Visualising inertial motion sensor data: the design and evaluation of a horse rider assessment and feedback interface

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Abstract

Postural assessment and delivery of feedback to horse riders have historically been based on subjective observation by equestrian practitioners or video analysis. With the emergence of technology-based assessment within health and other sporting contexts, there has been an increasing interest in its application to rider postural feedback but such tools, to-date, have only provided feedback retrospectively.

This thesis presents research investigating how motion-based assessment, combined with visual prompts, might be used to provide concurrent dynamic postural feedback to riders. A prototype tool was built using a Raspberry Pi with sensors and lights, with bespoke software presenting alternative visual interfaces, providing either correctional or informational feedback on the rider's posture.

Results showed that rider preference varied in selection of preferred visualisation with no statistically significant differences between choice of correction or feedback, and some evidence that posture could be negatively affected by a less-preferred interface. A statistically significant reduction in asymmetry was achieved using the correction visualisation in walk and the feedback visualisation in trot, irrespective of rider preference. Qualitative evaluation showed the tool to be effective in a field-based study, with potential for application in practical contexts.

The contribution to knowledge of this research was the novel application of wearable technology, in the form of an IMU sensor on the rider's pelvis transmitting motion data wirelessly to an LED light strip on the horse's head to provide customisable visual presentations of dynamic motion data with either correctional or feedback information to address asymmetry or other postural issues.

A further contribution was the development of a novel customised version of contextual inquiry for carrying out contextual analysis specifically in situations where the participant is themselves engaged in observational activity. This used a body-mounted camera recording of a coaching assessment with a retrospective think-aloud recall and structured interview to determine requirements for the tool developed and the protocol for its evaluation.

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Fronarth George

Table of Contents

Abstract i

Acknowledgements ii

Table of Contents iii

List of Figures vi

List of Tables viii

Chapter 1. Introduction 1

1.1. Background and Motivation 1

1.2. Research Questions 2

1.3. Contribution to Knowledge 3

1.4. Methodology 4

1.5. Structure of the Thesis 5

1.6. Summary 6

Chapter 2. Literature Review 8

2.1. Introduction 8

2.2. Background 8

2.3. Feedback Mechanisms 16

2.4. Equestrian Contexts 17

2.5. Comparative Contexts 19

2.6. Limitations and Issues 26

2.7. Validation of Technology 26

2.8. Summary 27

Chapter 3. Methodology 29

3.1. Introduction 29

3.2. Research in the wild 29

3.3. Data Requirements 30

3.4. Understanding Context (Study 1) 31

3.5. Evaluation of Tool (Study 2) 33

3.6. Summary 36

Chapter 4. Study 1. Understanding Usage Contexts for Rider Postural Assessment 38

4.1. Introduction 38

4.2. Field Study Method 39

4.3. Study Methodology 40

4.4. Participants 42
4.5. Health and Safety Considerations 43
4.6. Coach Assessment Method 43
4.7. Coach Assessment Data Analysis 45
4.8. Coach Assessment Pilot Study 47
4.9. Coach Assessment Contextual Analysis Results 49
4.10. Summary 52
Chapter 5. Tool Design and Development 54
5.1. Introduction 54
5.2. Hardware Development 54
5.3. Software Development 63
5.4. Incremental Development and Testing 65
5.5. Pilot Testing 67
5.6. Device Operation 68
5.7. Tool Constraints and Limitations 80
5.8. Summary 81
Chapter 6. Study 2. Tool Evaluation Method 83
6.1. Introduction 83
6.2. Method 83
6.3. Procedure 85
6.4. Data Analysis 87
6.5. Summary 89
Chapter 7. Study 2. Tool Evaluation Results 91
7.1. Introduction 91
7.2. Quantitative Analysis 91
7.3. Qualitative Analysis 99
7.4. Sentiment Analysis 119
7.5. Summary 120
Chapter 8. Discussion and Conclusion 121
8.1. Introduction 121
8.2. Discussion of Results 121
8.3. Summary of Research Findings 123
8.4. Contribution to Knowledge 125

8.5. Limitations 126
8.6. Further Work 126
8.7. Concluding Remarks 127
References 129
Appendix A. Research Questions Contribution 140
Appendix B. Observation Guide (Study 1) Draft Version 142
Appendix C. Observation Guide (Study 1) Final Version 145
Appendix D. Study 1 Conclusions and Contribution 146
Appendix E. Visualisation Interface for LED-CORRECTION 147
Appendix F. Visualisation Interface for LED-FEEDBACK 151
Appendix G. Software Development Sprints 154
Appendix H. Ethics Paperwork 159
Appendix I. Risk Assessment 165
Appendix J. Study 2 Rider Information Questionnaire 167
Appendix K. Study 2 Line Plots 168
Appendix L. Study 2 Density Plots 188
Appendix M. Rider comments on visualisation interfaces 208

51,320 Words

List of Figures

Figure 2.1. Studies and methods used to address the research questions. 4
Figure 2.1. Shoulder-hip-heel line. (Dove and Wanless, 2015). 15
Figure 2.2. Visualise jacket and horse markers (Centaur Biomechanics, n.d.). 15
Figure 4.1. Arena Markers. 46
Figure 5.1. How the tool development fits within the link between Study 1 and Study 2. 54
Figure 5.2. Rider IMU device with sensor (left) and power/charging shim (right). 55
Figure 5.3. Horse LED device, with Blinkt LED strip. 56
Figure 5.4. Initial testing of Horse LED device, with Blinkt LED strip in Pibow case. 56
Figure 5.5. Alternative LED shim, which was subsequently rejected. 57
Figure 5.6. Portable connectivity provided by PQI Air Pen Express Wireless Router. 59
Figure 5.7. Early prototype rider IMU case and dismounted feasibility testing. 60
Figure 5.8. Feasibility pilot testing of LED device, wired to USB power bank. 60
Figure 5.9. Telerein C IT (left) and Equla Vert (right). 61
Figure 5.10. Cases for IMU rider (left) and LED horse (right) devices. 61
Figure 5.11. IMU Rider(left) and LED Horse (right) devices in position. 62
Figure 5.12. Structure of software for both rider and horse devices. 64
Figure 5.13. Example software development sprint. 66
Figure 5.14. Rider tool dismounted prototype pilot testing. 67
Figure 5.15. WinSCP FTP connection screen (running on Windows). 68
Figure 5.16. WinSCP main screen showing PC files on left and rider IMU files on right. 69
Figure 5.17. Bash scripts to start the rider IMU and horse LED device software. 71
Figure 5.18. Root folder contents and software start-up for rider IMU device. 72
Figure 5.19. Root folder contents and software start-up for horse LED device. 72
Figure 5.20. Menu option 2 completing with rolling mean and final calibration offset. 74
Figure 5.21. Initiating a separate thread to start polling the IMU. 74
Figure 5.22. Horse LED device interface shown while the rider IMU device is polling. 75
Figure 5.23. Sub-menu to select or enter range of IMU values for visualisation. 76
Figure 5.24. Example data file imported into Excel. 78
Figure 5.25. Using Angry IP Scanner on the PC to confirm connections to the router. 79
Figure 5.26. Commands used to resolve an issue of the server device freezing. 80
Figure 6.1. Alternative attachment for horse who would not tolerate device on head. 86
Figure 7.1. Angle of lateral rotation across the timeline of the test for sample rider. 93

Figure 7.2. Mean absolute asymmetry (Walk). 94
Figure 7.3 Standard Deviation - Range of Motion (Walk)..95
Figure 7.4. Mean absolute asymmetry (Trot). 96
Figure 7.5. Standard Deviation - Range of Motion (Trot). 96
Figure 7.6. Density plots of proportion of test in each data range for Rider P4. 97
Figure 7.7. Density plots of proportion of test in each data range for Rider P1. 98
Figure 7.8. Spreadsheet of transcription from semi-structured interview recordings. 99
Figure 7.9. LED device obscured by thick mane in windy conditions. 112
Figure 7.10. Alternative position of LED device for horse who was a head shaker. 113
Figure 8.1. Python function to display LED-CORRECTION visualisation. 147
Figure 8.2. Python function to display LED-FEEDBACK visualisation. 151

List of Tables

Table 3.1. Mapping of data types to questions. 31
Table 3.2. Methodological Technique selection for Study 1. 32
Table 3.3. Methodological Technique selection for Study 2. 35
Table 4.1. Data required for each research question to be addressed by this study. 38
Table 4.2. Alternative themes for coding biomechanical markers. 47
Table 4.3. Frequency of gait, rein and exercise across all participants. 50
Table 4.4. Number of references to each body segment, across all participants. 52
Table 5.1. Columns recorded in CSV format data file. 78
Table 6.1. Data required for each research question to be addressed by this study. 83
Table 6.2. Riding movement protocol for data collection. 86
Table 6.3. Semi-structured interview questions. 87
Table 7.1. Order of visualisation testing with preference scores. 92
Table 7.2. Summary Statistics – Walk. 94
Table 7.3. Summary Statistics – Trot. 95
Table 7.4. Qualitative feedback (visualisation interfaces). 100
Table 7.5. Qualitative feedback (general positive feedback on both interfaces). 102
Table 7.6. Qualitative feedback (impact on horse). 103
Table 7.7. Qualitative feedback (rider comfort and sickness). 104
Table 7.8. Qualitative feedback (rider concentration and focus). 105
Table 7.9. Qualitative feedback (rider posture). 107
Table 7.10. Qualitative feedback (comments on specific postural issue or adaption). 109
Table 7.11. Qualitative feedback (ROM, visibility and sensitivity). 109
Table 7.12. Qualitative feedback (setup, fit and use). 111
Table 7.13. Qualitative feedback (study experience) 114
Table 7.14. Qualitative feedback (use of technology). 116
Table 7.15. Qualitative feedback (general comments on benefits). 117
Table 7.16. Qualitative feedback (comments on frequency of use). 118
Table 7.17. Qualitative feedback (comments on frequency of use). 119
Table 7.18. Sentiment analysis on qualitative feedback. 120
Table 8.1. Contribution from each research question. 146

Chapter 1. Introduction

1.1. Background and Motivation

This project designs and evaluates an inertial motion sensor (IMU) based screening tool for the automated postural assessment and provision of feedback to horse riders. Research seeks to determine an appropriate protocol for the collection of rider postural data, identify the key biomechanical measures required for postural assessment of the rider and select data visualisation techniques that are most appropriate for providing feedback to the user in the wild, taking account of user context. The aim of the project is to provide equestrian practitioners with a computer-based solution to improve consistency and provision of feedback in rider postural analysis.

For those who participate in equestrian sports, the incidence rate of low back pain is up to 5 times higher than the general population with values reported as high as 85% (Lewis et al., 2023) and causal links found to range of motion (ROM) muscle tightness and asymmetry (Cejudo et al., 2020a). There is a need to find accurate and consistent methods of measurement to provide the rider with feedback that will enable them to make adjustments to their posture where required (Gandy et al., 2014).

The current approach to rider postural assessment is primarily observational and is, therefore, highly subjective. It also relies on a coach being present to provide the correctional coaching cues and feedback, which can vary from coach to coach. A technology-based solution would remove the human perspective and enable a more consistent, accurate and objective assessment of the rider to be carried out.

Historically, measurements were limited to those which could be taken statically but this does not take account of changes in the rider's posture when the horse is in motion (Gandy et al., 2018). Motion analysis using video technology is commonly used but significant limitations affect its use, for example limited field of view, and the use of IMU technology has been demonstrated to be a practical alternative (Li et al., 2022).

Data collected using dedicated IMU systems includes a large number of biomechanical parameters, making its software difficult to interpret by practitioners and requiring this to be performed retrospectively. Before such technology can be integrated into rider assessment and feedback tools in the wild, there is a need for the development of customised software to automate data analysis and further research is required to determine the data visualisations most appropriate for this context of use, in particular whether this could be provided via dynamic concurrent mechanisms whilst riding (Gandy et al., 2014).

Previous scientific studies on rider posture using IMU technology lack consistency in the biomechanical measures considered and the data collection protocols used, focusing on differing small subsets of body segments or joint angles during a range of movements in a restricted set of gaits (Egan et al., 2019). Research is required to determine which parameters are core to rider-specific analysis and to determine the most appropriate visualisation techniques for provision of feedback to the rider.

Several commercial technology-based tools have been developed in recent years to support the assessment of rider posture but these provide retrospective feedback and, despite their popularity, there is a lack of scientific evidence to support design choices used. There is a need to consider whether any lessons can be learnt from technology-based solutions in other sporting contexts, particularly in cases where HCI aspects can be supported by scientific research and subsequently applied to new contexts within equestrian sport. However, a review of health and wellbeing smartphone passive sensing applications (Cornet and Holden, 2018) revealed a lack of research into feedback mechanisms used, suggesting that this was an area that warranted further research. Results from this study may subsequently, therefore, also be used to inform future research in a wider context than rider analysis.

1.2. Research Questions

The aim of this PhD project is to investigate the requirements and interface design implications for the presentation of inertial motion sensor (IMU) data to equestrian practitioners, resulting in the development and evaluation of a software solution for the postural assessment and provision of feedback to horse riders.

The primary research question is "What are the most appropriate interface design and data visualisation techniques for the presentation of IMU data for rider postural analysis and feedback?"

To address this, the following specific questions have been identified:

- Q1. What are the current practices, focal points and key stakeholders in the postural analysis of riders in a real-world context?
- Q2. What is an appropriate protocol for the use of IMU data as an assessment and feedback tool, taking into account the practical considerations for the use of IMU analysis during riding motion?
- Q3. Which is the most appropriate data visualisation technique for the presentation of rider analysis data feedback according to the usage contexts identified in Q1?

Questions Q1 and Q2 are addressed by Study 1 (S1) Understanding usage contexts, which utilises a customised version of contextual inquiry, comprising a combination of observation, video recording and retrospective think-aloud recall with structured interview questions.

The objectives of this study are to determine who are the key stakeholders, what tasks are carried out and what biomechanical measures are used in an observational assessment of a rider's posture, carried out by a coach.

The results identify appropriate biomechanical measures to be incorporated into an automated rider assessment protocol and determine the hardware and software specifications for an IMU-based assessment and feedback tool/interface. A prototype hardware and software tool for IMU-based assessment and feedback has been developed and pilot data collection carried out according to the protocol, to confirm reliability and evaluate the tool.

Question Q3 is addressed by Study 2 (S2) *Interface design and data visualisation implications for rider postural analysis*. Two interfaces have been developed for visualisation of IMU-based rider postural analysis data using the prototype tool developed and user-centred field-studies have been utilised to carry out data collection in the wild, according to the protocol resulting from S1. Empirical analysis of postural data recorded via the tool, alongside retrospective semi-structured interviews with participants, has been carried out to evaluate the comparative effectiveness of each software visualisation interface within its context of use.

The objectives of this study were to determine environmental factors and practical implications of fitting and using the prototype tool in the context of rider feedback; and which is the most appropriate feedback visualisation interface – feedback or correction?

In addition, the overall project considers the methodological implications of carrying out research in the wild, applied within the context of horse riding.

1.3. Contribution to Knowledge

This work contributes to knowledge in the novel application of data visualisation techniques to the postural assessment of the rider and provision of concurrent correctional feedback, whilst riding the horse.

Current techniques for postural analysis of riders are based on subjective observation by equestrian practitioners, video analysis or the emerging use of commercial products, with feedback provided retrospectively. This PhD project breaks new ground by applying scientific principles to the design and evaluation of a novel practical alternative via the design and development an automated hardware and software tool visualising IMU data to provide concurrent feedback in the wild.

This contribution takes the form of a standardised protocol for IMU-based rider postural data collection, together with the development of a prototype hardware and software tool, incorporating data visualisation techniques appropriate for the presentation of concurrent feedback directly to the rider, whilst they are riding. Two alternative interfaces have been developed to determine rider preference for the visualisation to take the form of correction or feedback, evaluating these within a practical context.

Further contribution is present in the application of usability techniques and associated technology to understand the context of use, specifically the necessity to replicate human behaviour in analysing rider posture using an automated technology-based alternative. This contribution is a novel protocol for a customised version of contextual inquiry, appropriate for carrying out contextual analysis in the wild in situations where the participant is themselves engaged in observational activity.

The outcome of this PhD project is a novel tool to enable equestrian practitioners to develop a deeper understanding of the effect on the rider of their interaction with the horse. Such a system may ultimately be used as a coaching and screening tool for riders, providing feedback on performance and an automated early warning of potential injury risk.

A table showing the contribution to knowledge to be gained from each research question and objective is provided in Appendix A.

1.4. Methodology

Given the complex demands of the usage contexts, there was a need for a mixed methods approach, with appropriate methods selected for each phase of the research.

A detailed contextual analysis in the wild was necessary to confirm the tasks to be incorporated in a standardised rider assessment protocol, the necessary biomechanical factors to be obtained from the IMU data and appropriate functionality and visualisations to be included in software that will present meaningful results to the user. Due to the observational nature of the rider assessment process, the software requirements elicitation needed to be carried out in the wild, without interfering with the user. The challenge of carrying out an observation of a user who is themselves carrying out an observation of a third party is addressed in the method selected for the contextual analysis. Similarly, the evaluation phase was designed such that is it appropriate for carrying out in the wild to ensure the functionality and visualisations incorporated into the software tool are effective within the proposed context of use. Figure 2.1 provides a diagrammatical representation of the studies used to address the research questions and the methods used within each.

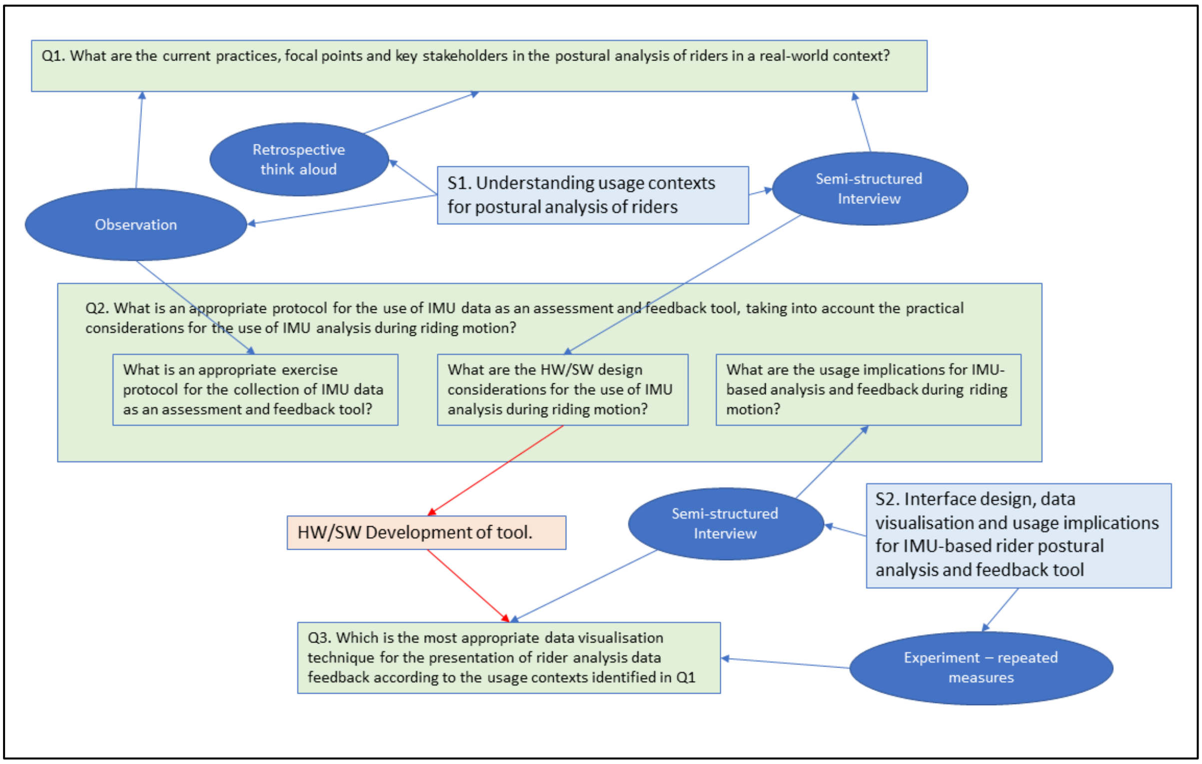


Figure 2.1. Studies and methods used to address the research questions.

The first phase of the project was to evaluate current practices for rider postural analysis in a real-world context. Study 1 (S1: Understanding Usage Contexts) identifies the contextual factors and requirements elicitation using customised contextual inquiry, incorporating a mixture of observational, retrospective think-aloud and semi-structured interview techniques. A representative sample of riders and coaches are included to ensure any differences between user groups are identified and accounted for.

Results of S1 determine requirements and identify appropriate data collection protocols and biomechanical measures. A prototype IMU/LED-based hardware and software tool was then developed using an agile development methodology, incorporating two alternative data visualisation mechanisms for rider posture feedback. Pilot testing was carried out throughout the development via a series of sprints, initially on the ground then moving on to testing while mounted on the horse.

The final phase of the project was carried out in Study 2 (S2: Interface design and data visualisation implications for rider postural analysis). The two LED feedback visualisations were compared empirically using a user-centred field-study with a crossover repeated measures design to evaluate the effectiveness of each interface design within the usage context of rider assessment and feedback. Independent variables are the variations in interface design techniques used in the visualisation interface and dependent variables are measures relating to usability and applicability of the design to its context of use. Quantitative analysis was carried out from postural data recorded by the tool and observational and semi-structured interview techniques were used for qualitative evaluation of usage within a riding context. The evaluation included environmental and practical considerations of the use of the tool alongside rider preference and empirical analysis of the effectiveness of the two interface visualisations.

A qualitative evaluation was also carried out from a personal perspective on the methodologies used and their implications for carrying out research in the wild.

1.5. Structure of the Thesis

Chapter 2 reviews the existing body of literature in the areas of the research questions and identifies gaps in evidence that demonstrate the effectiveness of interface designs, when applied to the postural correction of horse riders.

Chapter 3 discusses the scientific approach to selection of the methodology, supporting the choice of a customised version of contextual inquiry and field-based research as appropriate methods for this project.

Chapter 4 discusses the initial work carried out to understand usage contexts for rider postural assessment and feedback (Study 1), identifying key stakeholders, tasks and biomechanical measures used in an observational assessment of a rider's posture.

Chapter 5 discusses, from a software engineering perspective, the design, development and testing of the prototype tool. It includes both hardware and software considerations.

Chapter 6 discusses the method used for Study 2, to evaluate the interface design and data visualisation implications of using the prototype tool for rider postural analysis.

Chapter 7 presents the results of the comparative evaluation of the two visualisations incorporated into the prototype tool in Study 2. The results of both qualitative and quantitative analysis are provided.

Chapter 8 discusses how the results of the research have met the project aim and answered the research questions that were proposed. It then concludes by identifying the contribution to knowledge that has been made, both from a research perspective and implications for practice within the equestrian context. It also suggests future directions for this work, within equestrian and wider fields.

1.6. Summary

Current approaches to rider assessment and feedback are primarily subjective, carried out either via a coach or by video recording, viewed retrospectively. To address the potential injury risk to rider and/or horse or poor performance caused by incorrect or asymmetric posture, there is a need for a more objective and instant approach.

Research studies have demonstrated the potential for use of IMU sensor technology to gather data for rider postural assessment but have been carried out with restricted protocols, using complex, expensive technology. There is a research gap in identifying and evaluating appropriate technology to obtain rider postural data and provide feedback suitable for use in practical contexts. In particular, there is a gap in research into data visualisation techniques that are appropriate for providing dynamic feedback to the user while they are riding rather than retrospectively. To achieve this, there is a need to identify the key biomechanical measures required for postural assessment of the rider using IMU technology, to develop a tool that could be appropriate and cost effective to use in practical contexts and to determine an appropriate protocol for evaluating such a tool within its context of use.

The aim of this research is to provide equestrian practitioners with a computer-based solution to improve consistency and provision of feedback in rider postural analysis. The contribution to knowledge and novelty of the research is summarised below:

- The novel use of wearable technology, via a single IMU sensor to capture rider pelvic motion and concurrent use of LED technology mounted on the horse, to provide feedback.
- The provision of selectable dynamic data presentation mechanisms, providing the rider with a choice of either correction or feedback visualisation interface, utilising LEDs attached to the horse.
- The development of a novel method, using a customised version of contextual inquiry, within a field-based study, to obtain the observational data from the coach's perspective without interfering with their communication with the rider.

- Evaluation, via qualitative analysis, of the environmental factors and practical implications of fitting and using the prototype tool within the context of rider postural correction.

The existing body of literature in the areas of the research questions, to identify gaps in knowledge that will be addressed in this thesis, will be reviewed in Chapter 2.

Chapter 2. Literature Review

2.1. Introduction

This chapter focuses on addressing how the existing literature answers the question of what is the most appropriate protocol for the collection of rider postural data and provision of feedback to them, which can be used in a practical context to correct postural issues? In doing so, it seeks to identify the postural measures that can be used and possible correctional feedback visualisation interfaces. In particular, it aims to identify the gaps in knowledge that suggest the need for further study in order to define an appropriate technology-based protocol for rider assessment and feedback.

2.2. Background

2.2.1. The need for rider postural intervention

For those who participate in equestrian sports, the incidence rate for low back pain has been reported as 3-5 times greater than that of the general population, with rates reported as high as 85% (Lewis et al., 2023) and 81% (Deckers et al., 2021).

Further studies have focused on competitive riders, breaking down according to discipline, with 74% elite dressage riders reporting pain, 76% of which was in the lower back (Lewis & Kennerley, 2017); 96% of international event riders, 52% of which was lower back (Lewis & Baldwin, 2018); and 61% of showjumpers, 62% of which was lower back (Lewis, 2018). While these studies were carried out at single events with limited numbers of participants, they still indicate pain, particularly lower back pain, to be a significant issue. In addition, all of them report a greater than 55% of riders finding the pain affected their riding performance.

It is important for balance and stability that the rider is in synchrony with the horse and an asymmetrical posture, in addition to the negative effect on performance, can increase the risk of injury to both rider and horse (Nevison and Timmis, 2013). Asymmetry, together with muscle tightness that restricts range of motion, has been identified as a causal link to lower back pain (Cejudo et al., 2020a). Of the three studies reporting on rider pain in the three disciplines, all mention asymmetry but only the showjumping study (Lewis, 2018), specifically quantifies this as 45% of riders stating that the most common effect was on their postural asymmetry.

Historically, Symes and Ellis (2009) used video motion analysis to provide the first quantitative assessment of asymmetry in riders (n=17), confirming previously-held anecdotal beliefs. They attributed the asymmetry to rider leg length inequality combined with horse anatomical and gait asymmetry, concluding that further research was needed to both define asymmetry in riders and to develop suitable methods to reduce it.

Further studies investigating asymmetry in rider hip flexion (Gandy et al., 2018), pelvis motion (Clayton et al., 2023), knee flexion (Eckardt et al., 2014) and hip external rotation (Gandy et al., 2014) confirmed that asymmetry was prevalent amongst riders and identified a significant bias in directional asymmetry to the right. Hobbs et al. (2014) carried out a dismounted postural assessment of a large population of dressage riders (n=132) dismounted and found significant increases in both anatomical and functional asymmetry with number of years riding and level of competition, concluding that riders competing at higher levels of dressage are predisposed to an increased risk of developing asymmetry and subsequent chronic back pain.

Comparing studies is difficult due to the differences in gait and joint angles being measured, however, there does appear to be a general bias towards directional asymmetry to the right (Clayton et al., 2023).

Early studies were carried out statically and did not take into account any postural changes of the rider during motion, which impact on the angle of hip extension as the rider position alters dynamically through the different phases of the horse's stride cycle (Gandy et al. 2018).

There is a gap in knowledge here that can be addressed by this thesis, via a tool to help riders to address an asymmetrical posture dynamically whilst in motion.

2.2.2. Historical approaches to rider postural assessment

Much of the early research on horse and rider posture and asymmetry was carried out using video analysis (Byström et al., 2009; Kang et al., 2010; Symes and Ellis, 2009) or saddle pressure testing (Peham et al., 2010) but these techniques have limitations for use in practice. All these authors suggested the need for further studies and the need to find a method of measuring it accurately and consistently.

Research studies that include rider postural assessment include a range of assessment protocols, with variations in the gaits assessed and the actions performed by the horse and rider during data collection. Choices are made to reduce variables and focus on the particular research question to be addressed by the particular study, rather than the determination of an agreed protocol for assessment. This thesis proposes the development of a protocol for assessment that could be utilised in further studies to extend the data available, particularly using the tool to be developed, enabling the collection of a body of standardised data which could be combined across studies to increase sample sizes for future analysis.

Trot is the most common gait to be assessed but studies include a mixture of both rising (Gandy et al., 2014; MacKechnie-Guire et al., 2020) and sitting trot (Walker et al., 2020; Gunst et al., 2019). Gandy et al. (2018) compares the seated phase of rising trot with halt. Egenvall et al. (2022) investigate the motion of the pelvis in walk; and halt, walk, trot and canter are compared by Wilkins et al. (2020). The rider is assessed dismounted, compared to mounted, by Engell et al. (2019).

The majority of ridden studies assess the rider in straight lines but Gandy et al. (2014) additionally included circles as a means to compare asymmetry.

Studies using video analysis are necessarily restricted to straight lines due to the limitations of the technology, but it is perhaps surprising that more of the studies using IMU technology have not started to investigate a wider range of movements. This is likely to be due to the initial studies being preliminary in nature with a focus on confirming the effectiveness, repeatability and accuracy of the technique but there is also a need for assessment and feedback protocols to provide a more holistic view of the rider's posture and incorporate the full range of movements carried out whilst riding in the wild (Clayton et al., 2023).

This thesis can address this gap in knowledge via development of a tool which can be used to gather data and provide feedback to riders whilst free moving around the arena rather than being restricted to specific movements.

2.2.3. Assessing the rider in the wild

Riding is a very complex movement which is difficult to characterise due to the three-way interaction between horse, saddle, and rider. Movements of horse and rider influence each other and rider skill level is an important consideration, with a skilled rider disturbing the motion pattern consistency less than a novice rider, and a need for further research to determine approaches that can improve the education of riders and so improve horse welfare (Williams and Tabor, 2017).

There is a need to address the current lack of a standardised protocol for rider assessment and inconsistencies that exist between coaches, both in the factors which are considered important and in the interpretation of observational measures (Clayton et al., 2023). As mentioned previously the protocol proposed as an outcome of this thesis can help to address this lack of standardisation, particularly when used with the tool to be developed.

Subjective techniques used in the wild for rider assessment and subsequent feedback suffer a lack of consistency between assessors. Although historical, still of relevance is a study by Blokhuis et al. (2008), who found no statistical agreement between a panel of 5 experienced trainers and judges when assessing 16 deviations in rider seat position for 20 riders. They report differences in the interpretation of the terms "unbalanced seat" and "unstable seat", with some judges/trainers recording these riding faults interchangeably and others considering them to be equivalent. Variations were also found in the number of deviations recorded for each rider and bias towards particularly favoured deviations by each judge/trainer. Furthermore, a pilot study was used to identify the rider seat deviations with a subsequent focus group discussion between five judges resulting in the 16 deviations selected for use in the full study. Whilst the judges formed a homogenous group, which is considered advantageous for focus groups, caution was recommended on the use of this method in isolation due to the risk of bias and subjectivity (Khan et al., 1991).

A technology-based solution, as developed and discussed in this thesis, would remove the human perspective from the assessment process and enable a more consistent, accurate and objective postural analysis of the rider to be carried out in order to provide consistent and accurate feedback. To identify requirements for such a tool and software to support it, there is a need to carry out a contextual analysis of stakeholder requirements, to confirm the key factors that contribute to the assessment of rider posture and develop a protocol by which appropriate technology can be used to obtain accurate and repeatable measures for them.

2.2.4. Limitations of current methods

Although limited in quantity, much of the early research on horse and rider posture and asymmetry was carried out using video analysis (Gandy et al., 2014) and this is reflected in practice within the industry. Whilst much of the postural assessment of riders is carried out via direct observation by coaches, the use of video technology to support their practice is still common, particularly when riding without a coach present. Generally, this will take the form of a third party operating a hand-held video camera from the edge or external to the arena, although the development of commercial automated tracking cameras such as GoPro removes the need for the camera operator and has becoming more affordable and popular. Video technology enables the rider, either with or without the coach present, to review the coaching session retrospectively in order to observe their own posture both before and after adjustments suggested by the coach. This approach is popular and effective but does suffer from a number of limitations if used for more detailed scientific analysis of posture.

A systematic review by Hulleck et al. (2022) report that observational gait analysis is still popular amongst clinicians for reasons of simplicity, cost and availability but that this is being questioned due to issues with validity, repeatability, specificity and responsiveness. Marker-based optical motion capture (Mocap) in clinical settings provides high accuracy and reliable data but has limitations with operating factors such as infrastructure, non-portability, cost, setup and calibration time, operational complexities and the requirement for indoor settings.

A key disadvantage of optical motion cameras for equestrian use is the limited field of view (Greve and Dyson, 2013a), restricting analysis to straight-line capture or very short view in the sagittal plane whilst passing the camera on a circular path. A wider field of view is possible using multiple camera systems, but these are expensive and lack portability, making them difficult to utilise within a riding arena, so impractical for use beyond research studies. Parallax errors are also present and need to be corrected for. Research has been successfully carried out with ridden horses on an equine treadmill (Byström et al., 2021) but this technique is unsuitable for use in the wild, limited by the restricted availability of such equipment, the necessity for the horse to be experienced in working on a treadmill and the high experience level required of the rider. The natural gait, speed, tempo and symmetry of movement was also found to be compromised (Peham et al., 2004).

Accuracy of optical motion analysis relies on correct placement of biomechanical markers (Colyer et al., 2018) meaning that the reliability of any assessment would be dependent on the availability of a suitably trained practitioner to apply the markers. It is also critical that the markers remain reliably in position, however, keeping them attached to horse and rider during motion is difficult due to the effects of dust and sweat on adhesive attachments. Automated motion tracking via reflective markers is provided in software tools such as Dartfish™ but was found to be problematic in environments with inconsistent light levels and cluttered backgrounds (Garcia-Garcia et al., 2020), common features of riding arenas. Another limitation is that parts of both horse and rider's bodies may be hidden from view, restricting the analysis that can be accurately performed (Greve and Dyson, 2013a).

These limitations of current methods show a gap in knowledge which can be addressed by the tool to be developed in this thesis.

2.2.5. Physiotherapist involvement

Physiotherapy has become firmly established at elite and higher levels of competitive equestrian sport but there is a need for more widespread physiotherapist involvement in the postural assessment and education of grassroots and leisure riders Dyson et al. (2015).

Whilst historically, few research studies into rider posture included any form of physiotherapy assessment, later studies including a dismounted assessment of rider posture do exist (Hobbs et al., 2014; Nevison and Timmis, 2013). This indicates an increasing awareness of the importance of addressing rider anatomical issues that may either affect or be caused by riding.

Physiotherapist intervention is an integral component of elite rider development programmes (British Equestrian Federation, n.d., b), with a focus on prehabilitation and the prevention of injury rather than rehabilitation. The British Equestrian Federation (BEF), through its Long-Term Participant Development Framework (British Equestrian Federation, n.d., a), recognises the importance of physical development, in particular symmetrical movement patterns, from an early age (5-9 years). The framework provides greater focus on specificity of postural training as puberty is reached (approximately 15 years), with the introduction of musculo-skeletal screening. For those reaching the "Training for Excellence" stage of athlete development into adulthood, interventions to monitor and sustain body alignment, functional stability and mobility are recommended, with the focus on prehabilitation and recovery to ensure optimal performance. At this stage the necessity for medical and regeneration support is also emphasised.

There is also a need for trainers to pay greater attention to rider "crookedness" (Greve and Dyson, 2013b). In a sample of 276 riders, 103 (37%) were found to sit crookedly, with 62 (60%) of these riders reporting previous injuries. Some riders were unaware of their crookedness, despite regular training. The authors recommend that riders are assessed for physical and postural asymmetries by a physiotherapist so that any predisposing issues can be addressed.

Dyson et al. (2015) recommend the use of specialised postural assessment of riders, carried out by a physiotherapist. Such assessments may be performed dismounted or with the aid of a mechanical horse, enabling the physiotherapist to prescribe a customised exercise programme which will address particular postural asymmetries and limit the injury risk for both horse and rider.

Within other sporting contexts such as running and cycling, location is less of a limitation than in the equestrian disciplines. The use of a treadmill or cycling turbo trainer at the physiotherapist's location means that sport-specific biomechanical screening can easily be incorporated into a physiotherapy session, meaning that costs and time can be kept to a minimum and such a service is accessible to grassroots as well as elite athletes. For a physiotherapist to assess a rider in the wild, it would be necessary for them to travel to the riding venue, which is not always practical and increases time and therefore the costs involved. Whilst it would be possible to carry out assessment using a mechanical horse (Dyson et al., 2015), such systems are expensive and only currently available at a limited number of specialised equine physiotherapy clinics, so this would not be a practical solution for more widespread inclusion of physiotherapy into riding postural assessment. Their motion, and thus the rider kinematics, have been found to be different to that of a real horse, with a 70% higher displacement in the medio-lateral axis on the simulator (Clark et al., 2021).

Development of a technology-based rider postural assessment tool would enable data collection to take place in the wild without the physiotherapist present and then reviewed later in the presence of the physiotherapist via customised software. However, this would be an expensive approach for the grass-roots rider, so an alternative consideration is whether any automation can be incorporated into the data analysis, a feature which could provide assessment feedback and coaching cues to the rider, without the need for a physiotherapist to interpret the data. The tool to be developed and evaluated in this thesis can fill this gap by providing direct feedback to the rider during the time they are riding.

2.2.6. Preliminary use of IMUs on riders

A number of preliminary investigations with riders indicated that IMU technology provided a practical solution for postural analysis.

Münz et al. (2013b) analysed pelvic rotations in the anterior-posterior and lateral axes at walk, rising trot, sitting trot and canter. Results showed good intra-rata repeatability of the technique but identified inter-rata variability, when considering two riders on the same horse. A further study (Münz et al., 2013a) used individual inertial motion sensors to investigate the dynamic interaction between rider pelvis and horse, comparing professional level riders with beginners. This study reported a greater tendency towards anterior pelvic rotation in the beginner rider group in walk, sitting trot and canter gaits.

Eckardt et al. (2014) extended the work of Münz et al. (2013b), using a full-body inertial measurement system (Xsens™ MVN) to capture kinematic data for the head, trunk, pelvis, elbow and knee of the rider during sitting trot. They confirmed both the intra-rata repeatability and inter-rata variability of the method for a larger sample size (n=10). Gandy et al. (2014) used the Xsens™ MVN motion capture system to measure rider hip rotation asymmetry in both straight lines and circles (12 horse and rider combinations, 7 individual riders). Both studies found the technique to be efficient and practical, enabling the assessment of riders to be carried out during dynamic motion, with potential to further advance the analysis of horse and rider interactions within more realistic training and competitive environments.

However, limitations were reported (Gandy et al., 2014) in the time-consuming process of manual extraction of CSV files from the XML data exported from the MVN Studio™ software, a step which was necessary to carry out statistical analysis. The authors suggest that the development of customised software to automate this process would significantly reduce analysis time for future research studies and this could further provide a tool which could be used by practitioners within the equestrian industry.

This is not a new problem, or one that is specific to rider assessment or the use of IMU technology. An early review of pervasive technologies in sport (Baca et al., 2009) refers to the potential conflict between advancement of technology, which often requires highly skilled and knowledgeable operators, and the development of feasible methodologies for use of such technology within practical sporting contexts. Gandy et al. (2018) quantified the improvement in data extraction time by automating the analysis of hip flexion and pelvic posture, via the use of a specially developed C# software tool but this was still only used for retrospective research purposes rather than the provision of direct concurrent feedback to riders whilst mounted on the horse.

Although these, and later studies have confirmed the potential for use of IMUs in the postural assessment of riders, there is a lack of consistency in the biomechanical measures considered, focusing on differing small subsets of body segments or joint angles (Egan et al., 2019). Further research is required to determine the most appropriate method of capturing the necessary data to present a visualisation of the postural assessment results to the user, a gap which could be filled by the knowledge gained from the proposed tool and discussion in this thesis.

2.2.7. Historical Biomechanical Measures for Rider Assessment

This section addresses the question "What are the key biomechanical measures that need to be included the analysis component of a rider postural assessment tool?", investigating current practices for rider postural assessment both mounted and dismounted. In particular, we aim to identify whether the existing literature can provide us with evidence to support the choice of biomechanical measures to be included in a technology-based tool for rider assessment or whether gaps and inconsistencies in the literature indicate that there is a need for further investigation.

There is general agreement that pelvic kinematics, referred to in the riding context as the "seat", is an important measure since it provides the interface with the horse (Izzo et al., 2020). However, a range of other biomechanical measures have also been studied, as previously mentioned in Section 2.2.1.

