively strong and long lasting, however that it probably lasted because its wearer's could not walk for long periods in it (1887: 71). The Anglesey at its height would have been considered complex and thus being able to access someone who could offer repairs swiftly when required would have been vital. However it is possible that one of the reasons the wealthy discuss the longevity of their Anglesey legs may in part be to do with the fact that they were wearing them for less time and under less intense conditions as those utilising the peg-leg, so they just lasted longer. Likewise, these individuals were rich enough to afford more than one leg for different activities, such as the Marquis of Anglesey and so each was being used for less time leading to increased lifespan. Regarding the biomechanical changes identified in this research therefore, if the limbs were uncomfortable and were not worn for as long as peg-legs, it is possible the long-term effects of their Anglesey styles would take a lot longer to appear skeletally than on a working-class individual who relied on a peg-leg to maintain employment and would therefore wear the leg for a lot more prolonged periods of time. This would mean that the wearer of a box-leg would see detrimental effects occur more quickly than someone who perhaps only wore their limb on special occasions and for shorter periods of time, performing less labour-intensive tasks.

7.7 Representation of the History of Disability

Gerber (2012) and Kudlick (2003) both discuss the importance of adding to the poorly represented history of disability, with both arguing that whilst war has long been a focus for archaeologists and historians alike, few have considered some of its 'major consequences'. Economic and political policies as well as military strategies have all been focal points regarding war but as Gerber points out 'Disability and disfigurement are not incidental to war's purposes nor marginal to its effects, but rather, alongside the murder of those killed, the point to begin with…only in making victims can war achieve its political ends.' (2012: 3). Adding '…disability is the dependent rather than the independent variable – it is the concept that helps to analyse and explain a larger phenomenon rather than the thing to be explained.' (2012: 32). What is evident in Gerber's writing and concurred within this research, is that discussing disability inevitably leads to the discussion of war and the discussion of war cannot be fully understood without the appreciation of disability and their interconnectivity. This research has shown that disability exists and has existed as long as mankind has, our perceptions of it are dictated by cultural and societal beliefs of the time and it has affected a lot greater number of people than the history books initially allude to. Even throughout the century under discussion here, there was a change in attitude towards those with a disability, which has been identified within this research as in part due to a combination of the growth in military technology and the improvements in medicine. New weapons brought about new injuries requiring amputation and better medicine saw the increased survival of these individuals who upon reintegration into society, needed artificial appliances to make these transitions easier. As such, an entire new specialised trade was created and therefore the physically disabled were inevitably more 'seen'. The old beliefs about sin being connected with a bodily difference began to change until government legislation was created, in order to protect the rights of the disabled in the workplace.

This research has created a discussion throughout its chapters around disability, how it was represented, how it changed lives and how it was perceived during the nineteenth century, with a focus on the relationship with war. It has been proposed that during the nineteenth century in some nations such as the USA, injury and disability due to military service, were regarded as a badge of honour or a worthy sacrifice for a national cause. Whilst there was some of this belief in Britain, evidenced by the increasing supply of prostheses and pensions throughout the nineteenth century compared to what was provided for civilians who had gained similar injuries but perhaps through their employment, the reintegration into society and the ongoing relationship with the government was both complicated and challenging. Similarly, as Gerber explains, despite governments struggling to find a balance between maintaining civilian morale and being honest about the extent of death and trauma that a particular battle has caused, it is generally accepted that the disabled veteran acted as a '…warrior hero…' and '…a particularly potent symbol for inspiring war efforts' (2012: 5-6). This has been seen and discussed in chapter 2 regarding masculinity, national identity, and the reintegration of wounded veterans. Firstly, only officers who had given their lives for the country were named in commemoration, and publicity such as theatrical re-enactments largely told the stories of these officers, generating a heroic bubble surrounding these few men. As far as wounded or disabled soldiers were concerned, their priority lay with gaining employment upon their return which, as discussed, was limited in availability.

The common theme that ties these together is the relationship with the state (Gerber, 2012: 7), as such the social identity of disabled veterans in the nineteenth century, was contributed to through the unavoidable interaction with the government. It is impossible to say that this is how these individuals themselves felt at the time, but it has become clear that once the military relationship was started, it was difficult to escape. All our identities are to a degree, impacted and shaped by our ever-changing relationship with our governments. However, much like today, the nineteenth century had other influential factors that helped to shape and mould the identities of disabled veterans, such as cultural representations as noted in chapter 2 section 2.2.3, where literary representations of physical loss helped to generate a fear of disability. This is in addition to religious beliefs sparking concerns about morality, sin and demons as mentioned in chapter 2 (Covey, 1998). Interestingly, whether a positive or negative connotation connected to the disability, the perception itself, acts as a way of distinguishing the disabled from the able.

7.8 Summary

This research makes it possible to argue that the artificial devices that were developed for people with disabilities during the period under investigation demonstrate a level of compassion by at least the manufacturers of these appliances, as they manufactured something that aided the everyday life of an invalided individual. Likewise, the functionality of the limbs, tells us that whilst wearers may have been in some discomfort long term, the limbs worked and would have sufficed for men that wanted to return to employment. Establishing the motive behind manufacturers creating artificial legs, i.e care or profit, is challenging, however as this research has noted, the fact many working-class individuals had to create their own as they couldn't afford to buy even basic peg-legs, suggests profit was a major driving force. Comparatively, many artificial limb makers as noted, were amputees themselves, suggesting they found employment helping fellow wounded men whilst also generating a new skill and essentially acting as catalysts behind the growth of a more standardised and specialised industry.

As Dettwyler (1991: 382) proclaims; '…there is a wide gap between survival and being treated nicely…', unfortunately, compassion leaves little evidence in the archaeological record. Yet, as this research has shown, particularly the data produced in chapter 5, the artificial limbs that were produced and available to disabled veterans during the nineteenth century, were successful in providing aid to mobility, therefore it is argued that there was some level of benevolence for the disabled. Similarly, the Anglesey leg, being available to the wealthy does not suggest that these elite members of society were cared for any more than the poorer disabled who could only afford pegs. Like today, there are cheaper and more expensive variations of everything, the intended purpose and function are the same, and as the data shows, increasing cost did not ensure a more efficient limb with the Anglesey. Instead, what was being offered was a way of maintaining an aesthetic of elitism and distinction for the common disabled man.

This data has proven that these artificial appliances would have functioned well enough to work in them. What this also demonstrates is that while most stereotypes of the disabled in history, conclude they fell into disrepute, the development of artificial limbs intended for the wealthy and the pride with which one individual – Marquis of Anglesey – wore his appliance, not all those who found themselves disabled in military combat ended up unable to reintegrate back into society. Likewise, it is also possible to argue that reintegration into society regarding physical employment such as labouring or agricultural roles, would not have been made easier using Anglesey leg appliances. The results of the experiments conducted here, do not demonstrate an improved gait or one that more closely resembles a natural bipedal gait, whilst wearing the articulated Anglesey leg. Therefore, the challenges faced daily by those who had peg-legs were likely to be as challenging had all lower classes worn Anglesey legs. Adapting to life was possibly easier for the wealthy individuals who wore Anglesey legs because their lives before becoming disabled were less physically challenging. Comparatively, concealment was important within these circles and as evidenced by the data in chapter 5, gait changes would have made this challenging, likewise, the working class circles experienced higher levels of disability and therefore were more used to seeing impairments and possible artificial appliances.

Nevertheless, the reintegration back into society for returning wounded veterans of lower social standing, was not only a challenge due to their amputation, in terms of securing work, but being able to physically get to work through the unsanitary, grimy, polluted streets as discussed in chapter 4 section 4.4.1. Firstly, the construction of artificial limbs at this time from organic materials such as wood and leather, meant they were likely to rot and rust through their use in wet, dirty and muddy weather which made them difficult to clean and maintain. Secondly, they were heavy, with the peg having a small surface area at the point of contact with the ground meant that wearing them on soft ground would lead to the likelihood the wearer would get stuck in the mud, making it harder to walk and move with stability. Thirdly, as noted in chapter 6 (6.2.3), people who underwent amputations often found their limbs never fully healed and with the pressures placed on the soft tissues, ulcers and sores could allow for infections to take over the wound. Manoeuvring through a polluted and dirty city would have made it highly possible that people wearing limbs – such as the peg - that did not offer full support and caused skin irritation at the stump, could have been more prone to infections and thus earlier death than those who did not find themselves within the polluted streets of inner cities.

Those wearing Anglesey-style limbs, would not have faced the same challenges, they could be transported in carriages, so manoeuvring in the unstable ground for prolonged periods was avoided or at the very least minimised. This would have meant two things, firstly that the Anglesey legs would possibly have been less prone to wear and tear because in theory they were used for less strenuous activities, in less hazardous conditions. Secondly, it offers another reason as to why some wearers of the peg-legs worn by poorer people were homemade; they were likely to require frequent upkeep and be prone to breakage. The creation of their leg meant that minimal expense was invested in it and they could make them suit their comfort levels. It is possible to propose, however, that without a full understanding of anatomy, the avoidance of pressure points on the stump, or a secure stump fit, in combination with the difficulty and discomfort of walking through the polluted streets, the likelihood of an altered gait observed in these individuals was increased.

The biomechanical data in chapter 5, demonstrates that despite the Anglesey leg being considered the more sophisticated of the two legs, the gait changes it causes are more extreme and detrimental than the changes observed with the box-leg. Firstly, there is a greater level of imbalance evident for the Anglesey leg, with an increase in double support required to maintain stability. Whilst the box-leg also had instability, this was remedied slightly by the more secure feeling straps around the thigh and hips. Secondly, the ground reaction forces are increased throughout the ankle, knee and hips for both artificial appliances, but again this is greater in the Anglesey leg, due to the extra time spent placing weight on the sound limb during the stance phase. As noted the consequences of this are increased stresses and strains on the sound side of the body which ultimately could lead to difficulty walking. Postural changes such as trunk tilt were also much more exaggerated for the Anglesey leg compared to the box-leg. Finally, the biomechanical gait changes such as hip and knee flexion or abduction were all affected by both artificial limbs but most intensely by the Anglesey leg. The importance of these findings lay in the fact that they contradict the written advertisements from the nineteenth century, which suggest the Anglesey design held unrivalled superiority. Whilst its mechanisation and articulation were cutting edge, demonstrating anatomical understanding, the data here suggest that its weight and material usage impinged upon its mechanical efficiency because of the discomfort and lack of sense of security the limb possessed. Also, these findings tell us that whilst the Anglesey leg was aimed at upper-class disabled individuals, their money was being spent on aesthetics rather than functionality, which based on their lifestyles seems to have been efficient enough. Concealing disability was the goal for these individuals and so a leg which looked more realistic and moved more realistically was achieved via the use of the Anglesey. Comparatively, the box-leg and its target audience had to work under gruelling conditions for up to 16 hours a day, functionality was paramount and the results here suggest what they could afford or what they were supplied with, was the best option for them.

This research has produced evidence that can be compared to modern biomechanical data to offer insight into the possible discomforts and efficiency of nineteenth-century artificial limbs. By using experimental archaeology in combination with cutting-edge techniques more familiar with medicine, rehabilitation and sports clinics, evidence suggests that whilst the nineteenth-century peg-leg and Anglesey leg function as artificial legs and there was an anatomical understanding of the body, they do however cause biomechanical changes to the wearer that could prove over time to be harmful. The results of this study firstly show that the loading rate and peak forces of GRF were affected by prostheses, as was the walking speed which decreased. The GRF decreased during the prosthetic gait, which is likely due to the use of crutches, but also due to the increased support placed on the sound limb, which explains why during the gait cycle, although it decreases, it is by much less. The temporal parameters show us that whilst wearing artificial limbs, more support is placed on the sound limb which during gait leads to an increase in double support time. Likewise, the restriction in knee flexion, as well as hip flexion, affects the vertical GRF in the prosthetic limb which again leads to the COM being shifted towards the sound side for stability.

The musculoskeletal pathologies identified in prosthetic gait, bring with them further complications for amputees which may lead to mobility issues and reduced quality of life. It is unsurprising to see a change in gait biomechanics because of prostheses use, which demonstrates the individual placing more confidence in their sound limb. The undesired result of this is extra stress for prolonged periods which can lead to degenerative changes in the sound limb. These are identified as osteoarthritis, osteoporosis, and scoliosis, which result from excessive or insufficient loading of certain bones and joints. The prosthetic fit, alignment and leg-length discrepancy affect both comfort and posture, which again can lead to osteoarthritis and scoliosis if incorrect as well back pain. The benefit of today's practitioners in understanding these potential concerns is that they can act to prevent or limit the chances of these pathologies developing in lower limb traumatic amputees. The understanding here is this knowledge was not available to prosthetic limb makers during the nineteenth century. As discussed in previous chapters, there was anatomical understanding and increased knowledge of pressure points causing discomfort to the wearer toward the mid-latter half of the century. However, a complete understanding of the musculoskeletal effects these aches and pains were causing the individual was not understood and therefore it is highly likely that as with the case studies in this chapter, many prosthetic wearers at this time, would have adapted their gait to produce the most stability and comfort, yet unbeknown to them, they were causing detrimental effects to their bones and joints, which as archaeologists we can identify if an amputee is found archaeologically.

Chapter 8: Conclusions

8.1 Introduction

The aims of the research were to develop an understanding of the skill set involved in manufacturing a box-leg and an Anglesey leg artificial limb, to establish the functionality of the artificial appliances, their impact on gait and to understand perceptions surrounding disability and lived experiences of the disabled during the nineteenth century.

8.2 Conclusions

8.2.1 Reconstruction - Skill Set in Production

The reconstruction has allowed an assessment of the different materials used in the production of the limbs which were not present in historical accounts. One model of each artificial limb was produced of a variety of possible designs for both limbs. The experimental data, therefore, presents a generalised model and results which may be subject to slight variation, and subjectivity cannot be entirely removed from the process.

1. The reconstruction of each of the limbs showed their manufacturing processes to be of varying complexity, requiring a skilled understanding of materials and the necessary tools required to shape the wood, probably learnt through practice rather than instruction manuals. Their construction also required the ability to work with a variety of materials such as wood, leather and metal (Appendices A and B).

2. Reconstruction showed the personal preferences of the manufacturer would have generated variability between limbs of the same design made by different specialists. Variability in design and construction would have also been influenced by material availability and cost (Chapter 3 and 4 and appendices A and B).

3. The Anglesey leg required a higher skill level and knowledge to construct, using more diverse and costly raw materials, and a better understanding of anatomy. It also required the manufacturer to understand the interconnecting skills of other specialists. This made it more costly to buy and available only to those who could afford it. The box-leg was more widely produced and involved a less complex build and so could be made relatively easily using household commodities and by those with relatively little skill. It therefore became more affordable to the government who were providing these for wounded soldiers (chapter 2 section 2.5).

4. The experimental method utilised in this research has demonstrated the importance of reconstruction of material objects, alongside and informed by artefactual, literary and

documentary sources. It also offers a device which can be tested without damaging the original and allows the development of new skills sets in the researcher.

8.2.2 Biomechanics - Functionality and Impact on Gait

The research aims for the biomechanical analysis were simple, firstly, were the limbs functional as artificial appliances to aid mobility, secondly, did these appliances differ in the way they allowed a person to move, thirdly, were any identified gait changes considered detrimental enough to cause the individual possible harm if worn long term?

1. The biomechanical gait analysis demonstrated that both limb designs are functional and both meet the basic requirements for aiding mobility.

2. Both prosthetic legs caused gait changes, such as restricted movement, slower velocity and a change in posture producing a compensatory gait pattern which would be impossible to disguise. However, the box leg offered the greatest level of stability and allowed the wearer better balance.

3. Comparison of gait analysis of modern prosthetics with those obtained here showed that the long term use of both limbs would lead to pain, osteoarthritis and scoliosis, and if left uncorrected, bone necrosis and loss of mobility. The Anglesey leg also triggered an increase in instability and GRF through the sound limb, the extent to which this occurred was less intense, suggesting that the box-leg was less physically damaging to the wearer than those who wore the Anglesey leg.

8.2.3 Cost, Lifestyle, Use and Social Perceptions

1. The analysis has shown the more expensive Anglesey leg was not better in terms of functionality or as an aid to mobility than the box or peg leg. It was however more aesthetically accurate and resembled a leg in its shape and articulation. Neither artificial limb would allow the wearer to conceal their disability, and the effect was more exaggerated with the Anglesey leg, despite manufacturers claims that it would conceal the disability from their peers.

2. It is estimated that these limbs, the peg or box leg and the Anglesey leg, were used by different socio-economic groups and so individuals who wore peg-leg variations such as the box-leg, were likely to have done so for a much longer time period whilst it is probable that the Anglesey leg was worn for shorter periods. Whilst the Anglesey leg has the potential for more intense gait variations and thus detrimental consequences to health, the effect on an individuals

health cannot be predicted as its duration or frequency of use cannot be determined, however it may have served to differentiate wealthy amputees from working class ones.

3. However, it is likely the consequences of ill health would have been more severe in peg- or box-leg users and affected their ability to work and support themselves. The effect on wearers of the Anglesey leg may have been either related to perception of them as heroes (the disability enhanced this) or their physical masculinity (noticeable disability reduced this).

4. Reconstruction and testing allowed a broad understanding of not only the movements but feelings individuals wearing these appliances may have experienced.

5. Findings from the research suggest that contemporary literary documentation suggesting the Anglesey leg was superior to the peg leg is not supported in this thesis and the opposite is true for balance, gait and comfort.

8.3 Further Research

Several future studies are indicated by the results of this investigation, for instance a broader range of age, gender and anthropometric considerations as well as a more long-term study with individuals who had undergone amputation. For a wider dataset, more subjects would need to be involved.

Prostheses have been a popular mechanism for material and metaphorical interest in scholarly research over the recent decade. Analysing specifically military artificial limbs is only one route through the vast plethora of prosthetics and orthotics that could be of interest to the archaeological record. Likewise, the concentration here has been the nineteenth century, this could be extended further back to earlier examples, however, many early lower limbs follow the same design as a peg-leg and as such it may also be interesting to delve into the world of upper limbs and analyse the movements and functionality of artificial arms.

Research into cross-cultural relationships with disability may also be of interest. What do the histories of Chinese prostheses look like for instance? How were artificial limbs responded to in the Viking era, and what sort of prostheses were available at this time. We already have some insight into artificial limbs, whether functional or not, during the ancient Egyptian era, but the discovery of the Capua leg may provide further insight and act as a teaching mechanism into the role and perceptions of disability during the Roman era for instance. There are many drawings by Pare depicting metal prostheses used by soldiers wearing armour, the functionality of these whilst being worn on horseback and holding swords for instance could provide valuable insight into the usability and likelihood that these military appliances would allow a soldier to do his job on the battlefield. Not all this research has to involve the reconstruction of these artificial parts, but as this research has offered up a new methodology of how to further explore these artefacts, the addition of and analysis of their functionality allows for a more efficient contextualisation of them in their space and time.

It would be fascinating to undergo research into the treatment of disabled individuals who were also victims of the slave trade, as this is under-researched. It has the ability to teach us about an important part of history of which written sources by individuals who lived it, are scarce and so taking an artefact based narrative would inform our understanding of disability within the slave trade. Whether congenital disability, accidental or punishment based disability, the care these individuals received would enhance our understanding of slave ownership, their value or disposability by their owners. Slave consent for treatment was non existent, instead medical decisions were up to slave owners (with no medical knowledge), slave medical experimentation has been found by Londa Schiebinger (2017) to have been rife within the colonies during the eighteenth centuries, particularly in relation to smallpox and syphilis. Furthering this research into the treatment of the disabled by their owners could be an important research path which the research within this thesis could contribute to.

The collection and recording of this information have been the priority here, however there is information which has been unachievable to ascertain given the time limits of this research. The artificial limbs' deterioration and understanding of the lifespan of the limbs. For instance, one example suggests that a First World War veteran was fitted with a peg-leg for an intended period of two weeks, however he ended up wearing the leg for forty years and continued his job as a thatcher whilst wearing the peg. Throughout the lifespan of his leg, it required extensive home repairs which included the use of cement and glue, making the leg very heavy. Interestingly, when the wearer eventually accepted a new articulated leg after forty years, he requested it be heavily weighted because this is what he had grown used to (Science Museum, 2020). Whilst it is possible therefore to reconstruct and map this process as well as its initial use and effect on gait, what is not possible and what would be incredibly informative to the investigative process, is the long-term analysis of the manner in which the limb reacts to weather, daily use because from this we could understand exactly how much of a commitment wearing this sort of limb was. We could answer more accurately, how often an individual may have needed to repair or replace their limbs. Likewise, we could also see how used to and comfortable with these limbs people could get and with practice, whether people's gait readjusted itself to a more normal bipedal gait. It was never the goal of this research to record the life cycle of the artificial limbs, nevertheless, it would make for an interesting further study to add to the current findings.

From a biomechanical perspective, assessing orthotic as well as prosthetic appliances, including those for upper limbs, from a range of historical periods and cultures would generate a comparative dataset from which a rich understanding of disability treatment, knowledge and perspectives could be ascertained. As Southwell-Wright (2013) has previously argued and with which this thesis has concurred, disability studies research has primarily focussed on the modern marginalisation and discrimination that disabled people face in modern societies. However the historical importance of understanding the various ways in which societies have understood, perceived and treated those with impairments is key to understanding how, why and in which ways our perceptions have changed or manifested themselves contemporarily. Therefore, future research must utilise ways of understanding what life was like to be disabled in the past, in order to truly appreciate how lived experiences have, if at all, improved and in what ways it can continue to improve.

Appendices

Appendix A: Peg-Leg Reconstruction

(Fig. 9.1, Box-leg depiction in Bigg, 1885: 101)

Introduction

This experimental reconstruction began by gathering data about nineteenth-century peg-legs. Their various typologies were analysed, considering their materials and form from descriptions, photographs and archaeological artefacts studied by the author after researching surviving appliances at the Museum of London. The appropriate measurements based on Bigg 1885 recommendations (discussed in chapter 3) were taken and utilised to inform the reconstructive process here. From this information, it was decided the best variation to reconstruct would be a peg-leg of the 'Box-leg' style (fig. 9.1). It is important when attempting to reconstruct an artefact based on historical and archaeological data, that the production processes are identified and ordered into a sequence relative to each other (Cooper, 2013). Fortunately for this research, there is literature depicting phases of production processes, but unfortunately, they are undescriptive and limited. It appears that the processes were often personal to the individual maker and that there were no set rules to follow. Nevertheless, the main stages of the production of a peg-leg are fairly self-explanatory and there is also information that tells us the materials used and even some tools used (see Bigg, 1885 and Lazenby, 1993).

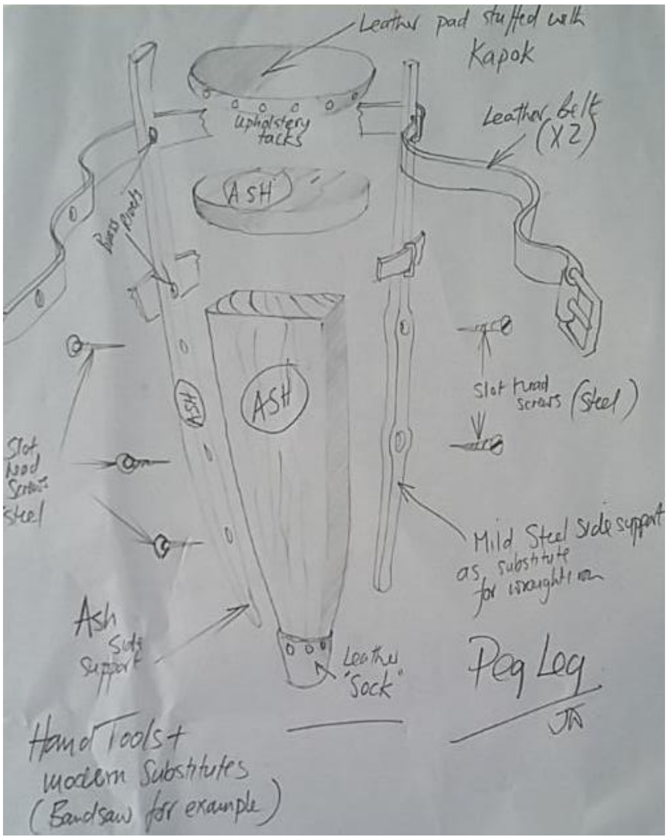
There are stages in the manufacturing process which might be difficult to place because they could have been added at any stage, for example, the leather support straps form an area of focus during this phase of the study. By leaving decisions such as this down to the experimenter, specific observations could suggest the potential order of production and subsequent conclusions be drawn. The decision to add the straps before an amputee had tried the leg on may have affected the fit and comfort for the wearer, however to add straps after, suggests a more custom-made product which contradicts the literature when it states these were not customised appliances.

The leather straps must fit around the waist and thigh of the wearer and be secure enough to support them during their gait cycles. The sequence used involved the construction of the wooden sections, the attachment of the three wooden components and then fitting of the leather padding and straps. The final element to be added was the waist and thigh straps which were left adjustable, so should a stump undergo changes in size due to swelling or infection, the straps would be easily tightened or loosened accordingly (see Bigg, 1885: 108).

The last process involved in the manufacturing of the artificial limb was to polish the wooden sections with wax. Those who worked with wood, would have known the benefits of this process such as, creating an aesthetic finish and a sealed coating that would resist bacteria and moisture. Therefore the woodworking specialist (James Waller) here employed the same process to complete the reconstruction. However, in hindsight, by waxing the finished product, there were inevitable sections which were missed such as in the joins between the different wooden sections. These would possibly be more susceptible to rot and bacteria, compromising the longevity of the product. Nevertheless, the target audience for these legs were lower classes and veterans and as Bigg (1885: 103) notes, simplicity was essential, as was ‘economy, strength, and durability’ - production was completed as cheaply as possible.

What follows, is an overview of the methodological processes undertaken during this reconstruction. The section has been divided into three parts – wood, metal and leather – the main components of the peg-leg being constructed, these subsections demonstrate the material processes and decisions involved in production.

Materials and Methods



(Fig. 9.2 initial sketch and proportions by woodworking specialist based on the design and measurements of the original box-leg, author's own image)

The analysis of documentation made it apparent the wood used for construction of peg-legs was a fine-grained hardwood such as hardwood like oak and ash (Gray, 1858). However, the simple nature of the peg-leg design saw it created from a variety of wooden materials which had previously been used as chair or table legs for instance. Despite its simple structure, there are at least three separate sections of wood that have to be placed together to create the main structure; as such, it is apparent that each section of wood has to be shaped first before assembling together.

The handling of examples and corresponding information also suggests the use of oak, ash and lime with an article written by Lazenby (1993: 22) about an archaeologically discovered peg-leg dating to the late nineteenth century also confirming this. These woods were also widely available and affordable during this time. Selecting woods here involved the collation of small samples of different wood species to see the ease of which they were carved by hand, their aesthetics and their potential durability (fig.9.3). Pieces of oak, lime and ash were carved into smaller fragments using a hand chisel and their grains compared to archaeological material, descriptions about their appearance and records of desired functional attributes such as water resistance and hardness. The wood selected after the test carving was ash because not only had it been referenced in original descriptions but it also matched the desired attributes noted for original peg-legs. Amongst others, the main attributes included durability, strength and accessibility, all characteristics seen in ash wood. Oak was not chosen due to its current availability, and high tannic acid levels which when in contact with metal pins to secure the leather straps or thigh supports, it causes fast rates of corrosion and rust (Knight, 2016), and it was more expensive than ash during the nineteenth century (Clark, 2003) so possibly not an appropriate choice for a financially economic, peg-leg variation. Likewise, lime although easily carved, is not as durable as ash and is best kept indoors.

(Fig. 9.3 Lime (L) and Ash (R) test pieces author's own)

Before any carving and construction could begin, it was important to establish how much wood was required. This was done by taking measurements from the person whom the leg was being constructed to fit. Although no records which include this in their manufacturing descriptions were found, it was required for this reconstruction to ensure it was a secure and safe fit for the wearer. The left limb length is 96cm, the right thigh circumference (where the leather strap attachment will sit) is 52cm and the waist circumference (for the leather attachment) is 81.5cm. As a consequence of these measurements, it was established that the amount of wood required for reconstruction was about $0.007125m^3$. The wood was sourced from a local boat yard and was partially prepared as seen below in fig. 9.4.

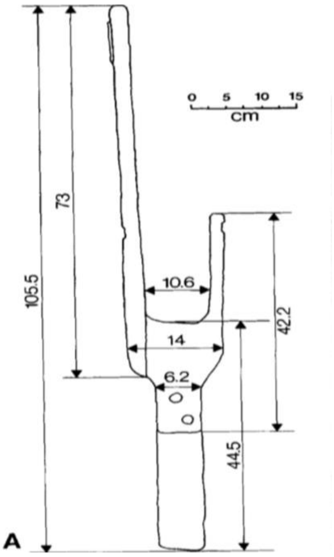
(Fig. 9.4, 2x4 inch 2m boat yard wood being sourced, author's own image)

Carving the Wooden Components

Chapter 3 discusses some of the main types of artificial legs used by soldier amputees, including the flaws in their production and effects on those wearing ill-fitting artificial limbs. Upon initial inspection of the appliances in museum settings and the separate components prior to reconstruction, a rigidity and hardness of the materials suggests potential discomfort for the wearer of most peg-legs. The main structure of the 'box' peg-leg consists of three individual wooden components (fig.9.4 and 9.5 below), these are the lateral stabiliser, a base to hold the stump and the peg.

(Fig. 9.5 Depiction of the three main wooden components during the reconstruction. It shows a lateral stabiliser attached with nails to the peg and stump support sitting on top of the peg, author's image)

The wood was sourced in a large solid block (fig. 9.4) and based on Lazenby's (1993: 22) description of the proportions of each three sections (fig. 9.5), the wood was measured and divided into three parts. A ruler and pencil were used to mark out the areas which would be cut to size, with the offcuts highlighted by the hashed pencil marks (figs. 9.7, 9.8 and 9.9).



(Fig. 9.6 Schematic anterior view (A) of peg-leg depicting heights and widths of the wooden components in cm, Lazenby, 1993)

(Fig. 9.7 beginning of the measuring process)

(Fig. 9.8 Rough outline of peg shape with hash lines marking what will be offcuts)

(Fig. 9.9 Rough outline of peg shape with hash lines marking what will be offcuts)

What is apparent from the initial measurements, is the amount of offcuts and waste that would be generated from this piece of wood. The stump is 45.2cm tall, 15cm wide at the bottom, and its thickness is 5 cm. The stabiliser is 87cm tall and 2cm wide by 2cm thick. Finally, the stump support block is 2 cm tall, 15 cm by 8cm wide. In total this makes 0.003978m^3 which means the off cuts and potential waste is approximately 0.003147m^3 almost half the original amount of wood sourced. As there are few records which explain the production processes of a peg-leg, especially ones which suggest a use for the off cuts of wood, it may be practical to propose this wood was used for other purposes. In order to minimise waste, the offcuts may also have been used to make a number of supports for other peg-legs. Likewise, as explained in chapter 2, artificial limb makers were often originally manufacturers of other products, such as shoes, clocks and furniture. The lack of manufacturing restrictions placed on ‘box-leg’ and other peg-leg variations by the government, meant that anyone could potentially produce them regardless of medical, anatomical or scientific expertise. As such the off cuts may have been utilised in their other production processes such as clock or shoe making, or perhaps the wood used in peg-leg production was the off cuts from their primary trade.

Discussions with the woodworking expert made it clear that to source a piece of wood thick enough to produce the Box-leg today, would prove very expensive as this type of thickness required is an unusual size. He combatted this by utilising the offcuts to build up the thickness in areas which required more strength to withstand weight. He secured this with a hide glue and then carved it into a rough peg shape, he then sanded the harsh edges down in order to create a smooth surface and ensure the joins were almost invisible. Evidence of this practice is observed upon close inspection of the original artificial legs, where fine lines display areas where wood has been secured with hide glue (fig. 9.10) (*History of the Prosthetic Limb*, 2019). It is worth noting that the offcuts initially present in the reconstruction and the decision to use them to add thickness and strength to the peg, may have been a decision made by initial manufacturers as well to minimise waste and maximise profits. However, a 10% price decrease in fire and construction wood during this period meant that prices dropped from 17s 68d cm^3 to 8s 50d cm^3 in 1870 (Clark, 2003), this was due to the huge increase in farmland being used within England and Wales for the growth of timber, probably as a result of growing need due to new industrial processes since 1750. Therefore, the affordability of wood to specialised craftsmen was increasing and so minimising waste may not have been so important.