When assessing riders in a practical context, it is necessary to take a holistic approach and consider the multitude of factors influencing the rider's ability to attain the "correct seat" and posture, to enhance performance and reduce injury risk. There is a need for further scientific research to develop an objective assessment method, ensuring that all factors are incorporated (Clayton et al., 2023). The development of a technology-based solution to automate rider assessment and provide a visualisation of postural issues would require consideration of these factors, providing a standardised assessment protocol to ensure consistency of data comparisons.

Despite the general lack of consistency between coaches and limited scientific research on correct rider posture, there is some agreement amongst coaching practitioners on key visualisations to assist riders in achieving a correct and effective riding posture.

Perhaps the most widespread postural visualisation referred to by practitioners is the "shoulder-hip-heel line". That is, if a straight vertical line can be drawn from the rider's shoulders, through the hip, to the heel (Figure 2.1), they are more likely to be in balance, with an effective posture that the horse is better able to carry (Walker et al., 2020).

Figure 2.1. Shoulder-hip-heel line. (Dove and Wanless, 2015).

However, even the visualisation of shoulder-hip-heel suffers from a lack of consistency in terms of the exact positioning of the line through the ankle joint or back of the heel and pragmatic decisions may also be necessary to take account of any limitations within the chosen technology to identify and record specific joint positions. For example, the Xsens^{TM} IMU motion capture system records ankle but not heel position.

As discussed earlier, asymmetry has been identified as a key factor to be considered in the postural assessment of riders. The use of specially marked clothing, for example the Centaur Biomechanics "Visualise" jackets and "Symmetry Marker Set" for attachment to the horse (Centaur Biomechanics, n.d.), provides visualisation of the rear-view symmetry but this relies on correct alignment of the clothing and is obviously only visible to a coach whilst riding or via video for retrospective feedback (Figure 2.2).

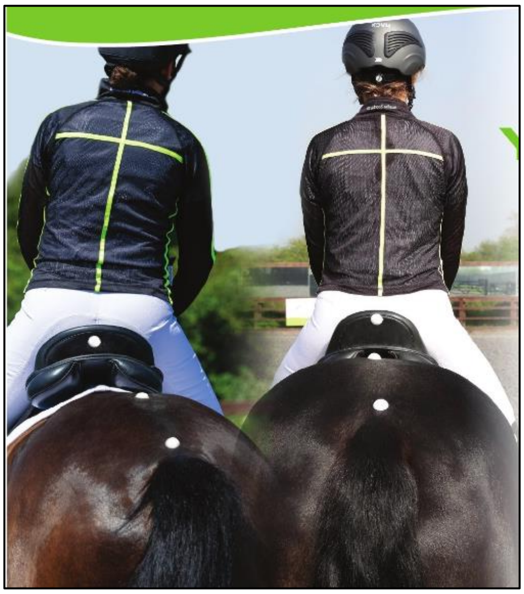


Figure 2.2. Visualise jacket and horse markers (Centaur Biomechanics, n.d.).

The gaps in knowledge and limitations of the rear-view symmetry tools, only visible to a coach or retrospectively, can be addressed by providing direct feedback, visible to the rider as in the proposed tool to be developed and discussed in this thesis.

2.3. Feedback Mechanisms

In answering the question "What data visualisations are most appropriate for providing feedback to the user, within multiple contexts of use (coach and rider)?", we need to consider not only the elements of the biomechanical assessment to be included in the visualisation but also the theoretical aspects of data visualisation, in particular, those appropriate for providing timely and context-appropriate feedback in the wild.

The wide range of visualisations identified for tools used to support biomechanical assessment in other sporting and health contexts means that we need to consider carefully the type of data visualisations that will be most appropriate for the proposed context of use. More specifically, we need to fully understand the implications of providing a software tool that will be used in the wild.

Egidi & Sillari (2020) discuss theories that can be applied to understanding real world behaviour, in particular that of bounded rationality, which considers how humans can make "reasonable" decisions within constraints of time, information and computational ability. This theory, and its application within the design and evaluation phases of the prototypes to be developed, may be of particular relevance to this study since the assessment of riders is often carried out under limited time pressure, with a commercial riding session lasting typically 30-60 minutes. The time to review the results of the assessment with the coach would need to be incorporated into this time period and therefore the design of any software to present the results to the user would need to take this into account.

Bounded rationality includes "fast and frugal" heuristics for interface design focused on providing only the salient information that can be presented in context. As discussed in detail by (Gibbons & Stoddart, 2018) with regard to clinical decision making in accident and emergency departments, fast and frugal heuristics rely on a one-reason making decision process and most useful in situations where there is a single factor that is considerably more important in the decision making process than other factors. They have been shown to outperform the model of combining factors using additive weightings, supporting the view that the human mind has evolved to make quick decisions based on a few important cues, ignoring other information. We have already seen that, to obtain a holistic assessment of a rider's posture, we need to consider a large number of factors and this would point towards use of the weighted additive model. However, the time efficient benefit of bounded rationality means that we should consider whether it is possible to incorporate algorithms into the proposed rider postural assessment software that could automate the data analysis and combine the factors into one simple visualisation that has the desired impact. The proposed tool to be developed and discussed in this thesis can address this gap.

Todd et al. (2013) discusses the challenges of designing persuasive technology to modify shopping behaviour, via the provision of information displays placed on the trolley. They describe supermarket shopping as a high time-pressure activity and, whilst the context is different, we may be able to apply some of their recommendations to rider postural assessment due to the similarities in requirements for presentation of information to the user in order to modify behaviour. Key elements of their discussion surround the use of colour (red or green) to indicate the value of the contents of the trolley on the dimension of interest (e.g. fat content score below a particular value or population average). Within the context of rider postural assessment this could be equated to, for example, asymmetry beyond a pre-determined value. In a suitable riding arena, with availability of display equipment, such a system could be used to provide instant visual feedback.

Of 34 studies reviewed by Adesida et al. (2019), 26 took place in the field but only two provided real-time feedback and coaching cues to the athletes: auditory feedback given to runners (Wood and Kipp, 2014) and the ISWIM system providing haptic (vibration) feedback to swimmers (Li et al., 2016). They conclude that audio or haptic feedback is most suitable for feedback which enables athlete to focus on movement and/or environment, with visual feedback via a smartphone being more appropriate for coaches. However, none of the studies discussed cover non-screen-based visual feedback, so there is an opportunity for further research in this area.

2.4. Equestrian Contexts

Izzo et al. (2020) used IMU technology to measure the impact and compression on the lumbar spine, comparing walk, trot and gallop, although it is likely that this is a language translation which in reality refers to canter. Their findings indicated that trot and gallop were risk factors for spinal injury, which accounts for 5-15% of riding injuries, suggesting that riders should adapt their training routines to incorporate strengthening of the muscles supporting the spine.

In a comparison between professional and beginner riders in sitting trot and left canter, using a full body IMU system on the rider plus an additional sensor on horse girth to identify trunk movement, it was found that, in roll (forward/back), there was no significant difference between skill level of the riders but, in pitch (left/right), the greater the rider measure from the horse trunk the lower the correlation between beginner and professional, with it supposed that this is due to the professional riders being better able to move with the horse (Eckardt & Witte, 2016). This indicates that beginner riders could benefit from a tool, such as that to be developed and discussed in this thesis, providing feedback on lateral postural feedback.

Hobbs et al. (2023) used IMU technology to investigate the postural factors in the rider which contribute most significantly to judges' scoring of dressage tests, with sensors placed on the rider sacra (recording pelvis motion), rider thorax (T8), horse poll (between the ears), between the horse tuber sacral (hips), and over the horse lumbar region behind the saddle. They found that the most aligned riders who had more symmetrical trunks contributed positively with judges scores for the horses' gaits and that pelvis symmetry contributed positively with judges scores for rider position and effectiveness of the aids. The correlation between rider alignment and horse gait indicates that our proposed tool could have a positive effect, not just on the rider but also have an impact on the welfare of the horse, if the rider's posture could be more stable and symmetrical. This study also indicates that training with the proposed tool could benefit competition riders.

Although the study by Hobbs et al. (2023) was carried out by advanced level riders on advanced level horses, the movements included in the dressage test were those at a lower level, specifically collected walk (just from centreline to left rein), trot and canter in both directions plus transitions from extended trot to collected trot in both directions. They did not include any circles or the more advanced movements normal covered within the dressage tests for their level. This does, however, indicate that the simplified protocol for evaluation of the proposed tool to be developed and discussed in this thesis may be sufficient, although it could be argued that the inclusion of at least circles would add additional insight into the results.

Wang et al. (2018) also used a basic protocol, carrying out their data collection just around the outside of the arena, in walk and rising trot. This study compared beginner with professional riders, using bespoke IMU sensors placed on the head, chest, pelvis, upper and lower arms, thighs, and calves. A comparative analysis with an optical marker-based camera system (Polaris) was carried out to validate the system.

Cejudo et al. (2020b) carried out the first study investigating lower back pain in child equestrian athletes and found that, although a higher body fat ratio of 23% or more was the greatest predictor, lateral asymmetry was higher in the lower back pain group. They conclude that it is important to educate riders at a young age to reduce asymmetrical posture and the proposed tool to be developed and discussed in this thesis could provide a useful aid for child athletes, introducing a gaming aspect to riding lessons.

Haitjema et al. (2022) used eight IMUs placed on feet, lower legs, upper legs, pelvis and sternum, to investigate peak acceleration and calculate shock attenuation values for feet to lower leg and pelvis to sternum, in walk, sitting trot and canter. Their protocol for data collection comprised three circuits of an area in each gait, both with and without stirrups. Results showed that there was a decrease in attenuation values from pelvis to sternum in sitting trot, indicating an increase in shock to the torso and they conclude from this that it could be an indicator for lower back pain prevalence in riders. As in other studies, they highlight the need for postural correction and the need to address postural stability in riders to avoid risk of injury.

Stapley et al. (2020) provides an example of a wearable device in a research study evaluating pressures and rider joint angles for a range of stirrups, using a pressure sensor (Loadpad, Novel, St Paul, MN) connected wirelessly to an iPhone strapped to the rider's arm. The pressures exerted further support previous research in identifying rider asymmetry.

Looking to the future, there is potential for the incorporation of automated gait detection using feature extraction with machine learning models. A feasibility study (Casella et al., 2020) has demonstrated this via a Fitbit Ionic smartwatch mounted on the rider's wrist, providing both retrospective and concurrent feedback but at this stage is limited to presenting on the watch the gait being executed. The Fitbit watch does not provide storage of raw data but it does provide an API to enable direct communication with the watch via JerryScript "JavaScript engine for Internet of Things" (JerryScript, n.d.). The proposed tool to be developed and discussed in this thesis could be expanded in the future to address this limitation.

Thawinchai et al. (2020) carried out a feasibility study on the use of IMU technology to compare differences in trunk and pelvis kinematics between children with cerebral palsy (CP) and a control group without, whilst carrying out ridden therapy. They found differences that indicate the potential for use in the diagnosis and monitoring of the success of such therapy for the children with CP. This study performed retrospective analysis to investigate the differences but did not provide feedback directly to the riders. It does suggest there could be an opportunity for potential use of the proposed tool, in the delivery of feedback to riders with disabilities, to aid in equine assisted therapy.

Not yet peer reviewed or formally published, Pöhler and Van Laerhoven (2024) have produced a prototype system comprising open-source hardware and software components, which can identify the horse gait, plus detect and separate subtle movements of horse and rider to analyse interaction between them. The system comprises 10 IMUs placed on the rider's wrists, ankles, waist, head and the horse's legs (knees and hocks), combined with a PIXEM video camera to label the rider motion for input to classification models or further analysis using OpenPose software. The sensor data has been used to successfully train Transformer-based human activity recognition models, one for the basic gaits of walk, trot, canter and jump; the other for basic dressage movements. With testing so far limited to just two horses and riders, the authors recognise the current limitations of the system but they mention its potential for providing valuable postural feedback to the rider, however, there is no mention of the form such feedback would take or whether it would be concurrent or retrospective.

While many of these papers identify postural issues in riders and suggest that the use of IMU tools have potential to provide feedback to correct these or increase rider awareness of the issues, there is a gap in the literature when it comes to studies which provide such feedback or even suggest how this might be visualised. Of the studies discussed here, only Casella et al. (2020) includes a feedback visualisation and this is limited to identifying the gait of the horse as a prototype. The proposed tool to be developed and discussed in this thesis can therefore help to fill this gap but we need to consider other contexts to identify feedback or correction types and visualisations that may be appropriate for rider postural correction.

2.5. Comparative Contexts

Due to the limited number of studies on protocols and biomechanical measures for horse rider postural analysis, together with a lack of research on rider feedback methods, it is useful to carry out a wider review of the literature available within other contexts, particularly those relating to other sports and health. This section continues to address the question "What are the key biomechanical measures that need to be included the analysis component of a rider postural assessment tool?" but the focus turns more towards the feedback and visualisation aspects of rider assessment by focusing on the third of our key questions "What data visualisations are most appropriate for providing feedback to the user, within multiple contexts of use (coach and rider)?"

Although now dated in terms of the technology available for review at the time, Baca & Kornfeind (2006) provide three considerations for the use of biomechanical methods for technique and performance analysis that are still as important today. Namely: the need to establish accurate measurement systems for a precise set of parameters; the use of specific technique parameters; and minimal interference between the measurement system and the athlete.

Despite the lack of scientific evidence for the effectiveness of particular feedback mechanisms in commercial sensor-based tools, we can still gain useful insight by reviewing such tools and techniques used within these alternative contexts. In particular, we will review biomechanical assessment and feedback approaches used within scientific studies and those provided by commercial products.

A scoping review of equine gait analysis from 1978-2018, to identify future opportunities and barriers to equine gait analysis identified 13.5% of 510 articles included use of wearable technology plus 4.9% using IMUs in combination with alternate tools (Egan et al., 2019). They conclude that application frameworks based on wearable technologies are not well reflected in current literature and are therefore an interesting opportunity for future research, particularly supported by findings from human movement analysis. They also found that transition of evaluation systems to applied use is slow and challenges facing the use of wearables includes lack of software interfaces to support the needs of end-users. They indicate that the equine industry can learn from sports technology experience by using an interdisciplinary approach to promote user-centred design of easy-to-use software systems which are fit for purpose.

2.5.1. Medical/Health

Although historical and a single case study in a clinical setting, Ladha et al. (2016) demonstrated the feasibility of using low cost, fully open-source components via development of a Raspberry Pi-based and gyroscope tool used for gait assessment. Their algorithms were developed and tested initially in MATLAB but, due to cost and licencing constraints, open-source scripting language is used to analyse data directly from device. Analysis was carried out using Python selected for portability across different platforms. On completion data was analysed on the Pi and results transmitted via Wi-Fi to a server for retrospective viewing via browser. The data collection component of this system could be used as a basis for concurrent feedback in our rider tool, with the results transmitted to a more portable visualisation display mechanism.

Foltyn et al. (2018) highlight the issue of accessing the embedded code to control data acquisition and processing within commercially produced systems, necessitating the development of a custom tool for their multi-purpose human movement analysis sensor. This issue is also relevant for the development of the rider tool, with the need to develop customised feedback visualisation software for the purposes of the research and to address the potential conclusions as they could be used within a practical context. Their microcontroller software was written in C, with PC-based wireless configuration, data monitoring and storage controlled using a C# application, written in Visual Studio 2013. Data files provided a choice of either CSV or tab separated .TXT, with a facility for .XML-based offset calibration file storage, meaning multiple hardware devices could be controlled using the same software.

Hulleck et al. (2022) gave advantages of wearable sensors as being low cost, do not require specific operational space so can be used indoors or outdoors, and have reduced setup and calibration time. They balance this with limitations of the algorithmic requirements to combine the multiple sensor data with the need to account for drift bias and positional accuracy. Moving towards more emerging technologies, they found that computer vision marker-less gait detection is increasingly being investigated for sports and clinical biomechanics scenarios (Ardalan et al., 2021, Rupprechter et al., 2021, Li et al., 2019). Advantages are that they can reduce the number of cameras required, can incorporate moving cameras and can be used in diverse environments. However, these techniques are in the very early stages of research and there is a need for further work to determine accuracy and practicalities of field-based use.

While many of the research studies perform assessment and visualisation to provide feedback, others provide instructional visualisation with the aim of achieving correctional adaptations to the gait or posture, something we wish to achieve within the proposed rider tool. An example of correctional visualisation can be found in Collimore et al. (2023), who developed an audio-based autonomous system for rehabilitation of stroke patients at home. The system comprises IMUs placed on each shoe to record gait patterns, with music provided via headphones, customised to start with their current gait, increasing over time to achieve a faster more symmetrical gait.

A key decision for the proposed rider tool is whether to provide concurrent or retrospective feedback. Ferris et al. (2022) performed a direct comparison between concurrent and retrospective visual feedback, specifically targeted towards balance exercises in older participants, using a cross-over design. Visual feedback was provided on a screen 10ft from the participant with the centre approximately level with their eyes. Display was via a stabilogram plot of x=Medio-lateral, y=anterior-posterior sway angles with the concurrent feedback provided as a single dot/curser showing position. Retrospective feedback was provided as a trace of the full motion during the test. Participants were given instructions as to what the plot represented but no instruction on how to interpret or apply the feedback. Concurrent feedback resulted in an increased number of rapid corrections whereas retrospective feedback resulted in smaller, slower corrections. The conclusions drawn were that concurrent feedback accelerates training because errors can be corrected immediately whereas terminal feedback has less immediate improvement. However, in non-feedback trials carried out immediately after the training sets, the learning effect/improvement was greater for retrospective feedback, indicating a better retention of learning.

Contrary to the findings of Ferris et al. (2022), Yamamoto et al. (2019) found that, for participants identified as low-skilled in motor learning, only concurrent feedback produced retained improvement 24hrs after the original test. The test was to adjust the load provided by one limb onto a force plate at 1Hz intervals in response to sound. Three lamps (green, blue, red), displayed on a 21-inch monitor placed 1.5m from participant, were used to indicate when the load was within 2% either side of 55%, 65% and 80% of weight applied. The low skilled group with concurrent feedback improved to the level of the higher skilled group during practice trials but didn't improve retention during the post-test. One reason for this is suggested that the lamps just provided an indication of successful load (discrete feedback), so when unsuccessful they weren't provided feedback as to what the load was meaning, which made learning difficult. A recommendation from this study is that visual feedback should be designed to provide a suitable interface to improve performance during practice, using continuity of visual feedback.

Another choice for the rider tool is between the provision of a visualisation that provides feedback on their current posture or some form of correctional interface. Lawrence et al. (2022) developed a 3D printed cervical collar for neck posture correction, providing both haptic and visual feedback when the angle exceeds a specified limit, for example when using a smartphone. A gyroscope was inserted into the collar to record the angle of the neck and the haptic feedback was provided via a coin vibrator placed in the acupressure point of Heaven's pillar (nape of the neck). If the wearer maintained a poor posture for more than 5 minutes and exceeded a threshold neck deviation angle, an alert was sent to the app to provide visual feedback, although the format of this was not specified. The feedback is used as a correction for the purpose of educating the wearer and stops vibrating when the neck returns to within the limit angle.

Placement and attachment of the rider tool is an important consideration to ensure accuracy and reliability. Rispens et al. (2014) used an elastic belt as attachment and compared repeatability of walking in three positions: the lower lumbar spine (L5), middle of the lumbar spine (L2) and on the front hip at belt height (the anterior superior iliac spine, ASIS). They found that placement on the lumbar trunk was repeatable and robust to changes in position between L2 and L5 provided it was placed centrally, but that ASIS was not. This indicates that placement on the lumbar trunk, secured with a Velcro strap would be a candidate position and attachment mechanism for the rider assessment in the medio-lateral orientation. Del Din et al. (2016) supports this, indicating the gold standard of device placements as being L5 and that, for gait analysis, moving to other locations, e.g. waist or chest, affected algorithm results. Ferris et al. (2022), however, used an elastic belt with an IMU sensor positioned over L3 in their study on standing balance in older adults.

2.5.2. Sport

Tate and Milner (2017) used a decibel sound intensity meter, providing a visual representation on an iPad to evaluate effect in reducing ground reaction forces in runners. Participants attempted to reduce sound intensity while running on a treadmill.

Van den Berghe (2022) developed a similar system to Collimore et al. (2023), this time to reduce peak tibial acceleration in runners, with a view to providing a biofeedback system that can be used in the wild, not restricted to a lab setting. System comprised an IMU in a strap around the ankle.

Although historical, early studies demonstrated the effectiveness of both visual (Crowell et al., 2010) and audio (Wood and Kipp, 2014) concurrent feedback to reduce impact acceleration loading while running on a treadmill.

Despite their age, these studies are useful in considering methods of delivery for the proposed rider tool. Wood and Kipp gave an audible "beep" when an IMU peak positive acceleration (PPA) value reached a specified threshold. The pitch of the beep was scaled according to the difference between the threshold and the peak value achieved enabling the runner to adapt their running in response to the feedback.

Crowell et al. provided visual feedback comprising a motion trace with a solid blue horizontal line at 50% of the mean of the peak stride values achieved during an initial baseline capture. Runners were instructed to attempt to keep their trace below this line. A limitation was that only five participants were used. Three of them reduced their PPA values during feedback and this remained once feedback was removed, with one continuing to reduce after feedback stopped. One participant increased during feedback but then reduced during the post feedback period, although not to the same level of reduction, with reasons suggested that they were trying to find a strategy to adapt the running and attempted an unsuccessful strategy during the data collection period. One participant failed to reduce significantly but it was suggested that additional interventions such as shoe orthotics or a longer period in which to practice (they were given 10 minutes) might be confounding variables.

These studies provide useful considerations for the rider tool in respect of ensuring the visualisation chosen is based on thresholds customised to the individual rider during baseline data collection and that they are given time to practice before completing the testing phase.

Visual feedback in the form of animations of a bud opening to a full rose and back to simulate an abdomen and an umbrella opening and closing to simulate a chest used by Passafiume et al., (2022) were used to investigate the influence of visual feedback on training for breathing during treadmill running to exhaustion. The protocol used was a five-minute warm-up without feedback or instruction followed by one minute of rest, during which the animation was displayed for the group where feedback was to be provided and breathing instructions given, before running to exhaustion. Two tests were carried out at least one week apart with the visualisation provided only on one (randomly allocated). Results did not reveal significant improvement in breathing efficiently and this was considered to be due to the lack of time to practice, learn and adapt to the new breathing techniques and visualisation. It could be argued that this visualisation interface was simply instruction rather than feedback or correction and that a concurrent display of the animations while running, similar to meditation breathing techniques, would be more effective. This indicates that the proposed rider visualisation method should be applied while riding rather than retrospectively.

Other visual feedback animations found in tools which used camera systems on treadmill foot strike angles were a red circle on a horizontal axis, which participants were instructed to keep within a white bracketed area along the axis (Baggaley et al., 2017) and a clock with a red pointer which is set to the actual angle, with a green wedge indicating a 2.5 degree target range for either toe in or toe out from the ideal angle (Mousavi et al., 2021). The pointer updated on each stride and the participant was instructed to keep this within the green range, providing positive feedback but if they deviated outside of this range then the colour changed to red to provide negative feedback.

Commercial tools, which have been validated for running gait analysis include the Garmin Running Dynamics Pod (Garmin & subsidiaries, n.d.), comprising a single sensor which attaches to any waistband via a clip. An example of its use outside of the laboratory was provided in Lim & Mercer (2021), investigating differences in running parameters at a range of stride frequencies in overground running.

Although historical, the findings of Spelmezan et al. (2009) are still relevant in providing a comparative analysis of different concurrent feedback approaches, comparing tactile with audio feedback whilst snowboarding in the wild. This study found that both techniques were accurately recognised but that tactile instructions, received through vibration motors placed on relevant parts of the body, elicited a quicker response from the participant than audio feedback. Despite this, some limitations were identified such as the strength of the vibrations, identification of the tactile patterns and inappropriate timings of instructions, the latter specifically being reported as an issue for more experienced snowboarders.

In cycling, a range of techniques are employed for the assessment of bike fit and cycling position, including motion analysis using either 2D or 3D optical motion capture technology.

One such commercial example is the Retül Vantage 3D Motion Capture System™, which captures data dynamically with the cyclist mounted on a stationary bike fixed to a turbo trainer. This system is based on similar technology to the Microsoft Kinect™ but the range limitation means that it would not be feasible to use such technology with horse riders in the wild.

Brouwer et al. (2020) investigated the accuracy of a wireless IMU system for trunk motion in four specific dynamic motions used in four sports (golf- swing, one-handed ball throw, tennis serve, baseball swing) compared to a gold standard 12 camera Vicon system, with one IMU placed on the pelvis and one on the trunk at spinal vertebrae T1. Results found a reasonable accuracy of within 5 degrees in all measures and a "very good" to "excellent" similarity to the optical motion analysis. The study concludes that this is sufficiently reliable for non-lab-based sports performance, rehab or prevention of sports injury usage contexts.

In addition, they recommend that after calibration, the participant should remain stationary for three seconds to allow fusion algorithms to compute accurate orientation estimates before commencing motion. This is something that will need to be addressed in the proposed rider study, with the risk of horse motion being a potential limitation.

Incus Nova (Incus: Nova, n.d.) is a commercial wearable body sensor, placed on top of spine at the back of the neck, inserted in special clothing. Control is provided via a smart watch (requiring GPS) but it synchronises to the cloud for retrospective feedback via an iPhone or Android app. Software visualisation is customised for runners, cyclists and swimmers but no option is available for horse riders. The proposed rider tool would address this gap.

2.5.3. Industrial

Coulby et al. (2020) reviewed hardware/software technologies used for IoT based monitoring of gait within home environments. They referred to the historical use of Raspberry Pi devices with manual data download to analyse in MATLAB, more recently being replaced by customised devices (in this case using Arduino-based embedded systems) which can run analysis directly onboard the device using Python or Octave.

Lind et al. (2020) trialled a Smart Workwear System comprising an IMU placed on the upper back, sending a signal via Bluetooth to an Android mobile device which provided vibrotactile feedback to the sternum with stock pickers in a motor manufacturing plant. Positive feedback was received, although there was a need for size to be customisable for comfort.

The same system was later used in a usability study to assess whether such a device could be useful for improving the posture of manual sorting activities (Lind et al., 2023). Results showed that during and immediately following feedback there was reduction in time spent in bad posture but this improvement was not retained over a medium or long term. This contradicted a study by Kamachi et al. (2021), who tested an auditory feedback system on lumbar spine angle on care workers and found a retained improvement 2 weeks and 2 months after feedback.

Lim & Yang (2023) investigated the use of feedback provided via vibrations while completing three construction tasks. This system comprised 4 IMU sensors placed on T6, right thigh, right shin, dominant wrist, using software written in Python, with an interface using HTML/JavaScript. Qualitative results found that feedback does not need to be provided to the target area i.e. feedback on the wrist was effective when the postural issue was the back. This indicates that it isn't necessary for the proposed rider tool to provide the feedback directly to the area of the body being assessed.

In making the choice between provision of concurrent or retrospective feedback for the proposed rider tool, it is useful to consider the likely benefits in terms of longer-term learning taking place. Concurrent feedback obviously has an immediate effect, which could be combined with a longer-term learning effect, whereas retrospective feedback can only be of benefit if it produces a longer-term learning effect.

Kamachi et al. (2021) tested a concurrent auditory feedback system on lumbar spine angle with care workers. Based on the principle used in vehicle lane departure systems, an intermittent audible sound was delivered at 20% below threshold and continued until the threshold, at which point it became continuous. All participants were novice care givers, to replicate real world training, and use of the system was combined with a video shown prior to testing, demonstrating tasks, plus watching an experienced care giver carrying out the tasks. Participants were split into a trial group who received the audio feedback and a control group who received just the video and watched the experienced caregiver. Trials of working without feedback, with feedback for 1hr (control group had no feedback) then without feedback were carried out on two consecutive days with 100% feedback on day 1 fading to 50% feedback on day 2, a technique which followed research that gradually reducing feedback improves motor learning retention. A significant reduction in time spent above the threshold was shown in the trial group both two weeks and two months after feedback.

2.6. Limitations and Issues

A fundamental issue with current systems is the need to wait until the sampling period is complete before uploading data to the cloud for analysis, although this can be mitigated by using smartphone interactions with cloud computing (Coulby et al. 2020). Open-source cloud platform ThingSpeak, based on MATLAB, provides this facility but both cost and data transfer limitations make it suitable only for small data packets submitted intermittently (1 Hz), which is not appropriate for our system.

Godfrey et al. (2018) identified the negative issues of over-reliance on wearable technology at the expense of self-regulation and individual responsibility. This could be identified as an issue for riders in terms of frequency of use of the proposed tool so it wouldn't be recommended to use the tool during every riding session. Lind et al. (2023) suggest that feedback is not provided constantly, with their smart workwear feedback taking place over durations of 10-15 minutes for Lind et al. (2020) and 30 minutes for Lind et al. (2023). They also suggest that feedback frequency could be faded over longer periods as in Kamachi et al. (2021). For riders this would not be such an issue as riding sessions normally do not last significantly longer than 30-60 minutes.

Adesida et al. (2019) warn caution, particularly with phone-based apps, to provide interface which displays only data, which is useful and easy to interpret, particularly for those systems where the athlete or coach may not be a biomechanical expert.

2.7. Validation of Technology

Whilst most studies focus on the data that can be obtained from use of technology for motion assessment or the effect this can have on the participants' motion, a number of studies have been conducted specifically to confirm the validity and/or testing of the technology itself.

The Raspberry Pi-based system in Ladha et al. (2016) was validated against another pre-validated system with the conclusion that low-cost components do not significantly impact on the precision or accuracy of results. Hickey et al. (2016) and Del Din et al. (2016) both confirmed validity of accelerometer data captured from L5 for gait asymmetry.

Hulleck et al. (2022), in their review of the current state of research into clinical gait assessment and looking towards the future, cited test-retest validation studies of accelerometer-based gait analysis systems by Hsu et al. (2016), and Byun et al. (2016), plus a systematic review by Poitras et al. (2019). The latter concludes that the studies they have considered demonstrate potential for the use of technology, but they identify the need for further research into the responsiveness of use in free-living situations within hospital contexts.

Sama et al. (2022) confirmed both inter and intra reliability of arm motion accelerometer data for a wrist-worn Xsens IMU sensor and Apple watch for walk, fast walk and running, compared to a gold standard camera-based system. Their conclusion was to recommend further study of arm-worn consumer-grade motion trackers for clinical use due to their low cost, user friendliness and practicality for data collection in practical settings outside of laboratory settings.

Moving away from clinical settings, several studies have been conducted into the validity and reliability of use of sensor-technology for gait assessment in sporting contexts.

A validation study by Smith et al. (2022) confirmed repeatability of vertical oscillation (VO) measurements during running for a range of commercial devices (INCUS NOVA, Garmin Heart Rate Monitor-Pro, Garmin Running Dynamics Pod, and Stryd Running Power Meter Footpod). They compared them against video analysis of a single trunk marker and concluded that the devices were valid and reliable for detection of changes in VO and that results correlated with the video data. However, they did find between-device differences in absolute VO recorded. The NOVA device significantly underestimated, whereas the Garmin RDP, which was attached to the waist, overestimated. They issue caution when using wearables interchangeably with other devices but conclude that, for like-to-like comparisons, they are appropriate, which is sufficient for the proposed rider tool.

Miller & Kaufman (2019) go beyond previously validated IMU motion for straightforward walking and running, extending their validation to include treadmill disturbances, confirming that it was also reliable for sudden changes in acceleration. The purpose of this study was to validate the use of commercial IMUs for fall detection, where a fall would provide such a sudden change. This study is of relevance to riding, where there could also be similar sudden disturbances in motion due to unexpected and erratic motions of the horse, which could affect rider balance.

2.8. Summary

The historical approach to rider assessment and feedback by coaches and/or video analysis as a means of visualising feedback to the rider was primarily subjective and video feedback has limitations when it comes to positioning and field of view. Alongside this, asymmetry in rider posture has been identified as a particular risk factor for rider pack pain and injury so a means of quantifying this and providing feedback to correct postural faults has led researchers to explore opportunities for technology-based solutions. The development of IMU-based sensor hardware and software has provided such an opportunity, with the gaps in knowledge providing an opportunity to be addressed by the proposed tool developed and discussed in this thesis.

Early studies demonstrated the feasibility of using IMU systems, primarily just on the horse. More recently the research using IMUs with horses has moved towards use of AI/ML techniques for automated gait detection and detection of gait abnormalities and asymmetries as lameness indicators.

The development of multi-sensor human systems such as the Xsens MOCAP suit has enabled the rider to be studied but to-date most of this research has been carried out in a constrained environment, primarily in straight lines. These have proved successful in analysing rider kinematics and most suggested the potential for use in the delivery of feedback to improve rider posture as a potential outcome, yet there is little on how this feedback can be delivered and rider opinion and success of that feedback. The proposed tool is intended to fill this gap by focusing on the delivery of a feedback interface and evaluating this within its context of use.

Full body sensor systems such as the Xsens are too complex and expensive for general use in the field so there is a need to develop affordable systems which use a single sensor, which leads to the question of where to place it. Research studies which use a single or reduced number of sensors have positioned these in a range of locations, including head, torso, pelvis/lumbar spine, arms, hips, legs, feet, with the pelvis/lumbar spine being the most common. There is a need to compare this with current coach assessment practice to address research question 1 and identify the biomechanical marker(s) to enable the proposed tool to target its feedback in the most effective way.

The literature found on rider analysis has primarily been for the purpose of assessing rider posture for research purposes and despite suggestions within publications that the use of IMU-based tools is an opportunity to provide feedback to riders, this aspect is limited in the current literature. Research within health/clinical, other sports and a variety of other contexts has revealed a range of different feedback visualisations for consideration. These have included both concurrent and retrospective feedback, but the use of concurrent feedback is an opportunity not widely explored in the equestrian field. In addition to enabling the immediate correction to posture, there is evidence that concurrent feedback gradually withdrawn can improve learning retention over use of retrospective feedback alone. The proposed tool will be designed to fill this gap by providing concurrent feedback.

There is also a question of how best to present concurrent feedback to a rider who is mounted on a moving horse. The use of a screen such as in running studies, where running takes place on a treadmill, is not possible for riders and whilst auditory and haptic feedback are possibilities, they do have limitations as to the timing and ability to detect them whist in the noisy and rapidly moving context of riding. Most of the literature uses visual feedback so there is an opportunity to use the proposed tool to investigate this as a possibility. Obviously, it is not possible to mount a screen on the horse but the suggestion that the best feedback visualisation is a “simple” one and the evidence that the use of colour is effective, leads to the decision for the proposed tool to utilise coloured LED lights, positioned in the rider’s normal line of sight, attached to the horse.

Chapter 3 discusses the methodological approach that was taken to the research carried out for the two studies used to address the research questions.

Chapter 3. Methodology

3.1. Introduction

The aim of this chapter is to take a scientific approach to consideration of the wider methodological issues surrounding the choice of methods and demonstrate that the methodology chosen is appropriate to answer the research questions that have been set.

A detailed contextual analysis was necessary to understand usage contexts for the proposed tool. As part of the requirements elicitation, it was also necessary to confirm the tasks to be incorporated into the rider assessment protocol and identify the biomechanical factors to be obtained from the IMU data, due to the current lack of standardisation in these aspects. It was necessary to identify appropriate functionality and visualisations to be included in the software interface to present meaningful feedback to the user. This phase needed to be carried out in the wild, without interfering with the participant, due to the observational nature of the rider assessment process. The challenge of carrying out an observation of a participant who is themselves carrying out an observation of a third party needed to be addressed in the method selected for the contextual analysis. Similarly, it was also necessary to carry out the evaluation phase in the wild to ensure the functionality and visualisations used are effective within the proposed context of use.

The chapter considers, for each of the questions/studies used to meet the aim of the project, the methods used, why these methods are justified for this research and identify specific considerations in their implementation. This will be supported by existing literature.

The contextual approach used will be discussed; in particular, the need for a customised version of contextual enquiry to satisfy the requirements of carrying out HCI research in the wild. The reasons for this decision will be outlined, together with the choice of experimental design for the final study to evaluate the comparative effectiveness of two alternative visualisations, considering repeated and between subject differences, and identifying any confounds that may influence the results.

3.2. Research in the wild

A detailed contextual analysis was necessary to ensure the usage contexts were considered and understood. Due to the observational nature of current rider assessment processes, both the software requirements elicitation and evaluation phases of the project needed to be carried out in the wild, without interfering with the user. There was a need to consider what could be learnt from the existing body of literature in this field to ensure that correct decisions were made in selecting the methodological approach to be used.

Historically, there was a tendency for the focus of research in the wild to be on the evaluation and appropriation phases of the development lifecycle (Rogers, 2011) but Crabtree et al. (2013) suggested that this model should be revised, refocusing the emphasis to ensure that the user, within the proposed context of use, is involved throughout the whole of the development lifecycle. The authors emphasise the importance of understanding and considering the needs of the user.

Another important consideration is to ensure that users selected are representative of the context of use but that the selected user population needs to remain manageable in terms of numbers of participants (Hess et al., 2013). This is an important consideration for this research where access to riders and horses is a limitation affecting sample size (n=10).

In the example study discussed by Crabtree et al. (2013), user involvement was enabled via the use of action research but, in place of a long term field study that is often associated with ethnographic methodologies, the researchers instead used a short "sensitising" study to understand the processes carried out by users that could inform development of the proposed system (a mobile application enabling users to create interactive digital books from rich multi-media content, supported by external location-based services). Whilst this study was situated in a different application domain to equestrian the authors state that the purpose of their study was to provide a critical evaluation of the characteristics of the technique rather than a demonstration of research in the wild. It is, therefore, considered relevant to draw comparisons with this research since the work was carried out in remote rural locations which could be considered equivalent to riding arenas, in terms of being out with the norm for use of computing technology.

Rogers (2011) discussed the advances made in pervasive technology and emphasised the need for HCI research to understand aspects of "ordinary living" but rather than designing systems to fit in with existing practices, to experiment with technology and investigate possibilities for modifying current behaviour. This was something we needed to be aware of in this project since the proposed users of the tool developed do not necessarily have a current view of how technology will benefit them in their role and the production and evaluation of prototypes in the wild was key in demonstrating what was feasible, in order for them to make informed decisions on whether this would benefit them in their role.

3.3. Data Requirements

A range of data was required to answer each research question. To facilitate this, it was necessary to split research question 2 into three separate sub-questions as indicated below:

Q2. What is an appropriate protocol for the use of IMU data as an assessment and feedback tool, taking into account the practical considerations for the use of IMU analysis during riding motion?

- Q2a. What is an appropriate protocol for the collection of IMU data as an assessment and feedback tool?
- Q2b. What are the HW/SW design considerations for the use of IMU analysis during riding motion?
- Q2c. What are the usage implications for IMU-based analysis and feedback during riding motion?

The collection of data was carried out across two research studies. Table 3.1 provides a summary of the data type required to address each research question and how the collection of it was split across the two studies.

Research Question/Study	Data Type
S1. Understanding usage contexts for postural analysis of riders	
Q1. What are the current practices, focal points and key stakeholders in the postural analysis of riders in a real-world context?	Who is involved? Time taken for assessment (in relation to riding session). Riding movements used in assessment. Gaits used during assessment. Parts of body viewed in assessments. Data required/recorded outside of assessment (before/after).
Q2a. What is an appropriate protocol for the collection of IMU data as an assessment and feedback tool?	Riding movements used in assessment. Gaits used during assessment. Parts of body viewed in assessments.
Q2b. What are the HW/SW design considerations for the use of IMU analysis during riding motion?	How to attach IMU to rider to gather data. When to provide feedback (concurrent or retrospective). How to provide feedback (user interface). What functionality to provide.
S2. Interface design, data visualisation and usage implications for IMU-based rider postural analysis and feedback tool	
Q2c. What are the usage implications for IMU-based analysis and feedback during riding motion?	HW setup/attachment. Calibration. Health and safety implications (rider/horse). Comfort, Environmental implications.
Q3. Which is the most appropriate data visualisation technique for the presentation of rider analysis data feedback according to the usage contexts identified in Q1	IMU data. Preference values for choice of interface. Feedback or Correction?

Table 3.1. Mapping of data types to questions.

Given the wide range of data required to answer the research questions, it was necessary to use a mixed methods approach to utilise appropriate techniques for each question and data type.

The data required gave rise to a number of candidate techniques for data collection and the context which each study would be operating in was further used as a mechanism to identify the best techniques. The reasons for these choices are outlined in the following sections.

3.4. Understanding Context (Study 1)

The purpose of Study 1 was to understand usage contexts for the postural assessment of riders. A field-based research method was selected, with candidate techniques mapped against criteria relevant to the study provided in Table 3.2.

Candidate Technique Mappings								
	Avoid interference with observation of and interaction with rider	Identify participant thought processes	Identify processes and order	Health and Safety within environment	Practicalities of access to participants (sample size, time)	Avoid risk of affecting process due to participant over-thinking what they do	Mitigate risk of inaccurate information recall	Participant awareness of what is feasible with use of technology
Video-based Observation	✓	×	✓	✓	✓	×	✓	×
Concurrent Think Aloud Recall	×	✓	✓	×	✓	×	✓	×
Retrospective Think Aloud Recall	✓	✓	✓	✓	✓	✓	×	×
Apprenticeship, embodied learning in ethnographic practice	✓	✓	✓	×	×	✓	✓	×
Structured Interview	✓	✓	✓	N/A	✓	✓	×	×
Semi-structured Interview	✓	✓	✓	N/A	✓	✓	×	✓
Focus Group	✓	✓	✓	N/A	×	✓	✓	✓
Contextual Enquiry	×	✓	✓	×	✓	×	✓	✓
Process Analysis	N/A	×	✓	N/A	N/A	N/A	N/A	×
Condensed Ethnographic Interview	×	✓	✓	×	✓	×	✓	✓
Incident Diaries	✓	✓	✓	N/A	×	✓	×	×

Table 3.2. Methodological Technique selection for Study 1.

RAG ratings have been applied with green indicating where the chosen techniques meet the criteria and amber indicating where the chosen method has a limitation. No single technique meets all criteria; hence a mixed methods approach was selected, with those criteria marked as amber in the selected techniques being addressed by another of the chosen techniques. Red ratings against criteria provide the rationale for those techniques which were not deemed appropriate.

The combination of techniques selected can be described as a customised application of contextual enquiry, utilising a mixed methods approach comprising observation, retrospective think-aloud recall, structured interview and contextual enquiry techniques. The reason for this selection and rejection of the other techniques was to choose those which contained only green and amber ratings, excluding anything with a red rating deeming it inappropriate.

A limitation of contextual enquiry is that it may interfere with the participant coach observation of rider and interaction with them, so this aspect was avoided by utilising video observation, using the recording alongside retrospective think-aloud to recall and walk through the processes carried out during the rider assessment. Aside from the distraction aspects, this also avoids the health and safety issues that would be present in concurrent think-aloud as the researcher did not need to be close to the researcher while they were carrying out the rider assessment. The risk of the presence of the researcher asking questions causing a change in behaviour or over-thinking the rider assessment was mitigated somewhat by use of the video observation but it was difficult to remove this risk completely as the participant was still aware they were being observed.

The interview aspects of the technique required some flexibility to respond to context so, while there was a need for specific data to be gathered, the choice of semi-structured interview approach provided the flexibility to expand on the discussion. This was of particular use in gaining insight on what aspects of technological intervention would be of use within the context as the participant coaches did not have experience of what was feasible so discussion and interaction with the researcher at this stage was useful to provide potential suggestions. In this aspect an element of co-design provides a clearer insight.

Retrospective think aloud with video recall was considered appropriate as the video would be used as a prompt, being recorded from the participant's own perspective (with the video attached to their body). This would position them back in the situation so thought processes could be remembered. It was important to use video recall rather than attempt to obtain their views at the time, since the session involved communication with the rider so any interference with the coach while assessing the rider would interrupt the natural process of the session and thus potentially affect the data being obtained. Incident diaries were an alternative consideration, but this technique would have required participation over a number of weeks with significant time investment to write-up. This would increase the risk of respondent fatigue or non-continuation due to work commitments, or there could be a delay in recording, in situations where the participant had multiple sessions without a break, which would introduce a risk of forgetting some details.

There are limitations of the observation technique in terms of needing a coding scheme and it is necessary to address risk of the evaluator effect where to researchers looking at the same recording could come up with different results. However, the observation was carried out by the participant themselves in the case of the video recordings and the richness and accuracy of the data was obtained from the think aloud recall rather than the observation itself. For the observation aspects, from the perspective of the researcher, then this was used to obtain information on the movements and gaits of the horse. So, an observation coding scheme was created to ensure that this data was correctly interpreted. Again, using the video observation technique meant that this was able to be completed retrospectively, and the video could be replayed to ensure that data was not missed. An additional table of alternative themes was created so that differences in terminology between coach participants could be accounted for.

3.5. Evaluation of Tool (Study 2)

The purpose of Study 2 was to evaluate interface design, data visualisation and usage implications for the IMU-based rider postural analysis and feedback tool.

This study spans research questions 2c and 3, so required the collection of both quantitative and qualitative data, using a mixed methods approach to address each independently.

The decision was taken to use a quasi-experiment conducted in the context of use.

3.5.1. Evaluating data visualisation interface design for the presentation of rider analysis data feedback (Research Q3)

The data visualisation aspects of the feedback interface required evaluation of two competing designs. These were provided via two LED feedback visualisations, one of which provides correctional feedback (LED-CORRECTION), the other informational feedback on current posture (LED-FEEDBACK). To evaluate the effectiveness of the tool, it was also necessary to obtain baseline rider motion data, without the tool providing feedback, so a third control condition was added (LED-OFF). Under the LED-OFF condition, the device was still attached to the horse and rider, with the IMU device gathering postural data from the rider but with the LED device on the horse displaying no lights. An experimental design was, therefore, an appropriate method with the competing designs, plus LED-OFF as three levels of the independent variable.

Next to determine was the most appropriate experimental technique, with candidates for consideration being either between subjects or repeated measures. The key criterion in selecting the technique was the ability to account for individual differences, such as riders with different sizes of horse, riders of different abilities and riders with individual difference preference characteristics e.g. eyesight. With a repeated measures design these individual differences are controlled.

A repeated measures design was selected, with each participant rider tested with three levels of the independent variable: Interface designs LED-CORRECTION and LED-FEEDBACK plus control condition LED-OFF. Repeated measures was an appropriate technique because it removes all of the sources of variability and its key limitation of practice and order effects was mitigated for by using a Latin Square design with regard to the order in which each rider tested the competing interface designs LED-CORRECTION and LED-FEEDBACK. It was necessary to run the LED-OFF control first for all riders as this was used to measure baseline motion, which was required to set range parameters for the visualisations provided by the tool.

Dependant measures were: preferences for the interface (LED-CORRECTION or LED-FEEDBACK), rated using a point allocation scale; variability of motion as determined by time spent in each of three range zones, separated by walk and trot gaits; and extent of asymmetry, separated by walk and trot gaits.

In field-based research, the presence of extraneous variables, particularly those relating to the situational context of the data collection, is more likely than in laboratory-based research where such factors are more easily controlled. Steps were taken to limit such variables to ensure they did not become confounds, whilst acknowledging their potential to increase robustness and replicability of resulting effects within real-world, less controlled contexts (Maner, 2016).

An alternative to repeated measures would have been a between subjects design, with the benefit that each participant would be tested with only one condition (LED-CORRECTION or LED-FEEDBACK) plus the control condition LED-OFF, which would still have been required to gain baseline data for setting range parameters. This would have required two groups of participants and a prohibitively large sample size to cater for individual difference effects. Variation would be present within all of the dependent measures, and these could have even more of an effect in a study carried out in the wild than in the more controlled environment of a lab-based experiment e.g., using a mechanical horse. A matched-sample design could be used to balance out the conditions, however, in the context of this study, the number of variability factors would render this impossible, without screening a large number of potential participants to create equivalent groups.

3.5.2. Evaluating usage implications for the tool (Research Q2c)

The qualitative aspects of Study 2, to evaluate the usage aspects of the tool, required data to be gathered against the usability standards (ISO, 2016). In particular, it was necessary to evaluate the utility, effectiveness, and satisfaction of the tool within its usage context. Data was also necessary to measure the experiential aspects of the tool to evaluate how the riders felt during use i.e., was it helpful to them, was it easy to setup and use, were there any difficulties encountered using it in the wild and did it enhance or detract from or interfere with the experience of riding? Table 3.3 shows the mix of techniques that were used within the procedure of the study, using RAG ratings to map against criteria which provide the rationale for selection or rejection.

Candidate Technique Mappings							
	Avoid interference with riding activity	Evaluates context of use in the wild (while riding)	Identifies participant thought processes of using the tool	Health and Safety within environment (during data collection)	Identifies health and safety implications within usage context	Practicalities of access to participants (sample size, time)	Provides rich qualitative data (rider opinion)
Observation	✓	✓	✗	✓	✓	✓	✗
Concurrent Think Aloud	✗	✓	✓	✗	✓	✓	✓
Structured Interview	✓	✗	✓	✓	✗	✓	✗
Semi-structured Interview	✓	✗	✓	✓	✗	✓	✓

Table 3.3. Methodological Technique selection for Study 2.

An alternative would have been a lab-based study utilising a mechanical horse but access to such a device was not available and it wouldn't meet the criteria of evaluating within the context of usage in the wild, which would further limit its effectiveness in evaluating health and safety implications within the usage context of the tool.

Aside from potential health and safety risks of the researcher being in close proximity to the horse, it was important to allow the rider to work with the tool in the context of how this might work in the wild, as it is important to test out the use with both the rider and the horse. A mechanical horse would have provided partial data, but it was considered important to include in the evaluation consideration as to how the tool worked within, and the interface addressed, the variability of movement and interactions between the rider and the horse while in motion. For example, the real horse may exhibit asymmetrical or unexpected movements that a rider would need to deal with, and it was important to evaluate whether the tool could aid or hinder the rider's reactions to this. In addition, it was important to evaluate the reaction of the horse to wearing the device and identify any potential health and safety issues, although it was also necessary to constrain the data collection to some extent to ensure health and safety of the participants (horse and human) and researcher during the study. The measures put in place to ensure this will be discussed in detail in Chapter 6. It was also important to evaluate environmental usage contexts, which again pointed towards a field-based evaluation, rather than the artificial environment of a lab-based study.

As in Study 1, it was important not to interfere with the participant whilst carrying out the data collection as they would be engaged in riding the horse.

A mixture of observation and interview techniques were selected because, while observation was important for the researcher themselves to measure utility and determine any issues with the use of the tool, it was also important to measure the experiential aspects of it, through the rider's perspective. This gained qualitative data on how they might envisage using the tool in the context of their riding, plus any aspects that wouldn't be visible to an observer.

As in the interviews with the coaches in Study 1, a semi-structured interview technique was selected to gain rider opinions to enable responses to be categorised somewhat broadly for data analysis but with the opportunity for the rider to expand on aspects of their experience of using the tool that wouldn't necessarily have been predicted by the researcher. In particular, the structured interview would encourage the rider to reflect on their experience and the open-ended aspect of this technique would enable a richer set of data to be gathered.

As for Study 1, the rationale for rejection of other candidate techniques is identified by the red ratings against criteria mappings in the table.

3.6. Summary

The aim of this chapter was to consider, from a scientific perspective, the wider methodological issues surrounding the choice of methods chosen to answer the research questions.

To address Q1 "What are the current practices, focal points and key stakeholders in the postural analysis of riders in a real-world context?", a detailed contextual analysis was necessary to understand usage contexts for the proposed tool, confirm the tasks to be incorporated into the rider assessment protocol and identify the biomechanical factors to be obtained from the IMU data. A customised application of contextual enquiry, utilising a mixed methods approach comprising observation, retrospective think-aloud recall and structured interview techniques was selected for this aspect of the research in Study 1 Understanding Usage Contexts for Horse Rider Postural Assessment. This study will be discussed in detail in Chapter 4.

The results from Study 1 were used to address Q2 "What is an appropriate protocol for the use of IMU data as an assessment and feedback tool, taking into account the practical considerations for the use of IMU analysis during riding motion?" and Q3 "Which is the most appropriate data visualisation technique for the presentation of rider analysis data feedback according to the usage contexts identified in Q1?". This identified appropriate functionality for the proposed tool and visualisations to be included in the software interface, to present meaningful feedback to the rider. It was then necessary to carry out the evaluation of the tool in the wild to ensure the functionality and visualisations used are effective within the proposed context of use. A repeated measures design was selected for the evaluation phase of the research (Study 2), with each participant rider tested with three levels of the independent variable: Interface designs LED-CORRECTION and LED-FEEDBACK plus control condition LED-OFF. This study is discussed in detail in Chapter 6 and Chapter 7.

Chapter 4. Study 1. Understanding Usage Contexts for Rider Postural Assessment

4.1. Introduction

A detailed study of the contextual factors was necessary to identify user contexts and evaluate current practices for rider postural analysis in a real-world environment. A representative sample of riders and coaches needed to be studied to ensure any differences between user groups are identified and accounted for.

The aim of this study was to address the research questions Q1 "What are the current practices, focal points and key stakeholders in the postural analysis of riders in a real-world context?", Q2a "What is an appropriate protocol for the collection of IMU data as an assessment and feedback tool" and Q2b "What are the hardware and software specifications for an IMU-based assessment and feedback tool/interface?". These questions were addressed via the following objectives.

- Identify the key stakeholders.
- Identify the tasks carried out by a coach in an observational assessment of a rider?
- Identify the biomechanical measures used by a coach in an observational assessment of a rider?

From the results of these objectives, combined with the conclusions from the literature review to then:

- Propose an appropriate set of tasks to be incorporated into the assessment protocol.
- Propose an appropriate set of biomechanical measures to be incorporated into an automated rider assessment protocol.
- Identify hardware and software considerations for an IMU-based assessment and feedback tool/interface?

Data required to address the research questions is identified in Table 4.1.

Research Question	Data Required
Q1. What are the current practices, focal points and key stakeholders in the postural analysis of riders in a real-world context?	Key stakeholders.
	Tasks carried out in an observational assessment of a rider (gaits and movements). Biomechanical measures used in an observational assessment of a rider.
Q2. What is an appropriate protocol for the use of IMU data as an assessment and feedback tool, taking into account the practical considerations for the use of IMU analysis during riding motion?	Appropriate set of tasks to be incorporated into the assessment protocol
	Appropriate set of biomechanical measures to be incorporated into an automated rider assessment protocol
	Hardware and software considerations for an IMU-based assessment and feedback tool/interface.

Table 4.1. Data required for each research question to be addressed by this study.

The results of this study determined requirements and identified appropriate biomechanical measures to be included in the visualisation tool, together with the protocol for a standardised set of tasks that the rider was required to carry out using the tool to identify postural issues that may affect their riding technique. This formed the test protocol for Study 2, which evaluated the tool and comparative data visualisation interfaces.

As discussed in Section 3.4, field study was selected as a viable method for Study 1.

4.2. Field Study Method

Field study covers a broad range of techniques for data gathering, carried out within the user's own environment. These techniques include methods of observation, apprenticeship and interviewing, carried out while the user completes relevant activities within their own environment (Baxter et al., 2015). This provides the means by which a deeper insight can be gained into the tasks and processes carried out by the users within their normal daily work or living.

For this project, where the aim is to provide an automated tool which will be operated in the wild, it was of vital importance to consider how the proposed system would fit into the context of use. The functionality of the proposed system was designed to replicate the tasks and processes currently carried out within this non-traditional environment and therefore it was necessary to ensure that the chosen requirements elicitation method incorporated techniques which would help achieve a thorough understanding of the user context and environment.

Baxter et al. (2015) identify 12 goals that can be achieved through the use of the field study method. Of the 12 goals, five were selected as being of particular relevance to this project. These are listed below, with discussion on how they fit within the context of this study:

4.2.1. Identification of mismatch between users' current way of working and the tools/processes available to them

This goal was twofold; firstly, the identification of practical issues and constraints affecting the rider assessment process itself needed to be identified and evaluated. This included any tools used (e.g. video analysis), the assessment process (e.g. exercises executed and the position from where they were observed from) and which areas of the rider's body were considered most important in identifying postural issues which needed to be addressed. The riders would expect the tool to be developed to address issues reported with existing tools such as video analysis and that it would be designed to be attached to the area(s) of the body identified as most important. The tool would therefore be useful in providing direct feedback to the rider, whilst they were riding, to address the constraints and disadvantages of current tools/processes.

The second phase of this goal was to identify how and when the results of this assessment were presented to the rider in order that they could act on them by providing a new tool which would present an effective visualisation interface to give them feedback that would help them to address postural issues whilst riding, something which is not provided by currently available tools/interfaces. For example; verbal coaching cues; exercises to be executed immediately on the horse to make the rider aware of their position and how to correct it; or interventions which could be carried out either on or off the horse on a longer-term basis for sustained improvement and reduction in injury risk.

4.2.2. Understanding of the users' goals

It was necessary to consider the goals of both the user themselves in performing the assessment and the goals of the rider who was being assessed. In the context of a coach carrying out the assessment then the rider goals must also be considered. In the context where the user is the rider carrying out a self-assessment then only their own goals were relevant.

4.2.3. Determine a task inventory

There was a need to identify tasks involved in both the assessment of the rider and presentation of the results back to them, together with future tasks to be carried out if an intervention was necessary. It was also necessary to consider whether and how the task inventory varied according to user context.

4.2.4. Determine a task hierarchy

There was a need to consider the order of tasks carried out and any dependencies between them. It was also necessary to consider any dependency of tasks on tools or artefacts, such as video equipment and/or forms completed.

4.2.5. Observe actual users to develop personas

This enabled both inter and intra rata differences between the user contexts (coach and rider) to be evaluated. This aided in identification of dependent variables and choice of statistical techniques to be used in the evaluation of the proposed system.

4.3. Study Methodology

Having completed an evaluation of field study techniques and identified the aspects of each that would support the objective of understanding the context of use for this project, it was clear that no single technique would suffice. Instead, a hybrid method was adopted, customised for the purpose of this study.

An area of novelty for the methodology used for this study was that the researcher was required to observe a participant who was themselves carrying out an observation, with the necessity to understand and record the thought processes that were taking place during the rider assessment, whilst also being interested in the physical tasks being carried out by the rider.

For this study, where the participant being observed (the coach) was also communicating with the rider, it was important not to interfere with that interaction during the assessment process so any communication between the participant and the researcher was carried out retrospectively. Contextual Inquiry provided both observation and interpretation phases, with the addition of think-aloud recall enabling the thought processes to be recorded.

The full contextual inquiry technique required the researcher to spend a significant time with the participant in their own environment, forming a master-apprentice relationship to evaluate the full detail of their daily roles and activities. For this project, where only one focussed aspect of the role was being investigated, it was not necessary for the full process to be carried out.

Rosenbaum & Kantner (2007) proposed two alternative methods that reduce the time requirements: Condensed Contextual Inquiry and Field Usability Testing. In the three case studies discussed by Rosenbaum & Kantner (2007), all of the tasks involve the use of software, so it is easier to distinguish between Condensed Contextual Inquiry and Field Usability Testing. In the context of rider analysis, the investigation was of a physical activity carried out within a natural environment, without the use of a "product", so it was perhaps more difficult to distinguish between the methods. The question could be asked; was the requirement to carry out a rider assessment considered to be the participant performing their own task, within a pre-defined area of focus (rider assessment) or a task defined by the researcher (assessment of a rider), which the participant then implements in their own chosen way?

Condensed Contextual Inquiry was selected as the more appropriate method to select for this study because Field Usability Testing would imply a more structured set of tasks than those that would be carried out during a rider assessment, where choice and order of tasks were determined by the participant.

The main advantage of Condensed Contextual Inquiry was that it enabled the researcher to focus on a reduced set of critical issues of the coach's role, that being the coach and rider interaction during the assessment, whilst allowing the participants to retain the freedom to perform the tasks in their own chosen way. However, a disadvantage of this method was that it would only provide descriptive anecdotal data. In this context, it was also necessary for the researcher to use observation to obtain additional structured data on the use of arena movements and areas of the body analysed, to enable comparisons between participants to be carried out.

The video recording aspect of the "observing while not present" technique was employed as a recall method for the participant when completing the retrospective think-aloud, due to the necessity for the researcher to be placed in an observational role during the assessment part of the study to avoid distraction for either participant or rider. Strictly speaking, the rider assessment could be carried out without the researcher present but it was felt that their presence in an observational role provided the opportunity for additional questions to be identified during the observation and raised during the retrospective discussion.

4.3.1. Observation Guide

Condensed contextual inquiry requires the use of an "Observation Guide", which provides a structured list of questions and/or issues to be considered .

The use of an observation guide ensured that focus was kept on the key questions to be answered, given the specific nature of the contextual analysis for this study. With only part of the users' normal daily activity being considered relevant, it was important to ensure that understanding the context of use remained focused on aspects of the job role relevant to the system to be developed, i.e. replication of the rider assessment so that feedback on their posture could be provided within the software tool.

The guide was be refined as the study moved from initial pilot observations to the eventual implementation of the technique to carry out the full contextual analysis. The observation guide was used as a checklist during the retrospective think-aloud recall and structured interview phase. An initial draft set of observation questions, categorised according to the user context; rider or coach, is provided in Appendix B.

The draft observation guide was discussed with "expert" representative physiotherapist (Timothy Pigott BSc (Hons) MSc MCSP MACPSM, external advisor on the supervision team) and coach (Anne Bondi BHSI, British Horse Society Instructor) user contexts.

These representative users provided feedback on the language, relevance and appropriateness of the questions. This feedback is recorded as italicised comments in the draft observation guide (Appendix B) and was used to develop an updated version for use in the pilot testing with sample coach participants. The updated observation guide can be found in Appendix C.

It was suggested by the representative coach that the mounted rider observation should be carried out under a specific scenario to simplify the process and limit variables. This scenario is covered in detail in the next section.

4.4. Participants

Five experienced coaches were used for the observation, with a minimum qualification level equivalent to BHS Accredited Professional Coach (British Horse Society, n.d.), including historical qualifications or those which would be accepted as entry requirements for accreditation.

For riders who were assessed, the inclusion criteria were that both horse and rider were capable of riding at a minimum standard of British Dressage Novice level or equivalent, to ensure that the combination was capable of carrying out the basic movements requested by the coach unaided, as per the chosen scenario. Other inclusion criteria were that riders should be a minimum age of 16 years and horses should be a minimum age of 5 years (the age at which horses are deemed mature and eligible to compete in affiliated competitions). Riders and horses which met these criteria were readily available for data collection purposes at a local riding centre so this was considered a practical requirement.

This study focused on dressage movements for practicality and health and safety reasons, however, the method identified could be expected to work effectively for analysis of rider posture whilst jumping and this could be carried out as a separate study in the future.

4.5. Health and Safety Considerations

Data collection was carried out at a riding centre external to the University and involved the use of live horses. It is recognised that riding is a risk sport and any interaction with horses does pose a potential risk to health and safety, but the researcher is experienced with horses and familiar with safe practices for their handling.

To minimise risk, the horses used for data collection were always under the control of their handlers and/or riders and, for this study, no additional equipment was attached to the horses. Horses were either owned by or stabled at the establishment and carrying out activity that they were accustomed to, in a familiar environment.

Data collection was carried out within the confines of an indoor or outdoor riding arena and for the purpose of observation/recording of data the researcher was positioned either external to the arena (if possible) or adjacent to the perimeter of the arena. During all riding activity the horse remained at a safe distance from the researcher.

The horse was wearing its normal saddle/bridle and participants wore their normal riding clothing and footwear, including a British Standard safety approved riding hat when mounted on the horse.

The participants were advised that, if at any point during the data collection they experienced any problems or were uncomfortable with any activity they were asked to carry out, they should tell the researcher immediately and they would do what they could to resolve the issue and/or stop the data collection if necessary.

The establishment used was covered by the appropriate insurance and fire safety procedures and the researcher was using the facility for the purpose that it is normally used i.e. riding/coaching. The researcher had appropriate business insurance cover on her vehicle for driving to/from the establishment used.

In addition, as a requirement of their British Horse Society accreditation, all participant coaches had received first aid and safeguarding training.

4.6. Coach Assessment Method

4.6.1. Phase 1 (Ridden)

The chosen scenario was that the coach would carry out a visual screening assessment of the rider performing free riding in an enclosed arena, not on the lunge or lead rein. This scenario was selected after discussion with the representative coach, justification being that the coach would be free to assess the rider without needing to focus on control of the horse and they would be able to direct the rider to use a range of riding movements which would enable them to obtain the most accurate analysis of the rider's posture. It was felt that this most closely replicated the protocol that would commonly occur during a "traditional" rider coaching session, assessing the rider prior to making any necessary interventions to improve posture. It was advised by the representative coach that it would not be necessary to include assessment on the lunge as this technique would not provide additional information and could be considered more restrictive for rider postural assessment due to the fixed sagittal plane view and the effect of constant turning on the rider posture.

The assessment was initially suggested to be carried out over a maximum duration of 10 minutes. It was felt by the representative coach that this would be sufficient time to thoroughly assess rider posture and would replicate the activity carried out at the start of a normal coaching session.

The time limit was later relaxed in response to feedback received during the pilot data collection session as it was felt to be insufficient for the observation of a rider and horse combination that may not previously have been taught by this coach. In the full data collection phase, a guideline time of 10-20 minutes was suggested but the coach was free to assess the rider without time restriction if they wish to do so.

The assessment was recorded using both sound and audio, to provide an aide memoir for the coach during the retrospective think-aloud. Recording was carried out using a GoPro HERO3+ body-mounted camera, providing a recording of the coach's viewpoint, plus the researcher also recorded the assessment from one end of the arena (adjacent to the C arena marker), focused on the coach but keeping the rider in view as much as possible. This location was chosen as the most appropriate, being the same location as a dressage judge would be located to obtain the best viewpoint of the arena.

4.6.2. Phase 2 (Interview)

The retrospective think-aloud recall took place as soon as possible after the assessment, subject to the time taken to transfer the recordings to the computer, to improve recall by the coach. The recordings were played back to the coach using computer software that enabled them to pause and/or repeat sections of the video as required while they described their thought processes during the assessment. The pilot study was used to determine whether the coach's or external video viewpoint was to be the preferred recording for viewing during the retrospective think-aloud recall.

The coach was provided with a simple remit, to describe the reasons for the specific tasks they required the rider to complete and the areas of the body that they were focusing on during each task within the assessment. The coach was not at this stage provided with a copy of the observation guide and, unless they were having difficulty explaining their thought-processes or remaining silent for extended periods, the researcher did not interrupt the process.

A structured interview took place immediately following the think-aloud recall, where the researcher confirmed that all aspects of the observation guide had been covered and asked any questions or clarifications that had arisen during the think-aloud recall. This included a request for feedback on the method used and any suggestions for future improvement.

The computer screen and audio were recorded during the retrospective think-aloud recall and interview so that the coach's commentary could be related directly to the assessment video for data analysis.

4.7. Coach Assessment Data Analysis

Data obtained from the video recording of the observation phase was combined with the information gained from the coach during the retrospective think-aloud recall phase and transcribed onto an Excel spreadsheet. The full transcript of the coach assessment was captured so that answers to the questions detailed in the observation guide could be extracted. In addition, completion of a full transcript ensured that extra information that may be of general relevance to the project was not lost. During this process the data was split into rows based on the ridden movements the rider was asked to complete, with one movement per row. The transcript was also split to align the coach recall data with the ridden movement it was referring to.

The spreadsheet rows represented the individual tasks carried out by the rider. Columns provided the detailed information recorded for each task, as listed below:

A. Task Number
B. Riding Exercise. Movement carried out, written in language traditionally used within rider coaching.
C. Variation. Details of any variation or addition to the "standardised" riding school movement referred to in the description e.g. arm raised.
D. Arena Marker. Arena letter indicating the starting position for the task, according to standard 20x40 dressage arena (Figure 4.1).
E. Pace. Gait of the horse, coded according to H-Halt, W-Walk, TR-Trot Rising, TS-Trot Sitting, C-Canter, HW-Halt/Walk Transition, WH-Walk/Halt Transition, WT-Walk/Trot Transition, TW-Trot/Walk Transition, TC-Trot/Canter Transition, CT-Canter/Trot Transition.
F. Rein. Direction of travel; L-Left, R-Right.
G. Observation Position. Position of coach in relation to the rider, A-Anterior, P-Posterior, L-Left Side, R-Right Side, Outside-coach positioned outside the circumference of a circle or partial circle.
H. Start Time. From start of video in mm:ss.
I. End Time. From start of video in mm:ss.
J. Duration (mm:ss).
K. Instructions. Commands given to rider by the coach.
L. Interaction type (whether the coach was involved in coaching or assessing – only assessing aspects were relevant for this study)
M. Intervention. Any intervention made by the researcher
N. Transcript. Full detailed transcript, used to identify and copy relevant content for other columns
O. Body Segment. Area of the body identified as receiving focus during retrospective recall.

P. Description of Focus. Purpose of the focus, as related to the body segment e.g. looking for symmetry or assessing balance.
Q. Rationale. Any reason given for the particular focus.
R. Additional Info. Comments made during retrospective recall that do not relate directly to area of focus.

Following discussion with the representative coach, the tasks were further broken down to separate out transitions between gaits so that they can be considered separately from the riding movements themselves.

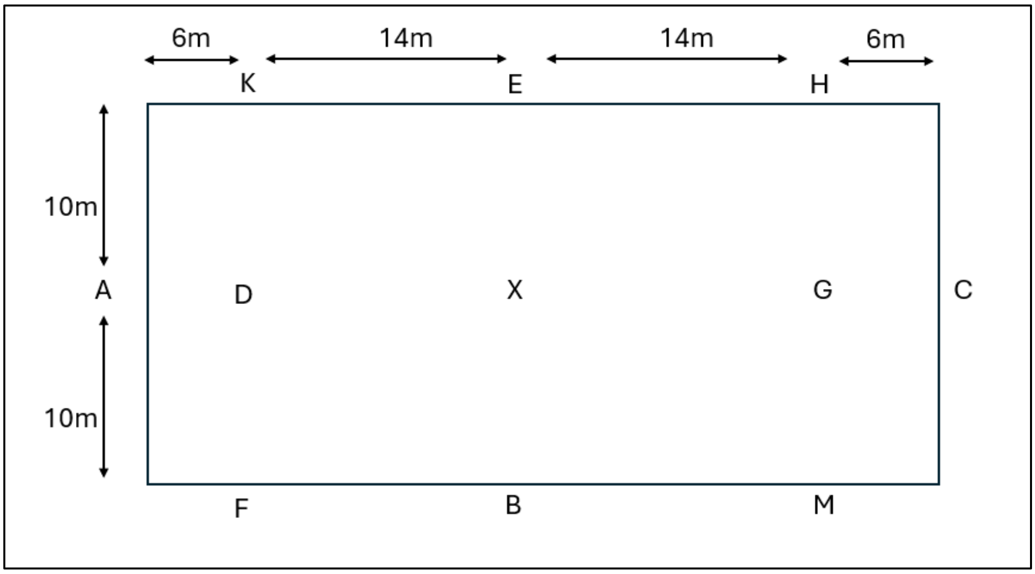


Figure 4.1. Arena Markers.

Columns A to L were filled in retrospectively by the researcher. Column L, the interaction between coach and rider was interpreted by the researcher so could potentially have been affected by evaluator bias but in such cases where an interaction between the coach and rider was incorrectly coded, this would have been detected from the retrospective think aloud recording as a mismatch in data gathered for that particular element. For example, if an interaction was incorrectly coded as assessment when it was coaching, the participant coach would not have subsequently provided any data on what they were assessing at the time.

Column O, body segment, was reported by the coach participant themselves and therefore would not suffer from evaluator bias. An additional table of alternative themes relating to each body segment was created so that differences in terminology between coach participants could be accounted for (Table 4.2). This was checked by a member of the supervision team with experience in biomechanics and terms were mapped onto standardised biomechanical markers.

Body Segment	Alternative Themes	Description
Ankle		
Cervical Spine	Lower Neck	
Elbow		
Finger		

Body Segment	Alternative Themes	Description
Foot		
Hand	Wrist	
Head		
Heel		
Hip Joint		Hip joint angle (Xsens)
Knee		
Leg		
Lower leg		
Pelvis	Seat, Hip	Hip relating to position/symmetry
Shoulder		
Spine		Specific to spine
Thigh		
Torso	Upper Body, Ribs	Whole upper body

Table 4.2. Alternative themes for coding biomechanical markers.

The resulting spreadsheets were then used to address the first two objectives of Study 1, from the coach perspective:

4.7.1. Identify tasks that the rider is required to carry out, to identify postural issues that may affect their riding technique.

An R script was written, using R Studio software package (RStudio, n.d.), to import the spreadsheets and combine the data from the riding exercise, pace and rein columns across all participants. This was sorted in descending order of occurrence and a frequency histogram plotted using the R native bar plot function.

4.7.2. Identify biomechanical measures used in the postural analysis of riders by coaches.

The spreadsheets for each participant were imported into the NVivo Qualitative Data Analysis software package (NVivo, n.d.). The table of body segment names and alternative themes was used to create a set of codes against which the biomechanical measures for each ridden exercise, as identified in the transcript from the retrospective think-aloud, were mapped.

The NVivo "Export Codebook" menu option was then used to generate a table containing the number of coaches and number of references to each body segment contained in the data. These were then sorted into descending order to identify the most common biomechanical markers used in the assessment.

4.8. Coach Assessment Pilot Study

A pilot observation was carried out at the participant riding centre. The data capture was carried out in a 20 x 40m indoor riding arena. The assessment was carried out during daylight hours, with the arena lit naturally via roof windows. Additional roof-mounted lights were available for use, if necessary, but the coach did not choose to use them during this session.

The coach participant was female and, as manager of the riding centre, they were familiar with the environment and the facilities available. The rider was a regular attendee of the centre and was regularly taught by the coach.

No specific instructions were given to the rider regarding clothing worn, to keep the session as realistic as possible. The temperature was such that the rider was able to ride comfortably in a t-shirt, jodhpurs, short boots and chaps. A BS standard riding hat was worn, together with gloves. The rider also carried a short whip, selected according to her own choice as to what was appropriate for the horse.

The horse was selected by the coach as appropriate for this rider, together with its ability to carry out the required movements. The coach had detailed knowledge of the horse's normal way of going, both with this rider and with others. The horse was considered sound and fit enough for the purpose of the tasks to be carried out.

The rider was familiar with the horse, although they do not exclusively ride this particular horse.

For the purposes of this study, the coach was considered to be carrying out a review of postural issues for a familiar rider and horse combination, as would be performed at the start of a coaching session, prior to working on interventions for improvement.

The observation was carried out according to the protocol described in Section 4.6.

The retrospective think-aloud recall and structured interview was carried out within 10 minutes of the riding phase, in an area adjacent to the riding arena. The rider was present during this phase but did not contribute to the process.

The retrospective recall and interview were recorded on a laptop computer using CamStudio Recorder version 2.7.4. Testing had been carried out prior to the session to confirm that this software was suitable for the purpose and to ensure the microphone on the laptop was set to an appropriate level.

The coach was given the option of which of the two video recordings to watch during the recall process, selecting the chest-mounted camera viewpoint. The researcher started both the screen/audio recording software and opened the selected video recording in Windows Media Player prior to commencing the recall process.

The researcher sat next to the coach during the recall process, but the coach was given control of the laptop so that they could pause the playback as necessary. In this case, the coach completed the think-aloud recall process without pausing or repeating the video playback.

The researcher referred to the observation guide during the recall process and noted down additional questions but did not interrupt the coach during the recall phase, however, this would have been done if they had not been providing suitable detail. Questions identified were asked at the end of the recall phase, before stopping the screen/audio recording.

The pilot study was used to determine the relevant aspects of the method and data required to answer the research questions, with identification of any changes necessary before collecting data with the following participants.

The method was found to be suitable, apart from the time allocation. It had initially been thought by the representative coach that 10 minutes would be sufficient time to thoroughly assess the rider posture and would replicate the activity carried out at the start of a normal coaching session. During the pilot data collection session this was found to be insufficient, with the time taken being 12 minutes, 20 seconds. It was decided the for the full data collection phase, a guideline time of 10-20 minutes would be suggested but that the coach would free to assess the rider without time restriction if they wish to do so. This would avoid any potential loss of valuable data due to them rushing.

The video recording from the HERO3+ GoPro camera was chosen by the coach as their preference for the Retrospective Think-aloud recall session. However, the body-mounted placement was found to move around and produce shaking in the video recording, so a head-mounted harness was purchased, together with the latest model at that time: HERO4+ GoPro camera (the version used for the pilot study had been borrowed) for subsequent data collection.

The spreadsheet recording the data was found to be sufficient to gain the required information and, in fact, contained additional data that was not required to answer the research questions for this study. A reduced set of columns was, therefore, used in the transcription process for the analysis phase of the full study:

A. Riding Exercise.
B. Pace. Gait of the horse, coded according to H-Halt, W-Walk, TR-Trot Rising, TS-Trot Sitting, C-Canter, HW-Halt/Walk Transition, WH-Walk/Halt Transition, WT-Walk/Trot Transition, TW-Trot/Walk Transition, TC-Trot/Canter Transition, CT-Canter/Trot Transition.
C. Rein. Direction of travel; L-Left, R-Right. [used to confirm that an even protocol was used]
D. Transcript. Full transcript [used to identify and copy relevant content for Body Segment column]
E. Body Segment. Area of the body identified as receiving focus during retrospective recall.

None of these changes affected the validity of the data collected for the coach assessment pilot study so their data was included in the analysis of results as participant C1.

4.9. Coach Assessment Contextual Analysis Results

Data collection was carried out according to the protocol outlined following the pilot study, with three additional coaches.

Coaches C2 and C3 observed the same rider as the pilot study. They rode different horses for each session, for practical reasons due to availability of horses within the riding centre on the dates of the data collection sessions. Coach C4 observed a different rider and horse.

4.9.1. Coach observation movements

Data analysis was carried out according to the protocol described in Section 4.7. Table 4.3. Frequency of gait, rein and exercise across all participants.

shows all ridden exercises carried out across all coach assessments, split by the gait (walk, trot rising, trot sitting, canter and halt) and rein (left, right or change of direction). Data is plotted in descending order to highlight the core exercises.

Movement	Frequency	Movement	Frequency	Key	
TR R Track	19	TS L 20m Circle	2	**Pace**	
TR L Track	12	TW L Transition	2	W	Walk
TW R Transition	11	W L 10m Circle	2	WH	Walk to Halt
W R Track	10	W L Centreline	2	H	Halt
WT R Transition	10	W LR Diagonal	2	HW	Halt to Walk
TR R 20m Circle	9	W R 20m Circle	2	WT	Walk to Trot
TR L 20m Circle	8	W R Centreline	2	TR	Trot Rising
W L Track	7	CT R 20m Circle	1	TW	Trot to Walk
TC R Transition	6	HW RL Transition	1	TS	Trot Sitting
CT L Transition	5	TR LR 10m Demi-volt	1	TC	Trot to Canter
CT R Transition	5	TR LR 20m Fig8	1	C	Canter
TC L Transition	5	TR LR Centreline	1	CT	Canter to Trot
WH R Transition	5	TR R 3 Loop Serpentine	1		
C R 20m Circle	4	TR RL Across School	1	**Rein (Direction)**	
TR LR Diagonal	4	TR RL Diagonal	1	L	Left
C L 20m Circle	3	TS L Track	1	R	Right
C L Track	3	TS LR 10m Demi-volt	1	LR	Left to Right Change
C R Track	3	TS R 20m Circle	1	RL	Right to Left Change
H L Halt	3	TS R Track	1		
HW R Transition	3	TWT L Transition	1		
W RL Diagonal	3	TWT R Transition	1		
WT L Transition	3	W L 10m Half Circle	1		
H R Halt	2	W LR Centreline	1		
TR RL 10m Demi-volt	2	W R 10m Circle	1		
TR RL Centreline	2	WH L Transition	1		

Table 4.3. Frequency of gait, rein and exercise across all participants.

Results, as might be expected, show a mixture of walk, trot and canter. Transitions between gaits form a large part of the coach observation as they link between the different gaits and movements so these would automatically occur during the assessment and proposed test protocol. Considering the gaits and movements themselves, excluding the transitions, trotting around the track (outer edge of the arena) is the most frequently used movement, which matches what would be the case in a novice level dressage test and provides the straight lines that the coach was observed to assess (these were observed in the video recordings by the position of the coach moving their position to view from the rear). Rising trot, as would be expected at this level is the predominant type of trot. In dressage tests, the rider is allowed to choose the type of trot, with sitting trot only specifically required at the higher levels.

All coaches made use of 20 metre circles in trot with a balance between left and right reins, although it is surprising that trot on the right rein features more frequently than trot on the left for both trotting large around the arena and for the number of circles. A dressage test would typically have an equal balance of left versus right movements and where a specific, but limited, dressage "test" has been used for data collection using IMUs in a previous research study, this has been the case (Hobbs et al., 2023). Given the balance in the literature and the small number of participants in this study, where a repetition of a movement within the observation or link between movements could have skewed the data, the proposed protocol was symmetrical.

Other movements in trot were included but only in individual cases (10m demi-volt, 10m half circles, serpentine). No use of extended trot or lengthened strides was included, despite this being one of the movements in a novice level dressage test.

Canter was included in all assessments, and this was again more frequent to the right, but the data was skewed in this by one isolated incident where the horse broke stride and repeated the movement, so that addition can be rejected. For health and safety reasons, canter was excluded from the proposed protocol for Study 2 during the risk assessment, in consultation with the coach advisor. This was due to the prototype attachment of the horse device, and it was felt that the rider would be able to obtain enough experience of the device in walk and trot to compare the interfaces and evaluate the tool in walk and trot.

For walk, the movements carried out were more varied, with walk around the track and down the centreline of the arena being key features to be included as they enable straight lines to be considered. Again, walk on the right rein features more than the left in the observation by the coaches. Walk movements are less clear as more of a range was included but combining the 10m walk full circles, demi vaults and half circles, would indicate that the circular movements in walk of 10m diameter was more popular with the coaches than 20m diameter, plus it would be likely that the rider asymmetry would be more obvious on a smaller circle and walk circles of 10m but not 20m diameter are included in novice level dressage tests. the decision was, therefore, for walk circles of 10m to be included in the protocol for Study 2.