(Fig. 9.10 image showing a late nineteenth-century version based on the Anglesey leg with evidence of splicing wood together to build the appropriate leg shape. A line up the back of the calf and a darker wood used for the socket in places. The image also displays evidence of varnishing that has over time begun to wear, image courtesy of Richmond Twickenham and Roehampton Healthcare NHS Trust, Science Museum Group)

The final shape is seen in fig.9.29 and shows a similarity between typical nineteenth-century designs. The reason the shape follows the common trajectory of designs observed in history for peg-legs is likely to be a consequence of the producer being exposed to these shapes in both the natural world and in historical images. As Byers (1991: 1) concurs in his discussion on the duality of material culture, humans almost always rely on the 'tangible medium of physical things in order to satisfy their intentions in wants and actions'. An interesting observation by Gray (1857) notes that the design of a peg-leg has taken its appearance from nature, concurrently, when initially discussing with James about the style of leg produced, photographs were analysed. As such, despite being allowed to shape the wood as preferred, it is impossible that the final shape was not influenced by initial expectations and observations.

(Fig.9.11, hand plane shaving the excess wood away, author's own)

(Fig. 9.12 rudimentary shape of the peg component before edges have been smoothed, author's own)

The next section that was measured and marked out for cutting was the lateral stabiliser, this needed to be cut to size in the early phases of the production because the process requires it to be steam bent, to generate a natural curve to accommodate the hip shape of the wearer. After initial measurements which corresponded to the length of the wearer's residual leg (fig.9.13), the stabiliser was carved into shape using various chisels and a hand plane (fig. 9.14, 9.15, 9.16). The number and range of tools available to James was as a result of his years of experience, not all were used during the reconstruction but the variety does suggest a level of expertise and high understanding of material properties.

(Fig.9.13 initial measurements of the lateral stabiliser, author's own)

(Fig.9.14 variety of chisels available for use during the process and also some hammers used to cut larger chunks away, author's image)

(Fig.9.15 trimming the tip of the lateral stabiliser with a chisel so it smoothly attaches to the leg component, author's own)

(Fig.9.16 hand plane in use to smooth the stabiliser down to size, note it is used towards the body not away and the maker is sat down during this phase, author's own)

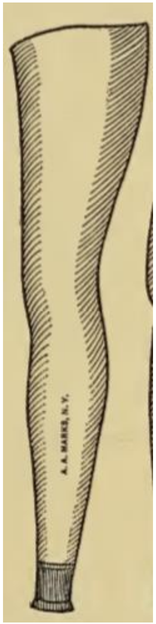
The final wooden element to be produced was the stump support (fig.9.17). This is a solid block which was used by the amputee to place their leg for stability, it is the point of contact between the prosthetic and stump and therefore requires the most attention to ensure pressure and forces on the stump are minimised to reduce pain. The support was chiselled and carved to the template drawn onto the block originally, the edges were then smoothed to remove any splinters or sharp edges which may eventually cause discomfort to the wearer or damage to the leather which will be attached.

(Fig.9.17 Curved edges of stump support attached to peg component, author's own)

It is apparent in some images and descriptions (Bigg, 1885:67) that the wearer's would most likely have been trans-tibial, '…the bearing of course, is gained on the knee as it kneels, that is, on the lower end of the femur, the patella, and the remnant of the tibia…'. However, the box-leg was not exclusively for trans-tibial amputees as Bigg (1885: 67) explains '…The Box-leg is used after amputations through the tibia, as well as sometimes for those through the knee-joint, although there can be no doubt that for the latter a leather bucket leg is the best appliance....'. A. A Marks (1905: 93) also describes the use of peg-legs for trans-femoral amputees 'peg-legs are occasionally used on thigh stumps. They are practically artificial legs without feet. As already stated we do not advocate the use of peg-legs, as they are of limited efficiency. The foot is a very important part of an artificial leg.'.

In these images and descriptions, there is occasionally a slightly different socket shape (fig.9.18 and 9.19) or a cushioned element placed under the knee on top of the wooden support component. 'Open socket peg-legs had cloth rags to provide cushioning for the distal end of the stump, allowing a free range of motion.' (Thomas and Hadden, 1945). However, these were not added by the manufacturer, they required extra materials and therefore expenditure so the amputees were told to 'rest the knee on a very full pad, otherwise it will soon become tender and incapable of transmitting the weight of the body to the artificial appliance.' (Bigg, 1885:67). It is not explicitly divulged in the literature what rags were used to create a cushioned socket, but it is assumed given that previous artificial limbs dating to the sixteenth and seventeenth centuries often used rags and cloth to protect the stump, similar materials were used by individuals during the nineteenth centuries. Gray (1857: 78) claims that the endeavour of artificial limb makers was 'to make the stump fit the socket, not the socket fit the stump' and as a consequence after a few days of use the patient 'begins to complain of pain…being advised to persevere…eventually the sufferer is worn out with pain, and completely dispirited, and the artificial leg is thrown aside.'. However, as the padding was not supplied originally by the limb maker and its use being at the discretion of the wearer, it has not been included in the reconstruction at this point. Cloth and rags will be available during the gait analysis process as an optional or comparative measure for the volunteer.

(Fig.9.18 An illustration taken from Charles Dickens 'David Copperfield' displaying a variation of peg-leg socket)



(Fig. 9.19 A. A. Marks 1905: 90 depiction of a peg-leg 'an artificial leg without feet')

The final process involved for the three wooden elements was their attachment together (fig.9.20). This required the use of metal nail fasteners, which will be discussed in the metal section below.

(Fig. 9.20 The 3 wooden components, smoothed and secured together, author's own)

Metal

The specific material used for the nails is not mentioned in production descriptions, however as artificial limb makers were also often cobblers or clock makers it seems logical to assume that the types of nails used were what they already had for these primary purposes. Consequently, it is acceptable to suggest the types of nails used may be copper-alloy, wrought iron cut or wire nails. The type of nail tacks used to secure the three wooden components together was a copper-alloy nail, this was because copper-alloy is commonly used where corrosion may be an issue, such as in furniture where contact with human skin salts will cause corrosion on steel nails. Similarly, it has a golden aesthetic and is good for applications where low friction is required such as locks, gears, bearings and where it is important sparks are not struck (Ashby, 2002).

A total of four copper-alloy nails (brass - copper and zinc) were used to secure the lateral stabiliser to the peg (fig.9.21), and two were used to secure the stump support to the peg (which will eventually be covered with leather). The holes for the nails to fit through were roughly made using a hole saw and then hammering the nails into the wood so they created a tight, secure fit.

(Fig.9.21 The 4 copper-alloy nails securing the lateral stabiliser to the peg component author's own)

Whilst it is important for authenticity for material and processes to remain as true to the originals as possible, it is important to highlight where this was not the case. As noted in chapter 4 wrought iron was used for the medial inner thigh support opposite to the lateral stabiliser, instead however mild steel was used here. It is difficult and expensive to acquire wrought iron today especially in the small quantities necessary for this experiment. Mild steel was used in this reconstruction, it contains slightly more carbon than wrought iron (0.33%) yet this changes its properties significantly, it is harder and hardens quicker when hammering, making it more difficult to forge-weld. The metal was sourced from a blacksmith who advised it to be roughly hammered on a knife maker's anvil to the shape of the leg, before securing it onto the wooden peg with five nails. Once the thigh support was roughly shaped using a hammer and anvil to around a centimetre thick and 58 cm in length, holes were punched using a cross cut chisel in order to make small slots for the nails to fit into in order to secure the thigh support to the peg (fig.9.22).

(Fig.9.22 The mild steel metal thigh support attached to the peg component, author's own)

Leather

It was at this stage that the leather components could be cut to size and secured to the leg. In accordance with the background information by Warne (2008: 3) (chapter 4 section 4.4.4), the leather that was sourced and secured to the artificial limb in this reconstruction was a reused belt leather. This decision also offered the opportunity to make the straps adjustable to fit the stump and waist of the wearer, not only a positive for this experiment which means a range of people can wear it but it also would have proven beneficial for original wearer's due to the changing stump sizes after amputation. Gray (1857) explains that for about two years after amputation, the stump goes through a series of shape changes as a result of swelling, possible infection, irritation from ill fitting sockets and prostheses. Therefore, whilst the literature does not confirm this, it may be suggested that a useful attribute of utilising adjustable belts as straps meant that the wearer could self-manage the fit of their artificial limb.

There are two leather straps attached to the lateral stabiliser, 30 cm apart. The lower thigh strap is 9cm wide, it sits 10 cm above the stump support and was attached to the lateral stabiliser utilising a slit in the leather that already existed. It slipped over the top of the stabiliser where after securing it to the wood with two copper alloy tacks, it was finally attached with another two copper-alloy nails to the thigh support.

(Fig. 9.23 Leather thigh strap in position and secured to the lateral stabiliser with 2 copper-alloy tacks with larger image depicting the positioning on the overall leg, below in figure 9.24, author's own)

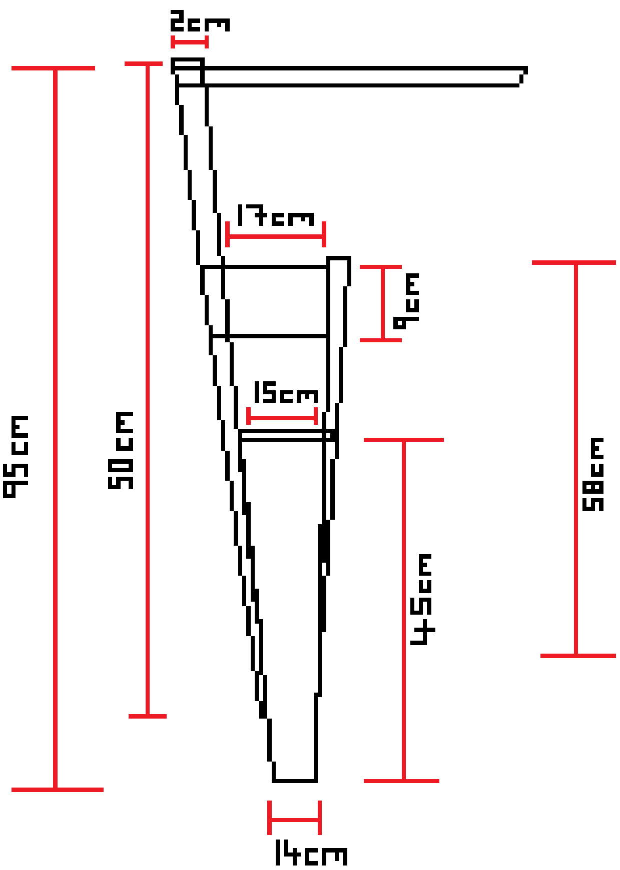
(Fig. 9.24 Leather waist support attached to the top of lateral stabiliser using 2 copper-alloy tacks seen in Fig. 9.25, author's own)

The next phase involved attaching the leather waist support to the lateral stabiliser, again that was secured in position using two copper-alloy tacks (fig. 9.24). The last leather that needed to be attached was the leather covering the stump support, this involved cutting to size the circular piece of leather required and then stretching over the wooden support block. It was secured in place using some hide glue and ten copper-alloy tacks, then the excess leather was trimmed away. The completed leg was then polished and varnished to bring out the wood's natural grain, making it waterproof (fig. 9.25). Fig. 9.26 shows the completed leg and fig. 9.29 shows the respective measurements of each section, fig.9.27 shows how the limb looks whilst being worn compared to fig.9.28 which shows an original nineteenth-century amputee wearing a Box-leg. fig.9.27 shows how the straps fit the torso and upper thigh.

(Fig.9.25 Completed peg-leg after varnishing and the attachment of the leather over the stump support, author's own)

(Fig. 9.26 Depiction of how the leather attachments secure to the thigh and torso, author's own)

(Fig. 9.27 Completed reconstruction worn by woodworker, author's own) (Fig. 9.28 A Photograph by James Gillingham depicting a Box-leg style peg-leg c. 1888)



(Fig. 9.29 Measurements of the reconstruction in cm, author's illustration)

Outcomes and Conclusions

During the production of the peg-leg, the manufacturing process was recorded using photographs and notetaking. What became clear during the process is that the wood working expert's familiarity with the material and tools created a fluidity to the process with decisions appearing to be made instinctively rather than calculatedly. The engagement with the material, the use of the same materials available during the nineteenth century have created a more reliable, comparative reproduction. Likewise, the effort, timescale and skill level involved in production is more comparable and due to employing the assistance of a woodworking specialist historical and scientific authenticity to the reconstructions has been made. With the overall time frame for production taking around 12 hours in total, with practice and more familiarity with the process, this time would undoubtedly decrease.

The woodworking expert's familiarity with the investigative and recording process, meant that they were aware that spatial movements, material, tool and technological decisions made during the manufacturing process were to be kept as truthful to the original production method as possible. For instance, he explained that it was unlikely that he would have all of the necessary woodworking hand tools required for the job and would therefore make extra tools for the specific job he needed it for (fig. 9.30). He made some chisels required to cut the metal and also a chisel which was capable of removing larger bits of wood to hollow sections such as the socket area that would be needed for the Anglesey leg (Appendix B). As documentation such as Kirkham et al (1987) has stated, it was not 'uncommon' during the nineteenth century for manufacturers to 'create their own tools' specific for a particular job as required. This anticipation of mechanical need demonstrates a material understanding and a familiarity with potential manufacturing issues but also the knowledge of how to overcome these issues.

(Fig.9.30 The handmade tools created during production)

The processes necessary to reconstruct a peg-leg style artificial limb (identified from Bigg 1887 documentation of a 'Box-leg', fig.9.1) were demonstrated and documented. This included identifying the potential order of manufacture process, the materials and methods utilised. By applying data collected from contemporary documentation and the various elements necessary for the production of a peg-leg, an identifiable artefact was produced. From here, the reconstruction will be subject to further analysis in order to determine the accuracy and effectiveness of its shape, size and material etc. and also through digital analysis in a gait lab, its efficiency in comparison to modern prosthetics and the Anglesey Leg (whose reconstruction will be the subject of Appendix B). This will allow a greater comparison and reflection on original peg-legs.

Appendix B: Anglesey-Leg Reconstruction

(Anglesey Leg image courtesy of Plass Newydd, National Trust)

Whilst chapter 4 section 4.4 ascertained certain manufacturing processes involved in creating an Anglesey leg and also justified the use of certain material choices, there are still gaps in the overall understanding of the chaine operatoire of production. James Potts' artificial leg patent lacks detail and therefore it misses vital information for the reader to establish a full understanding of how the limb is made. This appendix is designed to highlight these missing stages, suggest a potential order to the process where there is limited information and elucidate processes where written literature is restricted. Original characteristics, materials, tools and methods have been as closely maintained as possible. However, in some instances modern alternatives have been substituted for a variety of reasons, disclosed in more depth throughout. Some original processes have been omitted entirely from this reconstruction in order to maintain good ethical practice, upholding health and safety regulations. For instance, Gray (1857) describes the very first process of manufacture to involve the use of a wax moulding (see chapter 4) to be taken of the ‘to-be’ wearer's stump, explaining it would highlight the individual’s skin surface variations which meant the socket of the artificial limb could then be tailored to these distinctions.

Today, however, limb fabrication is a lengthy process which involves numerous stages of rechecking against the wearer to ensure the most comfort. For instance, as Tidewater

Prosthetic Centre describes these impressions are identified through measurements and a plaster-cast model, which once set is shaved to be millimetre perfect to the residual stump measurements. From this, plastic is heated and a vacuum formed over the cast to create a diagnostic socket which has moulded around the intricacies of the plaster cast limb, the socket is then tried on by the wearer to identify any discomfort and then adjusted accordingly by heated thermoplastic. Reference lines are made for foot placement and socket alignment, with the height being checked for accuracy, once all adjustments are made, the socket is then glued to the foot componentry and a vacuum hole drilled to allow suction so the limb will stay in position on the stump (Schall and Slemker, 2007). For this reconstruction, the original process of personalisation can only be presumed to involve the carving of the internal wooden socket because as discussed in chapter 4, technologies such as the pointing machine were not widely accepted amongst manufacturers and certainly not introduced into widespread manufacturing processes until the late nineteenth century. Therefore, the level of customisation required to ensure the limb produced for an amputee to wear, would not be achievable without the specialist equipment.

Secondly, the number of times each patient went for their stump to be checked against the socket for discomfort is also unknown and can only be guessed, there is no specific information recorded which provides this information and probably was unique to each individual. As, literature suggests that the Anglesey was worn by the wealthy and many of the sources which write about the efficiency of the limb itself, it may be suggested that clients went for fittings are written by manufactures attempting to sell their products and are therefore almost always positive (See Gray 1857, Biggs 1863 and Marks 1907). In order to identify the authenticity of the literature, as well as filling in the gaps in construction processes, this reconstruction is vital. It will highlight any problems with suggested manufacturing processes and perhaps suggest alternative approaches, it will also allow us to conclude the feasibility of a wearer walking long distances or dancing easily as some literature has suggested, based on weight and ease of movement.