4.9.2. Coach observation biomechanical markers

Data transcripts from the retrospective think-aloud interviews with the coaches were imported into NVivo for analysis. These were coded according to the number of references to each body part, according to the themes previously identified. Where alternative phrases were used to describe a particular body segment, these were combined. Table 4.4 shows the number of references to each body segment, across all coaches, exported from NVivo.

Theme/Code	Description	References
Pelvis, Seat, Hip	Hip relating to position/symmetry	52
Shoulder		27
Leg	General/Upper leg	22
Torso, Upper body, ribs	Whole upper body	13
Elbow		10
Hand, Wrist		10
Spine	Specific to spine	9
Knee		6
Heel		6
Foot		3
Lower Leg		8
Head, chin		4
Hip Joint	Hip joint angle (Xsens)	2
Ankle		1
Cervical Spine, Lower Neck		1
Finger		1
Thigh		1
	Total References	176

Table 4.4. Number of references to each body segment, across all participants.

It is very clear from these results that the pelvis (also referred to as "seat" or "hip") is the body segment most frequently used by coaches when assessing rider posture, with this at 52 (29.6%) instances being referred to 1.93 times greater frequency than the next most common, the shoulder at 27 (15.3%) references. It is worth noting here that the hip was manually coded due to its multiple use when referred to by some coaches as an alternative phrase to the pelvis, separately identified to the hip joint, when they were referring to the actual joint. This coincides with the findings from the literature review, where pelvis or lumbar spine is the most used attachment/analysis for IMU studies.

Given the pelvis is the closest connection between the horse and rider, via the seat in the saddle, this is likely where the most obvious visual evidence of any symmetry issues will originate, with the next most common locations of the shoulder (27 references) and leg (22 references) being where the effect of asymmetry or balance issue may show.

4.10. Summary

The aim of Study 1 was to address the first two research questions:

> Q1: What are the current practices, focal points and key stakeholders in the postural analysis of riders in a real-world context?

> Q2: What is an appropriate protocol for the use of IMU data as an assessment and feedback tool, taking into account the practical considerations for the use of IMU analysis during riding motion?

The conclusions that can be drawn from the field study contextual observation of the coaches assessing riders' posture and follow-up think aloud recall are collated in Appendix D. These address Q1 and were taken forward into the design, development and evaluation of the rider assessment and feedback tool, to address Q2.

The conclusions drawn have been based on both the results from this study and those of the literature review. In particular, the decision to include the protocol of movements for Study 2 was based on the commonly utilised movements assessed by multiple coaches (identified by this study), movements included in UK British Dressage novice level tests (ensuring that the research is carried out at the appropriate level for the target rider/horse combinations) and identified gaps in the literature.

The decision to restrict the biomechanical measure to one location is based on the dominance of the pelvis as the target of both the coach observation (identified by this study) and the findings of the literature review. It was also important to ensure that the tool developed was suitable for the proposed user context, with cost and practicality of use being factors to consider. The original intention of using a full-body multi-sensor system, whilst suitable for research use, would be unrealistic as a tool to be used within the wider equestrian industry as its cost would be prohibitive for grass roots riders or riding establishments to purchase. Also to consider, is the time taken to put the device on the rider as sessions in a riding centre are commonly only 30-45 minutes long, meaning there is a need for the tool to be quick to attach/remove. A single sensor device would better meet this need and would also be more easily adjustable to different sized riders and compatible with clothing normally worn as it could be attached with a simple belt that could be adjusted/changed and could be worn under additional clothing in colder weather.

The literature review provided the additional decisions on choice of visualisation interface and full details of the hardware and software choices to take forward to the visualisation interfaces for comparison are covered in Chapter 5.

Chapter 5. Tool Design and Development

5.1. Introduction

The conclusions drawn from Study 1 led to the decision to switch technology focus from a full body IMU system to the design and development of a bespoke system for rider postural assessment and feedback. This system incorporates a single IMU placed on the rider's pelvis, connected wirelessly to an LED light strip mounted on the horse to provide the feedback visualisation. This chapter discusses the design, development and testing of both hardware and software for the tool. Figure 5.1. provides a diagrammatical representation of the link between Study 1 and Study 2, showing how the development of the tool fits within the overall structure of the research and how it is used to address the research questions.

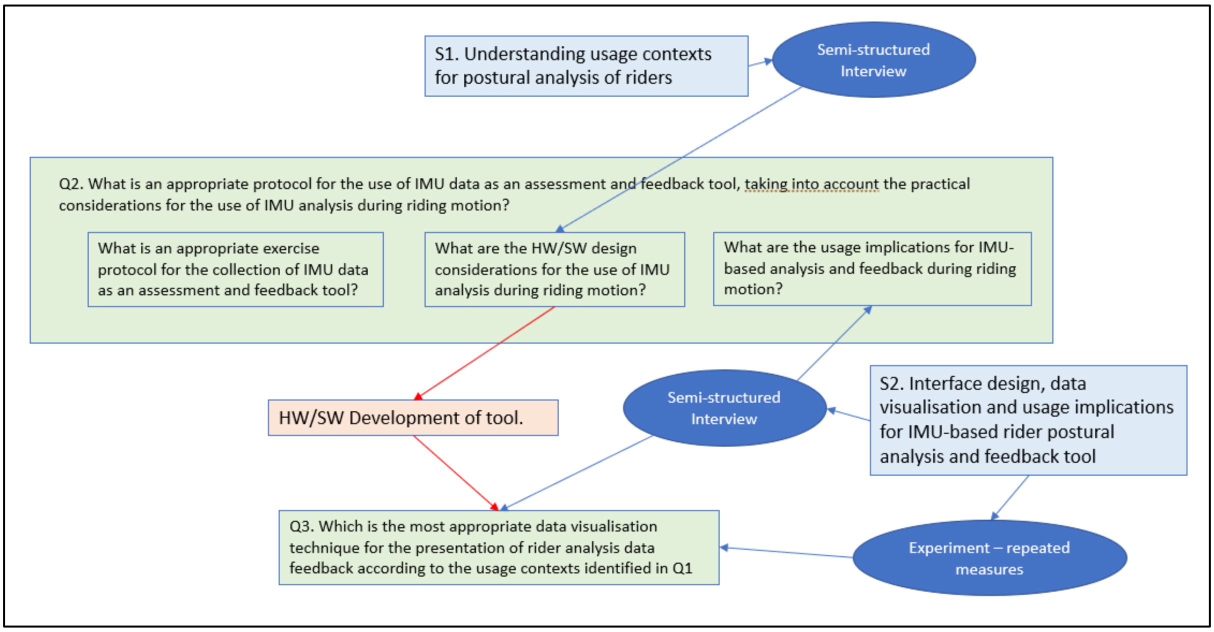


Figure 5.1. How the tool development fits within the link between Study 1 and Study 2.

5.2. Hardware Development

The prototype tool comprises two key components. The rider device comprises an IMU sensor to collect motion data and convert it into a format to be transferred to the LED feedback device, which is mounted on the horse.

Raspberry Pi Zero W was selected as an appropriate hardware technology due to its small size, low cost, efficiency of power consumption for use in the wild and compatibility with a wide range of associated open-source components. This meant the same technology could be used for both rider (IMU) and horse (feedback) devices, which made for ease of programming (using Python) both devices and the interface between them. It also allowed for an iterative approach to development, enabling the interchange of alternative components during the early feasibility phase, for example, trialling different LED display panels.

5.2.1. Rider Device

The rider device uses an Adafruit BNO055 IMU Fusion sensor (Adafruit, n.d. a) mounted on the lower side of the Pi Zero W.

This breakout, attached the Pi Zero via a soldered I^{2}C interface, incorporates a Bosch-manufactured sensor, comprising high-speed 32-bit ARM Cortex-M0 based processor, running Bosch Sensortec sensor fusion software. The built-in fusion algorithms blend motion signal data from a MEMS triaxial 16-bit gyroscope, 14-bit accelerometer and full performance geomagnetic sensor to provide real-time, stable, 3-axis orientation output. Performance of this sensor is reported at +/- 1.5-degree accuracy (McIver & Gahl, 2017). Fused output sensor data is provided in several formats but, for the purpose of this research, the tool developed uses just the Absolute Orientation output values, providing three axis orientation motion data (roll, pitch and yaw) based on a 360° sphere, of which the roll data value is used to determine rider lateral motion. This was captured at 100Hz. The decision to use this sensor was based on its small footprint, simple attachment to the Pi Zero and built-in fusion software with open-source library access to the required data from Python, without the need to develop bespoke fusion algorithms.

The cost of the rider device, including Pi with 16GB SD card, IMU and battery/charging setup as described in Section 5.2.3 was £83.95 (March 2019).

The rider IMU device, comprising the sensor, Pi and power setup (discussed in Section 5.2.3) is shown in Figure 5.2.

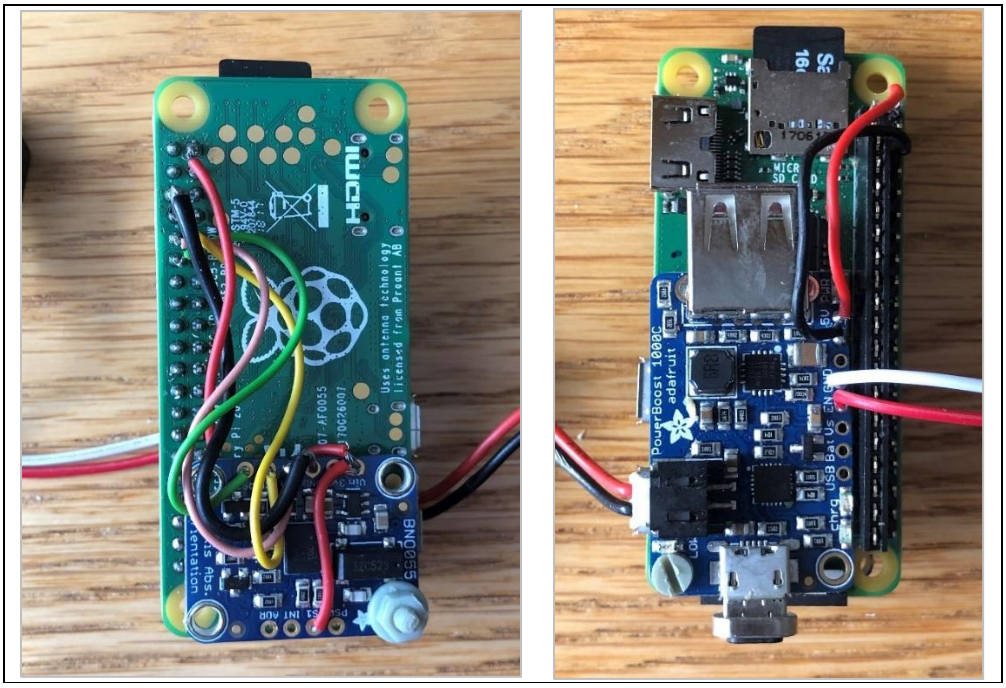


Figure 5.2. Rider IMU device with sensor (left) and power/charging shim (right).

5.2.2. Horse Device

The horse device uses an 8-pixel Blinkt LED strip (Adafruit Industries, n.d. b), mounted on the top side of a Pi Zero W, which is attached to the headpiece of the horse's bridle in a position where it is clearly visible to the rider. The Blinkt device consists of 8 APA102 RGB LEDs in a single 56mm long by 8mm wide horizontal strip, which is mounted directly onto the Pi 40-pin header (Figure 5.3).

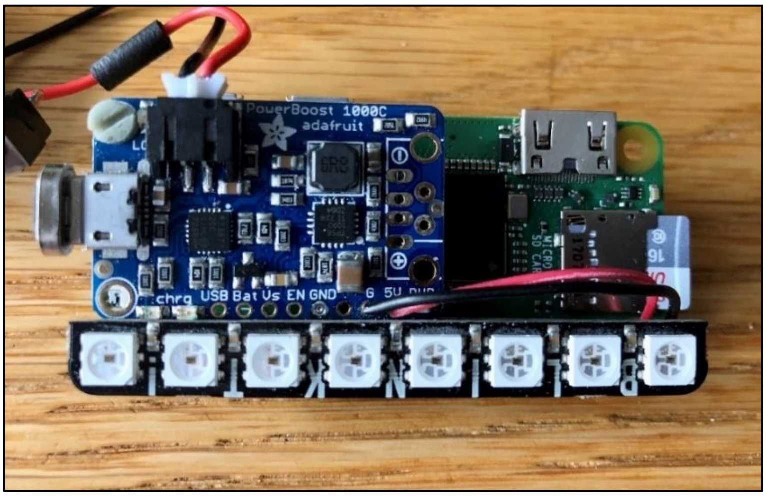


Figure 5.3. Horse LED device, with Blinkt LED strip.

The Blinkt LED strip protrudes from the Pi by 8.5mm, which was small enough for initial testing to be carried out with both Pi and LED strip housed in a Pibow Zero W case (Pimoroni, n.d. a). Figure 5.4 shows the original prototype version in the Pibow case, with wired USB connection, in use for early testing.

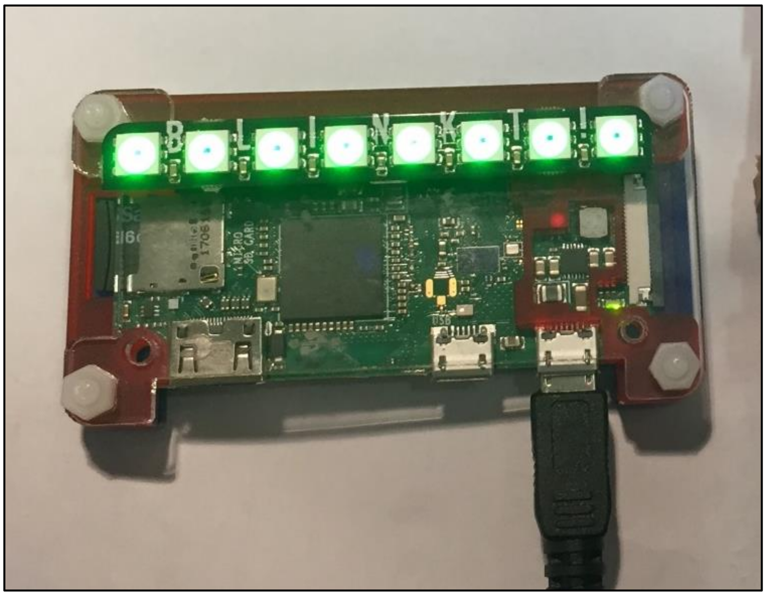


Figure 5.4. Initial testing of Horse LED device, with Blinkt LED strip in Pibow case.

Feasibility testing was also carried out using an alternative 28-pixel LED Shim, produced by Pimoroni (Pimoroni, n.d., b), which fits directly onto the Pi pins via a friction-fit header without the need for soldering (Figure 5.5).

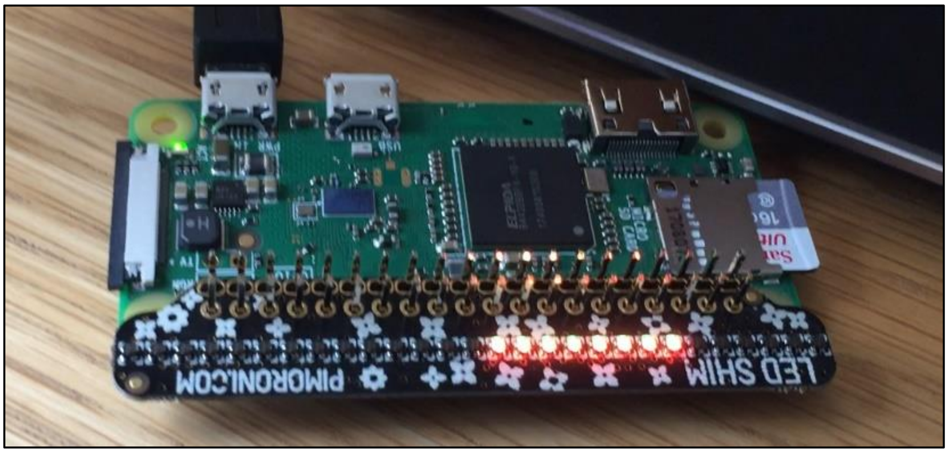


Figure 5.5. Alternative LED shim, which was subsequently rejected.

Whilst thinner form factor at 0.8mm thickness, this device protruded from the Pi, the LEDs were smaller and mounted closer together. This was found, during initial feasibility testing (dismounted), to be less clear to distinguish from the approximate distance of the horse's head. The Blinkt LED strip provided a clearer interface, of a size more suitable for use in this context and, therefore, testing of the LED Shim was suspended with the decision taken to use the Blinkt strip. Both devices incorporate the same IS31FL3731 LED matrix driver chip so the software produced could be easily adapted if such a device was to change in the future, with the availability of Python libraries providing equivalent functionality.

The cost of the horse device, including Pi with 16GB SD card, Blinkt LED strip and battery/charging setup as described in Section 5.2.3 was £53.57 (March 2019).

5.2.3. Power

Powering the devices required a balance between the increase in footprint size that the power supply and associated connectors and cables would add to the device, portability (a mains connection was clearly not feasible for use whilst riding), length of time the device could operate before changing or recharging batteries and ease of replacing/recharging batteries. The chosen power source, for both devices was to mount an Adafruit Powerboost 1000C charger (Pimoroni, n.d., c) directly onto the Pi, which would provide 5V power with USB rechargeable load-sharing connectivity via a 1200mAh LiPo Battery Pack (Pimoroni, n.d., d). The 1200mAh was chosen from a range of available sizes due to its dimensions (64mm x 35.5mm x 5.3mm), which provided the closest fit to the Pi (66.0mm x 30.5mm x 5.0mm), enabling it to be positioned underneath the Pi for a stable fit within the containers that were developed to house the devices for attaching to the rider and horse. The Powerboost was mounted on the top of the Pi, with length 45mm and width 23mm fitting within the case size of the Pi and depth requiring an increase in the case size depth for the IMU device of 10mm but, for the LED device on the horse this was just a 1.5mm increase in depth from the Blinkt LED strip dimensions of 8.5mm. The 12000mAh capacity provided sufficient charge to power the Pi and connected IMU or LED strip for in excess of 10 hours, which was acceptable for testing and data collection purposes.

Alternative power supply options were identified but rejected due to practical considerations. The use of external rechargeable USB power packs would have avoided the need for the onboard Powerboost charger, however, it was not practical to position them outside of the case for the IMU since any external cable, connected to the power pack in a rider's pocket could have an impact that would potentially interfere with the motion of the IMU device and they would not be a small as the combination of Powerboost and Lipo battery to fit within the case. For the horse LED device, the external cable issue is not such a consideration, but it would still be less practical to have to attach the power bank separately than to have the Lipo battery housed within the device itself. Other considerations were a coin cell battery power pack, which would have a small form factor, but which would require replacement batteries rather than those which can be recharged. For a production version of the device, this may be a practical option, but it was felt that, while carrying out the extensive feasibility testing and rider data collection, the advantages of the current rechargeable setup was more reliable. External battery holders are also available but with the disadvantages mentioned above for the USB power bank of the need for external wires.

5.2.4. Connectivity

Connection between the devices was achieved via the use of wireless router. For initial feasibility and dismounted pilot testing this was done via home or office wireless network, with software operated from a laptop or desktop PC (discussed in more detail in Section 5.5.1).

For use in the wild, it was necessary for this to be independent of any permanent wireless network to enable the devices to communicate with each other and with the controlling application in any potential riding environment.

For this study, an PQI Air Pen Express Wireless Router (Figure 5.6) was used but any equivalent device would be suitable. The cost of the chosen router was £17.97 (March 2019). This was powered by a USB power bank and provided a 2.4 GHz wireless network, with a range in excess of the distance required for operation in a standard 20mx40m riding arena. For data collection in this study the router was positioned next to the researcher, adjacent to the arena, but the device was small (81mm x 11mm x 24mm) and light (41g) enough that, in a practical real-world usage scenario, it could be carried in the rider's pocket with a small USB power bank.

Figure 5.6. Portable connectivity provided by PQI Air Pen Express Wireless Router.

Connectivity and software were managed via a mobile device, in this case an iPhone X, but again this could be achieved with any suitable alternative. Software applications are discussed in detail in Section 5.6.2 but involve the use of the Termius and IP Scanner apps (IOS versions).

5.2.5. Device Cases and Attachments

Customised containers were produced for housing both the IMU rider and LED horse devices on a Fused Deposition Modelling (FDM) 3D printer, using Polylactic Acid (PLA) filament. The important consideration in design of suitable housing for both devices was to ensure that they were of a size suitable for secure and stable placement of the IMU on rider's back and for attaching the LED device to the horse.

A basic casing for the IMU rider device was developed and tested on the ground (Figure 5.7), prior to any testing with a rider mounted on the horse. A Perspex cover was provided across the box opening and attached using an elastic band to enable the operator to view the LED indicators to show whether the device was powered up or not. During early testing, this was critical for diagnosing errors where data would not be transmitted to the LED device, as to whether these errors were due to software, connectivity, or power issues. The early prototype case had no built-in belt attachment and was simply tucked behind the wearer's trouser belt. It was also larger than the final version.

Figure 5.7. Early prototype rider IMU case and dismounted feasibility testing.

Initial feasibility testing of the horse LED device was carried out with power provided via a wired connection to a USB power bank, placed in the rider's pocket, prior to identification of the battery/power setup described previously.

For this initial pilot testing phase, the horse LED device was attached to the breast harness strap in front of the saddle for convenience (Figure 5.8) but it was always the intention that this device would be moved into a position on the horse's head to avoid the necessity for the rider to look down and change their riding posture. Good riding position requires the rider to look forwards, between the horse's ears, so there was a need to identify a method of positioning the LED device in this position for optimum vision.

Figure 5.8. Feasibility pilot testing of LED device, wired to USB power bank.

The decision on positioning of the LED horse device was informed by consideration of how a number of commercially available devices providing visualisation interfaces for different purposes were attached to the horse. In particular, the Telerein C IT (QPM Design, n.d.) which provides an LED visualisation of rider rein tension, via a wired connection to a weight tension gage attached to the reins close to the horse's bit and the Equla Vert (Equla, n.d.), which is a combined IMU/LED device providing a traffic light interface to indication of whether the horses head position is in front or behind the optimal vertical angle with the neck. Examples of these devices in position are demonstrated in Figure 5.9.

Figure 5.9. Telerein C IT (left) and Equla Vert (right).

The final cases were developed following several iterations. For both devices, the case was developed to be as tight fitting as possible to prevent the device from moving around in the housing, whilst still enabling it to be removed if necessary. The top of both cases allowed access to remove the device, with a Perspex lid sliding through slots in the side of the case to provide a tight fit. The cases provided space for the Lipo battery to sit in the base, with the Pi placed directly on top of it, and the Powerboost charger on top of the Pi. Holes were positioned in the case to enable connection to the charger via a magnetic micro-USB charging data cable, access to an on/off switch inserted into to the cable between the battery and the Pi and a viewing slot to the Pi status LED indicator. Figure 5.10 shows the two devices housed within the final versions of the cases.

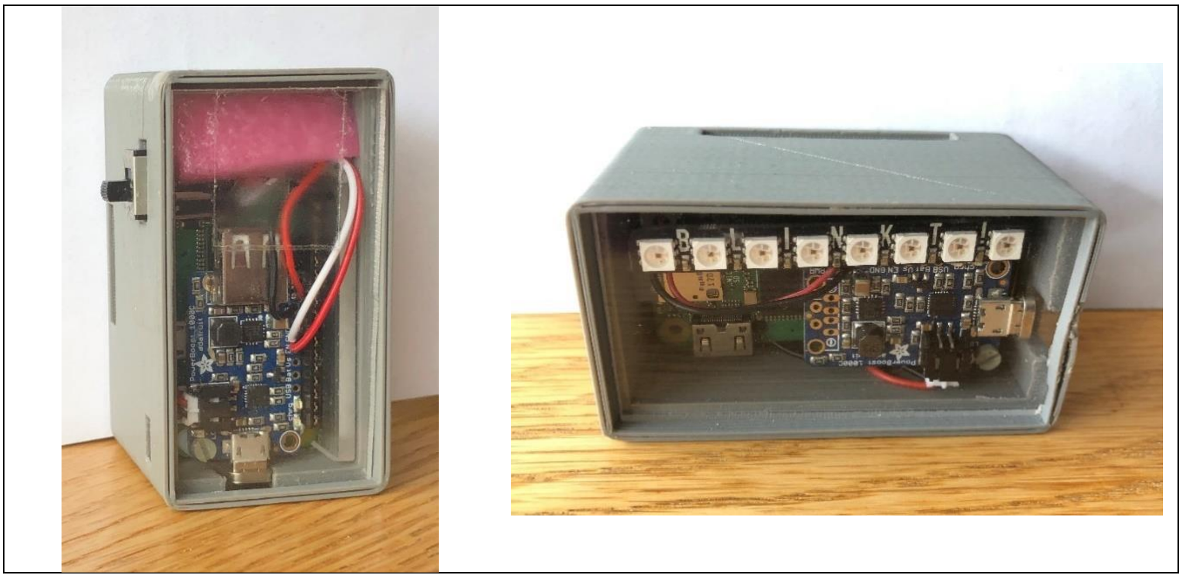


Figure 5.10. Cases for IMU rider (left) and LED horse (right) devices.

The IMU sensor attached to the base of the Pi on the rider device meant that it was not flush with the battery, so a small piece of wood was cut to fill the gap and support the Pi, with an additional piece of Perspex used to fill the empty space between the header pins and the case edge. Sponge was then used to pack any remaining gaps and ensure that there was no movement of the device within the case, critical for accurate measurement of rider motion.

The horse device was designed to the exact depth of the battery, Pi and Blinkt LED strip. While it isn't so critical from an operation perspective that the device doesn't move within the case, this was still important from the perspective of safety due to the close proximity to the horse's ears, which could be sensitive to any rattling noise that could upset the horse.

A slot was cut into the base of each case, enabling a belt or strap to be inserted. An elasticated cotton belt was slotted through for attachment to the rider, enabling a tight fit to ensure no slippage but with some cushioning from the hardness of the case. The case was rounded at the edges to ensure no sharp points that could cause injury to the rider and the case was always worn over clothing. A thin narrow strap with a buckle end was used through the slot of the horse device and this was wrapped twice around the headpiece of the bridle and buckled together. It was further secured with strong tape to fix it into position.

The final casings are shown in Figure 5.11, in position on a rider and horse.

Figure 5.11. IMU Rider(left) and LED Horse (right) devices in position.

5.2.6. Visualisation Interfaces

The visualisation component consists of 8 LED lights, providing a "traffic light" feedback mechanism to inform the rider of the position of their pelvis in the lateral plane of motion. Two visualisation options have been incorporated: LED-CORRECTION, which provides scrolling lights across the full LED strip to indicate the direction the rider should move to position themselves centrally; and LED-FEEDBACK, which provides an increasing number of lights from the central position (2 central green lights) according to the direction and distance that the rider has moved away from the vertical position. An alternative to LED-FEEDBACK was initially developed, which provided a single light rather than multiple lights, indicating the direction and distance away from the vertical position. However, this interface was rejected during dismounted feasibility testing due to difficulties in visibility for identifying how far across the strip the single light was from the centre when viewed from a distance equivalent to the length of a horse's neck.

Both visualisations also use change of LED colour to support the information provided, with green indicating centralised posture and a gradual change, through amber to red, as the rider deviates to one side or the other. If the rider deviates beyond the range limit set within the software, flashing red lights are displayed.

Appendices E and F show images of the different stages of each visualisation.

The range of lateral motion covered by the visualisation interface can be adjusted within the software, with three available options:

- Select from 3 pre-set values (4-8 degrees, 8-12 degrees, 12-16 degrees), based on those used in the commercially available CoreX Equine mobile app-based system (Perfect Practice, 2018).
- Enter specific range values in degrees.
- Automatically generate values for the range, based on asymmetry limits detected during a recorded period of motion.

In addition to the visualisation interface provided via the LED strip, the software also provides a facility to capture data from the IMU sensor during a selected period of motion and displays a simplistic text-based on-screen visualisation of the IMU data and LED status for use by the operator of the device.

5.3. Software Development

The software was designed with a two-tier client-server architecture, split across the rider IMU device and the horse LED device. Figure 5.12 provides a UML class diagram for the design of the system.

A multi-threaded approach was required on the rider IMU device to enable the menu to be used for control of the system at the same time as polling the IMU and running the server to enable connection from the horse LED client device.

The main thread on the rider device was used to display the menu, to enable the user to control the device, while a second thread (*threadIMU*) was started, running ProcessIMU.Run, which configured the sensor and started it polling in the background. When the menu option to start polling was selected, a third thread (threadServer) was started, running RunServer.run(), which established the connection with the client via the socket, obtained the data being polled from the sensor and generated the message string from the sensor data values to send back to the client.

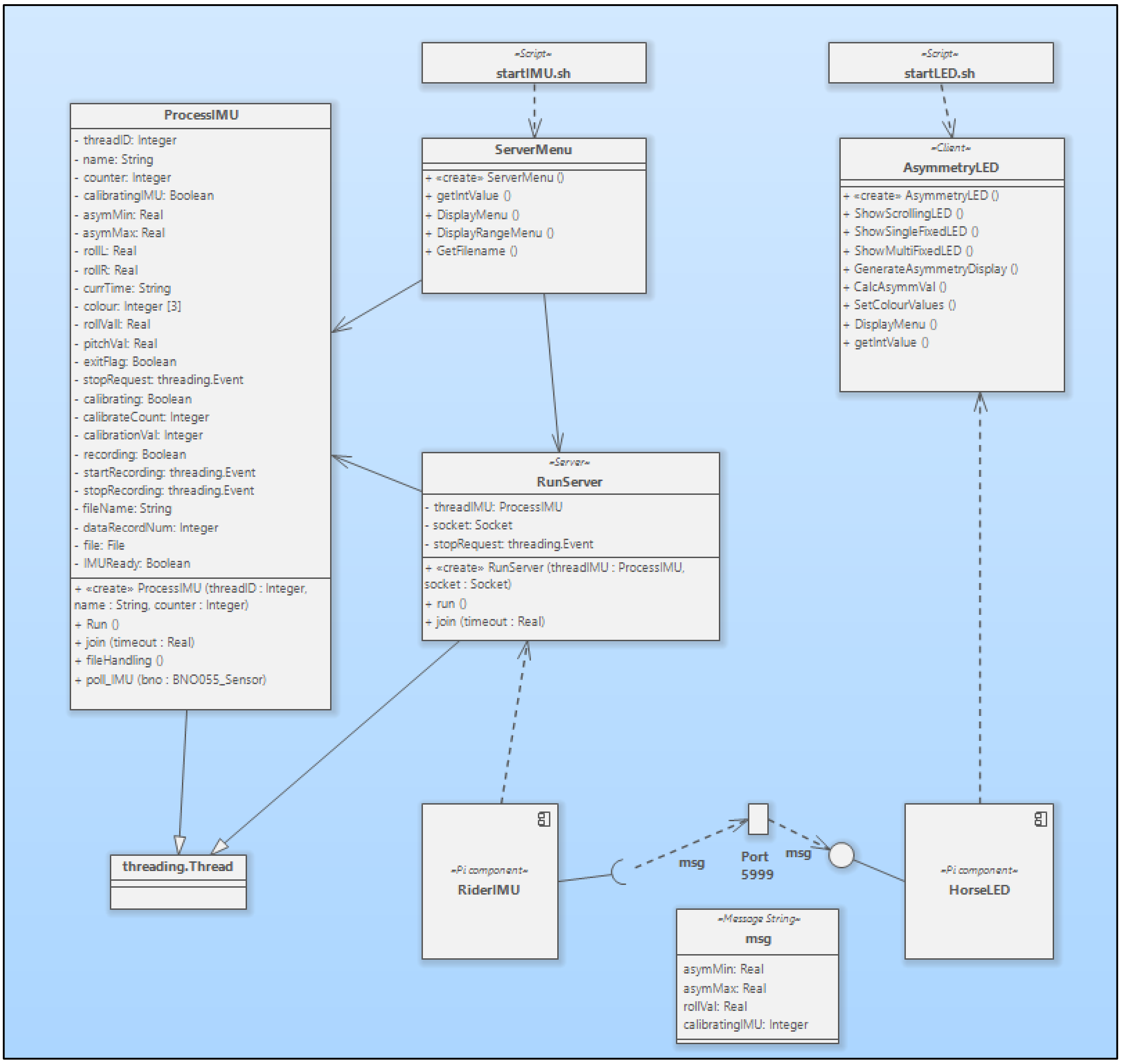


Figure 5.12. Structure of software for both rider and horse devices.

The horse device connected as a client, via the socket, to obtain the data. It then split it back into its component fields. One of the fields was the choice of visualisation, which was used to pass to the selected method to generate the visualisation.

Initially three visualisation interface methods were created: ShowScrollingLED (LED-CORRECTION), ShowSingleFixedLED (rejected feedback version) and ShowMultiFixedLED (LED-FEEDBACK). The code for ShowScrollingLED (LED-CORRECTION), together with images of the visualisation display is provided in Appendix E, and the code and images for ShowMultiFixedLED (LED-FEEDBACK) is provided in Appendix F. The initial provision of feedback, ShowSingleFixedLED, which displayed a single LED which moved across the LED strip was found during early testing to be difficult to view, so was replaced with the version with multiple LEDs lit to show the extent of the motion as feedback.

5.4. Incremental Development and Testing

Development was carried out via a series of sprints, with a desk-based testing phase incorporated into each sprint. The following is a summary of each sprint:

Sprint 1: Basic system with scrolling LED-CORRECTION interface.

Sprint 2: Menu with polling on/off and exit, addition of single (subsequently rejected) and multiple LED-FEEDBACK interfaces. Reading IP address from configuration file.

Sprint 3: Addition of calibration, choice of interface added to configuration file and modifications to threading.

Sprint 4: Enabling of configuration file editing on mobile device and adjustments to calibration.

Sprint 5: Addition of menu options to select LED display ranges, exception handling, validation of menu selections and other improvements.

Sprint 6: Primarily addition of file handling to record posture data for statistical analysis with other changes to correct errors and addition of configuration option to enable inclusion of a menu option for selecting LED visualisation interface rather via configuration file.

Sprint 6 is provided as an example in Figure 5.13, together with the Black Box test plan for this sprint.

Sprint 6

- Fixed error message for threadServer not defined if stop polling or exit is selected before polling
- Recording menu option (7) added with data saved to CSV file in data folder.
- Data format:

dataRecordNum	roll	pitch	LEDMinL	LEDMinR	LEDMaxL	LEDMaxR

- Selection of filename (prompts to replace if file exists)
- Tidying up of menu and string formatting with spacer ================= etc.
- Exit now menu option 8.
- Additional configuration option added to config.txt to determine whether a menu is to be displayed to override the LED display option from the config file.
- Changes to server and menu so that exit works even if LED has not been connected

Sprint 6 Black Box Test Plan

Test	Description	Expected Outcome	Actual Outcome	Result
T6.1	Stop polling selected before polling started	Error message displayed	Error message displayed	✓
T6.2	Exit selected before polling started	Error message displayed	Error message displayed	✓
T6.3	Select menu option 7 and record rotation from 0 to 90 degrees (left and right) for LED-CORRECTION to data file	Data file contains correct values from 0 to 90 degrees	Correct values recorded in data file	✓
T6.4	Select menu option 7 and record rotation from 0 to 90 degrees (left and right) for LED-FEEDBACK to data file	Data file contains correct values from 0 to 90 degrees	Correct values recorded in data file	✓
T6.5	Select filename for file not existing	File created	File created	✓
T6.6	Select filename for file already existing	File overwritten	File overwritten	✓
T6.7	Check menu formatting	Correctly displayed menu	Correctly displayed menu	✓
T6.8	Check menu option 8 for exit	Menu option 8 exits program successfully	Menu option 8 exits program successfully	✓
T6.9	Test configuration file option to display menu option for LED display choice	Menu option displayed and works for both LED visualisations	Menu option displayed and works for both LED visualisations	✓
T6.10	Test configuration file without display menu option for LED display choice	Menu option not included and both visualisations work from configuration file	Menu option not included and both visualisations work from configuration file	✓
T6.11	Test exit works even if LED has not been connected	Program exits without LED connected	Program exits without LED connected	✓

Figure 5.13. Example software development sprint.

Incremental software testing was carried out as a desk-based activity, prior to pilot testing. Black Box testing of the full system for each sprint was used, with additional White Box Testing of the visualisation methods.

The full set of sprints and corresponding Black Box test plans are provided in Appendix G.

5.5. Pilot Testing

5.5.1. Dismounted

The prototype tool was developed and preliminary testing carried out dismounted (Figure 5.14) to confirm that the device worked as expected and to investigate power options and Wi-Fi range. Further development was the addition of Adafruit Powerboost 1000C charger and Lipo battery to remove the need for external battery packs and reduce the size of the devices. The 3D-printed casing was also produced and tested at this pilot stage for housing the IMU device in a size suitable for placement on the rider's back, plus a similar casing for attaching the LED device to the horse.

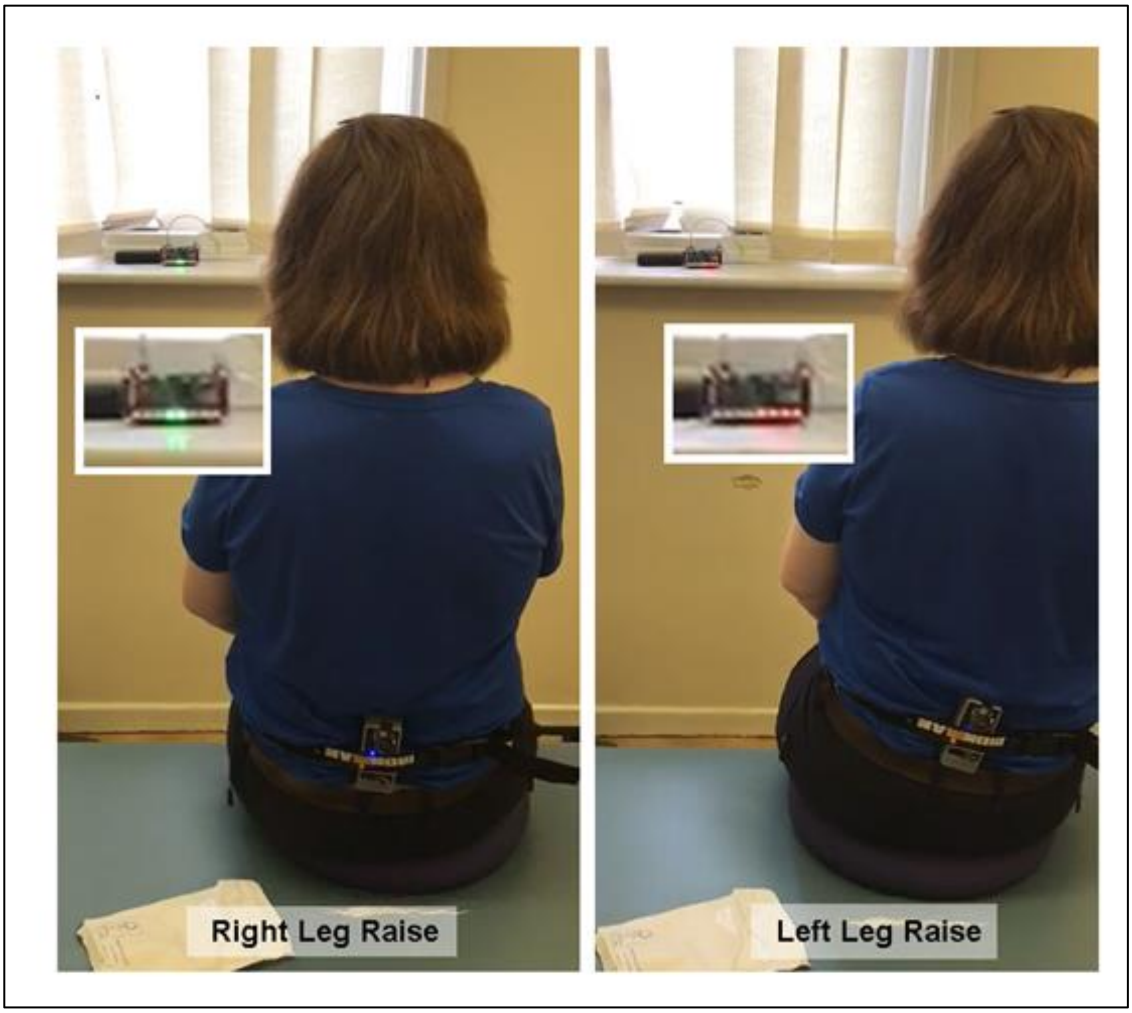


Figure 5.14. Rider tool dismounted prototype pilot testing.