(Fig. 10.1 Drawing from Henry Bigg 1885: 13 showing the points at which the weight of the body should rest)

However, to maintain health and safety regulations, this limb will not be produced to be worn by an amputee as originally intended, instead, it will be created in keeping with the knee-bearing stump appliances identified by Marks (1907:74) and be worn by a non-amputee. The design does not differ in authenticity from Potts' design, it is an example of the type of variations that could occur under the umbrella of the Anglesey leg definition. This slight variation will only be noticeable from the rear of the leg and it will maintain the manner in which the leg secures to the wearer. In order to ensure this is approached ethically, the wood specialist will draw on the manufacturing processes utilised by COPE in Vientiane, Laos. COPE provides artificial limbs to victims of landmines and motor accidents amongst other things, it is a manufacturing and life-long rehabilitation centre. The visitor centre which helps raise money for their appliances, has provided its visitors with a unique experience of trying on adapted prosthetic legs for able-bodied people in order for them to understand how challenging simple tasks such as walking up the stairs can be for amputees. Therefore, the wood specialist will make note of how the rear of the thigh socket allows for knee bearing non-amputee to wear it securely and authentically.

The more complex nature of the Anglesey leg means that unlike the construction of the peg-leg which involved three main sections of wood, this instead will have four wooden components along with moveable joints, springs and leather straps. And whilst it is clear that each wooden section has to be shaped before assembling, the order in which to attach the straps will be ascertained through the experiment. By using images, measurement and proportions of the original leg ascertained by the author from the Household Cavalry Museum as a guide, the specialist will utilise the method and order of construction he feels is most efficient and appropriate for this reconstruction. By leaving certain decisions such as when to attach the pieces together or when to attach the leather to the experimenter, conclusions about potential order of production will be possible, as will drawing conclusions surrounding how much the materials used, drive the processes and decisions made during production.

In an attempt to maintain as much loyalty to original processes, and having left certain decisions to the woodworking specialist, the sequence utilised involved the construction of the wooden foot, followed by the main calf and thigh sections of the limb, the, varnishing of the wood, followed by the attachment of the pieces together with the springs secured in place and then finished with a linen padded lining on the thigh socket and then the straps were the final item to be added. It felt most logical to leave the aesthetics such as the straps to the end and it also meant that they could be positioned against the wearer which felt most comfortable to them. This decision by the specialist reinforces the idea that a more personalised approach felt more natural with a leg that had overall been a lot more complex to construct. Similarly, if we also consider that amputated stumps take a long time to heal and whilst healing they change shape, leaving the thigh strap in particular to the very end, gave the wearer's stump the maximum time to settle into its potential long term shape. As such, like the peg-leg, this strap was left adjustable to allow for changing shape and also personal comfort and security (Bigg, 1885: 108).

What follows, is an overview of the methodological processes undertaken during this reconstruction. The section has been divided into four parts – wood, metal, shearling and leather – the main material components of the Anglesey leg; these subsections demonstrate the material processes and decisions involved in production.

Materials and Methods

Wood

The initial stages of production involved choosing which materials to use and also sourcing the production constituents. As with the peg-leg, the main material used as the fabric of limb is wood, with records suggesting the use of two different woods, visible in fig. 10.2. Frederick Gray (1857: 67) notes the use of willow and mahogany in his description of the manufacturing process, willow was widely available throughout England, it would have been easily accessed. Mahogany, however, would have by the mid-nineteenth century become largely replaced by substitutes due to its over-cultivation and therefore for the sake of the reconstruction. Sapele was used during the nineteenth century as a substitution for Jamaican mahogany, due to its similar attributes and aesthetics, its accessibility today means it is an appropriate material to be sourced and used to manufacture the foot, knee joint and thigh socket, with willow to be used for the rest of the structure.

As with the peg-leg, the first major task is to establish how much wood will be required for production. Measurements that are required from the wearer are height, thigh width, residual leg length and waist taken (Gray, 1857). This measurement ensures a safe and secure fit for the wearer in order to help maintain their natural gait as described by Gray in his example of creating a limb for an Austrian general (Gray 1857: 124). Whilst the peg-leg only required three main measurements, limb length, thigh circumference and waist circumference, the Anglesey requires more precision due to the joints at the knee and ankle, to ensure the least likelihood of a limp being noticeable during gait cycle. The left thigh length from the hip bone to the top of the patella is 40cm, the length of the whole left limb is 87cm the right thigh circumference is 50cm (where the socket will fit), the length of the left foot is 25cm, its width is 12 cm at its widest part near the toes and the height from the heel to the ankle bone is 10cm. We do not need the waist circumference as these legs were not often attached in such ways instead they were secured to the wearer mainly via the thigh straps and occasionally popper-like clips which were attached to undergarments or as braces over the shoulder. In order to establish the amount of wood that would be required for the reconstruction, these measurements must be used to work out the volume of a cylinder (rough shape of a leg). Firstly, the surface area; $2\pi r$ gives us the circumference but we need the radius to ascertain the surface area so to begin with the measurements were used for this: $50/2 = 25/\pi = 7.96$. From this it is possible to establish the surface area using πr^2: π x $(7.96$ x $7.96) = 63.89$ x $\pi = 199\text{cm}^2$, then in order to work out the volume of the cylinder the surface area must be multiplied by the legs height measurement; 199 x 87 = 17,317cm^3 or 0.0173m^3. Finally, the volume of the amount of wood required for the foot element can be worked out by establishing the volume of a cuboid - Length x Width x Height – 25cm x 12cm x 10cm= 3000cm^3 or 0.003m^3. Overall the volume of wood that is required to produce the Anglesey leg for a 5ft 5in tall person weighing 67 kg is approximately (coinciding with demographic data, see chapter 2 and 4), 0.0176m^3 and therefore the amount of wood sourced will be 0.0200m^3 (fig.10.2) to allow for off cuts for the shaping of the limb. The wood will be sourced from two separate locations, the willow from the Queen

Victoria estate of the Isle of Wight and the Sapele (being non-native) will come from a wood yard also on the island (fig.10.3). The Isle of Wight is the base for the woodworking specialist.

(Fig.10.2 willow and Sapele wood in the workshop, partially prepared after sourcing but not worked by specialist)

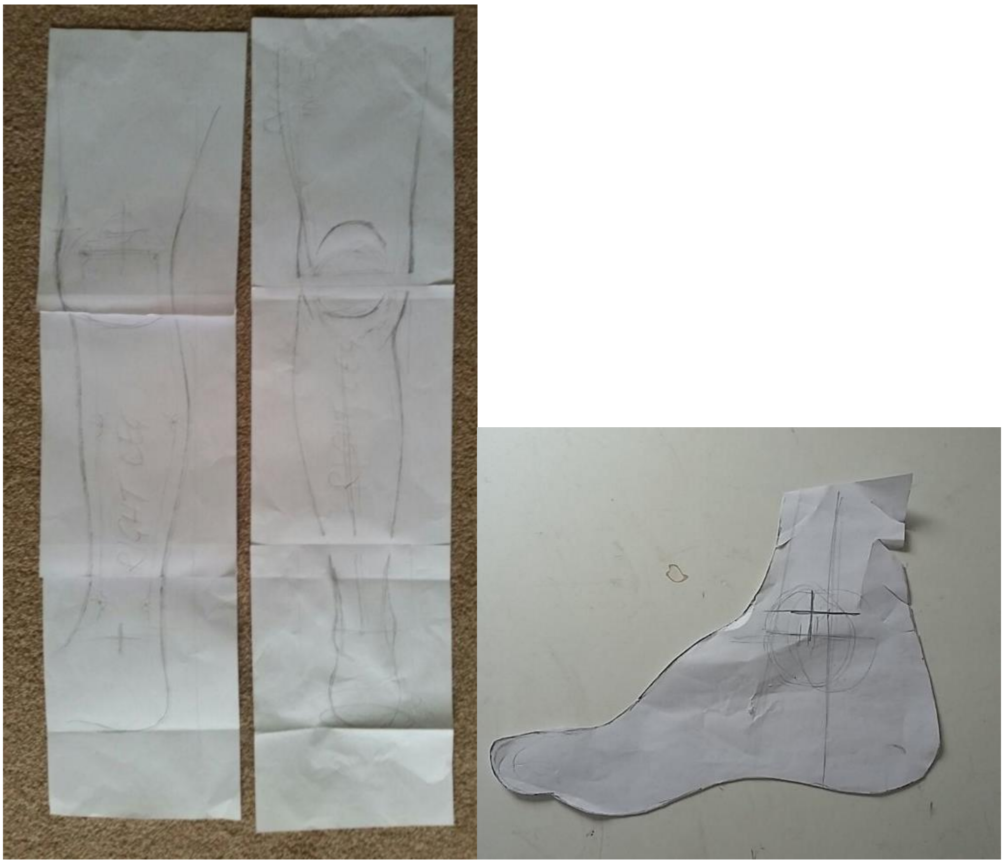
(Fig.10.3 wood in the wood yard)

Before the carving can begin the wood must be left to dry very slowly or ‘season’, so that it does not shift and move as this would cause it to crack and split, if the wood has too much moisture, the ideal amount being around 12% (Moore, 2011), it could shrink and change dimensions. fig. 10.3 shows how wood looks if it is left to dry too quickly or if it is not fully seasoned before construction is commenced. Therefore, the wood that was used here has been left to dry throughout the summer of 2018.

(Fig.10.3 cracked wood not left to season efficiently, author's own)

Carving the Wooden Components

As it was decided this reconstruction would not be made to fit a specific amputee, there was no need to recreate the method of taking a wax mould of the stump described by Gray (1857: 67). However, it was made to fit the author and so measurements were taken of the author’s legs, both the width of the thigh and the height to ensure a secure fit and joint locations. The next stage involved sketching out the shape, joint location and establishing where the springs would be attached, based on measurements taken, the first process which took place involved transferring these markings to the wooden blocks. Whilst there are three main wooden elements to this limb according to Gray (1857); one for the foot, one for the calf and one for the thigh/socket area. This was done using a ruler and pencil, with the offcuts highlighted by hashed pencil marks (fig. 10.4). The specialist began by making the foot shape from one solid piece of sapele; there is no evidence that this was the first piece to be constructed originally, but this was where it felt most natural to begin for the modern woodworker. Perhaps because it was the smallest element and least complex, so would take less time and would enable the specialist to get used to working with the tools and specific wood ready for the larger elements.



(Fig. 10.4 rough sketches of leg outline and foot shape with markings for joint location)

Sourcing a block of wood thick enough to produce the artificial limb today, would have proven very expensive due to its unusual dimensions. Therefore to combat this, the specialist utilised cut offs from the wood to build up thickness where he required more strength to withstand weight and forces. There is no written evidence to suggest the manufacturers during the nineteenth century did this, however, looking at images of Anglesey legs suggests that manufacturers at the time may have done something similar because you can identify the join of the wooden pieces together in some variations (see chapter 3 and 4) (fig.10.4). However the visibility of these joints are so minimal, they are made to be unnoticeable and so confidently identifying them on original pieces is challenging.   Therefore, the specialist divided the wooden blocks up into smaller fragments that would naturally form a more leg and foot shaped piece. The woodworker used a saw to cut the larger pieces up and then used a hide glue to secure the pieces together again in smaller parts. The foot for instance, was made by securing two pieces of wood together – one smaller on top of a larger piece – to make a very rough foot outline (fig. 10.5). By using a variety of tools (fig. 10.6) most of which were used in the manufacturing of the peg-leg (chapter 3), this was then sawn and chiselled into the shape into a rough foot form (fig. 10.7) before a hand plane was used to smooth the edges (fig. 10.8).

(Fig. 10.5 Slightly visible join of two wooden pieces in an Anglesey Leg, author's own image taken at the Household Cavalry Museum, London)

(Fig. 10.6 two blocks of wood secured with hide glue to make the beginnings of the foot piece that would attach to the ankle joint and calf section, author's own)

(Fig. 10.7 chisels used during chiselling process)

It is important to note that the specialist had to take time during the reconstruction away from physically working the wood to maintain the integrity of his tools, this means sharpening his chisels for instance with a leather sharpening ‘strop’. Working with a blunt chisel makes it difficult to control the cuts and it can also cause problems to the worker, blisters, tired hands and blood, so it was important for the specialist to maintain sharpened chisels.

(Fig. 10.8 nineteenth- Century Strop from V Linof Huddersfield)

Fig. 10.9 shows the unrefined beginnings of the foot after the initial chiselling into shape, it also shows how the chiselling process itself has begun to hide the join between the two pieces of wood that were glued to make one piece. The process of joining two pieces together like this, not only would have reinforced the strength of the wood in areas that were to be subjected to more force, but it would have also led to less overall waste because you can utilise pieces that may have been an unusual shape or size. As discussed above, due to the unusual size of wood required for this part of the production it seems likely that original manufacturers would have possibly utilised their offcuts in the same manner as the modern specialist. Mahogany and its substitutes would have been an expensive product to waste and so seems unlikely that waste would have been discarded, however, willow much like the lime used for the peg-leg actually saw a price reduction in the Industrial Revolution and so may have been more disposable.

(Fig. 10.9 three images showing rough foot outline after initial chiselling, author's own)

The next stage was to carve out the section of the ankle area which would attach through a knuckle joint to the calf section. This involved chiselling out a circular area and producing a hole through the centre of it, the second image of fig. 10.9 shows the outline and final shape for the ankle joint area.

(Fig. 10.10 showing the two wooden blocks joined together)

The specialist sanded the harsh edges in order to create a smoother surface and ensure the joins were almost invisible. Fig. 10.10 shows two up close images of the wood once it has been completely smoothed, whilst it is possible to see the join up close, it is very discreet. The shape of the foot was left to the specialist's discretion, after analysing photographs, drawings, literature and artefacts, the foot was a pretty standard shape but would differ in proportion based on the length and size of the leg it was attached to. Consequently, the residual foot was measured and the wooden replica was accurately made to the same measurements. The final foot is seen in figure 10.9 and shows a similarity in shape and form to originals seen in fig. 10.5. Gray (1857:71-72) notes that those who produce artificial limbs have '…Nature for his guide and instructress. She supplies the models, and lays down rules for his guidance which are unerring, and to which the exceptions are but few. She teaches in an intelligible manner what he who imitates her must do; and if he follow her directions, his efforts will be successful.'. Unlike during the manufacture of the Box-leg, the specialist here was restricted in his formation of the leg to match the original designs that still exist, because they were all originally produced from the blueprint of James Potts' innovative design and did not vary in shape. Their purpose was to aesthetically emulate the appearance of a natural leg and so there was very little opportunity for the specialist to deviate from this.

(Fig. 10.11 smooth and sanded foot shape ready for attachment to the calf section of the limb, author's own)

(Fig. 10.12 pencil markings and beginnings of the calf shape being formed, author’s own)

The next stage of the production was the marking out and shaping of the wood that would become the lower leg or calf area. The specialist began by measuring the pieces of wood against the scale drawings made of the leg shape and roughly sawing the wood into this silhouette. As before, the wood was made to the correct thickness by joining two blocks together with hide glue – joint visible in the third image of fig. 10.12. The pencil markings of where the knee and ankle joints were then made, as were the marks of the location of the knee cap. Much like the variations of Anglesey leg described by Marks (1907), the calf section had to be manufactured in a way which allowed the internal mechanisms to be accessible, for maintenance and alterations (chapter 4). It was requested to the specialist that the internal mechanisms that allow the leg to spring back into position during gait cycles were able to be viewed and consequently, the side of the calf was made detachable. This also meant that like the original Anglesey's, the spring strength could be adjusted to suit the wearer (chapter 4).