5.5.2. Mounted

Mounted pilot testing was carried out with the representative coach over a series of iterations, following the dismounted pilot testing.

The operation of the devices was found to work successfully but the casings to house both devices required further development and inclusion of padding, to prevent the contents moving around during motion. This was of particular importance for the horse device, since its position close to the horse's ears would be a safety risk if it rattled and upset the horse.

Following a number of iterations, the casings were made as close fitting as possible, with the addition of foam inserts to keep the contents from moving during motion.

5.6. Device Operation

5.6.1. Software Installation

Based on prior experience and suitability of functionality, WinSCP (WinSCP.net, n.d.) running on a Windows machine and connected via Wi-Fi, was used to upload the tool's Python scripts to the respective Raspberry Pi devices for the rider IMU and horse LED components. This application was also used to download data files captured on the rider IMU device, for subsequent data analysis.

Figure 5.15 shows WinSCP, running on the PC, with connection details completed for the rider IMU Pi, with IP address 192.168.200.102 on Port 22. File protocol SFTP was used to provide a secure connection, and the default username of "pi" and password "raspberry" were used for login to both Pi devices for testing purposes. In a production version the password would be changed for security purposes, but this was not considered necessary for the prototype testing.

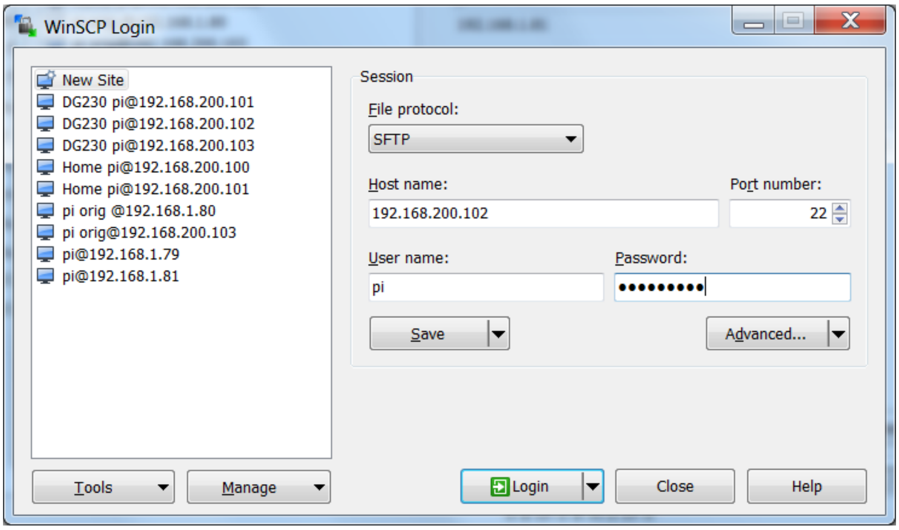


Figure 5.15. WinSCP FTP connection screen (running on Windows).

Following login, the user is provided with a dual window, with PC files on the left, pi files on the right. The PC location of the source files can be located using the Browse facility and the files are transferred to the root folder "/home/pi" on the Pi device. Figure 5.16 shows this for the rider IMU device, with the required Python scripts transferred.

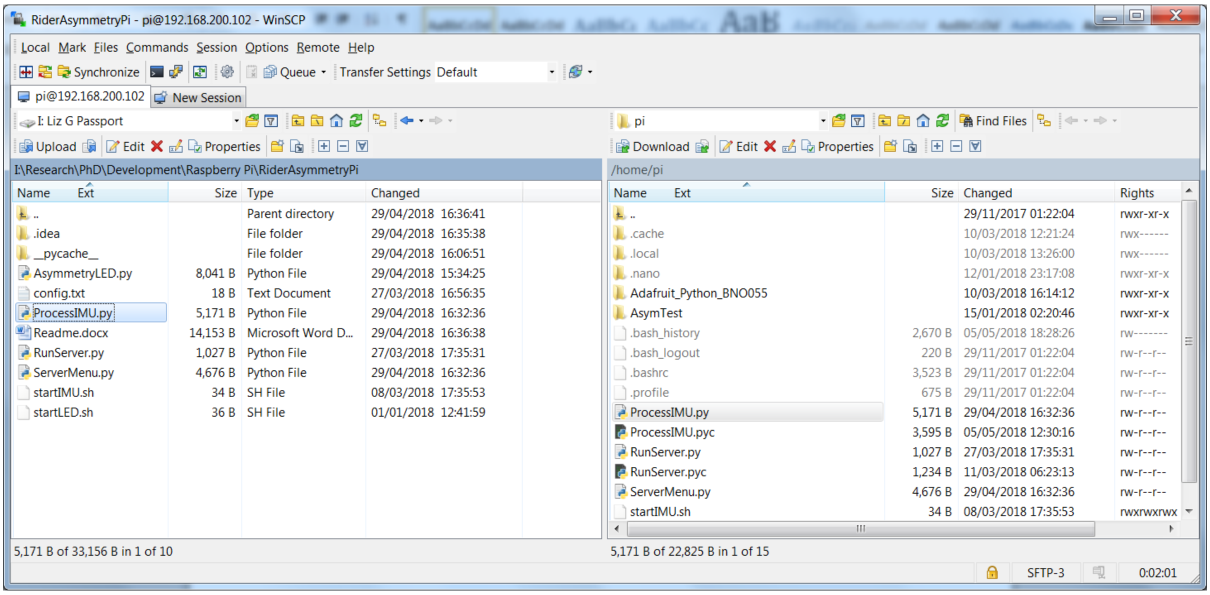


Figure 5.16. WinSCP main screen showing PC files on left and rider IMU files on right.

The files ProcessIMU.py, RunServer.py, ServerMenu.py and StartIMU.sh were transferred to the rider IMU device (used as the server), with a separate WinSCP session created and connected to transfer AsymmetryLED.py, config.txt and StartLED.sh to the horse LED device (client). Additional files shown with .pyc files extensions were generated on the Pi devices at runtime.

The key benefits of this application were ease and efficiency of use, with the ability to create multiple tabbed sessions and store login details and folder selection via a named workspace, giving the ability to quickly switch between Pi devices and retrieve connection/login details. Files can be transferred in either direction so download of data files was also carried out using the same process, after navigating to the "/data" subfolder on the rider IMU Pi, the location to which output data files were stored.

5.6.2. Connection and Basic Operation

The first step in the connection process was to power up the Wi-Fi router and connect the machine used to control the rider and horse devices. For this study, the Wi-Fi router was setup with a SSID name "Air Pen express" and configured with password "lizgandy230". Initial dismounted testing was controlled via a PC using the open-source Windows platform SSH client PuTTy (PuTTY, n.d.), chosen through having experience of using it in a similar environment, and knowing that it provided all of the necessary functionality. Carrying out initial testing via the PC enabled quick and efficient code editing, carried out on the PC and transferred to the devices for testing.

Control during mounted testing and data collection was transferred to an iPhone IOS mobile device, for ease of portability and use within the riding arena. Based on reviews and functionality, the Termius app (Termius Corporation, n.d.) was selected to provide SSH connection functionality, providing multiple simultaneous connections with ease of switching control between the two devices. In addition, the IP Scanner app (Matia Labs inc., n.d.) was used during early pilot testing to confirm devices were operational and check IP address allocation, for connection to be made from Termius.

During early testing, IP addressed were allocated by the router and varied according to the order that devices were connected. The final versions of the tool were assigned a fixed IP address of 192.168.200.102 for the rider UMU Pi to enable the software on the horse LED device to connect to it without needing user intervention, meaning that PuTTy session options could be saved for re-use. Both devices were connected using Port 22.

Both devices were controlled from separate PuTTY windows. When using Windows on the PC, the PuTTy SSH client windows could be arranged so that both are visible on the screen simultaneously, which was an advantage of using the PC for testing/debugging. On the IOS mobile device used for testing in the wild, it was necessary to name each connection and switch between views as required. This option was available within the Termius App interface and was used to switch between the menu on the rider IMU device for controlling the tool and viewing the screen representation of the visualisation on the horse LED device to monitor the rider's motion obtained from the IMU.

Raspian Lite was an obvious choice for the operating system, as a command-line interface was sufficient to control the tool during operation, with neither of the devices incorporating a GUI or need for an external monitor that would have required a full Raspian installation. Raspian Lite enabled connection via Wi-Fi from a PC or mobile device for configuration and external control, together with transfer of data files exported from the tool to a PC for future analysis. Python was selected as programming language for its compatibility with the hardware components, both the BNO055 IMU and Blinkt LED strip being supplied with Python libraries.

Both devices were setup to boot into the operating system to enable error diagnosis or software/file manipulation to be carried out before running the software to control the tool. In a production system, it would be preferable to configure the respective python scripts to run automatically at start-up, but this was considered impractical whilst testing as it was sometimes necessary to access the file system for diagnostic testing or file modification.

A bash script was provided in the root folder of each device to initiate the running of the Python script for the respective device, primarily to reduce typing when operated via the mobile phone but also for ease of use if operated by a non-technical user. The devices were started using the commands ./startIMU.sh on the rider IMU device and ./startled.sh on the horse LED device. The contents of both bash scripts are shown in Figure 5.17, each simply initiating the running of Python with the appropriate starting script for that device.

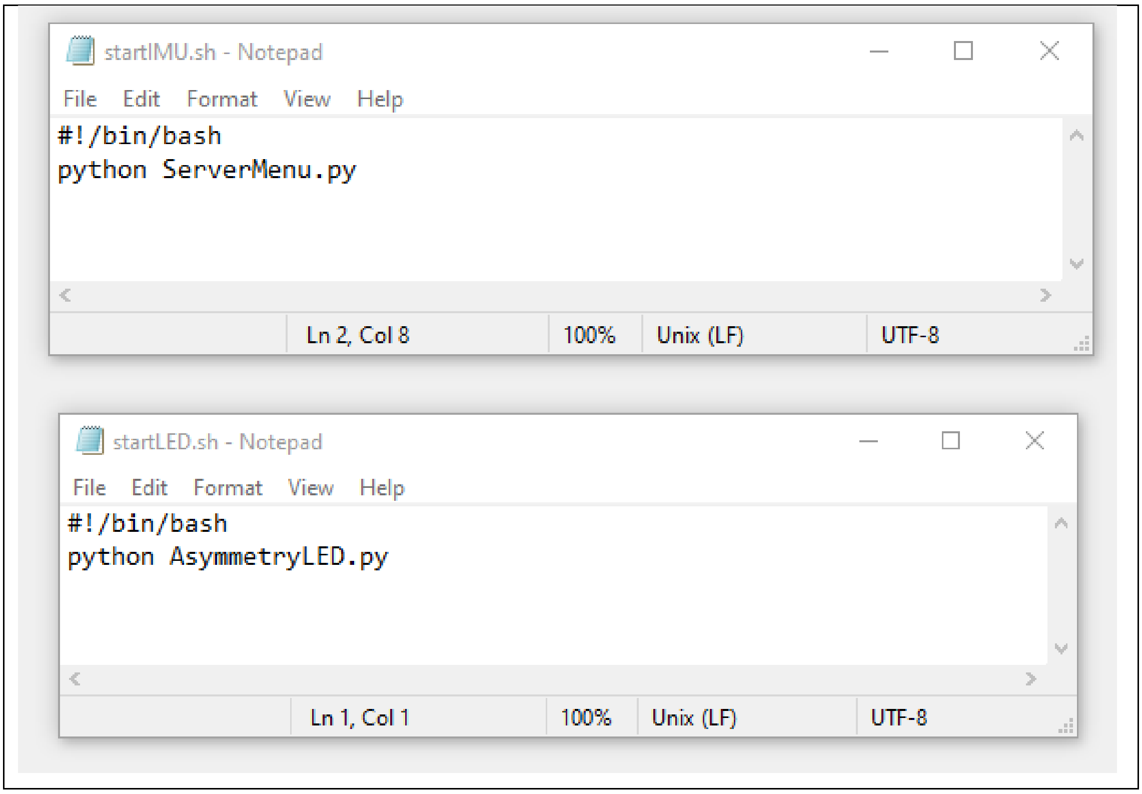


Figure 5.17. Bash scripts to start the rider IMU and horse LED device software.

The rider IMU device provides the server, with the horse LED device connecting to it as client, so it was necessary to start the software on the rider IMU device first and wait for confirmation that it was ready before starting the horse LED device software. The reason for the choice of the rider IMU device as server was that there would only ever be one rider IMU device in operation within the tool, whereas there could ultimately be multiple client devices providing alternative visualisation interfaces e.g. the horse device and a separate visualisation for a coach. Having the rider IMU device as the server provides this flexibility.

As discussed in Section 5.3, the software on the rider IMU device comprises three Python scripts, with the starting point being ServerMenu.py, which starts the IMU, checks the return status to confirm successful start-up, initialises the server and then displays the menu which provides the user functionality. Figure 5.18 shows the newly booted-up Pi with a list of files in the root directory, followed by initiation of the bash script startIMU.py, then status messages as the IMU is started and the menu interface is displayed ready for use.

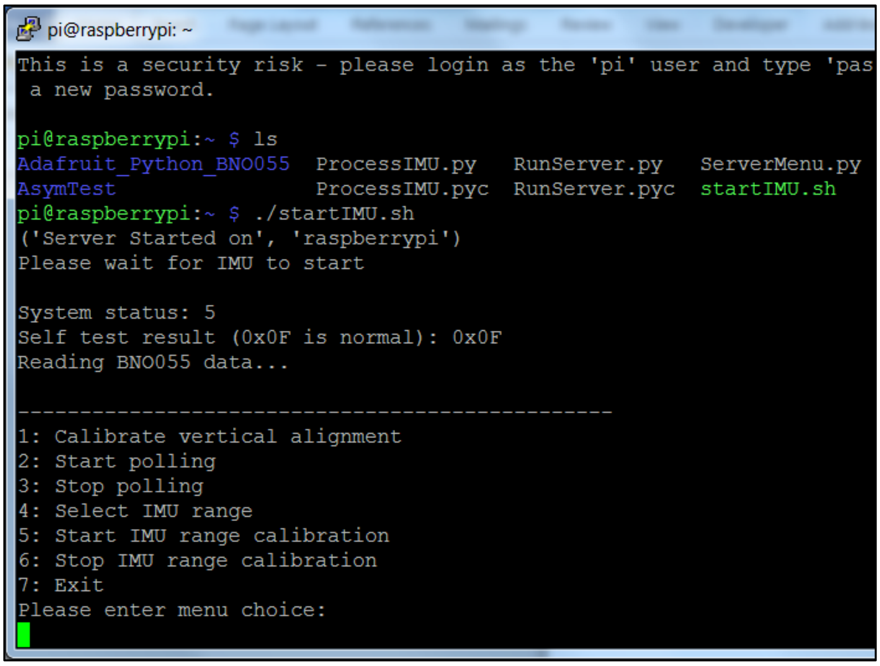


Figure 5.18. Root folder contents and software start-up for rider IMU device.

Once this screen is obtained, the bash script startLED.sh on the horse LED device can be run to start the Python script AsymmetryLED.py, which creates the client connection to the server. At start-up, the LEDs are turned on with a full set of blue LEDs, to show that the device is operating but not yet polling the IMU. Blue provided a contrasting colour to distinguish it from the green, amber, red used for the feedback interface.

Figure 5.19 shows the files contained in the root folder of a newly booted horse LED device followed by software start-up and successful connection to the server on the rider IMU device, using the fixed IP address 192.168.200.102. This is now in a state of waiting for the polling menu option to be selected on the IMU device.

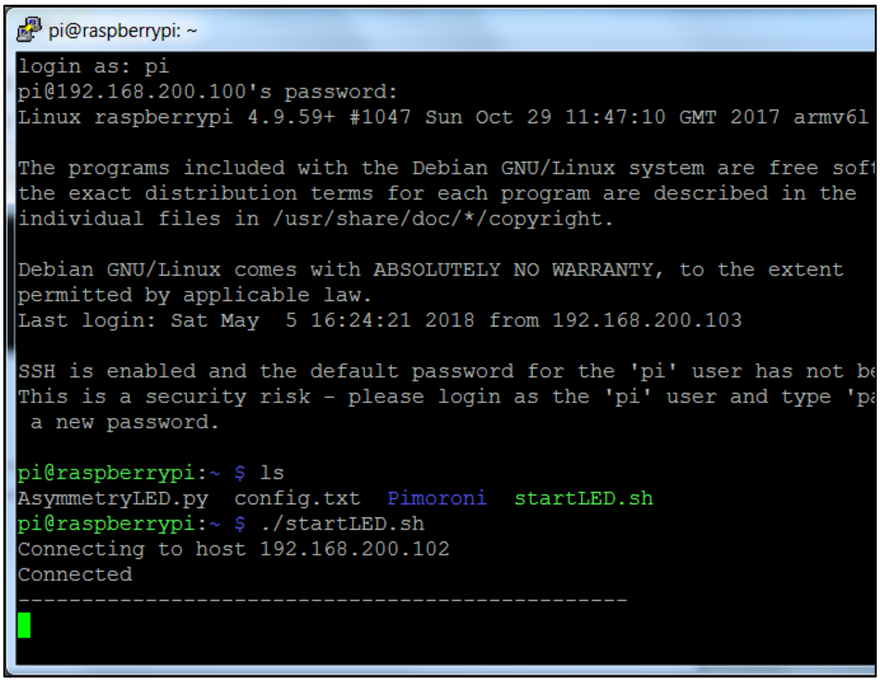


Figure 5.19. Root folder contents and software start-up for horse LED device.

The menu on the rider IMU device is used to operate both devices, as discussed in detail in Section 5.6.3. The devices continue to operate until menu item 8 is selected to stop the IMU polling, close the connection to the client and close the program.

5.6.3. Menu and Functionality

The menu provided on the rider IMU device runs on the main thread to calibrate, set parameters, control the operation of the devices and record data as required. The functionality provided within the system, as identified by each menu option, is discussed below:

Option 1. Calibrate vertical alignment

Vertical calibration is required before commencing riding activity to account for any inaccuracies in the positioning of the device on the rider's pelvis. This was carried out whilst mounted on the horse at halt, to ensure that the device was not dislodged during the mounting process and to enable feedback to be provided for dynamic motion from a baseline position that was considered optimum. Carrying it out whilst mounted on the horse also allows a coach or observer to correct the rider's initial position to the optimal vertical alignment, as has been done in previous research studies (Gandy et al., 2014). The rider was required to sit in a vertical position at halt and remain as motionless as possible during the calibration process. To ensure any small deviations of the stationary motion in the rider are accounted for, the calibration polls the IMU sensor for 10 seconds and records the mean of the roll data value. Any longer could be problematic as horses generally struggle to remain motionless so this time slice falls between the 20 seconds required for full body calibration of the XSens motion capture equipment, carried out dismounted in previous studies (Gandy et al., 2014), and the 5 seconds used for data collection when assessing rider posture whilst mounted on the horse at halt (Gandy et al., 2018).

The calibration at halt provides an offset value from true vertical, which was used to adjust the IMU values recorded whilst in motion to correct for alignment errors in positioning of the device. During the calibration process, all of the LEDs are set to blue to differentiate from the green, amber, red used during feedback, so that the rider had visual feedback that the process was taking place. The interface for the horse LED device on the computer/mobile device shows the rolling average value for checking by the operator, who could monitor to ensure no significant deviations occurred and repeat the calibration if necessary. At the end of the process the interface showed the offset, in degrees, to be applied to future IMU readings, with the LED interface considering this value as it's zero position, i.e., the position with the rider in vertical alignment. Figure 5.20 shows the result of the calibration process for a rider who remained motionless during the part of the calibration processed visible, with the device recording a rolling mean of 1.38 degrees to the vertical and this value subsequently applied as the offset. This is displayed as rounded to the nearest integer, but the offset applied to the roll values recorded by the IMU is the underlying real number.

```
pi@raspberrypi: ~
222: Roll  1.38, Calibration Value  1.38
223: Roll  1.38, Calibration Value  1.38
224: Roll  1.38, Calibration Value  1.38
225: Roll  1.38, Calibration Value  1.38
226: Roll  1.38, Calibration Value  1.38
227: Roll  1.38, Calibration Value  1.38
228: Roll  1.38, Calibration Value  1.38
229: Roll  1.38, Calibration Value  1.38
230: Roll  1.38, Calibration Value  1.38
Calibration Complete, value = 1
1: Calibrate vertical alignment
2: Start polling
3: Stop polling
4: Select IMU range
5: Start IMU range calibration
6: Stop IMU range calibration
7: Exit
Please enter menu choice:
```

Figure 5.20. Menu option 2 completing with rolling mean and final calibration offset.

Option 2. Start Polling

This option initiates polling of the IMU by starting the server and passing *threadIMU* and the socket (*s*) to it (Figure 5.21), enabling the horse LED device to connect and obtain the IMU data.

```
    elif menuOption == 2:
        threadServer = RunServer(threadIMU, s)
        threadServer.daemon = True

        # Start thread for the server
        threadServer.start()

        print("Polling IMU Started")
```

Figure 5.21. Initiating a separate thread to start polling the IMU.

This then transmits the vertical alignment (roll) values to the horse LED device, which activates the LED visualisation interface, lighting the LEDs according to the chosen display configuration LED-CORRECTION (Appendix E) or LED-FEEDBACK (Appendix F). Polling of the IMU roll values takes place at an interval of 1ms with the LED device reading the latest value and updating the visualisation at intervals of 5ms, providing a refresh rate of both LEDs and its user interface of 200 Hz. This was the fastest refresh rate possible to allow for a smooth display of the visualisation interface, taking account of data transmission and processing time.

Alongside the horse LED device visualisation, the software interface provides a rolling display showing the current IMU roll value (degrees either side of the vertical position), together with an increasing number of dashes representing the direction and extent of asymmetry in the five bands which match the LED configuration bands (Figure 5.22). When the IMU records a roll value beyond the range of motion selected (equivalent to the LEDs flashing red) the line turns to an arrow.

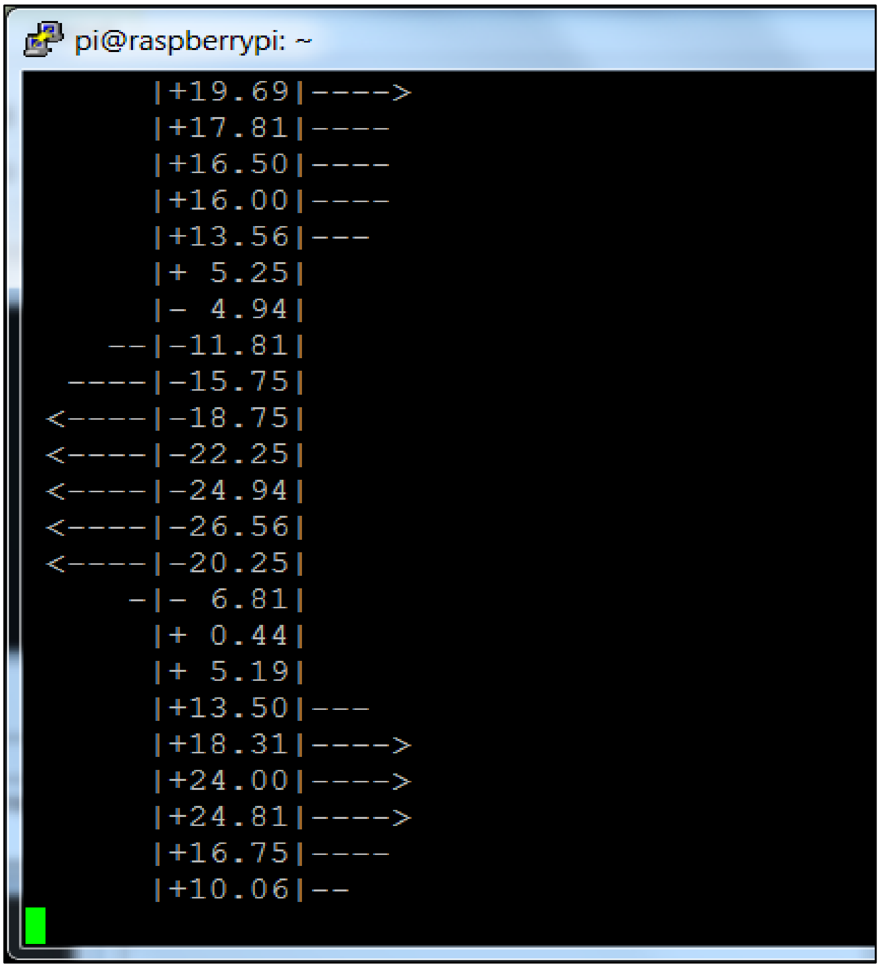


Figure 5.22. Horse LED device interface shown while the rider IMU device is polling.

This is a basic interface to provide the device operator with a representation of what the LEDs are showing to the rider, giving them confirmation that polling is taking place when the LEDs on the horse are not in line of sight.

Option 3. Stop polling

This option suspends polling of the IMU if it is in progress and turns the LEDs off on the horse LED device. It also stops/closes file saving, if this functionality was turned on (Option 7). It does not shut down the IMU, so the system is ready to recommence polling if Option 2 is subsequently selected again.

Option 4. Select IMU range

This option displays the current range of IMU roll values covered by the visualisation on the horse LED device, specifically the values between constantly green and flashing red. It then provides a sub-menu to select from three pre-set ranges or to provide full manual control by allowing the user to enter a custom range as in Figure 5.23. There is also then an option to return to the main menu.

```
pi@raspberrypi: ~
1: Calibrate vertical alignment
2: Start polling
3: Stop polling
4: Select IMU range
5: Start IMU range calibration
6: Stop IMU range calibration
7: Exit
Please enter menu choice:
4
Current IMU range: 3 - 18
1: Novice 12-16 deg
2: Intermediate 8-12 deg
3: Advanced 4-8 deg
4: Custom
5: Return to main menu
Please enter menu choice:
4
Enter min range value (deg):2
Enter max range value (deg):5
IMU range set: 2 - 5
1: Calibrate vertical alignment
2: Start polling
3: Stop polling
4: Select IMU range
5: Start IMU range calibration
6: Stop IMU range calibration
7: Exit
Please enter menu choice:
```

Figure 5.23. Sub-menu to select or enter range of IMU values for visualisation.

The three pre-set range values were based on those used in the commercial product Level Belt Pro (Perfect Practice Inc., n.d.), identified as Novice, Intermediate and Advanced. These provide reducing levels of lateral motion tolerance in the green zone as the range levels move from novice towards advanced. In each case, the LEDs then provide their respective feedback through a 4-degree range before flashing red if the rider's lateral motion moves beyond the upper range limit. The range options were named to be consistent with the Level Belt Pro, however, it was found during the evaluation study that the range of motion for each rider varied according to the gait, with more lateral motion experienced typically in trot than in walk. In a production system these level names would be renamed to something more appropriate as results showed they were not necessarily associated with rider experience levels but required adjustment according to horse's gait.

The IMU range menu also provides a "Custom" option for full manual control, to enable the operator to enter the upper and lower values, in degrees, for the feedback range. This means that the device can be operated with a user-selected level of tolerance for lateral motion within the green zone and for the range of feedback provided by the LEDs before they flash red if the motion exceeds the upper value, providing more flexibility than the 4 degrees range in the pre-set options.

Options 5 and 6. Start/Stop IMU range calibration

This pair of options provide the facility to automatically calibrate and set the LED range values based on asymmetry of the rider's lateral motion, specifically to provide a custom range whereby the LED visualisation can be used to inform the rider of when they are in the zone where they typically exhibit asymmetry. The LED range is set to the difference in maximum range of motion between left and right during the calibration process, which would typically be recorded whilst carrying out chosen movements.

For example, if the participant moves between -10 degrees (left) and +15 degrees (right) then the LED range will be set as 10 - 15 degrees on both left and right sides, with the lights green between 0 and +/-10 degrees, providing feedback between +/-10 to 15 degrees, and flashing red above +/-15 degrees. The LEDs show blue whilst calibration is taking place, to inform the rider that range calibration is taking place.

There is no time limit to this calibration, to enable flexibility in the movements that can be carried out to determine the rider's natural asymmetry. The calibration phase continues until the stopped by the operator (menu option 6), after which the software will report the asymmetry values detected and the new LED range values set for subsequent feedback to the rider.

Option 7. Saving to file

After selecting the file saving option, the user is prompted to enter a filename or press return to accept the default "datafile.csv", to which they receive a further request to confirm whether to overwrite the file if it already exists. The user is prompted again to enter a carriage return to start recording. This additional prompt was added following initial testing as the starting point of recording would normally be required to coincide with the rider commencing a particular activity or movement, usually whilst already in motion. In the earlier versions of the software, the file recording activation originally happened at the point of selecting the filename and there were occasions where the operator forgot that the file already existed. The prompt to confirm file overwrite or enter a different filename then interrupted the planned start of recording, meaning the rider and horse had to abort the planned movement to be recorded and re-position themselves to start again.

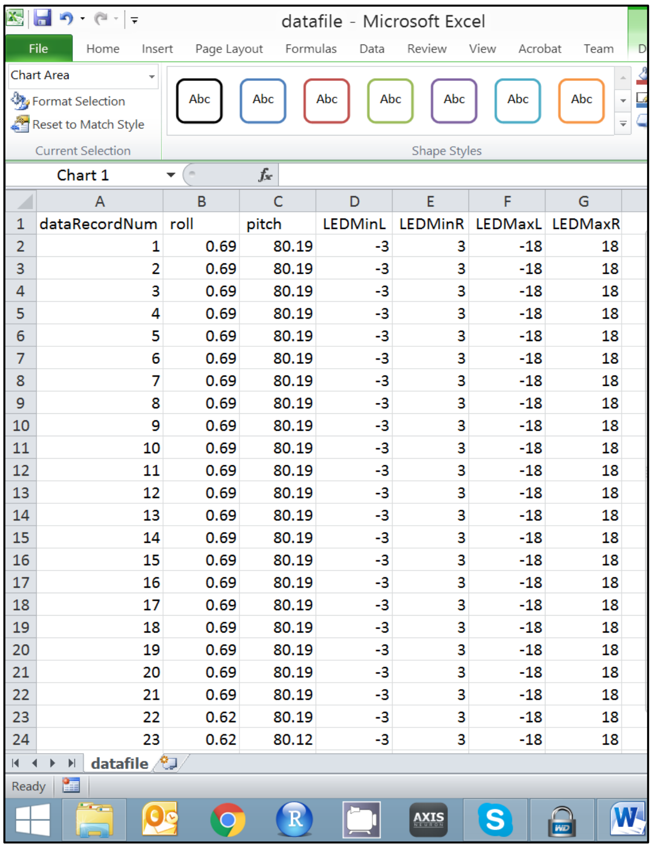
Once recording has successfully started, a message is provided to indicate that recording is taking place, and the software remains in a holding state until the user enters another carriage return to stop recording. The use of a single click carriage return enables precise control of the start and stopping point of data recording, however, this does mean that the menu is not available during file recording so any calibration, selection of range values, starting or stopping polling etc. would need to be performed first. File recording can take place irrespective of whether the polling option has been selected since the IMU is working in the background. This means that the rider's motion can be recorded whether visualisations are being displayed on the horse LED device or not, enabling comparative analysis of rider motion both with and without feedback being provided.

The data is stored in CSV format and includes the columns identified in Table 5.1. The pitch values from the IMU sensor were included but not used in this study.

Column name	Description
dataRecordNum	row count
roll	angle of lateral motion [used to control the LED visualisation]
pitch	angle of anterior/posterior motion [for future use]
LEDMinL	Lower value that will activate the left-side LED Pi lights (corresponding to negative roll values)
LEDMaxL	Upper value that will activate the left-side LED Pi lights (corresponding to negative roll values)
LEDMinR	Lower value that will activate the right-side LED Pi lights (corresponding to positive roll values)
LEDMaxR	Upper value that will activate the right-side LED Pi lights (corresponding to positive roll values)

Table 5.1. Columns recorded in CSV format data file.

Data files are stored in the *"..\data"* sub-folder of the IMU rider device and can subsequently then be transferred from the Pi for analysis or reporting purposes. Figure 5.24 shows a data file which has been transferred to a Windows machine and imported into Excel.



	A	B	C	D	E	F	G
1	dataRecordNum	roll	pitch	LEDMinL	LEDMinR	LEDMaxL	LEDMaxR
2	1	0.69	80.19	-3	3	-18	18
3	2	0.69	80.19	-3	3	-18	18
4	3	0.69	80.19	-3	3	-18	18
5	4	0.69	80.19	-3	3	-18	18
6	5	0.69	80.19	-3	3	-18	18
7	6	0.69	80.19	-3	3	-18	18
8	7	0.69	80.19	-3	3	-18	18
9	8	0.69	80.19	-3	3	-18	18
10	9	0.69	80.19	-3	3	-18	18
11	10	0.69	80.19	-3	3	-18	18
12	11	0.69	80.19	-3	3	-18	18
13	12	0.69	80.19	-3	3	-18	18
14	13	0.69	80.19	-3	3	-18	18
15	14	0.69	80.19	-3	3	-18	18
16	15	0.69	80.19	-3	3	-18	18
17	16	0.69	80.19	-3	3	-18	18
18	17	0.69	80.19	-3	3	-18	18
19	18	0.69	80.19	-3	3	-18	18
20	19	0.69	80.19	-3	3	-18	18
21	20	0.69	80.19	-3	3	-18	18
22	21	0.69	80.19	-3	3	-18	18
23	22	0.62	80.19	-3	3	-18	18
24	23	0.62	80.12	-3	3	-18	18

Figure 5.24. Example data file imported into Excel.

Option 8. Exit

The exit menu option shuts down the IMU and closes the rider IMU device software. It also closes the server and ends connection to the client horse LED device software, which shows the message “Connection refused”. This behaviour would also happen if the programme on the rider IMU device were to experience an unexpected error or interrupt.

It can take up to 2 minutes for the software to release access to the port used to communicate with the horse LED device so, if the software is restarted again within this time, the error message “Port is already in use” may be received. Waiting for 2 minutes then trying again resolved this issue.

Before powering down both devices by turning off the battery switch, it was found to be advisable to carry out an operating system shutdown first by running the command `sudo poweroff` on each device then waiting for 20 seconds for the green status indicator on each Pi to turn off. Failing to do this step occasionally resulted in corruption to the data card, requiring a full re-imaging of the operating system and software.

5.6.4. Operational Issues

Due to the multiple device interaction via the Wi-Fi network, connection issues were sometimes experienced when using the tool. Occasionally one or more of the devices would fail to connect on start-up, particularly if they were switched on too quickly after the Wi-Fi router was started, before it had time to initialise. The diagnostic tools Angry IP Scan (AngryIP.org, n.d.) on the PC or IP Scanner (Matia Labs inc., n.d.) on the mobile device were used to diagnose such issues. Both provided a display of which IP addresses were connected via the router and could be used to confirm that the rider IMU Pi and horse LED Pi were connected to the router and assigned to the correct IP addresses.

Figure 5.25 Shows an example of this on a PC, with an IP range search between 192.168.200.100 and 192.168.200.200 confirming that the two devices are connected as expected.

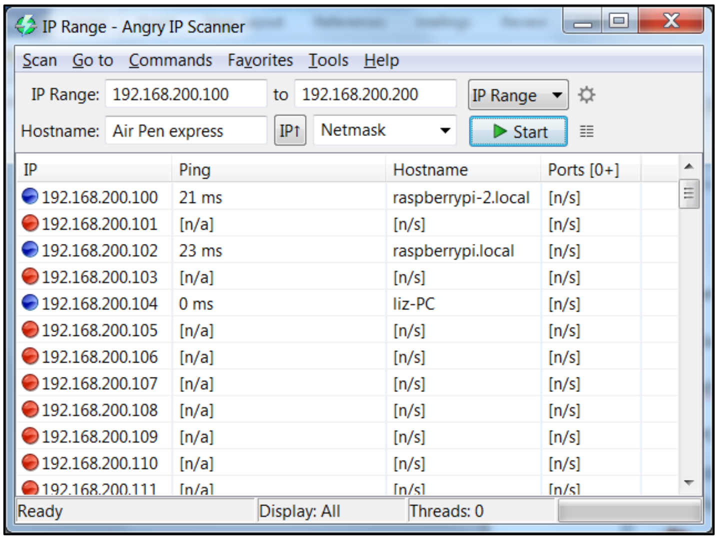
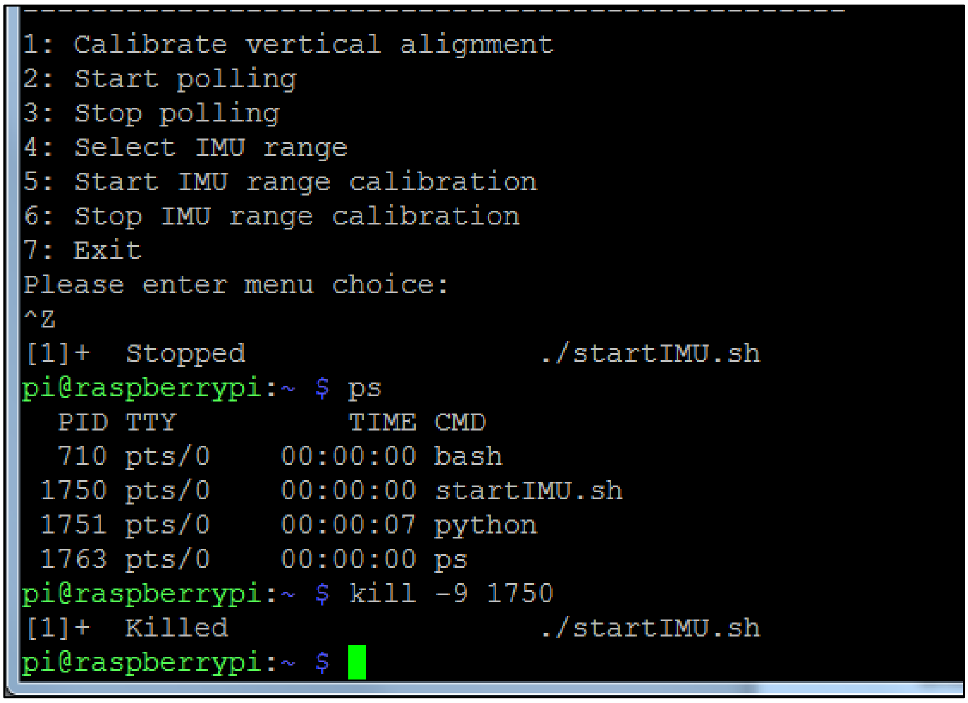


Figure 5.25. Using Angry IP Scanner on the PC to confirm connections to the router.

In general, this was used to pick up intermittent issues such as those associated with turning on of devices to quickly, as previously described. In such circumstances, switching off and restarting all devices again was sufficient to resolve the issue. The diagnostic tools did, however, help to identify the cause of more serious issues where one of the devices would repeatedly fail to connect, indicating a problem with the device itself. This occasionally happened when a data card was corrupted, requiring it to be re-imaged via the PC. It also happened on one occasion when the rider IMU device appeared to be running, with its power light turned on, however the power throughput was insufficient to run the operating system. This had occurred due to a soldering issue causing a loose connection with the battery pack being used to power the device, which had damaged the hardware. In this case, replacement Raspberry Pi device and PowerBoost components were required.

Another operational issue, which happened periodically, was that the server device (Rider IMU) would freeze whilst running and stop responding to menu input. This typically if polling was started then stopped without having connected the client device (horse LED) first, or if the horse LED device powered down or lost connection for some reason. When this occurred, a software interrupt using Ctrl-Z would enable a return to the command line, and the running process could be identified and shut down (Figure 5.26). The program could then be restarted, without the need for a full reboot of the system.



```
-------------------------------------------------
1: Calibrate vertical alignment
2: Start polling
3: Stop polling
4: Select IMU range
5: Start IMU range calibration
6: Stop IMU range calibration
7: Exit
Please enter menu choice:
^Z
[1]+  Stopped                 ./startIMU.sh
pi@raspberrypi:~ $ ps
  PID TTY          TIME CMD
  710 pts/0    00:00:00 bash
 1750 pts/0    00:00:00 startIMU.sh
 1751 pts/0    00:00:07 python
 1763 pts/0    00:00:00 ps
pi@raspberrypi:~ $ kill -9 1750
[1]+  Killed                  ./startIMU.sh
pi@raspberrypi:~ $
```

Figure 5.26. Commands used to resolve an issue of the server device freezing.

5.7. Tool Constraints and Limitations

The tool and installation used in this research was a prototype specifically developed for the PhD study and as a proof of concept. As such it did have constraints.

The size of the rider device and the housing designed to contain it was larger than would be expected in a commercial, constraining its use on the rider to be worn outside clothing. This meant that, to achieve closeness to the pelvis to detect the rider motion, the rider needed to wear thin, close-fitting clothing and not jumpers or coats, constraining use to dry, warmer weather. Due to the lack of a waterproof housing, the device itself could only be used in dry weather.

The horse device was also constrained by its size to use on a horse which would not react adversely to the positioning and any rattling noise on its head behind its ears. Even on a future commercial device the number and size of the LED lights would be constrained by the need to fit them in a position that could be seen by the rider but avoid upsetting a sensitive horse.

To operate the device and stop/start data recording in the prototype interface requires a separate operator so the use of the tool is constrained to the distance that it will operate with connectivity to the wireless router. This was found to be sufficient for the 40 metres of the 20x40 metre arena for the data collection for this research but would be a constraint for more general use.

The lack of automated gait detection in the prototype and the requirement for different feedback ranges from the data means that the tool requires an operator to select these manually through the interface. This constrains data collection to separate out collection and feedback for the different gaits of the horse and the riding movements rather than enabling use for full freedom of motion as would be required for a commercial version of the device. A limitation of the prototype software means that data files also require a manual FTP transfer for analysis rather than this being carried out on the mobile device or automatically uploading to a PC for analysis.

5.8. Summary

This chapter has covered the design and development of the tool, incorporating the IMU device which is placed on the rider's pelvis and the provision of visual feedback or correction interfaces provided via the LED device attached to the horse's bridle.

The hardware has been discussed in detail, together with methods of attachment, powering the devices and connectivity between the devices using a client-server architecture. The rider IMU device incorporates the server, with the horse LED connecting as client, with software developed using Python. In addition, a second client was developed in Python, providing a basic text-based visualisation of the rider's posture to be displayed on a mobile device or laptop for viewing by the researcher or a coach. Alongside this, a text-based menu was provided for controlling the devices and selecting the functionality to calibrate the rider IMU, start/stop polling of positional data, select display ranges for horse LED visualisation interfaces and save positional data to file.

The software provided two LED visualisation interfaces, LED-CORRECTION which provided scrolling LEDs indicating to the rider the direction they need to move to correct their posture and LED-FEEDBACK with fixed LEDs indicating to the rider the extent to which their posture deviates from the central range. In both cases, colour was used to add additional information on the extent of deviation from green acceptable range of deviation, through gradual levels of amber/orange whilst dynamic visualisations are displayed, to red flashing LEDs beyond the limits of correction/feedback.

The software was developed via a series of sprints, with testing at each stage, followed by pilot testing, firstly dismounted to confirm the operation of both hardware and software. Following this, pilot testing was carried out with one rider mounted on a horse. This included iterative development of the cases to house the devices and attachments, plus testing of the devices to ensure they were able to be controlled by the researcher within the size of the arena and that the rider could view the LEDs.

The evaluation of the tool developed within the proposed context of use will now be covered in Chapter 6.

Chapter 6. Study 2. Tool Evaluation Method

6.1. Introduction

In this study, the two LED visualisation interfaces (LED-CORRECTION and LED-FEEDBACK) were compared empirically, using a user-centred field-study with a crossover repeated measures design, to evaluate the effectiveness of each interface design within its context of use for rider posture feedback. Independent variables are the variations in interface design techniques used in the visualisation interface and dependent variables are measures relating to usability and applicability of the design to its context of use.

The study was split into two phases. A customised contextual inquiry method incorporating a ridden activity where the riders experienced the LED visualisations in practice followed by a structured interview to evaluate qualitatively the riders' visualisation preference, how the selected LED interface might be incorporated into a riding context and environmental factors which may impact use of the tool.

The aim of this study was to answer research questions Q2c "What are the usage implications for IMU-based analysis and feedback during riding motion?" and Q3 "Which is the most appropriate data visualisation technique for the presentation of rider analysis data feedback according to the usage contexts identified in Q1". These questions were addressed via the following objectives.

- Evaluate the comparative effectiveness of two visualisation interfaces using LED technology within a prototype IMU-based rider postural data assessment and feedback tool.
- Determine the rider's preferred choice from the two alternative LED visualisation interfaces for the prototype tool.
- Evaluate how the prototype tool may be used within a riding context to provide a rider with postural data feedback.

Data required to address the research questions is identified in Table 6.1.

Research Question	Data Required
Q2c. What are the usage implications for IMU-based analysis and feedback during riding motion?	HW setup/attachment. Calibration. Health and safety implications (rider/horse). Comfort, Environmental implications.
Q3. Which is the most appropriate data visualisation technique for the presentation of rider analysis data feedback according to the usage contexts identified in Q1	IMU data. Preference values for choice of interface.

Table 6.1. Data required for each research question to be addressed by this study.

6.2. Method

This section first explains the design and procedure of the experiment. Following this, it discusses how the data was processed and handled before presenting the results.

The procedure explained here was submitted and agreed by the University of Sunderland Ethics Committee (002448) and all participants were provided with an information sheet and consent form prior to commencing testing (Appendix H).

6.2.1. Participants

Ten adult participants were recruited for the study. They were self-selected and either a member of staff or client of the establishment used for data collection.

Participants were familiar with the horses used, although in the case of three riders, this was through their handling/coaching roles at the riding centre and they had not actually ridden the horse previously. These riders were experienced in riding a range of different horses, so this was not considered a risk to their safety or to have any bearing on the data collected.

Four horses were used for data collection. They were either provided by the establishment (three horses) or owned by the rider (one horse) and kept at livery at the establishment. All horses were at least 4 years old, identified as healthy, free from disease/injury at time of data collection by their owner, in regular work and accustomed to working in different situations.

Riders and horses were of an experience level equivalent to a minimum standard of British Dressage affiliated novice level and familiar with the activities that they were asked to perform.

It is recommended that participants selected for any study on the use of wearables should reflect the intended use of the device being tested (Düking et al., 2018). For this reason, participant riders were selected to represent the most likely common users and beneficiaries of the proposed system i.e. those within a riding school context, or riders training or competing at grass-roots level. Elite riders would generally have access to and requirements for more accurate systems such as full-body or camera systems. Longer term it is hoped that the system would be suitable for use by disabled riders, however, for convenience and safety reasons these were unable to be included in this study.

6.2.2. Health and Safety Considerations

It is recognised that riding is a risk sport and any interaction with horses does pose a potential risk to health and safety. All persons involved in the data collection were experienced with horses and familiar with safe practices for their handling.

To minimise risk, the horses used for data collection were always under the control of their handlers and/or riders and any attachments of equipment were carried out by the handler or rider under direction from the researcher.

Data collection was carried out within the confines of an enclosed indoor or outdoor riding arena and, for the purpose of observation/recording of data, the researcher was positioned either external to the arena (outdoor) or adjacent to the perimeter of the arena (indoor). All riding activity was carried out with the horse remaining at a safe distance from the researcher.

The required riding movements used for the ridden part of Study 2 were limited to walk and trot; and the horse was familiarised with the equipment before the rider mounted. The horse was wearing its normal tack and participants wore their normal riding clothing and footwear, including a British Standard safety approved riding hat when mounted on the horse.

The participants were advised that, if at any point during the data collection they experienced any problems or were uncomfortable with any activity they were asked to carry out, they should tell the researcher immediately and they would do what they could to resolve the issue and/or will stop the data collection if necessary.

The establishment used were covered by appropriate insurance and fire safety procedures and the researcher was using the facility for the purpose that it is normally used i.e. riding/coaching. The researcher had appropriate business insurance cover on the vehicle used for driving to/from the establishment used.

The riding centre used had accident procedures, first aid cover (for both human and horses) and fire safety procedures in place with appropriate signage posted within the venue, as required by their licence to trade as a riding establishment. This meant that a first aider was always present on the premises and a first aid kit was located within or adjacent to the riding arena.

A risk assessment was completed and is provided in Appendix I, for data collection carried out at Washington Riding Centre.

6.3. Procedure

6.3.1. Data Collection (Ridden Phase)

Participant riders were allocated randomly to one of two groups, each of size five. The IMU component of the tool was attached to the rear of rider's pelvis and the LED component was attached to the headpiece of the bridle or front of the saddle where it was in clear sight of the rider (as discussed in Section 5.2). The horse was walked from the ground prior to the rider mounting to ensure that the device remained in position during motion and that the horse was acclimatised to wearing the device and did not react adversely to it.

Once mounted, riders were given the opportunity to carry out a short, self-selected period of warm-up (approximately 5 minutes), which also served to ensure that the IMU component remained in position before data collection commences.

Once mounted, one of the horses showed signs of concern about the equipment on its head so the device was relocated to the front of the saddle. The effect of this on use of the tool is included in the discussion of the results. This alternative attachment is shown in Figure 6.1.

Figure 6.1. Alternative attachment for horse who would not tolerate device on head.

The horse/rider was positioned at halt with the rider sitting as straight as possible and remaining motionless while a 10 second calibration was carried out for the IMU device. The rider was be observed from behind and guided into the correct posture if necessary and to ensure that the posture was maintained for the duration of the calibration. The calibration was repeated if either horse or rider carry out significant movement during the process.

The rider was directed to carry out a series of riding movements, according to a pre-determined protocol, including straight lines and circles in each direction at walk and trot. The protocol used was derived from Study 1, which was discussed in Chapter 4, and is described in Table 6.2.

Gait/Movement
Walk
H – start from halt, walk on right rein
C – turn down centre line
X – circle right
X – circle left
A – track left
M – Halt
Trot
M – start from halt, progressive transition to trot on left rein
E – circle left 20m
FXH – change rein
B – circle right 20m
H – progressive transition to halt

Table 6.2. Riding movement protocol for data collection.

Data collection initially took place without the LED feedback interface, with the IMU tool used, under the control of the researcher, to assess natural riding posture and determine the baseline range of asymmetry in the lateral plane of motion. This test was also used to identify and set the LED visualisation range appropriate to that rider. The rider was then given time to ride with the LED feedback visible to determine whether this range provided sufficient sensitivity to provide a reasonable level of feedback. Where necessary the sensitivity was adjusted to provide a range that the rider felt was suitable for them.

The protocol was then repeated, with feedback provided to the rider using each of the LED visualisation interfaces. The rider was instructed to use the feedback to attempt to keep their lateral motion within the "green" display. Group 1 riders carried out the protocol using LED-CORRECTION then LED-FEEDBACK, Group 2 riders used LED-FEEDBACK then LED-CORRECTION. The motion data was recorded via the IMU device and later transferred to a PC for quantitative analysis.

6.3.2. Data Collection (Interview Phase)

After the ridden part of the data collection was complete, a recorded structured interview was carried out with the rider using questions relating to their experience of using the tool and preferred choice of feedback interface. They were also be asked to complete a short questionnaire containing questions relating to their riding level and experience (Appendix J).

Table 6.3 shows semi-structured interview questions.

Question
Confirm Participant Number
Setup – initially putting on horse, putting it on self, comfort. How did it feel?
Reminder of which set of lights was which i.e. feedback versus correction
For first set what did you think in walk then in trot?
Which do you prefer and why?
Are you already aware of what was shown?
Did you find the lights made it easier to correct?
Did it feel better once corrected?
Overall impression on use of the technology for riding?
Would you like to use them again?
If you had your own set how often and when would you use them?
Was routine enough to get a feel for them?
Any negative issues about concentration or looking at lights?
Any feelings of sickness?
Overall impression, any changes you would make to any of it?

Table 6.3. Semi-structured interview questions.

6.4. Data Analysis

6.4.1. Quantitative

Quantitative analysis was used to determine whether there was a preference for the LED visualisation interface and whether the order of testing affected the preferred choice of visualisation. Due to the small sample size (n=10), a non-parametric test was most appropriate and a paired-samples Wilcoxon statistical test was selected for its suitability to determine statistical significance for the difference between two related, paired samples. The following hypotheses were tested:

For preference of LED visualisation interface, the null hypothesis (H0) was that there is no significant difference in preference scores awarded across all riders for LED-CORRECTION or LED-FEEDBACK, with the alternative hypothesis (HA) being that there is a significant overall preference for either LED-CORRECTION or LED-FEEDBACK.

For order of testing, the null hypothesis (H0) was that there is no significant bias in preference scores awarded to the visualisation interface provided first (LED-FIRST) or second (LED-SECOND), with the alternative hypothesis (HA) being that there is a significant bias in preference towards LED-FIRST or LED-SECOND.

Line plots were produced from the IMU data recorded, with smoothing applied, over the duration of each test, with visualisation colour ranges and mean values added.

Statistical analysis was performed on the IMU data recorded to identify whether there were any significant differences between LED-OFF and the LED-CORRECTION and LED-FEEDBACK visualisation interfaces for mean values, indicating lateral asymmetry and standard deviations, giving range of motion in the lateral plane. Due to the small sample size (n=10) a non-parametric test was appropriate and, since there were more than two related groups (in this case three conditions), a paired-samples Friedman Test was selected, with a 0.05 level of significance.

For lateral asymmetry, the null hypotheses (H0) were that there is no significant difference in mean values across all riders when LED-OFF is compared to LED-CORRECTION; LED-OFF is compared to LED-FEEDBACK; or LED-CORRECTION is compared to LED-FEEDBACK. The alternative hypotheses (HA) being that there is a significant difference in mean values for these respective comparisons.

For range of motion in the lateral plane the null hypotheses (H0) were that there is no significant difference in standard deviation across all riders when LED-OFF is compared to LED-CORRECTION; LED-OFF is compared to LED-FEEDBACK; or LED-CORRECTION is compared to LED-FEEDBACK. The alternative hypotheses (HA) being that there is a significant difference in standard deviation for these respective comparisons.

Density plots were produced to show the overall relative proportion of IMU data from each test, within each visualisation colour range, also with mean values added.

Again, due to the small sample size (n=10) and three conditions being tested, statistical analysis was carried out using a Friedman Test to assess for statistically significant differences between the distributions of LED-OFF, LED-CORRECTION and LED-FEEDBACK and between LED-OFF and the riders' preferred and less-preferred visualisations. A paired-samples Friedman Test was used, with a 0.05 level of significance.

For distribution of time spent in each zone according to visualisation interface, the null hypotheses (H0) were that there is no significant difference in distribution across all riders when LED-OFF is compared to LED-CORRECTION; LED-OFF is compared to LED-FEEDBACK; or LED-CORRECTION is compared to LED-FEEDBACK. The alternative hypotheses (HA) being that there is a significant difference in distribution for these respective comparisons.

For distribution of time spent in each zone according to rider preference, the null hypotheses (H0) were that there is no significant difference in distribution across all riders when LED-OFF is compared to preferred visualisation; LED-OFF is compared to less-preferred visualisation; or preferred visualisation is compared to less-preferred visualisation. The alternative hypotheses (HA) being that there is a significant difference in distribution for these respective comparisons.

Statistical analysis and plot generation was carried out using R Studio software package (RStudio, n.d.), apart from boxplots showing comparisons between mean absolute asymmetry and standard deviation (showing range of motion) for each interface, which were produced using the online statistical analysis calculator (Datatab, n.d.).

6.4.2. Qualitative

The responses from the semi-structured interviews were transcribed and imported into the NVivo Qualitative Data Analysis software package (NVivo, n.d.) for qualitative evaluation of usage implications for the tool.

The coding phase was carried out in stages according to both inductive and deductive coding. This was primarily deductive coding within pre-determined theme categories, but indictive codes were added for additional comments that were not originally anticipated. The set of themes is included below, with full set of codes within each provided alongside the results and discussion in Section 7.3, to avoid repetition.

- Feedback from Visualisation Interfaces
- Impact on Horse
- Rider Comfort and Sickness
- Rider Concentration and Focus
- Rider Posture
- Range of Motion (ROM), Visibility and Sensitivity
- Setup, Fit and Use
- Study Experience
- Use of Technology

In addition to discussion of the qualitative interview results, an overall sentiment analysis was carried out using the NVivo automated functionality to determine overall impression of the use of the tool in a practical context. This is provided in Section 7.4.

6.5. Summary

This chapter covered the method used for Study 2 to evaluate the tool and answer research questions Q2c "What are the usage implications for IMU-based analysis and feedback during riding motion?” and Q3 “Which is the most appropriate data visualisation technique for the presentation of rider analysis data feedback according to the usage contexts identified in Q1”.

A field study was used with data collection split into two phases. A customised version of contextual inquiry was used first to address Q3, via a ridden activity where the riders followed the ridden protocol proposed as an outcome of Study 1. Initially recording baseline data with the LEDs turned off (LED-OFF), then a cross-over repeated measures design with half of the participants repeating the ridden protocol with LED-CORRECTION followed by LED-FEEDBACK and the other half of the participants using LED-FEEDBACK then LED-CORRECTION.

Data collected from the tool in phase 1 of the study was analysed quantitatively using a paired-samples Wilcoxon statistical test for user preference between the two visualisation interfaces and paired-samples Friedman tests used on the exported IMU data to identify whether there were any significant differences between the LED-OFF and the LED-CORRECTION and LED-FEEDBACK visualisation interfaces for mean values, indicating asymmetry and standard deviations, giving range of motion in the lateral plane. Line and density plots were also produced to visualise the data.

The second phase of the evaluation study, to address Q2c, was a structured interview to evaluate qualitatively the riders’ visualisation preferences, their ideas of how the selected LED interface might be incorporated into a riding context and environmental factors which may impact use of the tool. The responses from the semi-structured interviews were transcribed and imported into the NVivo Qualitative Data Analysis software package (NVivo, n.d.) and coded using nine themes for qualitative evaluation of usage and environmental implications for the tool.

The results of both the quantitative and qualitative data analysis will be presented and discussed in Chapter 7.

Chapter 7. Study 2. Tool Evaluation Results

7.1. Introduction

This chapter covers the results and discussion of Study 2, the evaluation of the tool within its context of use.

Quantitative statistical analysis is included for the choice of rider preference between the two visualisation interfaces and to investigate any differences between LED-OFF and the two interfaces, covering asymmetry and range of motion. Boxplot, Line and density plots are also included for the data captured.

Qualitative evaluation is included for the results of the semi-structured interviews, coded according to nine themes. For each theme, a codebook exported from NVivo is provided showing the number of participants with references to codes within each theme are provided, together with detailed discussion and example comments for each theme.

7.2. Quantitative Analysis

Statistical analysis has been carried out on overall asymmetry/range of motion across the timeline of the tests (line plots) and proportion of timeline spent in each range (density plots). Each are covered separately below.

7.2.1. Visualisation Interface Preferences

Visualisation preferences are provided in Table 7.1, which includes the order of testing to ensure that any results were not biased due to the order of the tests. The LED-OFF test was carried out first in all cases to record baseline data, but the lights were turned off during this to prevent it having any impact on the results. The table also includes the choice of range for display of the LED correction/feedback, which differed between walk and trot for all riders apart from P3 and P7, who selected the same range for both gaits.

Preference scores were selected via pairwise comparisons, with each rider allocating a total of 10 points across the two interfaces according to preference. This choice was made to distinguish strong preferences from those where riders were less strongly drawn to one or other of the two interfaces.

The LED-FIRST group had lower values (Median=4) than the LED-SECOND group (Median=6) but a Wilcoxon Test, with a Bonferroni adjustment and significance level of 0.05, indicated that this difference was not statistically significant, $W = 23$, $p = .644$. Therefore, it is assumed that there was no bias due to order of testing. The effect size r is 0.15, which is a small effect according to Lachenbruch and Cohen, (1989).

Rider	LED-FIRST		LED-SECOND		LED display range	
	Interface	Preference Score	Interface	Preference Score	Walk	Trot
P1	LED-CORRECTION	2	LED-FEEDBACK	8	4-10 deg.	8-14 deg.
P3	LED-CORRECTION	1	LED-FEEDBACK	9	8-14 deg.	8-14 deg.
P5	LED-CORRECTION	6	LED-FEEDBACK	4	4-10 deg.	8-14 deg.
P7	LED-CORRECTION	4	LED-FEEDBACK	6	8-14 deg.	8-14 deg.
P9	LED-CORRECTION	4	LED-FEEDBACK	6	4-10 deg.	8-14 deg.
P2	LED-FEEDBACK	9	LED-CORRECTION	1	4-10 deg.	8-14 deg.
P4	LED-FEEDBACK	2	LED-CORRECTION	8	4-10 deg.	8-14 deg.
P6	LED-FEEDBACK	4	LED-CORRECTION	6	4-10 deg.	8-14 deg.
P8	LED-FEEDBACK	7	LED-CORRECTION	3	4-10 deg.	8-14 deg.
P10	LED-FEEDBACK	7	LED-CORRECTION	3	4-10 deg.	8-14 deg.

Table 7.1. Order of visualisation testing with preference scores.

Regarding the preferences themselves, the LED-CORRECTION group had lower values (Median=3.5) than the LED-FEEDBACK group (Median=6.5) but a Wilcoxon Test, with a Bonferroni adjustment and significance level of 0.05, indicated that this difference was not statistically significant, W = 12.5, p = .123. The effect size r is 0.49, which is a medium effect according to Lachenbruch and Cohen, (1989).

The conclusion therefore is that for this sample (n=10) there is no statistically significant preference for one or other of the two interface visualisations, although more riders (n=6) preferred LED-FEEDBACK. Given the closeness of this result to statistical significance for the small sample size used, further testing with a larger sample size may indicate that there is a statistically significant preference for LED-FEEDBACK.

7.2.2. Line Plots

Data values represent the angle of lateral rotation of the rider's pelvis across the data capture timeline. Figure 7.1 shows an example of the data captured for one representative rider as an example, with the full set of plots provided in Appendix K. Data has been plotted separately for each condition (LED-OFF, LED-CORRECTION, LED-FEEDBACK) and colour bands have been added to show where data falls within each of the three range bands, with green representing time when the lights were indicating green (i.e. within the acceptable motion range), yellow while the lights were providing feedback or correction and red while the lights were indicating flashing red (i.e. beyond the limit at which the rider was in an acceptable posture).

Values greater than zero represent a lateral rotation to the right, negative values represent a lateral rotation to the left. The data shows that, for rider P4 in trot, during the initial part of the test while the rider was traveling on the left rein and completing the left circle, there was a tendency for the rider to rotate to the left, whereas once they changed direction and repeated the movements on the right rein, there was a tendency to rotate to the right. This was a pattern that was repeated across all riders but the extent of the tilt varied by rider and by LED interface. Mean value of lateral rotation is indicated by the dashed blue line.

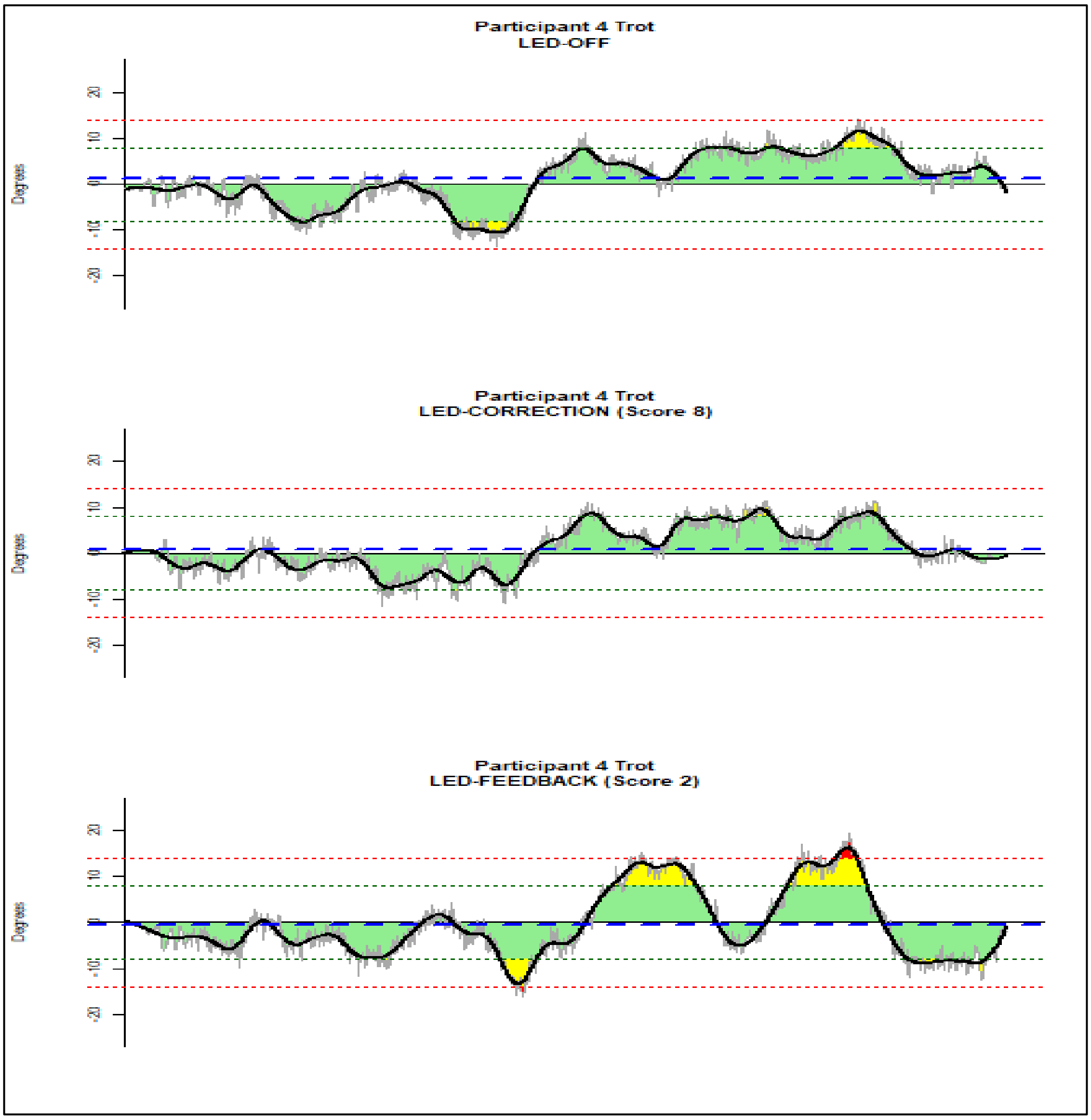


Figure 7.1. Angle of lateral rotation across the timeline of the test for sample rider.

Table 7.2 provides summary statistics data for all riders in walk, showing mean and standard deviation for LED-OFF and each of the visualisation interfaces. The preferred interface for each rider is shaded, with the minimum mean (most symmetrical) highlighted in red and minimum standard deviation (least range of motion) highlighted in blue to highlight the pattern of results.

For mean values, which show the extent of asymmetry across each of the three test routines, the table includes the sign for completeness to show whether the rider is asymmetric to the left (negative) or right (positive).

Rider	LED-OFF		LED-CORRECTION			LED-FEEDBACK		
	Mean	SD	Mean	SD	Score	Mean	SD	Score
P1	0.96	2.26	0.04	2.36	2	-0.13	3.73	8
P2	0.90	2.99	0.67	2.79	1	0.85	2.51	9
P3	3.33	3.51	3.14	3.25	1	3.16	5.03	9
P4	1.92	2.87	0.87	2.32	8	2.39	2.77	2
P5	-0.74	2.68	0.02	2.38	6	-0.28	2.32	4
P6	-1.16	2.70	-0.92	2.86	6	-0.70	3.24	4
P7	-0.20	8.29	-0.51	9.52	4	-1.37	7.41	6
P8	0.28	5.05	0.26	3.36	3	0.69	3.49	7
P9	1.47	4.46	1.39	3.37	4	1.26	2.96	6
P10	0.73	4.52	0.26	4.70	3	0.53	4.48	7

Table 7.2. Summary Statistics – Walk.

For the purpose of statistical analysis, to determine if there is a difference between using the tool compared to LED-OFF, the direction of asymmetry is not relevant, so absolute values are used (Figure 7.2).

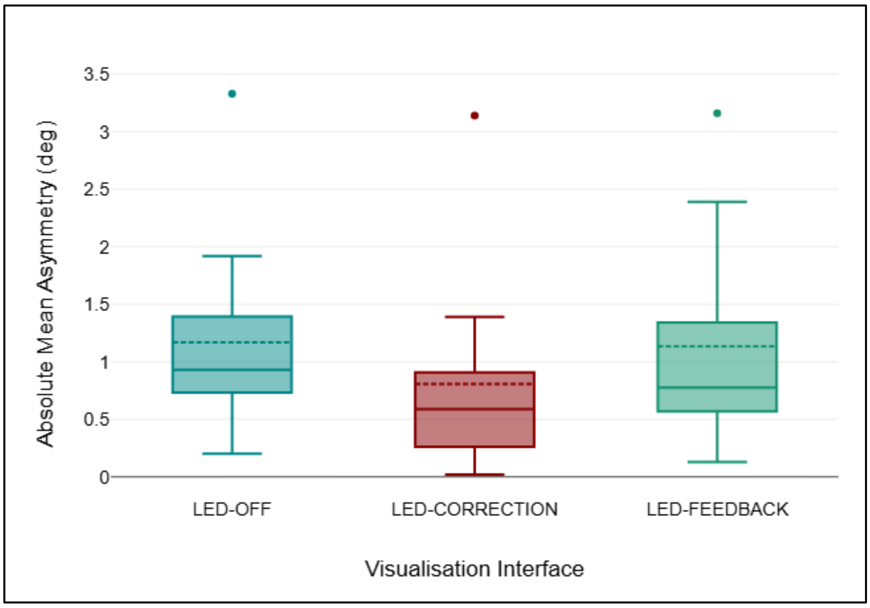


Figure 7.2. Mean absolute asymmetry (Walk).

A Friedman test showed that there was a significant difference between the dependent variables for the mean values (LED-OFF, LED-CORRECTION and LED-FEEDBACK), $p = .014$. Although the sample size is small this indicates that there is a significant reduction in asymmetry using the tool with LED-CORRECTION despite more riders preferring the use of LED-FEEDBACK.

A Friedman test showed that there was no significant difference between the dependent variables for the standard deviations indicating that the range of motion was not dependent on the visualisation, $p = .497$. Figure 7.3 shows the plot for this data.

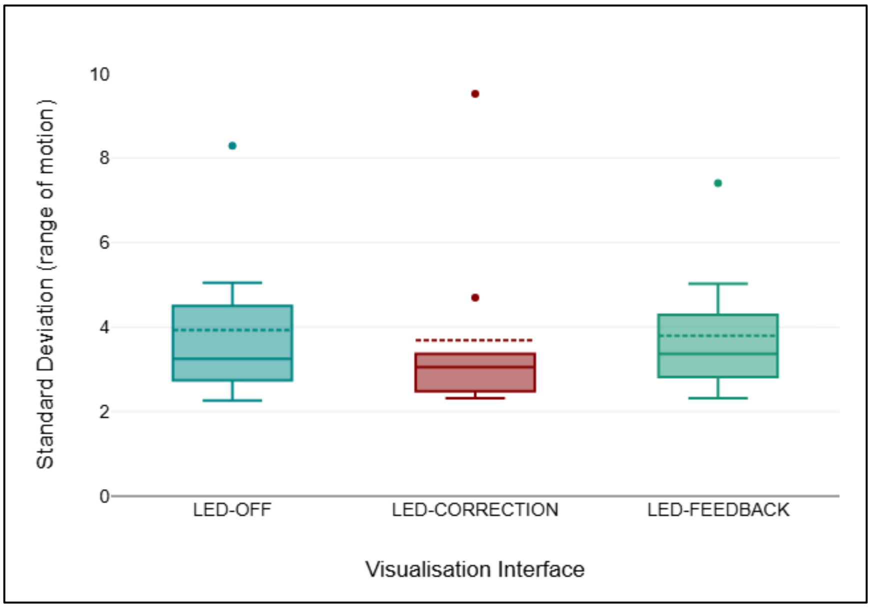


Figure 7.3 Standard Deviation - Range of Motion (Walk).

Table 7.3 provides the equivalent data for the trot tests. A Friedman test showed that there was a significant difference between the dependent variables for the mean values (LED-OFF, LED-CORRECTION and LED-FEEDBACK), p = .014. However, for trot, the significant reduction in asymmetry using the tool is with LED-FEEDBACK, which aligns with greater rider preference for the use of LED-FEEDBACK. Given the statistically significant reduction in asymmetry with LED-FEEDBACK and its closeness to significant result for rider preference, it could be concluded that this interface is more effective and further testing with a larger sample size would be useful to confirm this.

Rider	LED-OFF		LED-CORRECTION			LED-FEEDBACK		
	Mean	SD	Mean	SD	Score	Mean	SD	Score
P1	-1.81	4.93	-0.96	9.90	2	-0.27	8.58	8
P2	2.66	7.03	2.38	5.73	1	2.06	6.14	9
P3	4.51	5.36	4.24	5.82	1	3.88	3.98	9
P4	1.16	5.74	0.89	4.92	8	-0.56	7.39	2
P5	-1.21	5.49	-1.42	4.71	6	-1.16	6.12	4
P6	-0.56	5.19	-0.28	5.85	6	0.40	5.16	4
P7	2.29	7.16	2.52	6.52	4	1.78	6.46	6
P8	1.30	6.99	4.13	5.31	3	3.58	5.53	7
P9	2.58	6.01	1.21	4.66	4	0.67	5.14	6
P10	-0.55	4.99	0.03	4.69	3	0.27	4.69	7

Table 7.3. Summary Statistics – Trot.

The plot of data for absolute mean values of asymmetry across the three tests is provided in Figure 7.4.

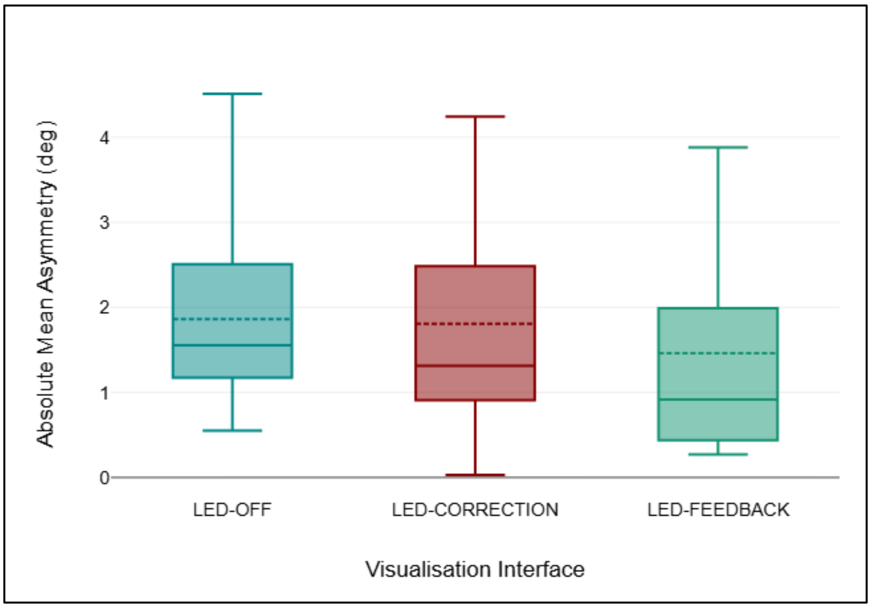


Figure 7.4. Mean absolute asymmetry (Trot).

For trot. the Friedman test showed that there was no significant difference between the dependent variables for the standard deviations indicating that the range of motion was not dependent on the visualisation, p = .294. Figure 7.5 shows the plot for this data.

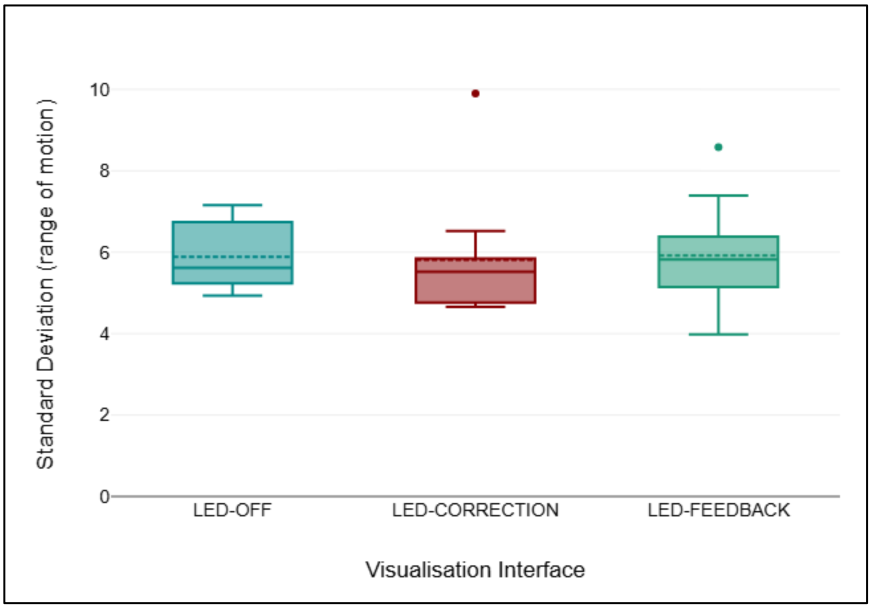


Figure 7.5. Standard Deviation - Range of Motion (Trot).

Applying a Benjamini Hochbergh correction for multiple testing across both gaits did not affect the results, with adjusted p-values of p = .014 for mean absolute asymmetry and p = .497 for standard deviation (range of motion).

7.2.3. Density Plots

Data was also analysed according to the proportion of the test spent within each of the data ranges, for each interface. Figure 7.6 provides density plots for Rider P4, as an example, with the full set of plots provided in Appendix L. Colour bands are equivalent to the visualisation provided to the riders, with green showing the range they received the green LED display, yellow the range of correction/feedback provided and red outside of the limits when they would receive red flashing LED.

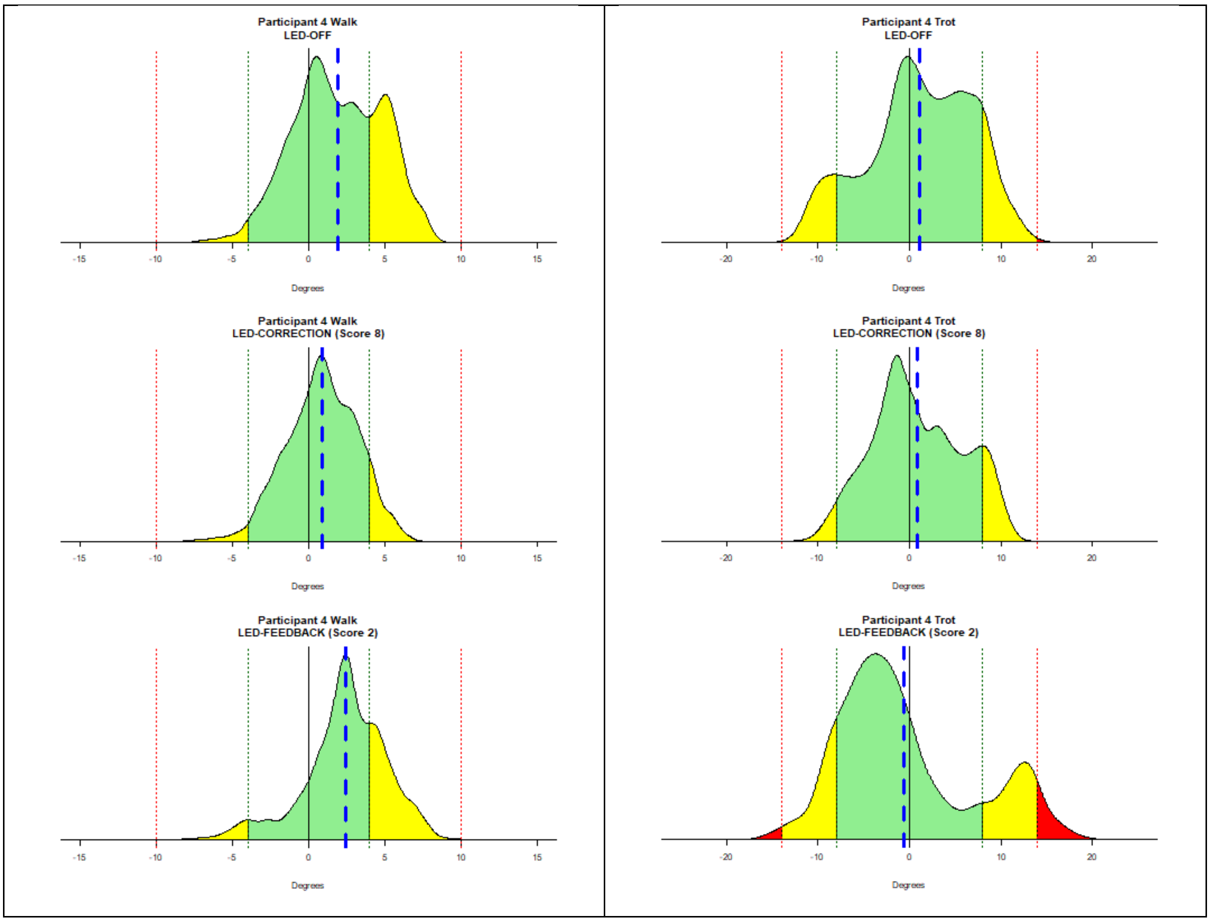


Figure 7.6. Density plots of proportion of test in each data range for Rider P4.

The plot for Rider P4 has been chosen as a case study because it shows most clearly the difference between the plots. For this rider, their preferred visualisation was LED-CORRECTION. Their time spent outside of the green range is reduced for this visualisation in both walk and trot, when compared to LED-OFF and their asymmetry was also more obviously reduced (blue dashed line). However, this rider reported that they found LED-FEEDBACK made them over-compensate, which is clearly shown in the trot with an increased proportion of the test spent in the red zone and the asymmetry moved across to the left of centre.