(Fig. 10.13 internal construction of Anglesey legs including springs, cords and joints, from Mihm et al 2002: 285)

(Fig. 10.14 A later example of the Anglesey leg now being produced by and therefore named 'Hanger' being advertised showing internal construction, found online at Age of Stock (2021) https://www.agefotostock.com/age/en/Stock-Images/diagram-artificial-limb.html)

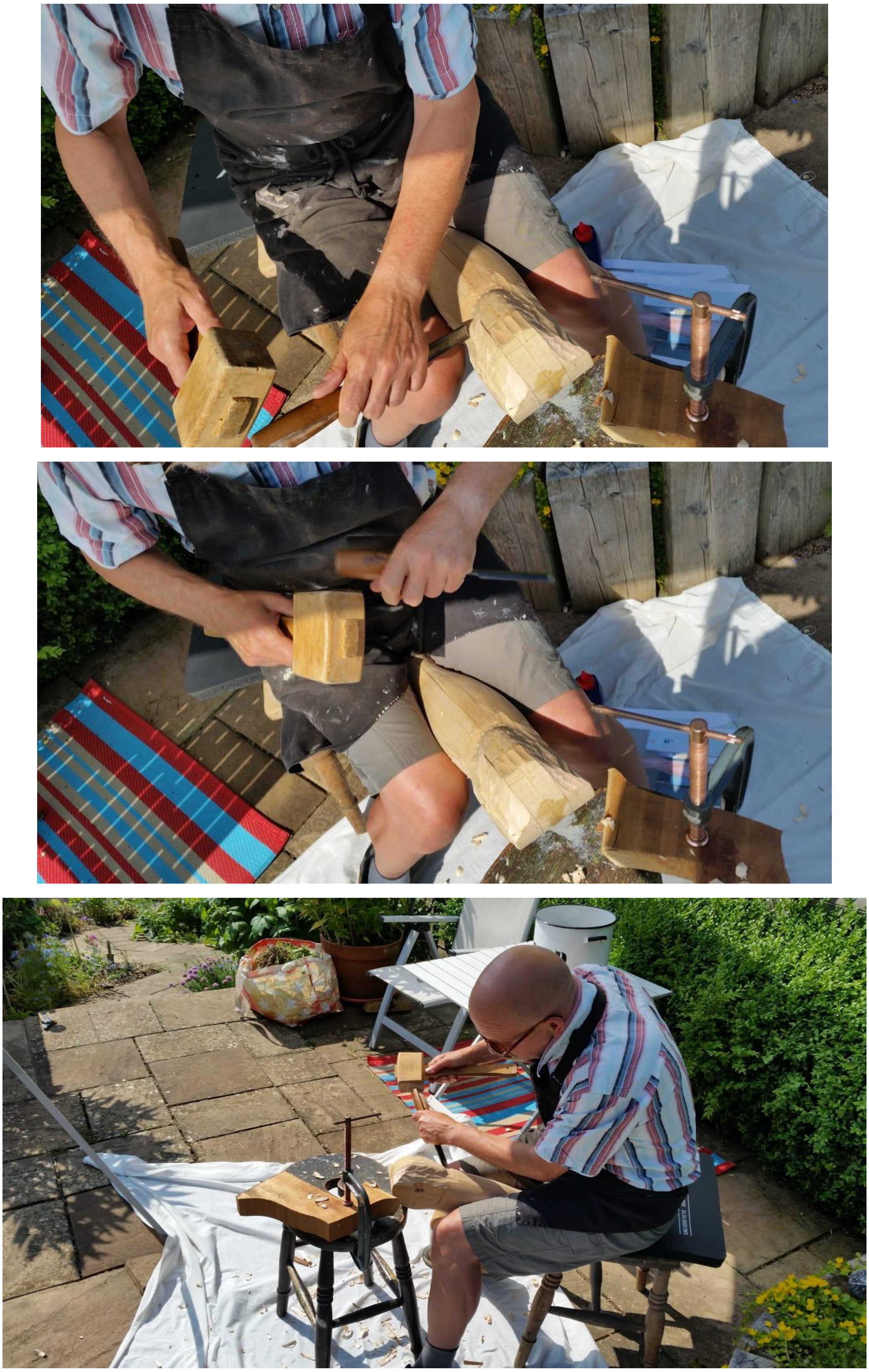
The measurements taken and lines of the leg and where the weight would be borne proved vital at this stage. The foot/ankle joint and the knee joint all must be aligned because as Gray (1857: 71) states, the precision of the 'lines' affect the comfort and effectiveness of the limb. Gray uses an example of people wearing artificial limbs where the lines are not perfect as often complaining that; 'I cannot imagine, for the life of me, what is the matter with this leg! The socket fits me admirably; it is much lighter than any other leg; the joints do not bend, but are delightfully free; the tendons are right, and yet when I walk, it causes me absolute fatigue. Can you explain what is the matter with it ?'. He suggests that this is a consequence of the joints not being in the correct position, and as a result the wearer's gait would be affected, the limb would be heavy and uncomfortable to wear and cause issues with the amputee's stumps. Therefore, it was a vital stage for the specialist to ensure the centre of the wood was clearly marked, so that he would know where the joints would be fitted and also where the internal spring mechanism would be positioned.

The specialist used a hand plane and chisel to shape the wood, there is some evidence that suggests some artificial limbs could be turned on a wood lathe, however, the intricacies and specific shape that is required from an Anglesey leg would suggest a wood lathe may produce a too cylindrical shape that does not include any muscular or kneecap formations that are achieved through using hand chisels. Figure 10.15, displays the wood specialist shaping the calf section by hand, fig. 10.16 shows a hand plane and the effect it has on the wood by scraping and shaving thin layers off by pulling the plane towards the body. Usually, the chisel would be used first to remove larger sections of wood and form the base shape and then the hand plane to smooth the surfaces and make it more curved.

(Fig.10.15 hand plane author's own image)

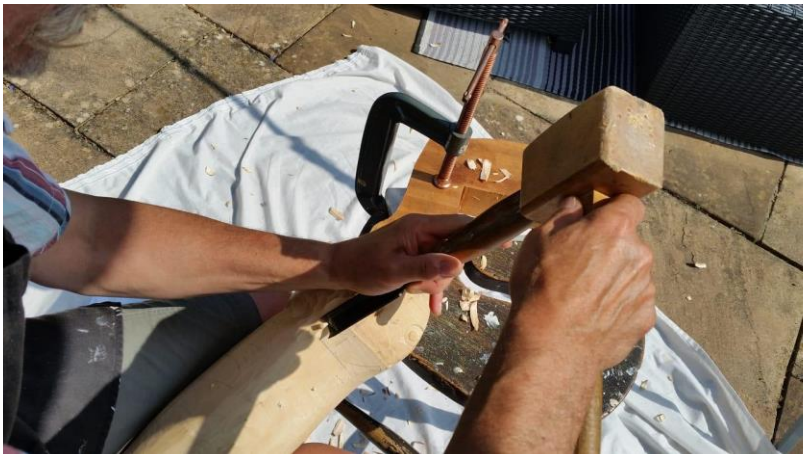
(Fig.10.16 specialist working the wood using a mortise chisel author's image)

Once the rough shape of the calf was formed, it was then possible to create the kneecap shape which is present in almost all of the original Anglesey legs (fig.10.17). Again this was created using a variety of gouge chisels, there is no evidence to suggest the addition of a kneecap shape was functional, rather it seems its addition was purely aesthetic making the leg appear as realistic as possible.



(Fig. 10.18 specialist working with a mortise chisel to create a kneecap)

The next phase involved the carving of the two opposite ends of the calf section, the areas which would eventually form the joints that connect to the foot and thigh socket and that bend during the gait cycle. As with the formation of the knee cap, the process of removing the wood to form the knuckle joint began with chiselling out the redundant wood, fig. 10.18 and 10.19 displays this and fig. 10.23 shows the final appearance of the ankle end. The specialist then continued to smooth the sides with the hand plane to ensure there were no uneven surfaces.



(Fig. 10.19 mortise chiselling and gouging of the joint ends, author's own image)

(Fig.10.20 ankle end visible with wood removed and specialist smoothing surface author's own image)

(Fig. 10.21 knee cap being held against thigh section for reference of lines and size, author's own image)

Throughout this process it was important that the specialist kept referring to the initial scale drawings he made prior to commencing construction because this is how he ensured he was maintaining the correct lines and also ensuring that there would be enough room for the joints to slot into place during each gait cycle. At some stage the thigh and calf pieces would interlock during the bending of the knee and as such the calf section would need to have room to accommodate the wood that would be bending towards it. Fig. 10.21 and 10.22 shows the area at the top of the calf section that was cut away to allow the thigh section to fit into place, this was also mortise chiselled away.

(Fig. 10.22 cut away section at top of calf image own)

The next step involved sawing a section of the calf open and hollowing it out to incorporate the catgut/spring mechanisms. The hollowing process involved the use of a large gouge chisel, it was less important to make the internal construction area as smooth and aesthetic because this area would remain unseen so it seemed a waste of valuable construction time for the specialist to work too hard on making the inside surface as smooth as the outside (fig. 10.22). Once the inside was carved away, there was room to start planning on the best position for the internal apparatuses seen in fig. 10.42, although these were not officially attached until all three wooden sections were produced and positioned together.

The foot was the first section to be attached to the calf via a knuckle joint (seen in fig. 10.23) and secured in position with cap screws (fig. 10.28). The reason this was attached before the production of the thigh section was because the specialist explained that it gave him the limbs approximate standing height and could subsequently ensure the thigh section would be the correct height and size for the socket as a result of this.

(Fig.10.23 showing the calf and foot attached with a metal bolt, author's own)

(Fig. 10.24 knuckle joint which was used for both the calf and foot connection and also the thigh and calf connection, author's own)

The third wooden section to be created was the thigh socket area. This process began again by glueing two pieces of wood together to produce a piece that was wide enough for a thigh socket (fig.10.25). The specialist placed the calf and thigh sections together and drew the thigh proportions on to the wood in pencil, he did this so he knew where he was chiselling and removing wood would be accurately positioned while maintaining the correct lines that Gray (1857) discusses as so important. He then chiselled the joint that would slot into the respective section on the calf portion (visible in fig. 10.24).

(Fig.10.25 showing the wooden thigh section marked up prior to carving, author's own)

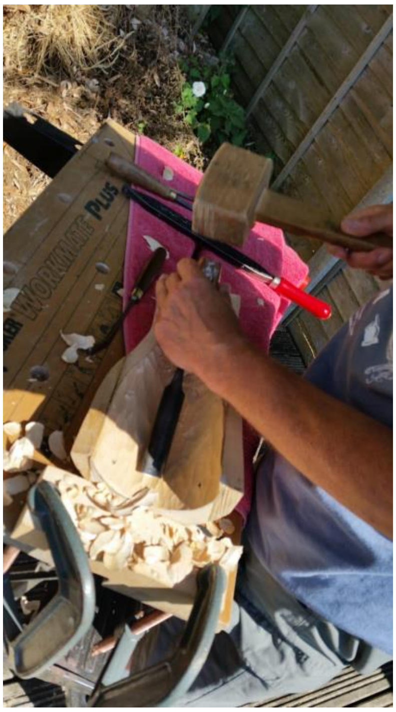
(Fig.10.26 thigh section placed next to calf section with pencil marks distinguishing proportions and hashed lines demarcating what is to be removed)

After the proportions were confirmed and the three sections aligned correctly, it was then possible to begin shaping the thigh section utilising the same methods and techniques used for both the foot and calf previously. Using a mortise chisel and gouge, the specialist hammered out the excess wood to produce a socket shape (fig. 10.28). It is important to add here that the final shape of this thigh socket would differ that of an original Anglesey leg, because it has been made for a volunteer to try on. Therefore, where the socket would encase the thigh stump originally, here it has been made to attach to the front of the thigh and allow for a kneeling stance much like the Box-leg (chapter 3, section 3.4, also see fig.10.27). Even though the leg would have originally been made with a full socket in most cases, there are original examples of the Anglesey leg style being utilised for trans-tibial amputees as well as trans-femoral. For instance, whilst Marks' example is slightly later than the nineteenth century dating instead to 1907, fig. 10.27 does show an Anglesey leg variation in which a knee bearing stump would have been suitable for use in this style, it also shows a leather frontage which laces us which was briefly discussed in chapter 3 as being in the original patent of James Potts.

Cut F 8.

Cut F 5.

(Fig.10.27 A. A Marks 1907: 74 knee bearing stump)



(Fig.10.28 showing the mortise chisel being used to hollow out the socket area to an appropriate thickness)

(Fig. 10.29 finished shape of the calf section's socket, author's own)

Once the calf section had been hollowed and the socket formed, it was possible to smooth the front surface and start shaping the top of the knee cap that would adjoin the calf's section of the knee cap. This was again done using a hand plane (fig. 10.24), the specialist is a sculptor and his ability to work with the material expertly meant he was able to shape the wood into a realistic form which highlighted the muscles in the thigh as well as the kneecap. This understanding of the material and the way in which it becomes malleable with certain tools, meant the aesthetic finish was effective and representative of a real leg – much more so than the basic form of a peg-leg.

Piecing the Leg together

Metal

Once the socket was carved to shape it was ready to be attached to the calf section and for the internal mechanisms to then be assembled. This began by aligning the pieces together and securing the knuckle joint seen in fig. 10.26 with a nut and bolt. Unlike the Box-leg, there was no manufacturing of any metal pieces, whilst its construction utilises the use of certain metal aspects, they would have been elements that were likely to have been acquired by the Anglesey manufacturer prior to assembling the leg. The specific metal used for the nuts and bolts and cap screws is not identified in the literature however by looking at original Anglesey legs they look like either gunmetal or wrought iron screws (Marks, 1907: 90) (fig. 10.30). Wrought iron is difficult and expensive to acquire today so therefore mild steel was chosen in this reconstruction.

(Fig. 10.30 wrought iron screws securing the knee joint, image of Anglesey leg at Household Cavalry Museum)

The bolts were placed in position after an auger was used to drill the holes to the correct thickness and depth. An auger was used instead of the drill press which was described in chapter 4 because the specialist was not able to access this apparatus whereas he had an auger in his tool collection. Similarly, the holes were made with the auger once the wood had been shaped into a cylindrical leg form and the bolts had to be positioned in exactly the correct position to ensure the pieces were accurately aligned. The use of the auger therefore, made it possible to position these holes after the main shaping had been completed because they could be created whilst the leg was balanced upright.

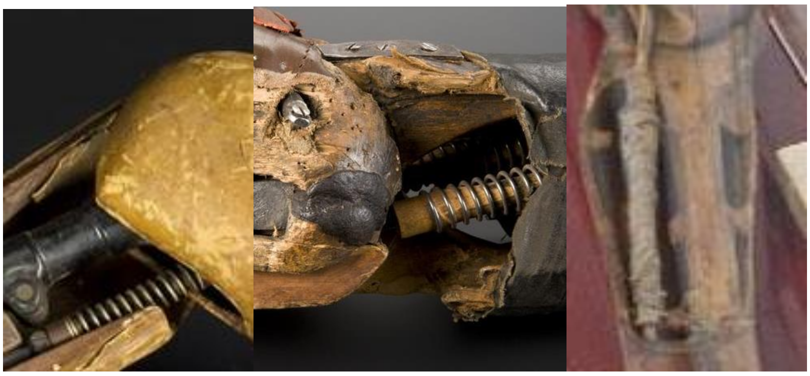
If a drill press had been used instead, the holes would have had to have been created prior to initially shaping the wood because they would have been flat pieces rather than round, which would prove difficult to securely balance on their rounded edges. Finally, the holes achieved with an auger were likely to be deeper than that of a drill press. The same method was employed to make the holes for the foot section. Once the holes were created, the bolts could be positioned and the legs' final form became apparent, fig. 10.31 shows the legs' wooden elements fully assembled prior to the addition of the internal mechanisms.