Although this is a common pattern in the plots across the riders, this was not the case for all. P1 has been selected as another rider to highlight (Figure 7.7) as they became more symmetrical in walk but their range of motion increased so they spent more time in the yellow range, with a particularly even spread in walk. In trot they became less stable, with increased deviation into the red zone, yet again showing a greater overall symmetry.

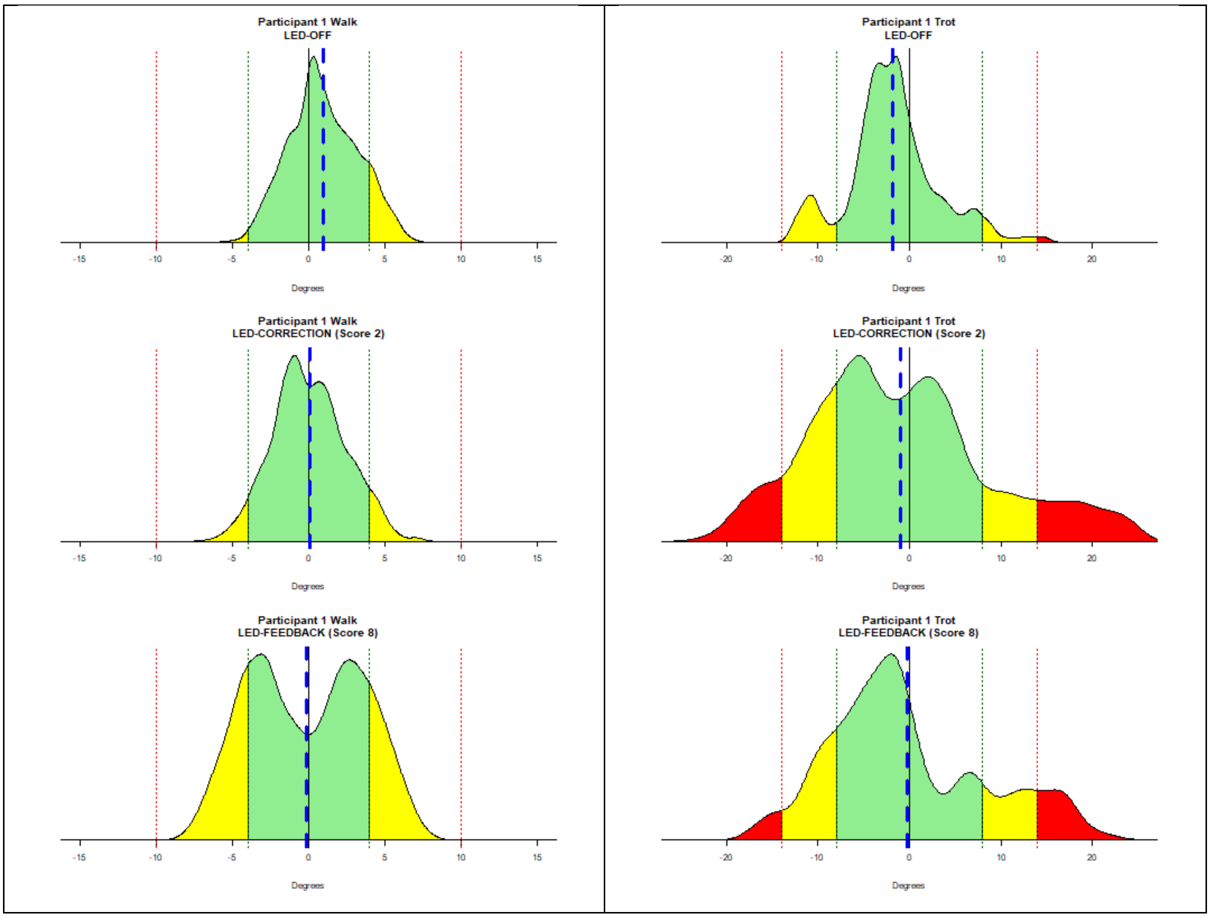


Figure 7.7. Density plots of proportion of test in each data range for Rider P1.

Statistical analysis was carried out using a Friedman Test to assess for statistically significant differences between the distributions of the three test conditions (LED-OFF, LED-CORRECTION and LED-OFF). This was done for each gait (walk, trot) separately and the following pairs of visualisations/conditions to determine if there were any significant differences between the three LED visualisation test conditions:

- LED-OFF, compared to LED-CORRECTION
- LED-OFF, compared to LED-FEEDBACK
- LED-CORRECTION, compared to LED-FEEDBACK

No statistically significant differences were found.

Further Friedman tests were carried for each gait (walk, trot) separately and the following pairs of visualisations/conditions to determine if there was any significant difference between the three LED visualisation test conditions based on rider preference:

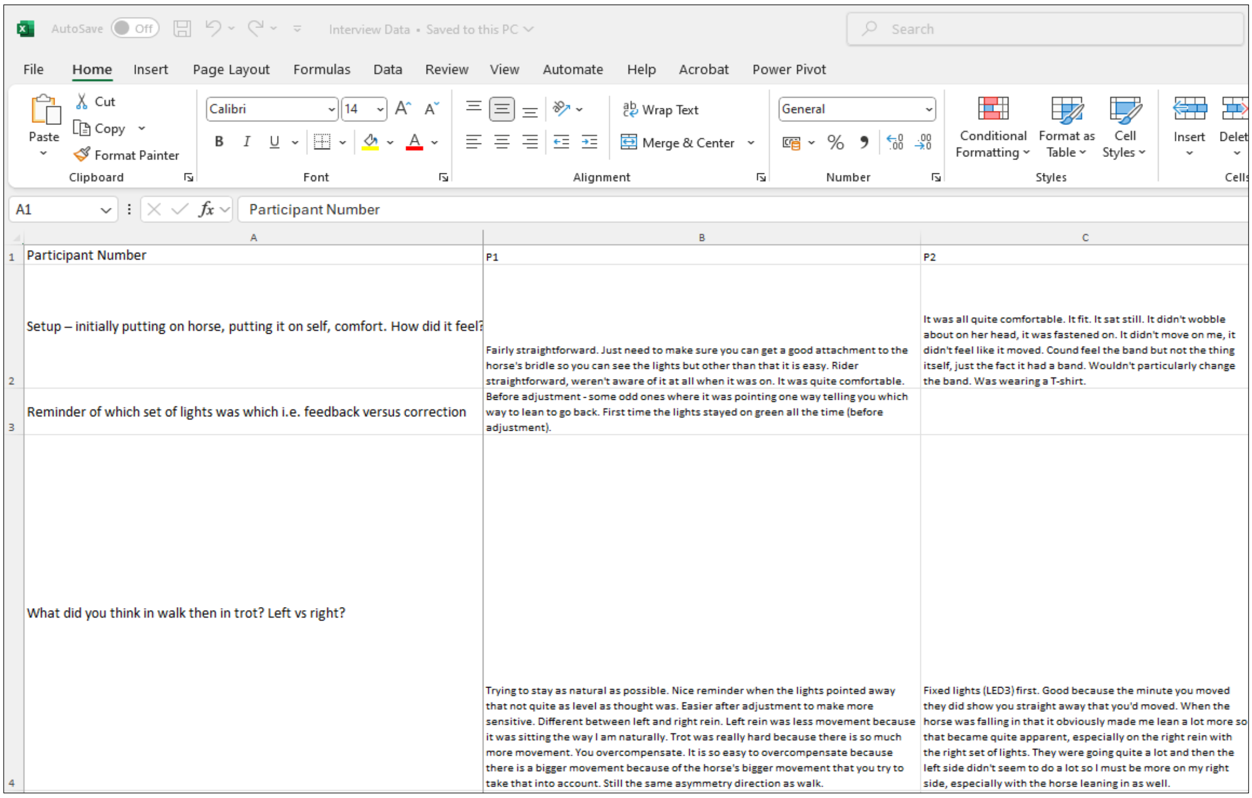
- LED-OFF, compared to preferred visualisation
- LED-OFF, compared to less-preferred visualisation
- Preferred visualisation, compared to less-preferred visualisation

In this case, just one of the conditions reported a statistically significant result; the time spent in the red zone in trot for the preferred visualisation when compared to the less-preferred visualisation p=.043. This result indicates that, in general, the riders were better able to stabilise their posture with their preferred visualisation than their less-preferred visualisation, but not to the extent of being able to keep it within the green zone.

The statistical results are included for completeness but are limited by the small sample size and the short timescale for familiarisation with the tool. The focus of this study was the development and qualitative evaluation of the tool within its context of use, particularly regarding rider opinion of the interface visualisations. A longitudinal study, with a larger sample of riders was beyond the scope of this research but would be required to draw conclusions regarding statistical significance.

7.3. Qualitative Analysis

Prior to importing the data into NVivo, the recorded transcript from each rider was transcribed and collated into an Excel spreadsheet, according to the semi-structured interview questions. A screen capture showing a sample section of the spreadsheet is shown in Figure 7.8. It was found that some riders commented across the interview questions as they added or elaborated on other aspects. This meant that there wasn't always a direct match between the responses and the questions.



	A	B	C
1	Participant Number	P1	P2
2	Setup – initially putting on horse, putting it on self, comfort. How did it feel?	Fairly straightforward. Just need to make sure you can get a good attachment to the horse's bridle so you can see the lights but other than that it is easy. Rider straightforward, weren't aware of it at all when it was on. It was quite comfortable.	It was all quite comfortable. It fit. It sat still. It didn't wobble about on her head, it was fastened on. It didn't move on me, it didn't feel like it moved. Cound feel the band but not the thing itself, just the fact it had a band. Wouldn't particularly change the band. Was wearing a T-shirt.
3	Reminder of which set of lights was which i.e. feedback versus correction	Before adjustment - some odd ones where it was pointing one way telling you which way to lean to go back. First time the lights stayed on green all the time (before adjustment).	
4	What did you think in walk then in trot? Left vs right?	Trying to stay as natural as possible. Nice reminder when the lights pointed away that not quite as level as thought was. Easier after adjustment to make more sensitive. Different between left and right rein. Left rein was less movement because it was sitting the way I am naturally. Trot was really hard because there is so much more movement. You overcompensate. It is so easy to overcompensate because there is a bigger movement because of the horse's bigger movement that you try to take that into account. Still the same asymmetry direction as walk.	Fixed lights (LED3) first. Good because the minute you moved they did show you straight away that you'd moved. When the horse was falling in that it obviously made me lean a lot more so that became quite apparent, especially on the right rein with the right set of lights. They were going quite a lot and then the left side didn't seem to do a lot so I must be more on my right side, especially with the horse leaning in as well.

Figure 7.8. Spreadsheet of transcription from semi-structured interview recordings.

Once transcribed, the spreadsheet was separated by participant and imported to NVivo for coding. Comments were applied to codes according to relevance, either as single or related sentences and, where appropriate, could be applied to multiple codes.

An exported codebook, showing number of participants and total references to codes within each theme are provided, together with detailed discussion and example comments are provided in the following sections.

7.3.1. Feedback from Visualisation Interfaces

This section covers feedback relating to comments on the visualisation interfaces provided and rider opinions of them. This includes any comments on comparisons between interfaces, asymmetry reported and differences between gaits of the horse. Table 7.4 summarises the number of participants and references made within each code of this theme.

Theme/Code	Description	Participants	References
FEEDBACK FROM VISUALISATION INTERFACES		**10**	**97**
Comments relating to first vs second test	Any comments which relate to the order of the tests. Either indicating that the test number could be relevant or that preferences are not biased by the test number.	1	1
Comments relating to left and right rein	Any comments which relate to the direction of the movement, either left or right rein or comparing left with right.	8	14
Comments relating to walk vs trot	Any comments which relate to the gait of the horse, either in walk or trot or comparing between gaits.	9	16
Contradictory comments	Preferences where positive or negative comments on either interface are contradictory	1	1
Negative comments (unspecified)	Negative comments on the visualisation in general, not specifying which LED interface.	0	0
Negative comments on LED1 (scrolling)	Negative comments on the visualisation from LED_CORRECTION, described in the interview data as LED1 (scrolling).	5	11
Negative comments on LED3 (fixed)	Negative comments on the visualisation from LED_FEEDBACK, described in the interview data as LED3 (fixed).	3	5
Positive comments (unspecified)	Positive comments on the visualisation in general, not specifying which LED interface.	5	8
Positive comments on LED1 (scrolling)	Positive comments on the visualisation from LED_CORRECTION, described in the interview data as LED1 (scrolling).	6	17
Positive comments on LED3 (fixed)	Positive comments on the visualisation from LED_FEEDBACK, described in the interview data as LED3 (fixed).	8	24

Table 7.4. Qualitative feedback (visualisation interfaces).

Only one rider (P1) specifically referred to the order of the tests, and this was to say that their choice of preference wasn't related to it being the second set of LEDs tested.

Eight riders (80%) referred to the direction of the lights, with seven of these (88%) commenting that they had more movement to the right or on the right rein. Only P5 reported that there was more correction on the left rein, interpreting this as being more accurate. P8 commented that their right rein was worse, but they also thought the horse was worse on the right as well which could have contributed to the effect. Three riders commented on this matching with their expectations based on knowing that they already experience asymmetry more to the right: P1 commented that there was less movement of the lights on the left rein because that's the way they naturally sit and they expected more to show on the right rein, where it matched the feedback normally received from their instructor. They qualified this with their interpretation of the lights being "*So on the right rein where it was more adjustment it was 'right, don't lean, lift and sit'. It was good*". P3, added that their increased feedback on the right was particularly on tight turns and was most noticeable in walk. P4 commented that their right rein is the strongest and they felt like they were moving too much to the inside so they had to move to the outside and on the left the lights barely moved. P9 also reported that they were *"…definitely leaning more to the right. They tended to go red a lot more on the right. The left wasn't so bad but I know I tend to sit to the right anyway. It's just the way I ride"*.

Nine riders (90%) made comments on the gait but P3 just stated that they didn't experience any difference between walk and trot. P1 reported that it was harder to keep the lights in the green zone in trot because of a tendency to overcompensate due to the bigger movement of the horse, however, they still had the same asymmetry direction in walk. P5 reported that it was harder in trot turning off a corner as they tended to tip inwards. P6 reported that the walk was more balanced, but they had issues with the horse's mane blowing across the LED strip in trot making it less visible. P9, who was riding the horse with the LEDs on the saddle reported that LED-FEEDBACK was harder than LED-CORRECTION due to having just 2 lights to keep in the middle in both walk and trot and when asked to clarify if this was due to having to look down responded *"Maybe a little bit but not the walk, I think it was just harder. Would still have preferred the same lights whichever*". P8 didn't think there was a difference in accuracy between walk and trot but that there was more movement in trot that reflected their increased asymmetry in trot.

P10 commented that there was less movement detected in trot, as did P3 but for them this was only on the right rein as they remained straight on the left rein. P4 found them more sensitive in walk and suggested this might be due to it being a 4-time beat rather than the 2-time beat of trot. P7 also found the light went off less in trot but that they were more aware of the issue causing the lights to go off in trot.

When asked for reasons behind preferences between the two interfaces six riders made positive comments on LED-CORRECTION compared to eight riders for LED-FEEDBACK. Five riders made negative comments on LED-CORRECTION compared to three riders for LED-FEEDBACK. The specific comments, excluding those which simply stated that they were good or their preference, are provided in Appendix M.

P6 made a comment that is difficult to interpret and is contradictory over whether they are referring to the scrolling LED-CORRECTION or fixed/2 lights LED-FEEDBACK when making the positive comment. This full comment has been provided below but excluded from the tables.

> *"I think the scrolling was easier to kind of see. Easier to correct myself from which way I was leaning. It was a lot harder with just the two dots to keep them in the middle because obviously you haven't got as many lights so it was a lot harder with just the two in both walk and trot. Easier to correct especially with just the two lights because I knew I had to work harder to try and keep myself in the middle. Query the two lights if only allowed one set: I don't know. It's harder with the two but it probably made it more effective. So, the fixed one more effective. Final choice 6 to the fixed. So even though preference initially was for the scrolling I've gone the other way now I think about it. Yes, because I think it's more effective."*

In addition, some general positive comments were made by five riders, which applied to both interface visualisations, so these are presented separately in Table 7.5. There were no such general negative comments.

Rider	Positive Comment
P1	It was good. It helps
P2	Good because the minute you moved, they did show you straight away that you'd moved
P4	you made me aware that it was sitting on the centre of the horse so it made me aware of where it was sitting, where I needed to be sitting Working through both sets of lights helped
P5	But I think they were both equally accurate
P8	I found both effective And then there were the options for which I preferred so I got to use the one that works best for me so someone else might have chosen a different one. To have that option I guess

Table 7.5. Qualitative feedback (general positive feedback on both interfaces).

7.3.2. Impact on Horse

This section covers comments made relating to any effect on the horse's motion as a result of using the tool. The codes within this theme relate to the horse's response to any changes in the rider's posture, not reactions to the device itself, which are covered in the "setup, fit and use" theme (Section 7.3.7). Table 7.6 summarises the number of participants and references made within each code of this theme.

Theme/Code	Description	Participants	References
IMPACT ON HORSE		**6**	**12**
General impact	Comments relating to the impact on the horse which aren't specific to the other categories.	4	5
Horse balance	Comments relating to the balance of the horse. Could include comments in other categories if they give context to the comment on balance.	1	1
Horse comfort	Comments relating to the horse comfort. Specifically in relation to the rider posture, not comfort of the device on the horse (this would be included in Setup, Fit and Use section).	1	1
Horse falling in	Comments specifically mentioning falling-in. Could include comments in other categories if they give context to the comment on falling-in.	2	3
Horse straightness	Comments relating to the straightness of the horse. Could include comments in other categories if they give context to the comment on straightness.	2	2

Table 7.6. Qualitative feedback (impact on horse).

Six riders (60%) reported impacts on the horse from the rider's use of the tool. Four of these were general in their comments and of these two (P4 and P10) specifically mentioned that the rider adjustment in response to the LEDs improved the horse, with P4 specifically mentioning that the horse *"…followed my movement and relaxed into it better, less tension and she relaxed better through my body and her reactions*". In addition, P3 commented that the tool made them think about the horse's position in addition to their own and having a visual cue that something was *"out*" and the need to correct it. P8 commented that they thought the horse was worse on the right rein in addition to themselves which might have also impacted on the asymmetry detected by the tool.

7.3.3. Rider Comfort and Sickness

This section covers comments relating to the rider's awareness and comfort of wearing the device and whether they experienced any effects causes by looking at the lights during motion. The aim here was to identify any negative impact of using the tool from a health or comfort perspective. Table 7.7 summarises the number of participants and references made within each code of this theme.

No riders reported any negative issues regarding comfort of the band or device and seven (70%) made specific comments relating to its being comfortable. Six (60%) of the riders made specific comments that they weren't aware the band and device was there at all.

Theme/Code	Description	Participants	References
RIDER COMFORT AND SICKNESS		**10**	**27**
Rider comfort and awareness	Any comments on comfort of rider, including awareness of the device while riding. Either setup or use.	10	14
Rider feeling of sickness or dizziness	Any comments on feeling of sickness or dizziness. Includes feelings of sickness and motion sickness	10	13

Table 7.7. Qualitative feedback (rider comfort and sickness).

Rider P2 was wearing a T-shirt and commented that they could feel the band but not the device itself. They followed this up by saying that they wouldn't change the band, they were just aware that it was there. Rider P5 commented that they were aware of it "*A little bit but it was light and comfortable, there was no problem. Just aware it was there*" and rider P7 made a similar comment "*I knew it was there but it wasn't an issue.*"

When asked about feelings of sickness or dizziness, nine (90%) of the riders reported no issues and P8 commented that they had been feeling dizzy before the session but weren't afterwards. One rider (P7) did experience issues with dizziness and reported that this was more pronounced in walk when they were focusing on the lights more, so they had to keep looking away. They felt that this was less of an issue in trot because they tended to look away more anyway. They found the effect increased when fixing their gaze on LED-CORRECTION, not so much the same sensation when looking at LED-FEEDBACK. They felt that this sensation was personal to themselves because they also suffer from sea sickness.

7.3.4. Rider Concentration and Focus

This section covers comments that provide insight into how the riders engage with the tool from a visual perspective and any impact this might have on their ability to split concentration between viewing the lights and riding. Table 7.8 summarises the number of participants and references made within each code of this theme.

The first consideration in this section was to consider where riders were focusing and how much they concentrated on the lights compared to looking where they were going. The majority of comments here were that the riders glanced at the lights then looked back at where they were going.

Three riders (30%) reported that they looked at them all the time, although one of these (P8) reported that they would probably do this less once they got used to them.

Seven riders (70%) said that they glanced at them then looked back to where they were going, with three of them (30%) reporting that initially they looked at the lights more but once they got used to them, they looked less and just glanced at them. P6 was particular about the frequency, stating that they looked at them approximately every 8 seconds. Particular comments were: P8 commented that they were *"…just looking like a little glance because you* *could see out of the corner of your eye as well with the lights being bright enough"*; P1 that it was *"…not difficult to ride movements just every now and again had to remind self to look where going*"; P2 commented specifically on the positioning on the head *"I think it's in a great place being on her head, however at points I was looking more where I was going and then thinking I need to look back to the lights now and then head up, looking round, and then back to the lights".*

Theme/Code	Description	Participants	References
RIDER CONCENTRATION AND FOCUS		**10**	**36**
Comments on concentration or distraction	Comments relating to negative effect of the tool on the rider's concentration, causing lack of concentration on riding.	6	9
Comments on eye focus	Any comments relating to where the rider is looking, or where their attention of gaze is and for how long.	9	18
Comments on health and safety	Any issues relating to health and safety. Includes either negative comments on risks of use or comments indicating there is no risk to health and safety. Includes particular situations where it may be a risk.	1	1
Comments on improving with practice	Comments related to need for practice to improve issues with concentration and focus.	4	4
Comments on rider balance	Any comments relating to rider balance and the effect looking at the lights might have on it.	2	2
Comments on staying natural or relaxation	Any comments which related to staying natural or relaxation.	2	2

Table 7.8. Qualitative feedback (rider concentration and focus).

Five riders (50%) reported that they found them distracting or made comments that indicated this effect. However, two of these were riding the horse who required the feedback tool to be attached to the saddle, which will be discussed separately below. Particular comments from those with the lights on the horses' heads were: P1 commented that they couldn't focus on riding because they were looking at the lights; P3 made a similar comment but said it was better towards the end. They also commented *"There was so many of them it kind of distracts a little bit to look through his ears and to look where I am going at the same time*" and that *"it was distracting sometimes, especially when I got a red light, thinking "what am I doing" and that kind of throws you a little bit but once I realised that's what it was showing it wasn't so distracting"*; P5 commented *"Maybe because you have to ride with your chin up. Maybe I shouldn't rely so much on them, I should just keep having a glance. I was riding with my head down because I was constantly looking at the lights"* but they also made a positive comment that they looked at them all of the time which was good to rely on that for correction; P4 made reference to the effect on the horse *"I am used to looking ahead because I always feel like if I start looking down the horse is going to go down so I do feel I was concentrating a little bit too much on the head".*

The two riders on the horse with the lights on the saddle (P9 and P10) reported more negatively because they had to look down to see the lights, with P9 commenting that they were looking down rather than up, but this was only distracting for looking around *"shapes and stuff"*, they felt it was just an issue with this horse, so positive otherwise. P10 commented that it wasn't ideal on the saddle looking down when they wanted to concentrate on where to turn but again was generally positive and appreciated that this was just an issue for this horse. They found it interesting having to put it in a different place and felt it made them concentrate on their riding more, although not ideal positioning.

Three of the riders who felt that looking at the lights were distracting, plus one other rider, felt that the use of the tool would improve with practice. P7, who had reported feeling seasickness felt that this would be reduced over time. P8 made the comment *"At first I was looking directly at the lights so I was riding around rather than maybe riding how I normally would but I guess you probably would get used to that as well"*

Only two riders (20%) made comments referring to their balance. P4 said they felt a little off balance and used the tool to positively improve this. P9 felt it affected their balance but commented that other things affected their balance too so they were particularly sensitive to this.

P1 commented that they were trying to stay as natural as possible and P4, on relaxation, that *"I wasn't to begin with because obviously it is something new but by the end I was relaxed and comfortable enough to move around the school"*.

Only one rider (P4) mentioned health and safety related to the potential distraction of using the tool and this was for hacking out. They compared it to cycling with a bike computer and that a cyclist would be moving faster so they didn't consider it would be an issue, although it would be necessary to ride in an arena first to get used to it.

7.3.5. Rider Posture

This section covers any comments made on the postural information provided by the tool, whether this agrees or disagrees with prior knowledge of postural issues, whether it adds to it and whether the rider finds the tool helpful in this regard. Table 7.9 summarises the number of participants and references made within each code of this theme.

For nine riders (90%), the tool reported issues with posture that they were already aware of and most comments in this category were just confirming what was identified. P10 commented that they knew they tipped to the right because they tilt their head as well so *"… it obviously kicks me over"* but they confirmed they were already aware of this. P5 commented that it was harder in trot and going round corners, when they tip inwards. The tool confirmed this, and they commented that, without the lights, they know this by the horse being off balance. The comment from P8 has been included in this coding because they did make a response and although it was "*not really*", they qualified this by adding *"That's because I haven't done a lot in the school recently*", which indicated that they may feel differently had they been working more in the school. Only one rider (P2) reported that the tool disagreed with their perceived knowledge of their asymmetry with the comment "*I'd say I lean to the left but I must lean to the right. I thought it was to the left but the way it showed was more to the right*".

Theme/Code	Description	Participants	References
RIDER POSTURE		**10**	**73**
Additional knowledge of posture	Any comments on additional knowledge gained from the tool on postural issues not previously known.	5	8
Disagrees with prior knowledge of posture	Any comments that indicate the tool does not agree prior knowledge of issues with posture or surprise at what was shown.	1	1
Does not help correction of posture	Negative response (and reasons if given) to the question "does the tool make it easier to correct posture?"	1	1
Fits with prior knowledge of posture	Any comments that indicate the tool confirms prior knowledge of issues with posture.	9	14
Helps correction of posture	Positive response (and reasons if given) to the questions "does the tool make it easier to correct posture?" and "Did it feel better once corrected?"	8	22
Helps improve rider comfort	Comments that indicate rider comfort is improved by use of tool	1	1
Postural corrections	Descriptions of the specific corrections to posture that are made. Includes parts of the body identified.	6	6
Postural issue to left	Comments relating to the tool identifying postural issues, or helping to correct issues, where the left is specifically mentioned.	1	1
Postural issue to right	Comments relating to the tool identifying postural issues, or helping to correct issues, where the right is specifically mentioned.	9	19

Table 7.9. Qualitative feedback (rider posture).

Five riders (50%) reported that the tool gave them additional knowledge of their posture. P1 made a link between their shoulder and pelvis, indicating that that the tool helped them to identify the correction "*whereas once I moved my shoulder everything settles up so clearly has an effect on shoulder and pelvis together. But I need to correct the shoulder not the pelvis which is what I was trying to do initially, trying to correct the pelvis which was making it worse* *but then when I corrected my shoulder it made it easier*". P10 commented that they needed a prompt to know when to correct and the immediacy of the tool made this easier to correct. P3 and P4 both commented that the tool indicated they needed a greater adjustment than they previously were aware of. P8 commented that they hadn't previously been aware of which side their asymmetry was worse, so the tool helped make them aware. They also referred to it identifying issues with the horse as well as the rider.

Eight riders (80%) thought the tool helped in the correction of posture and another (P3) reported that it helped improve comfort. The majority of comments in this category were simple positive responses that it helped but two riders elaborated on this. P3 compared the effect of the lights to the normal feedback provided by their instructor. The instructor would use the phrase "*drop your shoulder*" whereas their interpretation of the lights was "*my shoulder needs to go and then the lights went ok then"* and I corrected myself which was much easier to do and I just had to look down so I could concentrate on where I was going". P4 also referred to a correction of the shoulder "*The slightest little, even lifting my inside shoulder when she was falling out, lifting my inside shoulder straightened me up, straightened her up and it was in a couple of seconds so yes, very beneficial*". P8 felt that the visual aid was "*really helpful*" rather than just basing the correction on "*feel*" which might not be completely accurate. P9 found the LED-FEEDBACK interface was particularly helpful as they had to work harder with the two lights to keep their posture central. They did, however, comment that they could tell the difference after correcting their posture but it felt "*weird*" because they were used to the asymmetry so felt like they were falling off the other side of the horse.

One rider (P3) made a comment that indicated some negativity towards the interface, initially finding that they corrected the wrong way, but they subsequently reported the usefulness (as described above) once they had worked out how to interpret the feedback.

Nine riders (90%) found that the tool reported issues of posture either leaning towards the right, on the right rein or a combination of the two. P2 made the link to the horse "*falling in*" also a contributing factor. P1 expanded on their response to indicate their perceived benefit from the tool identifying the amount of asymmetry detected "*Lights gave you a realisation how much you are to the right. I know I am but I don't know how much to adjust. But with the lights you've got that adjustment."*

Only one rider found they were more asymmetric to the left and they gave the reason for this as having a weaker left arm and left leg.

Six (60%) of riders provided comments on the specific postural issue or adaption required and these are provided in Table 7.10.

Rider	Correction
P1	I need to correct the shoulder not the pelvis which is what I was trying to do initially, trying to correct the pelvis which was making it worse but then when I corrected my shoulder it made it easier
P2	I did feel like I was leaning more to the right then when I corrected it, when I put more weight down my left it corrected so it is to do with me leaning, I think
P3	I thought it was my hips but it isn't, it was my shoulder so when I corrected and when I'm riding I'm thinking back to lessons that I've had and all the corrections I make are with my shoulder so when I stopped thinking about pelvis, which is what I thought the belt was doing it's easier to correct with my shoulder and then once I got that the lights stayed where I needed them
P4	So even though they were on pelvis helped other parts of body
P6	Very beneficial because it can correct if you are crooked
P10	I tilt my head as well and it obviously kicks me over

Table 7.10. Qualitative feedback (comments on specific postural issue or adaption).

7.3.6. Range of Motion (ROM), Visibility and Sensitivity

This section covers comments which relate to the visual presentation of the device, particularly the range of motion of the rider covered by the LED feedback, the choice of sensitivity limits as to the selection of values for the colour range and the effect of environmental factors that impacted on the use and visibility of the lights. Table 7.11 summarises the number of participants and references made within each code of this theme.

Theme/Code	Description	Participants	References
ROM, VISIBILITY AND SENSITIVITY		**6**	**15**
Comments on sensitivity	Comments on sensitivity of IMU, including any comments on adjustments made to sensitivity.	5	7
Comments on visibility	Any comments on the visibility of the LEDs, positive or negative. Includes environmental considerations such as indoor vs outdoor, weather conditions, rider eyesight.	3	7
Range of motion issues	Any issues noted with the range of motion detected.	1	1

Table 7.11. Qualitative feedback (ROM, visibility and sensitivity).

Five riders (50%) commented on the sensitivity of the LEDs with P1 and P4 preferring them more sensitive, whereas P3 found the comparison of sensitivities interesting and felt that the more sensitive version picked up more but then found that the red lights came on too much and they preferred them less sensitive as that gave more "*thinking time*". They also commented that reducing the sensitivity in trot was better as it allowed more time to adjust.

Rider P4 tried two different sensitivities in trot before deciding to use the more sensitive. P8 commented that the sensitivity was "*perfect, it really helped me*".

Only one rider made a comment on sensitivity between the two different visualisations, P6 commenting that, with LED_FEEDBACK on the same sensitivity setting as LED-CORRECTION, they felt they *were "Good but I don't know if they weren't as sensitive but they didn't go on red as much*".

When considering the visibility of the two different visualisations there was a conflict of opinion between the three riders who commented. P1, who was riding in the indoor arena felt there was no difference between the two, whereas P6 and P7 who rode outside had different views with P6 preferring the scrolling of LED-CORRECTION in the sunshine, although they did comment that they would normally wear glasses but not for riding so this might have affected her view of them and that there wasn't a lot of difference. P7 on the other hand found LED-CORRECTION difficult to see in bright sunshine, finding them unable to be seen at all without sunglasses, whereas they commented that the fixed ones were "*definitely easier to see"*.

The two riders who rode outside also commented on the loss of visibility when the horse's mane blew across the lights in the wind, although P6 found this was only in trot and P7 didn't mention the difference in gait but felt it wasn't a major problem as the mane blew the opposite way when they changed direction.

Only one rider (P1) made a comment on range of motion. This was for LED-CORRECTION and was a comment that the lights stayed on green constantly at first before adjustment. In this case, once adjusted, they were fine so this comment was likely more about sensitivity or a connection issue so can be excluded.

7.3.7. Setup, Fit and Use

This section covers comments relating to the practicalities of using the tool, covering the positional and attachment aspects of both the rider and horse devices and their use. Also included in this section are any comments relating the horse's reaction to the device. Table 7.12 summarises the number of participants and references made within each code of this theme.

No issues were reported for use on riders with all reporting that the IMU device was easy to put on and that there were no issues with comfort whilst wearing it. Six riders (60%) reported that they were not even aware that they were wearing it at all, with one commenting particularly on the light weight of it. Riders were wearing a range of clothing and none reported the belt or device slipping or moving. One who was wearing a T-shirt commented that they could feel the band but not the device. Two riders commented specifically on the ease of putting it on due to the elasticated belt.

In all cases, the position of the device was checked visually from the rear by the researcher, prior to calibration, and observed during data collection for signs of movement. No movement or slippage was observed, however, one rider (P8) dismounted during the session to re-adjust the device on the horse so, to be sure that this did not cause movement of the device on the rider, recalibration was carried out after remounting.

Theme/Code	Description	Participants	References
SETUP, FIT AND USE		**10**	**46**
Easy setup and fit not specific	Any positive comments on setting up, attaching or the fit of the device where it is not specified or clear whether they relate to the rider or the horse.	6	11
Easy setup and fit on horse	Any positive comments on setting up, attaching or the fit of the device on the horse.	4	7
Easy setup and fit on rider	Any positive comments on setting up, attaching or the fit of the device on the rider.	6	8
General negative comments on ease of use	Negative comments or issues raised on the ease of use of the tool, not relating to the setup, fit, position or attachment.	0	0
General positive comments on ease of use	Positive comments on the ease of use of the tool, not relating to the setup, fit, position or attachment.	2	3
Issue with horse setup or fit	Any issues noted with either setting up, attaching or the fit of the device on the horse.	6	9
Issue with rider setup or fit	Any issues noted with either setting up, attaching or the fit of the device on the rider.	0	0
Issues with use	Comments on any issues experienced during use of the tool. Should include only issues noted that are relevant to the use of the tool not the fit or setup.	0	0
Position on horse	Comments on where the device is placed on the rider. Includes positive and negative comments.	4	7
Position on rider	Comments on where the device is placed on the rider. Includes positive and negative comments.	1	1

Table 7.12. Qualitative feedback (setup, fit and use).

Comments regarding the horse LED device on the were generally positive but there were some comments and issues with the attachment. P3 commented that it was "*tricky*" to attach, highlighting the importance of ensuring it wasn't against the ears, which may aggravate them.

P6 and P7 both rode the same horse outdoors on the same day. This horse had a thick mane, and it was a windy day. No adverse comments were made by P6 but P7 commented that the device was slipping to the side, and they felt that this was caused by the wind blowing the thick mane up against it. They were not bothered by it slipping to the side but, when that was in conjunction with the wind blowing the mane across to the same side, this obscured their view of the lights. Figure 7.9 shows the device mounted on this horse. The rider didn't consider this to be a "*major problem*" because "*you can see again when you turn and the wind blows the mane the other way*". They commented that it wouldn't have been an issue at all in an indoor arena. P4 also rode outside but this was not a windy day, and their horse did not have a thick mane.

Figure 7.9. LED device obscured by thick mane in windy conditions.

In two cases, adjustments were necessary after the initial attachment.

For P8, the strap holding the device in place on the headpiece was not initially tight enough, so it was moving around whilst in motion. The rider reported that it was moving to the side when the horse was shaking their head going round corners but that they could still see the lights. This horse had previously been used for 4 riders (plus the pilot study) and while they tended to shake their head whilst standing still, they had not previously shaken it whilst moving. The strap was tightened by a hole, which stopped the device slipping and touching the horse's ears and this fixed the problem. This horse was a thoroughbred with a very narrow neck, and this highlighted the need for consideration of the shape and/or attachment to be customisable to the individual horse. That said, P2 commented for the same horse that "*It didn't wobble about on her head, it was fastened on*." It wasn't tried in this study, but it is felt that taping the box to the headpiece would have fixed it more securely.

The horse used for P9 and P10 tended to shake its head when ridden. This was not caused by wearing the device as it was confirmed that the horse does this whenever ridden. This caused the device to move and make a rattling noise, which it was clear very quickly was causing the horse to become upset. This only happened after the rider mounted (the horse had been fine prior to mounting as their headshaking only occurred when being ridden) so they stopped and dismounted after just a few seconds to ensure safety. It was, therefore, not possible to use the device on this horse positioned on the headpiece of the bridle so, after some experimentation with keeping it in position, it was mounted on the martingale strap in front of the saddle and fixed to the saddle pad to stop it moving (Figure 7.10). The researcher was concerned that the angle of the new attachment would be an issue since it was not mounted straight across the neck but neither rider commented on this being an issue.

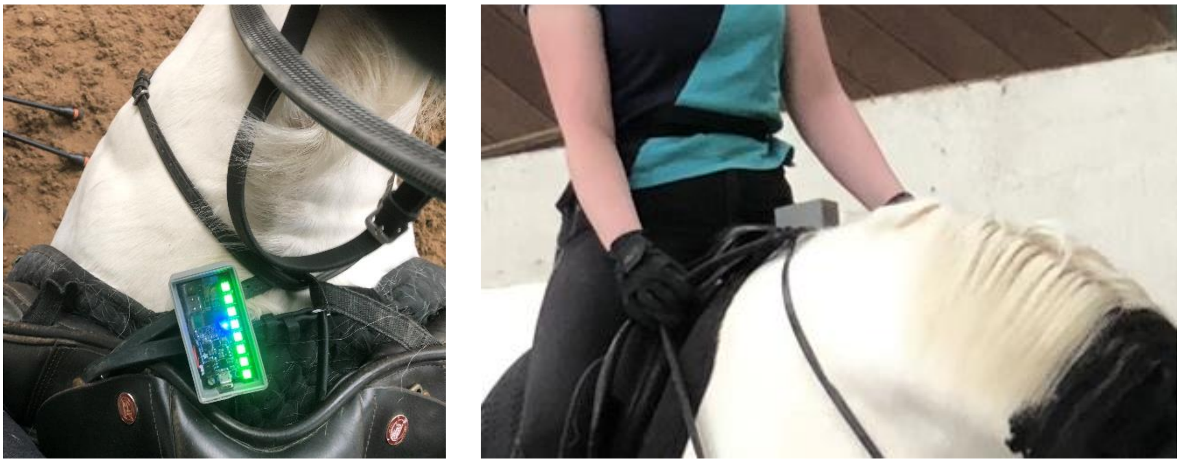


Figure 7.10. Alternative position of LED device for horse who was a head shaker.

P9 had used it for a few seconds on the original head position and commented that they could see how this would have been easier but that in the new position it was *"… alright, it was better in the walk than it was in the trot but you could still see it."* P10 only experienced riding with it in the new position and commented "*It was quite interesting having to put it on Molly being further down. It did make my riding a bit more like I had to concentrate more. It was a lot harder to look up.*" This rider reported that it was not ideal in the new position but that they could manage with it there. Of the eight riders with the unit attached between the ears then six of them also commented on aspects regarding concentration and the need to look at the lights whilst also looking where they were riding. This is discussed in more detail in response to the question on concentration (Section 7.3.4).

7.3.8. Study Experience

This section covers comments on the method used to evaluate the tool, in particular, whether the study protocol provided sufficient experience of the tool to be able to form reliable opinions of its use and effectiveness. Table 7.13 summarises the number of participants and references made within each code of this theme.

Seven riders (70%) found the study protocol was sufficient to gain enough experience of the tool to evaluate it but three (30%) would have preferred further testing. P3 suggested using it for three or four sessions and more in terms of movements rather than session time, P8 suggested using it for a full schooling session, although didn't specify the length that would be. P7, who rode outside and had trouble with the sunlight, thought that LED-FEEDBACK reacted more slowly yet provided more instant feedback but would like to repeat the testing in the indoor arena to review whether this would be the same. They also suggested testing for longer to get more familiar with the tool and its reaction. P2, who thought the timing was right, added that if it had been longer, they may have been affected by tiredness which could increase the level of asymmetry or reduce reaction times and give false readings.