(Fig.10.31 fully constructed leg with carved out socket and smoothed thigh section perfectly placed to fit the calf segment author's image)

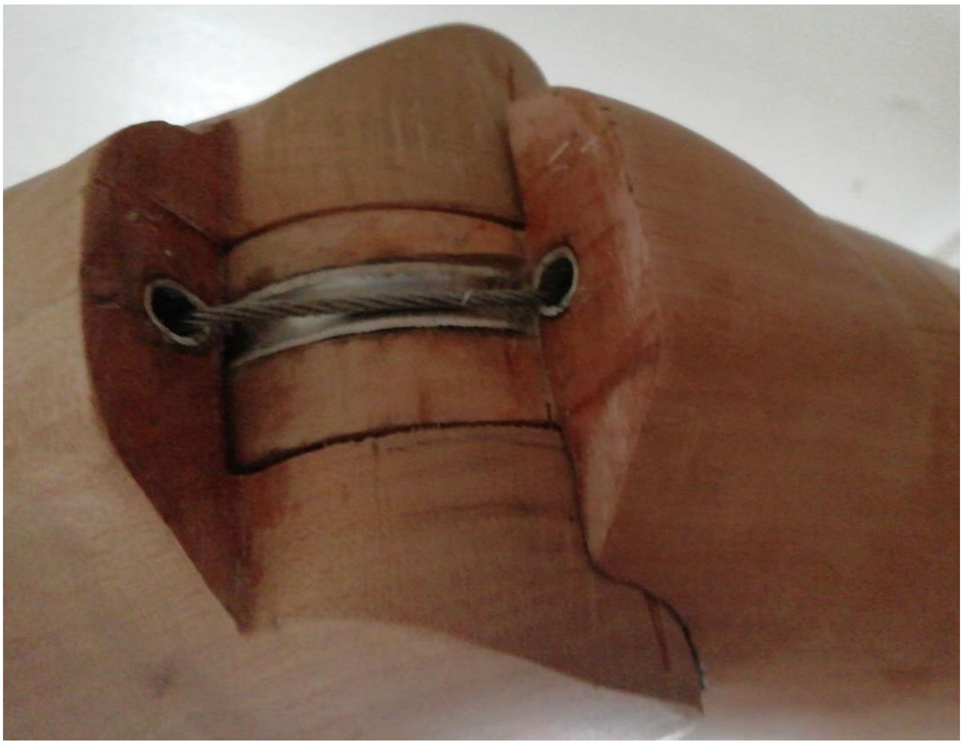
The most challenging phase of the legs manufacturing process was positioning and securing the internal mechanisms including the springs and metal wires that would provide the leg its elasticity during gait. In its current state the legs' separate pieces are uncontrollable, falling into different positions based on gravity and so the springs and wires act as stoppers by locking the leg into a secure position movable during a gait cycle.

(Fig. 10.32 cap screw securing the cable to the inside of the socket, author's image)

The specialist began this process by creating a channel for the wire rope to be fitted through, he did this by again using the auger to produce a hole and then hammered in a half-round metal channel cylinder as described by Marks (1907: 89-90). The specialist advised that the repeated extension and contraction of the wire during a gait cycle would quickly start to wear down the wood it was resting against and therefore affect the integrity of both the wire rope and the wood. To prevent this, he made the decision of placing a metal round channel cylinder to take some of the friction, through which it was also easier to feed the wire rope through and connect it to the springs that would be fitted in the calf section, fig. 10.34 illustrates the final appearance of the metal channel and wire through the knee section. The reason this had to be done whilst the leg was already assembled was to ensure everything lined up so the wearer's balance would not be affected (Gray, 1857). The same sort of adjustments are visible on some original Anglesey leg variations (fig. 10.33), with the examples displaying the use of cloth, metal and wood to add a layer of protection to prevent constant friction between the wire and wooden joints. Similarly, Marks (1907: 89-90) notes the use of a metal cylinder placed inside the wooden channel (chapter 4). He secured the wire rope in position by using cap screws as suggested by Marks (1907: 88).



(Fig. 10.33 Variations in internal mechanisms to protect the wood against perpetual rubbing from catgut or wire tendons, metal, wood and cloth all being utilised and options, author's own image taken at the Household Cavalry Museum)



(Fig. 10.34 half-round metal channel and wire positioned through the knee joint, author's own)

Once the wire had been threaded through the knee section, its exit location on the calf piece was known and as such the exact location for the positioning of the springs on which to attach it could be established.

(Fig. 10.35 springs in position and location of metal wire exiting the thigh area in the top left corner author's image)

(Fig. 10.36 top left corner of calf section showing exit area of the wire and also spring positioning, author's image)

The next element to complete was the hole for the metal channel to be hammered into, in the rear of the ankle joint. This process was exactly the same as for the knee joint and employed the same tools and materials. The wire was threaded through from the heel and was prevented from being pulled straight through by the use of a nail which also acted as a way of keeping it static so the springs could work. The spring features from the knee and ankle were then attached to their respective metal cables and also a metal loop which remains static inside the limb. The left hand spring in fig. 10.36 remains static at the bottom of the calf in the endeavour to allow the spring to expand and constrict as the knee bends and relaxes and the wire the spring is attached to pulls it longer during the bent knee phase and releases it during the extended leg phase. In contrast, the right spring remains static whilst connected to the top loop which allows the spring to extend and release as the ankle joint bends and contracts during each gait cycle.

(Fig. 10.37 wire cable passing through the ankle joint into the calf joint visible during mid gait cycle bending of the ankle, author's own)

The next metal mechanical element to be added to the limb was the ability to flex the toe area during the toe-off gait stance (fig. 10.46), for this the specialist sawed the toe section off the wooden foot in order to reattach it via the use of a spring, he made sure to create an area in each section big enough for a knuckle joint. The knuckle joint was produced in the same way as the ankle and knee joint, the specialist used a chisel to gouge out the unnecessary wood to create the correct shape and also an auger to punch to hole through for the nut and bolts. He also removed a thin slice of wood from the top of the foot down towards the base in order to allow room for the toe section when it was flexed (fig. 10.37). Fig. 10.38 shows the underside of the foot with a small section removed for the addition of a concealed metal spring, also the knuckle joint which was secured together with the use of a nut and bolt. The spring was used here to allow the toe section to bounce back into its relaxed position during the swing phase of the leg. All the newly sawn and chiselled wood was smoothed and sanded.

(Fig.10.38 spring element connecting toe section and heel section of the foot at base author's image)

(Fig.10.310 top of the foot with a thin section removed to provide a gap during toe flex author's image)

(Fig.10.40 toe off phase of gait cycle showing the bent ankle and toe section author's image)

Shearling

The specialist then added the woollen shearling (see chapter 4) to around the thigh socket. A light padding was added in between the wood and the shearling in order to create a slightly higher comfort level and emulate the addition of a sock which was often used over a stump to prevent rubbing and blisters. There is evidence to suggest padding of some sort was originally used, for instance, Marks (1907: 88) discusses the use of a ‘cushion’ for protection of the wearer's stump. However, too much protection would have interfered with the customised socket for the wearer's stump and would have defeated the purpose of customising it. Gray (1857) and Bigg (1885) also both talk about the use of socks by artificial limb wearer's however after his assimilation of a sculptor’s ‘pointing machine’ into his manufacturing process in 1853 (1885: 82) Bigg states that ‘…I could make a concave mould to a convex object, no matter how intricate and varied the outline. Every little hollow, minute protuberance, or partial inequality, would be represented with the most perfect fidelity; and every vein would have its allotted channel.’ (Bigg, 185: 84). It would seem therefore a wasteful endeavour to cover these so-called perfect carvings with a sock or any padding.

Slight padding was included, not only in an attempt to tidy the edges of the socket but also to provide a slightly increased level of comfort for the volunteer trying it on. The shearling was used because it is a material that would have been highly accessible during the nineteenth century. The woollen industry during the nineteenth century was so vast that according to Ashton (1968: 23) there was no county in England and Wales where peasants, farmers and agricultural labourers were not producing woollen cloth. The shearling has a suede effect on one side and a trimmed fur on the other side, the suede made it easily attachable to the wood with a hide glue (fig. 10.41). However, it is noted here that this section of the leg remains the least true to original manufacturing techniques purely because it was not produced for a specific amputee.

(Fig. 10.41 Shearling inside socket cavity author's image)

Leather

There is very little leather on the Anglesey leg (as fig. 10.42 and 10.43 display), consequently, there has been a limited amount used in this reconstruction. The first which has already been seen in fig. 10.39 is a small piece at the toe area to secure the toe and ankle section of the foot together at the top. Using a cross cut chisel this was punched with two holes and the same tools were used to punch two holes into the wood in alignment, and the leather secured in position with two copper-alloy nail tacks. Like the use of these tacks in the peg-leg construction, they are corrosion and rust resistant when in contact with human skin salts and water. As well as it being aesthetically appealing due to its golden hue. Ashby (2002) claims that this sort of pin is good where there is low friction and where sparks are not struck, hence the use of it on the toe area because there is very little stress and tension being placed on this area of the foot as most of the work is being done by the spring under the toes.

The next leather section was the specifically made leather straps that attach around the thigh socket to secure the leg in position. Unlike the straps used in the manufacture of the peg-leg – recycled belt straps – these were cut into strips of leather from a larger leather sheet and holes punched into it, using a hole saw. The buckles were purchased separately and sewed into place once the dimensions of the straps were established. These were made rather than recycled because it is highly likely that the straps used for original Anglesey leg wearer's were made to measure, partly because of the type of people they were being made for but also because of the fact that the straps used to secure the leg could differ for each wearer. The two leather straps are exactly the same size and measure 3 cm thick and 63 cm in length, they sit 0 cm and 14 cm from the top of the thigh socket respectively. Finally, once these were created they were secured to the wooden socket using copper alloy tacks, in total ten tacks were used, five on each strap (fig. 10.42), a cross chisel was used to create the hole in the wood for the tacks to fit into and a hammer was used to secure the tacks and leather straps in position.

The completed leg was checked for any wooden splinters, these were removed if present. The Anglesey Legs production process concluded by varnishing in wood. Varnishing the wood mainly for longevity and aesthetics, sealed the wood aiding bacteria and moisture resistance. By varnishing the finished product, it would hopefully help create a layer that would be resistant to rot and bacteria, compromising the longevity of the product. The target audience for this limb was wealthier than those who would receive peg-legs. The legs were described by one wearer as having '…succeeded in furnishing…with an artificial limb, which, as far as art can supply the want of nature, I may say is perfect…able to ride and walk without inconvenience or fatigue.' (Gray, 1857: 124). This wearer was a distinguished Austrian general who was also an ambassador for his country, as a man who likely experienced a lot of finery in life; he would have expected the same for his artificial limb. Production of the Anglesey was lengthier and involved a higher specification of material, therefore it seems more likely that not only would the wood used in production be better quality but it would have been varnished to maintain its integrity and aesthetics. Fig. 10.42 shows the completed leg from different angles and fig. 10.43 shows the legs during different gait phases.

(Fig. 10.42 Different angles of completed Anglesey Leg author's image)

(Fig. 10.43 Different gait stages of leg author's, own image)

Outcomes and Conclusions

During the production of the Anglesey leg, the manufacturing process was recorded using photographs and notetaking. Much like that of the peg-leg production process, the wood specialist's familiarity with the material and tools created a fluidity to the process with instinctive decisions concurrently being made with calculated ones based on the original leg. The process was more complex than the peg-leg reconstruction and thus more decisions were involved, particularly surrounding the use of the wire rope and how to protect the wood it would be adjacent to during a gait cycle - thus an understanding of mechanisms and mechanical workings was also an incredibly useful knowledge that the specialist already had in existence. Interestingly, on researching the methods by which a socket was carved and produced, to discover that an apparatus utilised primarily by sculptors created a nice unison between this reconstruction and original manufacturers because the specialist here is a trained sculptor. It may be skills like this that have helped with the reconstruction by one person alone, however in the nineteenth century, the close proximity people with certain material skills would have had could suggest a collaborative engagement between skilled professionals. For instance, leather makers and wood workers but also as Bigg highlights in 1885, his friendship with a sculptor called Mr Noble which contributed to the innovative use of the pointing machine in artificial limb making later on, demonstrating an interconnection between the two professions and their skillset.

The engagement with the material, the use of the same materials available during the nineteenth century as well as the utilisation of the same tools have created a more reliable, comparative reproduction. However, some elements had to be highlighted as not staying entirely true to the original process, the main being the socket being lined with shearling. Nevertheless, the effort, timescale – approximately 50 working hours – and skill level involved in the production, like the peg-leg production, is more comparable to original manufacturing processes, and due to employing the assistance of a woodworking specialist, historical and scientific authenticity to the reconstructions has been made. Guyatt (2001: 309) claims that the Anglesey leg could take up to six weeks to create due to the involvement of leather makers and repeated adjustments to ensure a comfortable fit. Similarly, the use of the same specialist for both reconstructions means that their decisions and material familiarity remain true to that person and therefore their opinions are more comparable, particularly as they encompass a familiarity with the investigative and recording process. Their spatial movements, material, tool and technological decisions, therefore, are to be trusted as embodying a realistic understanding of the overall production process with this type of material. For instance, the addition of the half-rounded metal cavity in the knee and ankle joint was not an element that was personally seen in the original Anglesey leg by the specialist, nor is this sort of element written about in the literature. However, it was an element that the specialist instinctively advised would be needed because the wire would soon wear away at the wood, knocking out the lines, which Gray (1857) stated as important to physical comfort and without, would render the leg useless for the wearer. So, after personally checking images of Anglesey variations it was agreed that the rounded cavity could be added, in the knowledge that similar variations existed in other original Anglesey legs.

As discussed in chapter 4, it is increasingly evident that production techniques of the Anglesey leg were not standardised, with manufacturers instead employing and developing their own way of producing the leg with each manufacturer therefore producing slight differences. As long as the fundamental elements were included, such as the bent knee, ankle and toe joints, and the springs, it could be considered an Anglesey leg. The specialist on the reconstruction, modelled it on the surviving limb at the Household Cavalry Museum, he demonstrated a material contingency that allowed him to make appropriate decisions about the manufacturing process and order and also demonstrated that had this not been a reconstruction and instead he had been allowed to just produce an artificial leg in the style of an Anglesey, there would also have been differences between the limbs as observed with legs during the nineteenth century.

The next chapter will investigate the functionality of both reconstructed legs in a lab-based analysis that will include an investigation into the way in which each leg changes the natural gait of the wearer. The aim is be able to determine how the leg changes gait and long term damage this may cause to a wearer, because although both Bigg (1885) and Gray (1857) discuss pain that could be caused by certain limbs not fitting correctly, they do not go into detail. Likewise, the investigation into gait changes will help us understand how noticeable wearing an artificial limb like these would have possibly been to onlookers thereby adding to understanding of perceptions of physical disability at the time. By comparing the lab-based evidence with modern medical understanding it will be possible to highlight what potential problems these legs were causing their wearers. Particularly interesting because the wearers were ex-soldiers trying to find their place back in civilian life, so how hard was it really when they were faced with not only discrimination for being disabled but also potentially suffering chronic pain as well.

Appendix C: Preliminary Home Experiment

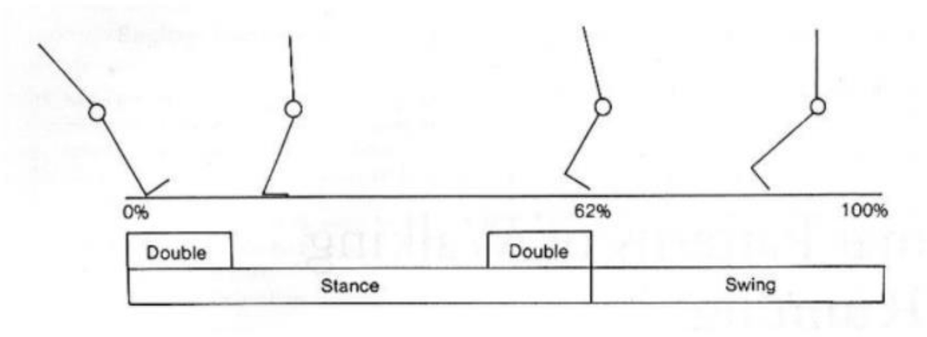
The preliminary experiment involved placing six markers on the leg and arm, between the shoulder and wrist and hip and ankle. The hip-to-knee distance was measured at 55cm, knee-to-ankle measured at 35 cm, shoulder-to-elbow measured at 30 cm and elbow to the wrist at 22cm. The purpose of these markers was to enable the plotting of loci to analyse their varying positions during the walking process. This process is closely based on the practice observed during the use of the technology involved in the main experiment. The novel home-based approach to gait analysis employs the use of a treadmill and cameras to visualise different parts of the body and highlight irregularities in gait movement, whilst using a peg and Anglesey leg reconstruction, compared to no prostheses at all. The degree of asymmetry visible will be plotted in graph and loci angle changes formats.

The proposed at-home method here has proven to be significant in generating gait data that is not only cheaper than Vicon but has identified changes that align with skeletal data found in studies such as Lazenby's. As such the proposed methods combined provide an overview of likely asymmetry that would have existed in artificial limb wearers, how this differs between prostheses and finally, offers some insight into the type of reported pain and pathological conditions that may have been present in an amputee's body because of post-operative treatment such as prostheses.

Abnormal or asymmetric gait can be caused by various factors such as bone malformations, hip injuries or even stroke (Moevus et al, 2015), which thus makes gait analysis an accurate indicator for a wide range of pathologies. This theory relies on the assumption that a healthy person has a symmetrical gait, which is why for these experiments a person who has no known conditions nor has undergone an amputation will wear the prosthetic reconstructions. By assuming an asymmetrical gait may be an indicator of certain pathologies, analysing the effect of historical artificial limbs on a symmetrical gait will identify potential pathologies that could result through long-term use. Gait analysis is an effective, non-invasive tool for detecting joint deficiencies during rehabilitation, however, it was not a tool that was widely used until more recently and so patients who underwent amputation and rudimentary rehabilitative processes during the nineteenth century, would never have had their personal gait pattern analysed and used in the fitting of a prosthesis. Specifically, the goal of this photo-based gait analysis tool is to generate a perceptual map of asymmetries of an individual wearing historical artificial limbs.

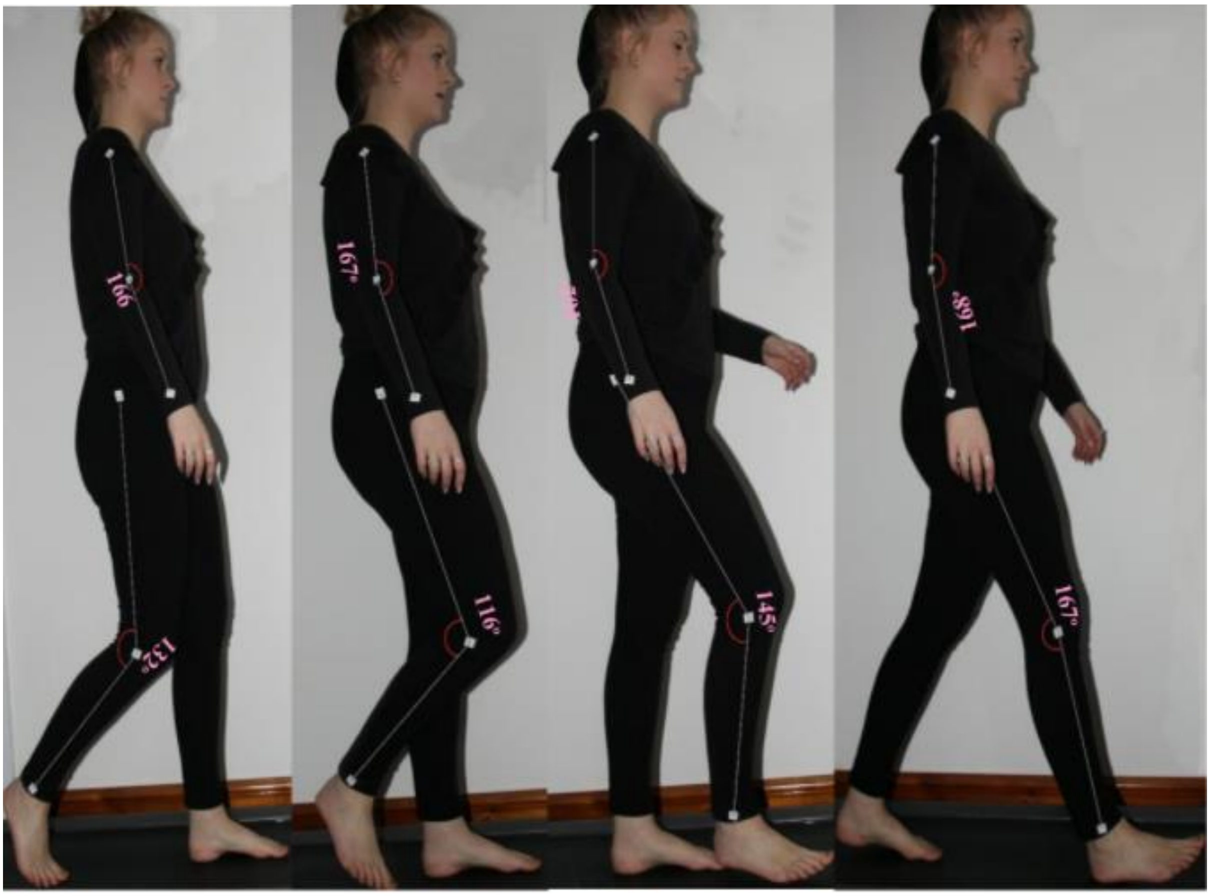
The coronal or frontal plane is the recording plane used for this experiment, to identify the shift in bodily movement efficiently. It is any vertical plane that divides the body into ventral (belly) and dorsal sections (back). The measurements that have been taken within this experiment, include the lateral and posterior perspectives of the individual's gait whilst wearing no artificial limbs, whilst wearing a peg-leg and whilst wearing an Anglesey leg. The angle changes within the elbow, knee and hip areas have been recorded whilst the wearer walks one gait cycle, which is defined by (Schultz, 2005) as involving two main phases, the stance and swing phase; the 'stance phase occupies 60% of the gait cycle while the swing phase occupies only 40% of it'. Gait involves a combination of open and closed chain activities. A more detailed classification of gait recognises six phases: Heel Strike, Foot Flat, Mid-Stance, Heel-Off, Toe-Off and Mid Swing (fig. 11.1). According to Schultz (2005 in Moevus, 2015); 'The gait cycle is a repetitive pattern involving steps and strides. A step is one single step, a stride is a whole gait cycle. The step time is the time between the heel strike of one leg and the heel strike of the contra-lateral leg. Step width can be described as the mediolateral space between the two feet.'.

The reason for the analysis of the hips, knees and elbows and identification of a natural gait in comparison to the gait whilst in prostheses, is because locomotion involves the whole body and the speed at which you walk determines the contribution of each body segment (Schultz, 2005 in Moevus, 2015). Normal walking speed mainly utilises the lower half of the body, with the arms and trunk maintaining balance and stability, compared to running which means the individuals must utilise the upper extremities for propulsion as well as balance. The joints within the lower limbs produce various ranges of motion and muscle responses to ensure propulsion forward. Although the centre of gravity moves both up and down and side to side during gait, the degree to which the individuals centre of gravity changes during gait cycles, defines the efficiency of the walk (Schultz, 2005 in Moevus, 2015) and can be used to identify underlying physical weaknesses and physiological conditions. For instance, it is assumed that there is an anterior-posterior displacement of the hips of around 4-5^{o} in healthy gait (Moevus et al, 2015) during this experiment. Should a greater deviation in angles be observed whilst in the use of artificial appliances, it can be said that these limbs do not recreate a healthy, normal gait pattern. Whilst this type of analysis is common today in the study of modern prostheses efficiency, an analysis of the efficiency of historical limbs has never been attempted and therefore this data is unique.

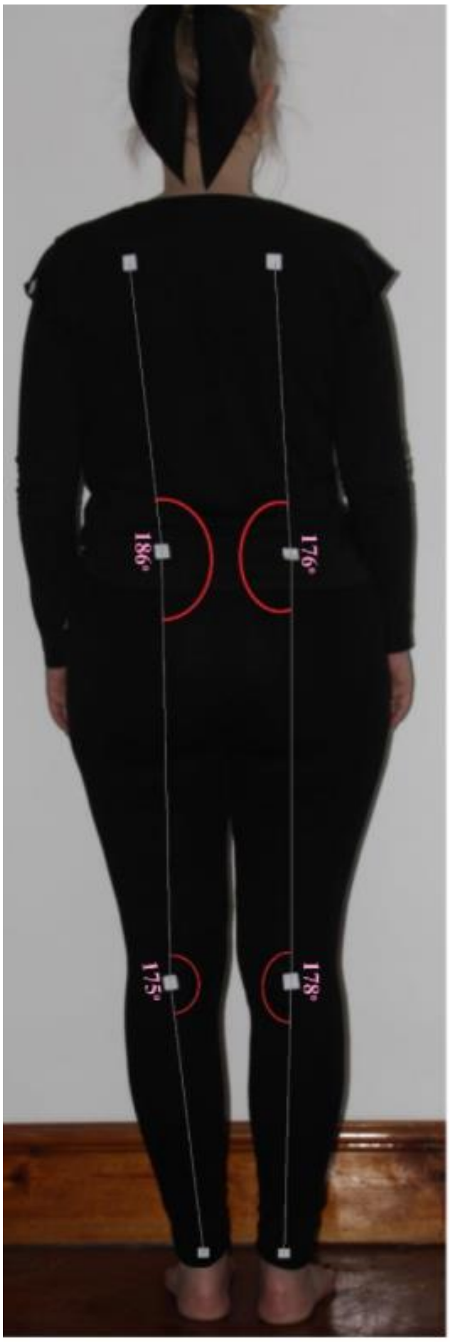


(Fig. 11.1 Gait cycle showing different phases)

The dataset here consists of gait pattern sequences of an individual walking on a treadmill and on the ground, the coronal plane being photographed at intervals during the gait cycle. The individual is female, with a height of 5’6 and a weight of 140lbs. There are a total of 50 sequence images which include the individual walking normally with no prostheses, then whilst wearing a peg-leg and then the Anglesey leg reconstructions. The individual walked normally whilst wearing markers; photographs were taken and the angle measurements were established and plotted into a graph in excel. The individual is not an amputee and so for the sake of the image clarity and aesthetics, the images had the limb digitally removed post-experiment. As such, this experiment replicates a below-knee amputation most effectively, which is why the potential impact of balancing prostheses on the knee joint will be assessed through the ground reaction forces. Anglesey legs could be worn by individuals who had below-knee and above-knee amputations due to the nature of the sockets. Likewise, the Box-leg was also best suited for below-knee amputees but it too, could be adapted with padding for above knee amputees. The results of the gait analysis are depicted below in the form of images and graphs. The first set of images displays the volunteer’s natural gait, with no shoes or appliances to demonstrate the uninfluenced stride motion (fig. 11.2, 11.3 and 11.4). These are followed by images showing the lateral and posterior gait whilst wearing a peg-leg and the Anglesey leg, the angle changes in the elbow, hip and knee positions being measured. Finally, these angles have been plotted into a graph format to demonstrate visually the changes taking place with each artificial limb.


166
132°
167°
116°
145°
168°
167°

(Fig. 11.2 Lateral natural gait cycle with bare feet)



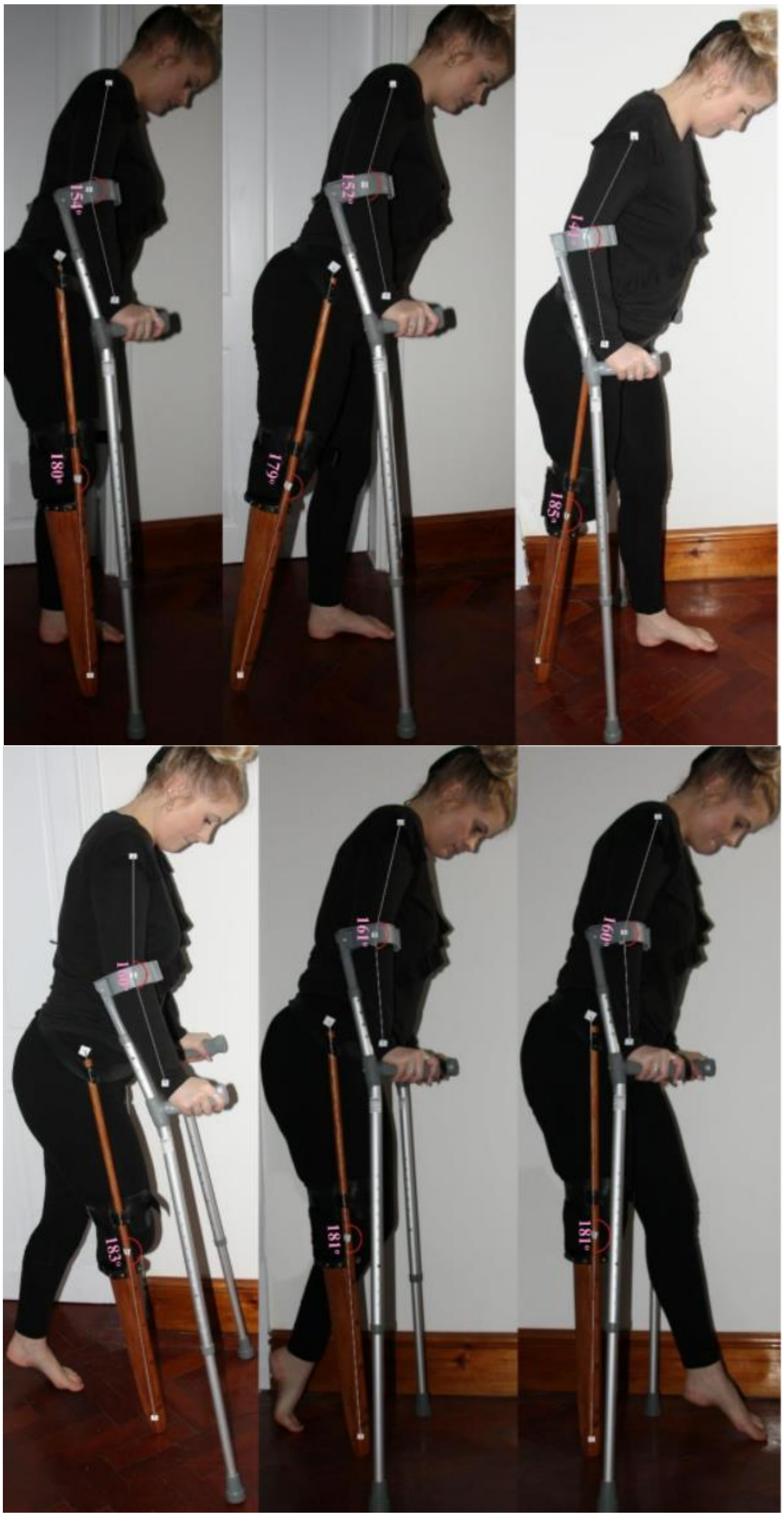
(Fig. 11.3 Posterior standing position with angles)

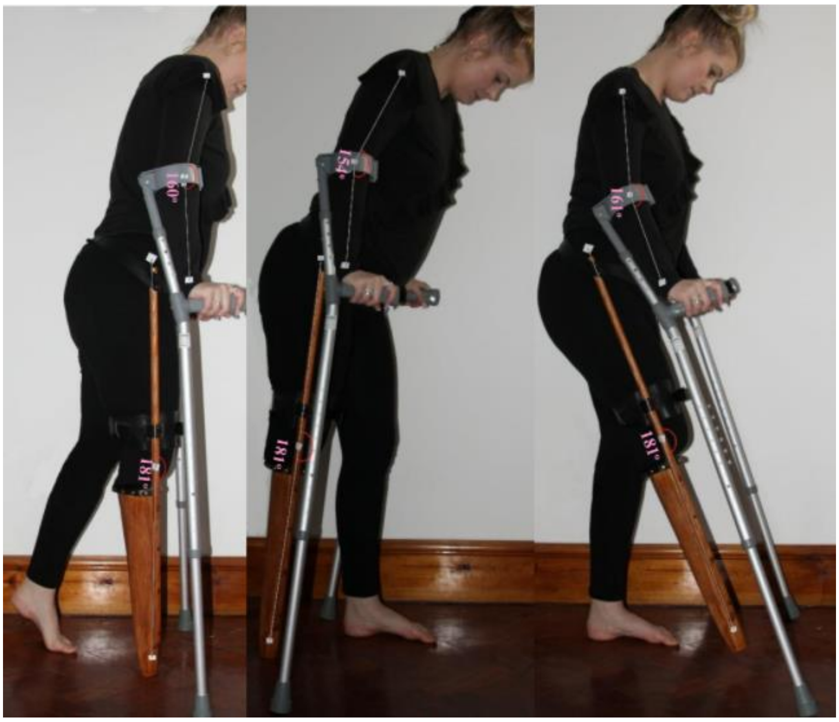

180°
173°
179°
184°
181°
178°
171°
186°
182°
178°
187°
170°
182°
179°
186°
175°

(Fig. 11.4 Posterior view of gait cycle with angle alterations

(Fig. 11.5 Posterior stationary stance whilst wearing a peg-leg)

(Fig. 11.6 Posterior view of angle changes during one gait cycle)


154°
180°
152°
179°
185°
183°
161°
181°
160°
181°



(Fig. 11.7 Lateral view of angle changes during peg-leg gait cycle)

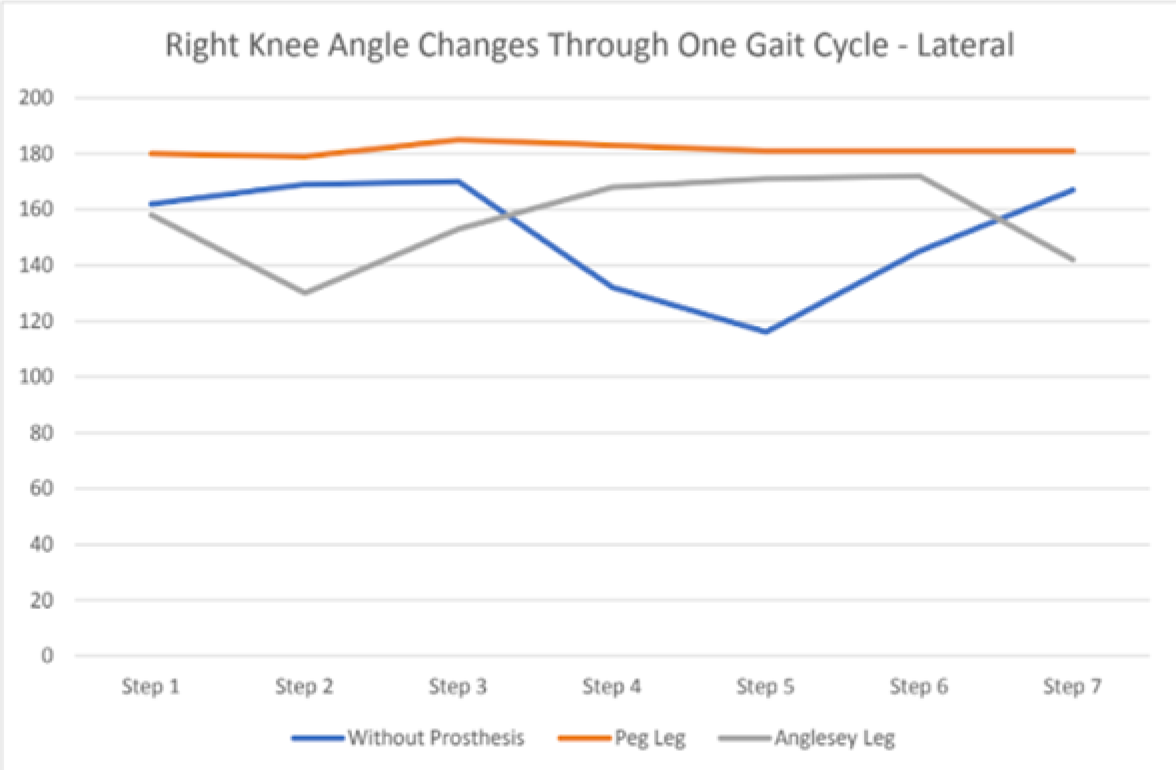
(Fig. 11.8 Posterior view of standing position in Anglesey leg)

(Fig. 11.9 Posterior view of Anglesey leg gait cycle)

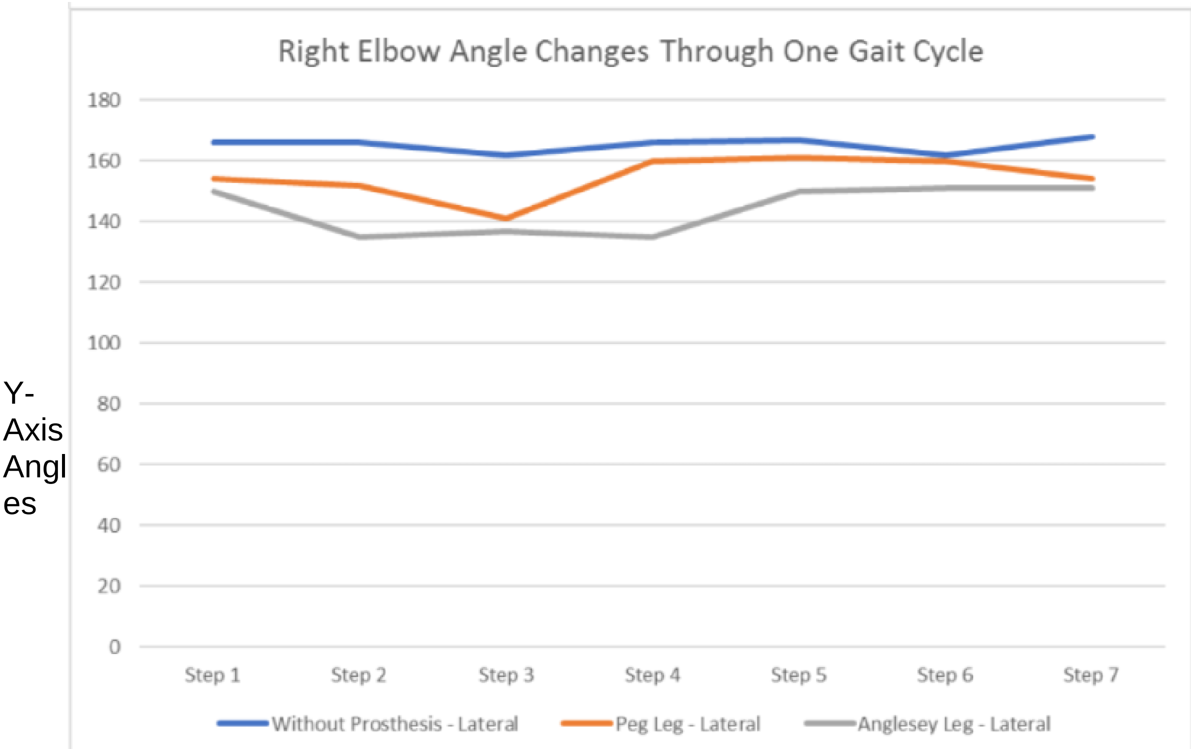
(Fig. 11.10 Lateral view of Anglesey Leg gait cycle)

Y-
Axis
Angl
es

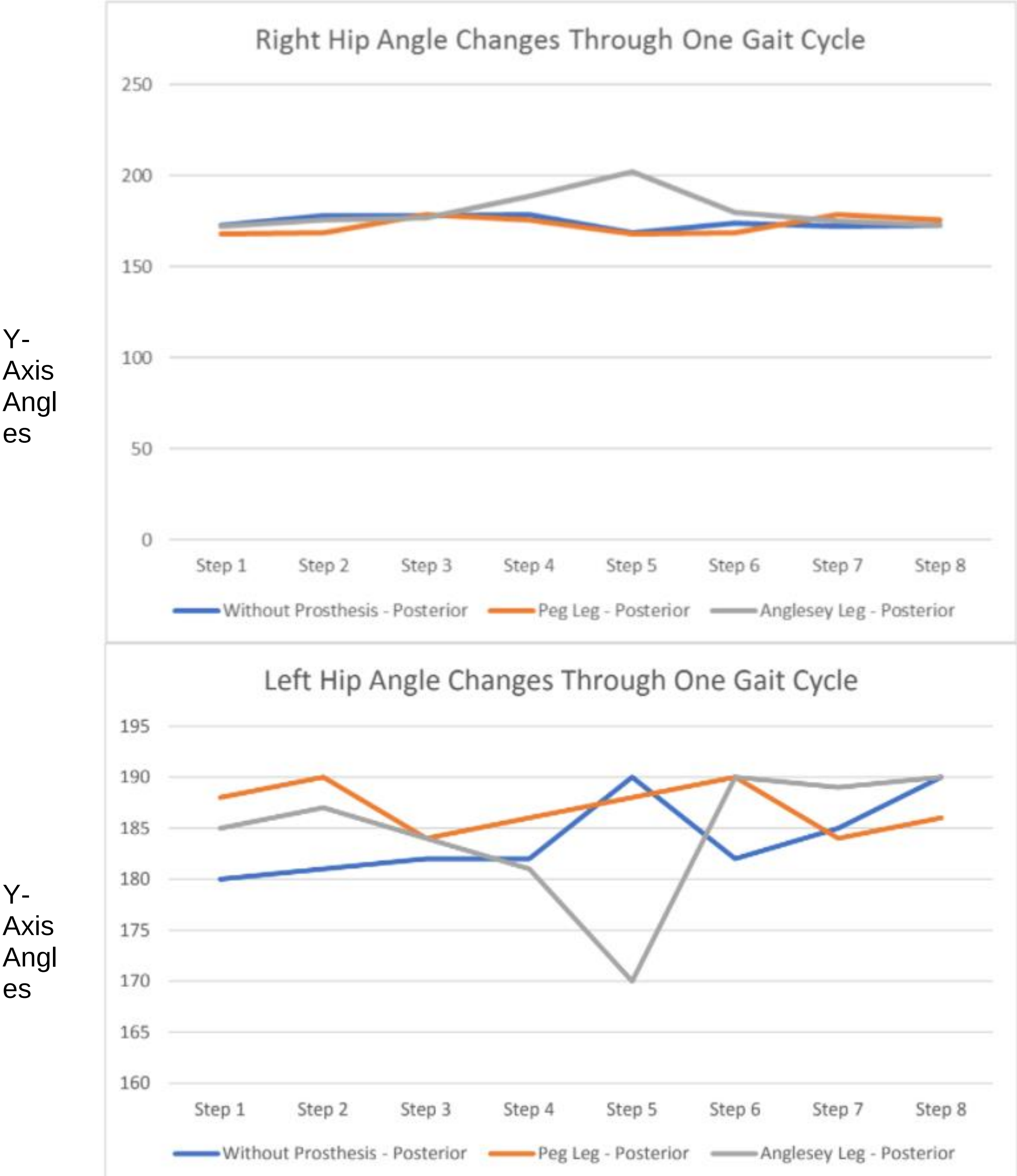
Results



(Fig. 11.11 Graphs showing the knee and elbow angle changes (Y-Axis) between the artificial limbs from a lateral perspective)

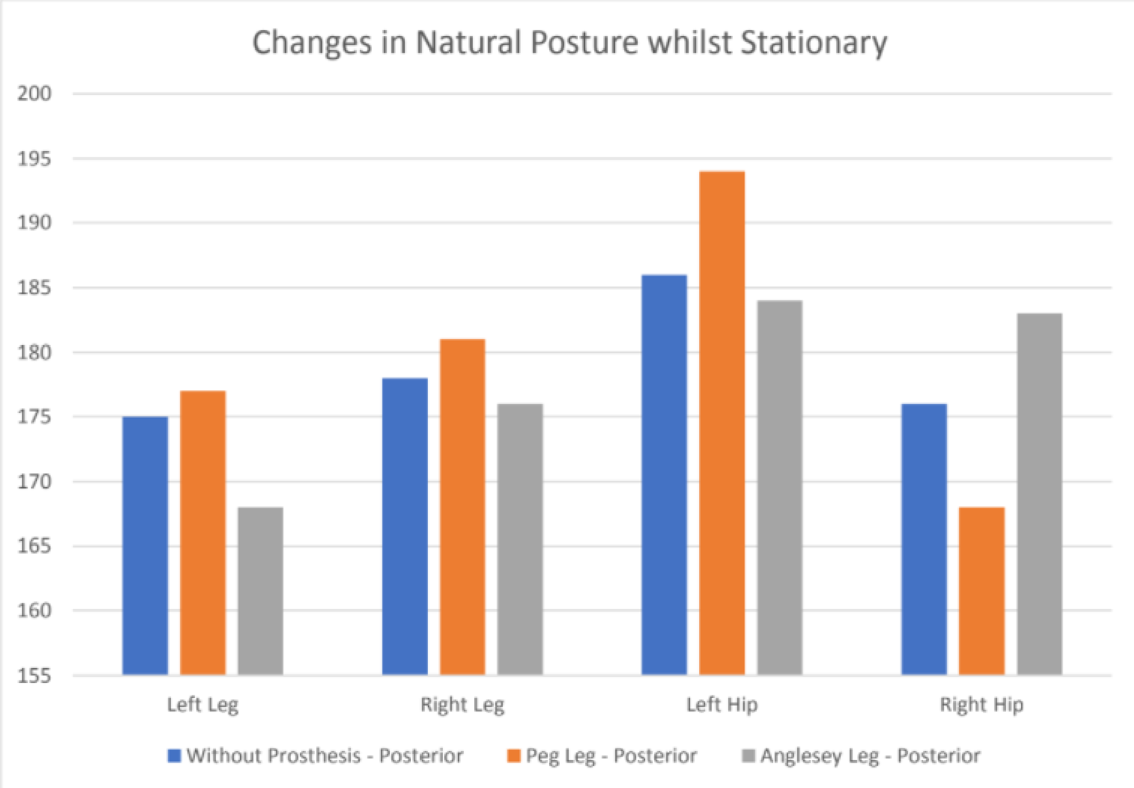


(Fig. 11.12 Graphs showing knee angle changes (Y-Axis) from a posterior perspective)



(Fig. 11.13 Graphs showing hip angle changes (Y-Axis) from a posterior perspective)

Y-Axis Angles



(Fig. 11.14 Graph showing effects of artificial limbs on posture as determined by the angle changes (y-axis) whilst stationary)

Angle changes are a good way to gauge the changes in the shallowness of steps during the different phases of a gait cycle. The differences represent whether the leg has been lifted higher or lower off the ground, whether the hips movement has been affected and whether the balance has been disturbed, which is also shown by how much reliance is placed on crutches. By analysing the angles during a gait cycle where no artificial limb is worn, the data is gathered that represents the natural movements of the individual with no external factors affecting this movement. This data acts as the control data from which comparisons can be drawn. This data is represented in all the graphs above by the colour blue, the orange represents the peg-leg data, and the grey is the Anglesey leg. What is initially clear from the knee angles in figure 11.11 is that a change in the stability of the cycle between each artificial limb and no limb can be seen. The movement with the peg-leg is very regular, it consists of almost no visible anomalies and a noticeable regularity to the angles which follow a fluid trajectory repeated through each cycle. This is because the peg-leg has no knee joint and is thus not capable of bending during the cycle, as such, the movement to thrust the leg forward during the swing phase is generated elsewhere on the body, most likely in the hip area. The graphs in section 6.2.4, show that the hips go through their biggest changes on the left side, which is the side without the artificial limb, suggesting that there is an increased reliance on this side of the body for stability. Even the cycle without any prostheses has the biggest changes on the left hip. Specifically, during step 5 – which is the swing phase, where the right leg moves forward – both hips demonstrate more distinct angle changes at this stage. Comparatively, the Anglesey leg stride appears to mirror the natural gait stride, with both their larger more obtuse angles at the hip around 170^{o}. However, their acute hip angles differ, with the Anglesey leg reaching 130^{o} compared to no prostheses reaching 116^{o}. This suggests that whilst walking with the Anglesey leg, the limb was not as efficient as expected despite its ability to bend at the knee and ankle, because it prevented the foot from being lifted as high as the unaided gait, consequently affecting the hip movements. In part, this was a result of the Anglesey leg being heavier for the wearer and much stiffer to bend at the knee. Due to the mechanisms within the Anglesey leg which were intended to create an elastic more natural swing phase, it required a lot more force by the wearer to consciously bend the knee to recreate a more natural stride and swing phase, expected during gait cycles. Likewise, a change in both the left and right hip angles during the same phase of gait whilst wearing the Anglesey leg compared to the unaided gait, suggests that there may be other changes such as increased forces and greater impact on the unimpaired leg as a consequence of increased reliance on it, which will be identifiable in the lab-based force plate data below.

The graphs in figure 11.12 illustrate the angle changes that occur in both knees during a gait cycle. The most notable change present in the knee measurements is observed whilst wearing the Anglesey leg as the movement becomes more erratic, specifically between steps four and seven, which is when the right leg is being brought forward during the swing phase of the cycle. When these angles are viewed in conjunction with figures 11.9, 11.6 and 11.4, it is clear why during these specific steps (4-7) the angle changes differ the most, as it is here, we see more pressure being dispersed onto one leg whilst the other is swung forward. Oddly, during the gait phase with no prostheses, the right knee undergoes the least alteration in angle acuteness. Whereas the peg-leg, despite observing a difference to the natural gait with no prostheses, does appear to adopt a more even change in its movement, likely since once mid-cycle, the pressure is dispersed onto the opposite leg and crutches, with little use of the right leg required and certainly no bending of the knee as none exists to bend.

The graph represented in figure 11.14, depicts the changes in angles whilst standing stationary. What is evident from this set of data is that in both cases where an artificial limb is used, greater support is placed on the left leg for stability, evidenced via the change in angle of the left hip. Likewise, we see a greater change in the positioning of the right leg because of the use of artificial limbs, most likely because the appliances changed the shape of the natural alignment of the limbs. Finally, it seems to be the case that the wearer places more weight-bearing support naturally on the left hip (without appliances) suggesting a weaker right hip-abductor (section 6.2.2) and this just becomes exaggerated when prostheses are in use.

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