Theme/Code	Description	Participants	References
STUDY EXPERIENCE		**10**	**33**
Comments on routine	Comments (positive or negative) relating to the test routine. Includes reasons given and any suggestions/issues noted, Covers riding movements and gait.	9	15
Comments on test duration	Comments (positive or negative) relating to the duration of the testing. Includes reasons given and any suggestions/issues noted,	2	3
General comments on experience	Any additional comments on the study test conditions not relating to the test routine, time or ability to gain sufficient experience of the tool.	2	3
Not sufficient to get experience	Negative response (and reasons if given) to the direct question "was the test/routine sufficient to give enough experience of the tool to form an opinion?"	3	4
Sufficient to get experience	Positive response (and reasons if given) to the direct question "was the test/routine sufficient to give enough experience of the tool to form an opinion?"	7	8

Table 7.13. Qualitative feedback (study experience)

Nine riders (90%) made comments on the routine and movements used for the testing. Six riders (60%) made positive comment about the overall routine (P2, P4, P5, P8, P9, P10) and P1 commented only on the circles, stating that "*Circles were very good because if anything is going to throw you out it is going to be the turns*". P3 also commented positively on the "*big movements*" as "*it was easier to correct than trying to do smaller stints of movements*" but had some additional suggestions (covered below).

P2 commented on the two long sides of straight in trot, plus the big circles, P4 also commented on the straight lines alongside the small circles, indicating these required the most balance. P5 commented that the same movements were done on each rein and that there were circles and straight lines. P8 commented on the different sizes of circles and changes of rein, which "*gives you a good overall view of how it's working*".

Two riders (20%) made suggestions of additional movements they would like to have added into the testing: P3 would have liked to include 10m circles in trot in addition to walk for comparison, lateral (sideways) movements, serpentines (S-shapes), different sized circles and canter, although they understood the health and safety restrictions on the latter; P6 would have liked to include transitions as they felt that was when "*a lot of people go more wonky*";

In addition to the comments on specific aspects of the study, two riders (20%) made general comments on the overall experience: P2 commented *"I think it all ran quite smoothly. So, yes, I think it was all quite good*"; P4 commented "*I really enjoyed it, thank you very much*".

7.3.9. Use of Technology

This section covers general impressions on the use and potential of the tool and suggestions for how it might be used in practical contexts, including any improvements that could be made. Table 7.14 summarises the number of participants and references made within each code of this theme.

Theme/Code	Description	Participants	References
USE OF TECHNOLOGY		**10**	**92**
Benefits	Any comments relating to benefits of using the technology. May be duplicated from justifications given within some of the other categories. Includes overall general positive comments.	9	25
Contradictory opinion	Comments which may refer to both advantage and disadvantage or non-committal or vague comments where opinion isn't clear	1	1
Disadvantages	Any comments relating to disadvantages in the use of the technology. May be duplicated from justifications given within some of the other categories.	1	1
Frequency of use	Comments relating to how often the tool could be used. Includes justification for suggested timescales or periods between use. Also includes comments relating to timescales that would be inappropriate, for example too frequent, which would also be coded under disadvantages.	10	13
Situations appropriate for use of tool	Any comments on the type of riding sessions which would be suitable for the technology to be used. For example, during lessons or while schooling on their own or hacking, includes how they might be used with an instructor present.	9	23
Situations when tool shouldn't be used	Any comments relating to session types or situations when it wouldn't be appropriate to use the tool. For example, when there could be health and safety issues such as riding on roads.	5	6
Suggested improvements	Responses to the question "would you make any changes, improvements?" Includes response plus details of any suggested improvements.	7	9
Would like to use again	Positive responses to the question "would you like to use the tool again?". Includes direct response any comments on why that don't fit into the other categories within this group.	10	14

Would not like to use again	Negative responses to the question "would you like to use the tool again?". Includes direct response any comments on why that don't fit into the other categories within this group.	0	0

Table 7.14. Qualitative feedback (use of technology).

Nine riders (90%) listed benefits of using the technology compared to one who provided a disadvantage, which was that using it for every ride would be too much. The 25 references coded within this category include general statements that it was beneficial or good, so just specific detailed benefits are highlighted in Table 7.15, with some of these combined where they are linked.

Rider	Benefit
P1	Definitely gave you a focus. To say "a little bit, just a nudge"
P3	I like it. I enjoyed it, enjoyed probably isn't the right word but it made me think a bit more and made me think about his position in relation to me and me to him and when my position was out
P3	that would act as the correction and hopefully in time the instructor would see a difference because I start to correct naturally myself with having that visual cue
P4	So having something like that would help me straighten myself up especially through lateral work where I feel like it would benefit me because I do fall in through the hips, the shoulders and it can have a symmetry effect on the horse. the straighter you are with the horse the straighter it is with you
P4	I like to write down after I have ridden my horse. I feel like if I was to ride with them on him, I would make a more accurate mark. Rather than saying "he wasn't doing this, he wasn't that" I can now say "I wasn't doing this, I was leaning this way too much, I wasn't applying enough pressure on that side" My balance was making a reflection on him so he's following my body so I could tell how tight I was in the left hip compared to the way of his movements and I could go back through my diary to see how my tightness and tension, how it could affect him
P6	Very beneficial because it can correct if you are crooked. So, it's permanently putting you in the correct position. So, you can then adapt that to your riding when you are not using the lights
P7	Very useful for somebody who doesn't have the benefit of an instructor, a competent instructor, to stand there and point out the faults. It was very informative
P7	Use it on your own or with an instructor: I think both really and obviously good for instructors to use with their clients as well
P7	Just like I wasn't aware of the right rein being worse so maybe it's bringing up issues that you weren't really aware of before. You and the horse
P7	There were the options for which I preferred so I got to use the one that works best for me so someone else might have chosen a different one. To have that option I guess
P9	It was helpful for me to correct myself
P9	I would use them because definitely effective for using your seat and your legs not just your leg

Rider	Benefit
P10	Kind of correct yourself and habits just general schooling especially if you are coming up to any competitions or anything. Say you have a dressage competition because your position is so important so you say "I've got that bad habit so I really need to think of that when I'm in my test"
P10	it is really effective for something so simple to be as effective as it was
P10	It's just like telling you where to move but so effective to be able to see it get yourself one side or the other and be able to correct it straight away

Table 7.15. Qualitative feedback (general comments on benefits).

One rider (P9) listed a contradictory opinion in commenting *"It didn't affect me personally in my riding so. But it was helpful for me to correct myself"* and another (P1) was coded as a disadvantage with the comment *"Doing it every time you ride would be too much"*.

All ten riders said that they would like to use the tool again and gave their opinion on how frequently they would use it. These responses are listed in Table 7.16.

Rider	Frequency of Use
P1	Once a month or every 6 weeks. Once you are aware of what you need to do you can go away and work on it. Doing it every time you ride would be too much. 4-6 weeks good to give time to work on it then re-assess
P2	Probably once a month
P3	Would use it a couple of times a week. I get a lesson once a fortnight so I could use it in between. On average I school 5-6 times a week so would use it at least twice a week. I'd use it at the start of my schooling week and the end of my schooling week, just to see if there's a difference. It would be interesting to see. If I've had a few days off or he's had a few days off, to see if there's a difference.
P4	I would quite possibly use them all the time because I hack out, I do a bit of jumping, I school and I feel like it would be beneficial for all way round because obviously the straighter you are with the horse the straighter it is with you
P5	Definitely at least once week
P6	Would depend how often you ride so I ride about twice a week. Initially I would use them every time then I wouldn't use them. Going back to them I would then see if there was a difference. Go back to them once a week I would say
P7	I think you never stop learning and you never stop training so I would imagine that if you were riding regularly, you would use them at least once a week. You probably wouldn't want to be using them every day because you would almost become fixed on them rather than perhaps some other aspect of the riding but as a refresher on your position and how you are sitting in the saddle, I would see them used every week, once a week
P8	You probably wouldn't want to be using them every day because you would almost become fixed on them rather than perhaps some other aspect of the riding but as a refresher on your position and how you are sitting in the saddle, I would see them used every week, once a week

Rider	Frequency of Use
P9	You probably wouldn't want to be using them every day because you would almost become fixed on them rather than perhaps some other aspect of the riding but as a refresher on your position and how you are sitting in the saddle, I would see them used every week, once a week
P10	I would probably say a couple of times a month maybe like once a fortnight

Table 7.16. Qualitative feedback (comments on frequency of use).

The most popular frequency of suggested use was once a week, with four riders suggesting this. There is no other consensus, with one rider suggesting each of: every time; twice a week; at least once a week; fortnightly; monthly; 4-6 weekly.

Nine riders (90%) gave situations for use of the tool, with five riders (P5, P6, P8, P9) saying they would use it both riding on their own and with an instructor in a lesson, four riders (P3, P4, P7, P10) saying they would only use it when riding on their own and one rider (P2) saying they would only use it in a lesson with their instructor.

P10 commented that it would be particularly useful for people who ride on their own a lot because they *"wouldn't know if someone hadn't told me that I tilt my head"*. They also thought it would be particularly useful in general schooling leading up to a competition, such as a dressage competition, to identify any bad habits that they would need to be aware of to think about during the test. P6 also said they would use them "*on the flat*" and for dressage schooling.

P2 thought it would be useful to use in a lesson so that the instructor could help with identifying the correction alongside the lights, then they could practice riding "*normally*", then re-assess with their instructor.

P4 thought the tool could be useful when out hacking on the roads in addition to when schooling. They commented that they do exercises such as lateral work (shoulder-in and leg yielding out) when riding out on the roads.

P8 said they didn't personally do any schooling but that if they did, they would use the tool or specifically if they had an event coming up, then they would use it to address any issues. They particularly noted that it would be useful for an instructor to use with their clients.

P3, who was a Riding for the Disabled instructor closed their session with a comment on how they would use the tool in their job role:

> *"I want a box to play with the kids. I work with kids with disabilities and getting them to focus would be hard but it is something I would love to have a chance to try. I know it's not part of the study but it would be interesting to see how the kids focus on that from my point of view as a coach and as a rider, just to see what the difference would be and see if we could get them to sit still and things so that for me would be something I would love to have a game, have a go at"*

Five riders identified situations where they didn't feel the tool would be useful or shouldn't be used. P10 felt that it would only be appropriate to use on their own as to use it with an instructor would mean concentrating on too many things at once. P3 also wouldn't use it in a lesson but their reason for this was that they've got *"someone's eyes on the ground"*. They also wouldn't use it every time they schooled. P7 thought it would be difficult to use in a lesson because *"you don't have so much free will. In a lesson you have to follow the instructions of the instructor so what you might want to be trying to improve getting the lights in the middle you may not be able to do because you've been told to do something else*". P6 wouldn't use it for jumping with the reason given being *"because it is totally the wrong equipment, you are always going to be a bit lobsided"*. P9, unlike P4, didn't think they would use it for hacking because their view was that *"obviously you just go for the fun don't you"*, highlighting the individuality and variation in how the tool would be used in practice.

Seven riders made comments regarding improvements but two of these (P2, P5) were to state that there were no improvements they could think of. The improvements suggested are listed in Table 7.17.

Rider	Suggested Improvement
P3	The box on the horse's head smaller. It's nice for what you are doing but if you are going to use it a lot, if it slides and catches the horses ears. So, if it was smaller, you might be able to use it on more horses that might be sensitive.
P7	I think probably just the size of them that to be useful in all conditions you would need to make the lights bigger. Bigger or brighter. Obviously, that has its downside in what you can put on the horses head but maybe just a slightly bigger display. I think probably it would work as well with six bigger
P8	Maybe just securing that front one a bit better, The one on the horse's bridle. [this followed issues with the horse device remaining in position]
P9	Obviously, it would've been easier if it was on her bridle but that just couldn't be helped really [this was the horse who reacted to the head-mounted device and had it moved onto the saddle]
P10	Suggestion for this participant stick on head as that's where the tilt is

Table 7.17. Qualitative feedback (comments on frequency of use).

7.4. Sentiment Analysis

An overall sentiment analysis was carried out on the qualitative interview transcripts, using the standardised functionality within NVivo (NVivo, n.d.). The results of this are provided in Table 7.18.

The sample size (n=10) was insufficient for a full sentiment analysis but these results do indicate an overall positive impression of the tool. Some care does need to be taken in the interpretation of these results as they include responses to the questions on which interface was preferred and why, which resulted in specific positive and negative responses. However, it is clear that more positive comments were made on the preferred interfaces than negative responses made on the less-preferred interface.

Sentiment	Number of Participants	References	Percentage
Very Positive	10	39	41.1
Moderately Positive	9	30	31.6
Moderately Negative	9	20	21.1
Very Negative	3	6	6.3

Table 7.18. Sentiment analysis on qualitative feedback.

To carry out a deeper sentiment analysis to reveal any statistically significant results would require further data collection for a larger sample size, with more specifically designed interview questions beyond the scope of this research.

7.5. Summary

This chapter has covered both the quantitative and qualitative results of Study 2 evaluating the tool developed. The following is a summary of the conclusions which can be drawn from the quantitative results:

- There was no statistically significant bias due to order of testing the two interface visualisations.
- There was no statistically significant preference for one or other of the two interface visualisations, although more riders (n=6) preferred LED-FEEDBACK compared to LED-CORRECTION (n=4).
- In walk, there was a statistically significant reduction in asymmetry with LED-CORRECTION despite more riders preferring the use of LED-FEEDBACK.
- In trot, there was a statistically significant reduction in asymmetry with LED-FEEDBACK, which aligns with greater rider preference for the use of LED-FEEDBACK.
- The range of motion was not dependent on the visualisation in either walk or trot.

The qualitative results have been discussed in detail in Section 7.3, within the nine coded themes. These results were generally positive and demonstrated the success of the tool and potential for use within a practical context. This was also supported by the basic sentiment analysis carried out in Section 7.4.

Chapter 8 will discuss these results further, in light of other research and a small number of improvements that have been identified from the qualitative evaluation that would benefit the tool for use in a practical context.

Chapter 8. Discussion and Conclusion

8.1. Introduction

Detailed discussion on the individual results of the evaluation study (Study 2) has been included with the results in Chapter 7. This chapter will take an overview of the key findings and discuss how these supports, contrasts or extends current published literature, linking back to the literature review (Chapter 2) where appropriate. It will also highlight some key points and areas for improvement of the tool, which were identified from the evaluation, followed by discussion of how the research has met the aim of the project and addressed each research question.

The chapter will then summarise the findings of the research as related to the research questions and objectives, outline the contribution to knowledge, the limitations and identify possible future work that could extend both the research and practical application of this research. It will then draw the thesis to a close with final concluding comments.

8.2. Discussion of Results

Study 1 supported the findings of the literature review, concluding that the pelvis was the most common location for placement of the IMU, accounting for almost 30% of references to body segments observed during rider assessment. The rider device was, therefore, designed with a single IMU sensor which was placed on the rider's pelvis. This also supports and extends the early recommendations of Rispens et al. (2014) and Del Din et al. (2016) as the gold standard of placement for gait analysis at walk.

The qualitative evaluation in Study 2 revealed no issues with comfort or attachment and riders found the tool effective to use. Whilst the placement of the rider device was on the pelvis, as determined from the conclusions of Study 1, three (30%) of riders referred to the correction that they needed to make as being to their shoulder, indicating that the tool helped them to identify the wider correction to posture identified by the tool.

Placement on the horse was also found to be suitable by eight (80%) of the ten riders, but one horse (ridden by two riders) was not happy with the head mounted device. In this case the trial continued but with the device moved to the front of the saddle. Whilst not ideal in that the rider had to look down to see the device, it was decided to include the results in the evaluation as it gave an additional perspective to the evaluation. The riders still found the tool effective but did comment on the placement from a visual perspective, confirming that, in a practical context, the saddle would not be a suitable placement for such a device. Suggested improvements to the tool, based on this feedback are listed below:

- An improved design of the horse device would be beneficial to provide a smaller footprint which could be attached to the bridle without the horse being aware of it.
- If the horse has a long mane or the device is used outdoors in windy conditions, then a plaited or tied section of mane to keep it from obscuring the device is necessary.

Regarding the test protocol, three (30%) of the riders would have preferred additional testing time to gain experience of the tool, two of whom would have preferred additional sessions and one who would have preferred a single longer session. Two (20%) of the riders would have preferred additional movements included in the test protocol, suggesting 10 metre trot circles, lateral (sideways) movements, although these are outside the remit of the Novice level dressage movements, serpentines, canter (this was a health and safety restriction) and additional transitions between gaits.

Macaire et al., (2022) reported a need for further research to identify benchmarks to determine an acceptable range of asymmetry before reporting the horse as lame. The same principle can be applied to rider posture and the tool has partially implemented this via the green range of allowable deviation of motion before providing feedback or correction. However, feedback to the rider has been graded, rather than a fixed on/off threshold as in their study, to enable the rider to observe the extent to which they need to modify their posture and dynamic information on their progress towards this.

Initial testing attempted to use the data from the LED-OFF control test to determine automated thresholds for the range of asymmetry reported but this was found to be too restrictive due to rider/horse combination individual differences and was rejected in favour of the rider selecting from three option ranges. It was found also that the range of deviation in trot was different to that in walk.

Nine riders (90%) found that the tool reported issues of lateral asymmetric posture to the right, on the right rein or a combination of both, which supports previous findings of 83% asymmetry to the right of hip rotation both on straight lines and circles to the right (Gandy et al., 2014) and greater hip flexion asymmetry on the right, with this being statistically significant on the right rein (Gandy et al., 2018). The 2018 study only considered straight lines, however.

Whilst a statistically significant improvement in asymmetry of the riders was found for both interfaces, there was no significant improvement in range of motion, although some patterns which indicated that, whilst not statistically significant, there was some reduction in time spent in the red zone. This supports the findings of Passafiume et al. (2022), who found no statistically significant improvement in breathing efficiently whilst running, as a result of the visual feedback. They concluded that this was due to the lack of time to practice, learn and adapt to the new breathing techniques and interpreting the visualisation. Further research is suggested to determine if a longitudinal study would show this to be the case and/or if a larger sample size would affect the results for postural stability of riders and potentially also to wider contexts, including running.

Godfrey et al. (2018) provides a warning of over-reliance on wearable technology at the expense of self-regulation and individual responsibility, which is recognised by rider comments on frequency of use of tool, with most riders suggesting that the tool is useful but should not be used for all sessions.

The design of the visual interfaces for correction and feedback, utilising graded ranges of coloured LEDs was positively received by riders, with variation in level of preference for each and no significant preference for one over the other. This ranged from those who were very specific about which visualisation they preferred, reporting that the other was distracting and or caused them to over-compensate (awarding proportions of a 9:1 split in preference scores), to those who were somewhat undecided and expressed less preference for one or another (awarding proportions of a 6:4 split). No riders awarded 10:0 or 5:5 splits in preference scores, however, indicating that they all had some level of positivity for both interfaces but also a preference.

The reporting of over-compensation of postural correction by riders was in relation to their decision as to which interface they preferred and was not common to one interface. This is similar to the findings of Ferris et al. (2022), in their study on balance exercises in older participants. However, they provided just a single interface and suggested this was an attribute of concurrent feedback, whereas it could be argued that the findings of this study indicate the importance of providing a choice of interface visualisation so users can select according to their preference.

Looking to the future, early work has demonstrated potential for automated gait classification using AI techniques (Serra Bragança et al., 2020), which will remove the need for the separate consideration of the different gaits and enable full automation. Further research is also required to determine if gait classification could be determined from rider data alone, rather than requiring additional sensors on the horse.

The development of a customised application of contextual enquiry, utilising a mixed methods approach comprising observation, retrospective think-aloud recall and structured interview techniques was found to be an effective method for research in the wild. Feedback from the participant coaches in Study confirmed that this was an appropriate method for situations where it was necessary to observe a participant who was themselves carrying out an observation and it was necessary to allow them to concentrate without distraction. Similarly for Study 2, with the use of the retrospective structured interviews, where the rider needed to concentrate whilst riding without distraction.

8.3. Summary of Research Findings

The primary research question was “What are the most appropriate interface design and data visualisation techniques for the presentation of IMU data for rider postural analysis and feedback?”

This question was divided into three sub-questions, which have been answered as follows:

Q1. What are the current practices, focal points and key stakeholders in the postural analysis of riders in a real-world context?

This question was answered by the literature review and Study 1 (S1) “Understanding usage contexts”, using a customised version of contextual inquiry. The key stakeholders in the postural assessment of riders were identified as the rider, the coach and the horse, included as their training and welfare is impacted by the posture of the rider.

The most referred to focal point was the pelvis at almost 30% of focus. As a result of this study, in conjunction with the literature review findings that asymmetry is a key risk factor for rider back pain/injury, the decision was taken for the proposed tool to utilise a single sensor positioned on the pelvis to capture motion in the lateral plane.

The tasks the riders were asked to complete for the assessment fed into the second research question, providing the protocol of riding movements to be used in evaluating the tool:

Q2. What is an appropriate protocol for the use of IMU data as an assessment and feedback tool, taking into account the practical considerations for the use of IMU analysis during riding motion?

The main answer to this question was achieved via the development of a novel prototype hardware and software tool, comprising an IMU sensor device attached to the rider's pelvis which transmits postural data in the lateral plane to an 8-LED light strip display mounted on the horse's head. The software provided two visualisation interfaces displayed via the LEDs: directional correction via scrolling lights; and feedback on deviation from centralised posture via fixed display of lights. In both cases, the level of deviation was supported by changing colour of lights from green, through amber to red. The software also provided facilities to be operated by the researcher via a basic text-based menu.

The tool was evaluated via Study 2 (S2) "Interface design, data visualisation and usage implications for IMU-based rider postural analysis and feedback tool", which used a cross-over field study evaluation with ten riders, carrying out the movement protocol from Q2 with a control without lights, plus both visualisation interfaces. Retrospective semi-structured interviews were used for a qualitative evaluation to identify environmental and practical considerations for the use of the tool (Q2) and address the third research question:

Q3. Which is the most appropriate data visualisation technique for the presentation of rider analysis data feedback according to the usage contexts identified in Q1?

Postural data recorded revealed a statistically significant reduction in asymmetry between the control and the correction visualisation in walk and the feedback visualisation in trot, irrespective of rider preference.

No statistically significant differences were found for rider preference scores between the two visualisation interfaces, with some evidence that posture could be negatively affected by a less-preferred interface. However, seven riders preferred the feedback visualisation and three preferred the correction visualisation, aligning with the more effective visualisation in the faster gait of trot.

No statistically significant differences were found for range of motion apart from the time spent beyond the range of correction/feedback (red lights flashing) in trot for the preferred visualisation.

8.4. Contribution to Knowledge

The contribution to knowledge can be linked to the research questions and benefits the rider, coach and, indirectly, the horse welfare through improved comfort. Benefits are included below within each research question:

Q1. What are the current practices, focal points and key stakeholders in the postural analysis of riders in a real-world context?

For this aspect of the study, a novel requirements analysis methodology was used. In particular, the use of a customised version of contextual analysis, within a field study, via the use of a body-mounted video recording to obtain the observational data from the coach's perspective without interfering with their communication with the rider. This method enabled the researcher to obtain the coach's viewpoint via a retrospective think aloud recall method without interfering with, or needing to observe, the coach directly. This contribution could be applied in future studies to any research where it is necessary to observe, without interfering with, a participant who is themselves carrying out an observation.

Q2. What is an appropriate protocol for the use of IMU data as an assessment and feedback tool, taking into account the practical considerations for the use of IMU analysis during riding motion?

The key contribution here is the development of the tool itself. In particular, the novel use of wearable technology, in the form of an IMU sensor on the rider's pelvis transmitting motion data wirelessly to an LED light strip on the horse's head to provide customisable (via software) visual presentations of the dynamic motion data. The benefit is to the rider, who can select the visual presentation interface of their choice to receive either correctional or feedback information to address asymmetry or other postural issues. In the tested case, the choice was for lateral motion of the pelvis; to address asymmetry but with minimal changes to the software, it would be possible to add an additional option to address pelvic tilt. It was beyond the scope of this study but there is potential for the coach to also benefit from the tool, via a second device showing a copy of the data presented to the rider. The horse would also benefit from any resulting improvement to the rider's posture.

Q3. Which is the most appropriate data visualisation technique for the presentation of rider analysis data feedback for each user context identified in Q1?

There is novelty in the provision of alternative dynamic visual presentation mechanisms via the option to select from either correction or feedback visualisation interfaces. This will benefit the rider in being able to select the appropriate interface according to preference and effectiveness, particularly considering the differences shown in the study between preference and horse gaits. The horse was also demonstrated to benefit from the adjustment of the rider's posture.

The knowledge gained from this study has potential for wider impact via application to additional contexts which also have the need for postural issues to be addressed, for example:

cycling, running, weightlifting, rehabilitation for Musculo-skeletal injury, stroke or neurological conditions.

8.5. Limitations

A limitation of this study was the single session data collection for the evaluation study (Study 2), meaning that in this case it wasn't feasible to determine whether long-term statistically significant improvements in posture would occur with increased experience and extended use of the tool. This was not possible due to access to the riders/horses at the establishment used for data collection but has been included in the suggestions for future work. Whilst this may have affected the quantitative results, there was sufficient richness of data achieved in the qualitative evaluation to determine the riders' opinions on the interface visualisation and the benefits and issues of using the tool in a practical context.

The sample size of 10 participants is a limitation but this reflects common practice amongst equine research studies, where the practicalities of carrying out data collection are complex and time consuming, with 55% of studies (from a scoping review of equine research from 1978-2018) having a sample size in the range 1-10 (Egan et al., 2019).

The gender balance of the participants was limited by being all female. This was due to access to participants at the riding establishment used for data collection, where no male volunteers were available. This has been reported as a common issue across equestrian research studies and is representative of the gender imbalance towards female predominance at the amateur/leisure level of riders (Bye and Martin, 2022). Although there are biomechanical differences between male and female that might impact the rider posture, the focus of this research is the design and evaluation of the tool from a computing hardware/software perspective rather than the postural issues identified. It could be argued that female riders might gain more benefit from the tool since they are more likely to have an asymmetrical posture (Bye and Martin, 2022) so the use of a single-gender group for participants limits any variability and a future study could be used to compare results with an all-male group.

8.6. Further Work

The opportunities for further work are extensive, given the findings from the literature review revealed that the equestrian research is currently somewhat behind other contexts at present. This is to some extent due to the complexities of carrying out research in the wild and the complex nature of the rider/horse interaction. With the emergence of new technology, some of these complexities will become easier to address moving forwards.

Suggestions for further work are listed below:

Inclusion of AI/machine learning models into the tool's software to automatically detect the gait of the horse so that the feedback ranges could be customised to the gait. By automating the gait detection, the software would be able to automate the changes in reporting ranges for each gait dynamically without requiring intervention from the user. Further research is required to determine if gait classification could be determined from rider data alone, rather than requiring additional sensors on the horse (Serra Bragança et al., 2020).

A longitudinal study, ideally with a larger sample of riders, would provide sufficient time for the users to become accustomed to the use of the tool and data for a detailed quantitative analysis to determine if its use would lead to improvements in rider posture. This would consider: the duration of the testing period; frequency of use within that period; testing frequency; testing after withdrawal of use (gradual and/or after a period of withdrawal).

A larger sample of riders would also provide the opportunity for future work on data extraction for statistical models, for example association rule mining and decision trees.

Given developments in the field over recent years, a larger sample size would enable the data to be further analysed with machine learning techniques, in additional to statistical analysis. There is scope to analyse which variables led to which results and to investigate the use of more advanced sentiment analysis on the qualitative feedback using recent models such as those discussed in Singh et al. (2024). A comparative study with a range of models could be used initially to select the most appropriate model which could then be used to determine more accurately the benefits of the tool and the areas where improvements could be made. Machine learning could also be used to train the tool to detect the movements being carried out in the arena, for example circles as distinctive from straight lines, and customise feedback more finely to adjust for individual rider, horse and movement.

Further research could investigate opportunities and benefits of the tool for use with children and disabled riders, particularly those with physical disabilities affecting posture. In particular, the use of gamification for children or riders with learning difficulties or physical issues, who might currently need constant instruction from a coach to remain upright and symmetrical. The provision of a visual display, with the challenge of keeping the lights in the green zone, could be used to incentivise the rider.

Improve the design of the hardware, boxes which house it and develop a fully functional mobile software application to move from prototype to a production device. In particular, the design of an integrated light strip device within a bespoke bridle attachment would improve the attachment to the horse and make it easier to attach and more secure, meaning that there was less chance of it upsetting a sensitive horse. This would enable safe operation in all gaits, for all horses and allow for extended use while cantering and jumping.

8.7. Concluding Remarks

This thesis draws to a close with the conclusions which can be drawn from the research carried out to visualise inertial motion sensor data via the design and evaluation of a horse rider assessment and feedback interface tool.

The novelty of this tool is in the provision of concurrent visual feedback to the rider, enabling them to receive a choice of either correctional or positional feedback on their posture whilst riding. This enables them to adjust their posture and view the effect of this immediately, while mounted on the horse, rather than retrospectively as in existing tools or requiring the need for a coach. The tool also provides novelty in enabling the provision of concurrent empirical, rather than current observational techniques for, feedback to both rider and coach.

Further novelty was provided in the method developed for use of customised contextual enquiry in carrying out field-based research in the wild, specifically where there is a need for incorporating observation of participants carrying out activities without causing distraction to them.

The overall conclusion from the study is that the design of an interface to present dynamic postural assessment to a rider should include optionality in selection of correction or feedback as the visualisation to present. This would enable riders to select the most appropriate visualisation on an individual basis, taking account of gait and preference.

The qualitative evaluation to determine environmental factors and practical implications of fitting and using the prototype tool found the placement of an inertial motion sensor on the pelvis of the rider with visual feedback provided from the horse's head to be effective, subject to improvements suggested within the discussion of the results.

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Appendix A. Research Questions Contribution

Research Question	Objectives	Contribution
Q1. What are the current practices, focal points and key stakeholders in the postural analysis of riders in a real-world context?	Who are the key stakeholders?	Identification of stakeholders and roles in rider assessment/feedback Rider, coach, therapist/medical practitioner. In Riding for the Disabled groups, additionally parent, carer, school.
	What tasks are carried out in an observational assessment of a rider? What biomechanical measures are used in an observational assessment of a rider?	Methodology for carrying out contextual inquiry in the wild. Issues encountered in carrying out contextual inquiry in the wild. Issues affecting biomechanical assessment of a rider in the wild. Coaching requirements for assessment/feedback interface. Conclusions (tasks/measures) to feed into Q2.
Q2. What is an appropriate protocol for the use of IMU data as an assessment and feedback tool, taking into account the practical considerations for the use of IMU analysis during riding motion?	What is an appropriate set of tasks to be incorporated into the assessment protocol?	Protocol for IMU-based rider assessment.
	What is an appropriate set of biomechanical measures to be incorporated into an automated rider assessment protocol?	Which area(s) of the body should form the focus for an IMU-based rider assessment/feedback tool, taking account of practical and environmental considerations?
	What are the hardware and software specifications for an IMU-based assessment and feedback tool/interface?	Specification for IMU-based assessment and feedback tool.
Q3. Which is the most appropriate data visualisation technique for the presentation of rider analysis data feedback for each user context identified in Q1?	What are the environmental factors affecting use of the prototype tool in the wild?	Environmental factors affecting use of IMU/LED technology for rider assessment and feedback in the wild.
	What are the practical implications of fitting and using the prototype tool in the context of rider feedback?	Practical implications for the use of IMU/LED technology for rider assessment and feedback in the wild.
	Which is the most appropriate LED feedback interface – feedback vs correction?	Identification of rider preferences for LED feedback interface style and considerations for development of future tools.

Research Question	Objectives	Contribution
	What are the methodological implications of carrying out research in the wild?	Methodological factors to be considered when carrying out research in the wild.

Appendix B. Observation Guide (Study 1) Draft Version

Used as a checklist during the retrospective think-aloud and structured interviews carried out as part of Study 1 – Understanding Usage Contexts.

Question/Issue to be considered	User Context
What exercises are carried out in order to assess the rider? *Rename as Scenario e.g. free riding in an enclosed arena, not lunging / lead rein. Max 10 mins. Minimum requirement for coach required e.g. BHSII, UKCC Level 2.*	RIDER/COACH
How many repetitions of each exercise are necessary? *Not relevant, will be identified by the assessment protocol.*	RIDER/COACH
What, if any, order are exercises/assessments carried out? *Rename exercises as assessment protocol*	RIDER/COACH
What areas of the body are focussed on? *Chronological order of assessment*	RIDER/COACH
What instructions are given?	COACH
What feedback is given to the rider? *Feedback implies coaching is being carried out. In this context the phrase guidance should be used*	COACH
Where are the exercises observed from?	COACH
How does the rider self-observe (video, mirrors, “feel”)? *Should be carried out without use of mirrors, only “feel”.*	RIDER
Is there any hands-on manipulation or assessment? *Manipulation implies an intervention which is not part of assessment process. A more appropriate term would be palpation*	COACH
How long does the assessment take? *Suggest assessment is timed, with a maximum limit of 10 minutes*	RIDER/COACH

Question/Issue to be considered	User Context
Are there any issues around clothing worn by the rider?	RIDER/COACH
Is the session interactive? If so, what discussion is carried out?	COACH
Are any questions asked by the rider?	COACH
When is guidance given (during or after exercise completion)?	COACH
Is the process documented? If so, is there a standardised form?	RIDER/COACH
Who is in control of the horse (is lunging used)? *Should be free riding, not on lunge or lead rein. This means that rider requires competence level of at least British Dressage Novice or equivalent*	RIDER/COACH
Is choice of horse taken into account? *Not relevant as in most cases in practical context rider would be on own horse*	RIDER/COACH
Where is the observer positioned in the arena?	COACH
Does the observer move around the arena?	COACH
Is the rider assessed both off and on the horse?	RIDER/COACH
Are arena mirrors used? If so, how often do they look in them and how much effect does this have in terms of posture? *Not relevant, this would be a coaching tool after assessmen*t	RIDER/COACH
Is video feedback used? *Not relevant. Coaching not assessment*	RIDER/COACH
Is the rider aware of asymmetries on the horse matching those off the horse? *Not part of assessment*	RIDER/COACH
Which coaching cues does the rider find most useful?	COACH

Question/Issue to be considered	User Context
Not relevant. Coaching not assessment	
Which exercises does the rider find most useful in understanding postural faults? *Not relevant. Coaching not assessment*	RIDER/COACH
Is there an iterative process? E.g. exercise (videoed if necessary), feedback, repeat. *Not relevant. Coaching not assessment*	RIDER/COACH

Appendix C. Observation Guide (Study 1) Final Version

Used as a checklist during the retrospective think-aloud and structured interviews carried out as part of Study 1 – Understanding Usage Contexts.

Question/Issue to be considered	User Context
Where is the assessor positioned in the arena?	COACH
How much does the assessor move around the arena during the assessment?	COACH
What is the assessment protocol?	RIDER/COACH
Is the rider assessed both off and on the horse?	RIDER/COACH
What areas of the body are focussed on?	RIDER/COACH
What instructions are given to the rider prior to the assessment?	COACH
What guidance is given to the rider?	COACH
When is guidance given (before or during individual movements)?	COACH
Are any questions asked by the rider?	COACH
Is the session interactive? If so, what discussion is carried out?	COACH
Is there any hands-on palpation or is assessment by observation only?	COACH
How long does the assessment take? (Timed up to a maximum of 10 mins)	RIDER/COACH
Are there any issues around clothing worn by the rider?	RIDER/COACH
Is the process documented? If so, is there a standardised form?	RIDER/COACH

Appendix D. Study 1 Conclusions and Contribution

Research Question	Objectives	Contribution
Q1. What are the current practices, focal points and key stakeholders in the postural analysis of riders in a real-world context?	Who are the key stakeholders?	• Coach: Performs the task currently and provides feedback and correction on posture to the rider. Proposed tool may be used in place of the coach for individual use or during sessions with the coach. • Rider: The target of the assessment and recipient of the postural feedback/correction • Horse: May be affected by rider postural issues from a welfare perspective or may impact on the rider posture from the perspective of their own asymmetries.
	What tasks are carried out in an observational assessment of a rider?	*Covered in results Table 4.3. Frequency of gait, rein and exercise across all participants.* .
	What biomechanical measures are used in an observational assessment of a rider?	Covered in results Table 4.4.
Q2. What is an appropriate protocol for the use of IMU data as an assessment and feedback tool, taking into account the practical considerations for the use of IMU analysis during riding motion?	What is an appropriate set of tasks to be incorporated into the assessment protocol?	Movements chosen from results of study (carried out on both left and right reins where relevant): • Halt – will be used for calibration • Walk straight line • Walk 10m circle • Trot straight line • Trot 20m circle • Canter 20m circle (excluded from tool testing due to health and safety)
	What is an appropriate set of biomechanical measures to be incorporated into an automated rider assessment protocol?	Based on the findings of the literature review and the coach observations, a single measure from the rider pelvis, measuring motion in the lateral plane, in particular identifying lateral asymmetry.
	What are the hardware and software specifications for an IMU-based assessment and feedback tool/interface?	Based on the findings of the literature review and the coach observations: • Single IMU sensor placed on the pelvis/lumbar spine. • Visual feedback provided via a device mounted on the horse in line of sight of the rider • Visualisation interface for feedback and correction to be provided for comparative evaluation

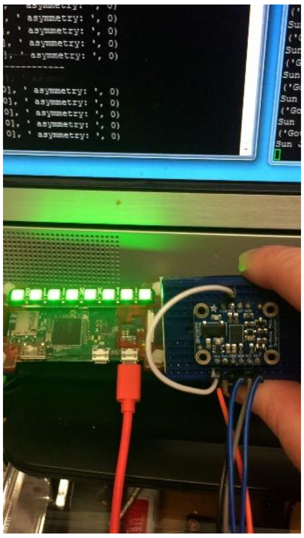
Table 8.1. Contribution from each research question.

Appendix E. Visualisation Interface for LED-CORRECTION

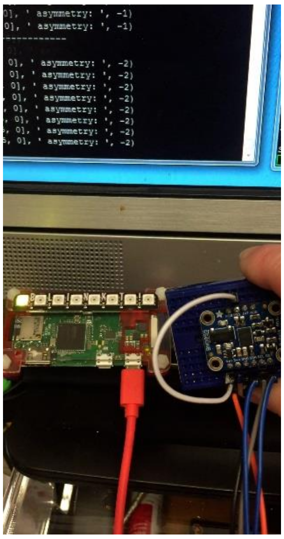
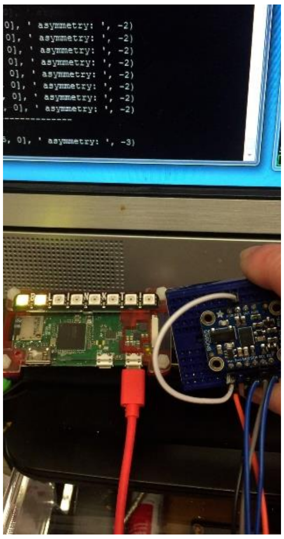
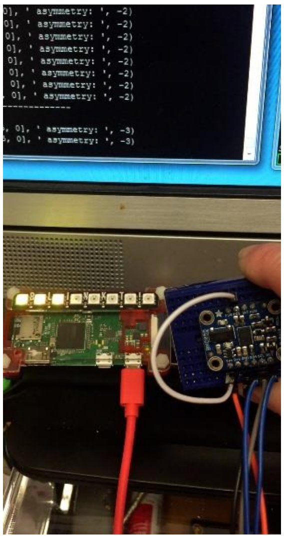
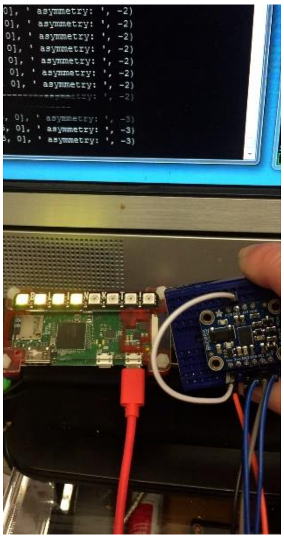
```python
def ShowScrollingLED(asymVal, rollVal, RGB, LEDCount):
    # set LED brightness
    brightness = 0
    if LED_Count == 8:
        brightness = 0.05
    elif LED_Count == 28:
        brightness = 1

    # set direction and starting LED (set to 0 unless reverse mode)
    LEDindex = 0

    if (asymVal > 0):
        LEDindex = LEDCount -1

    # clear any previous LED settings
    LEDstrip.clear()

    # Update User Interface to display roll value
    print(GenerateAsymmetryDisplay(asymVal, rollVal, LEDCount))

    # scroll through the LEDs, turning them on in sequence
    for i in range(LEDCount):
        if (asymVal == 0):
            LEDstrip.set_all(RGB[0], RGB[1], RGB[2], brightness)
        elif (abs(asymVal) <= (LEDCount/2)):
            if (i == 0):
                LEDstrip.clear()
                LEDstrip.show()

            # loop through LEDs from centre to current
            LEDstrip.set_pixel(LEDindex, RGB[0], RGB[1], RGB[2], brightness)
        else:
            # pause for 0.5ms to blink LEDs
            LEDstrip.clear()
            LEDstrip.show()
            time.sleep(0.05)

            LEDstrip.set_all(RGB[0], RGB[1], RGB[2], brightness)

        # display LEDs
        LEDstrip.show()

        # pause for 0.5ms
        time.sleep(0.05)

        # set next LED index
        LEDindex = LEDindex - sign(asymVal)
```

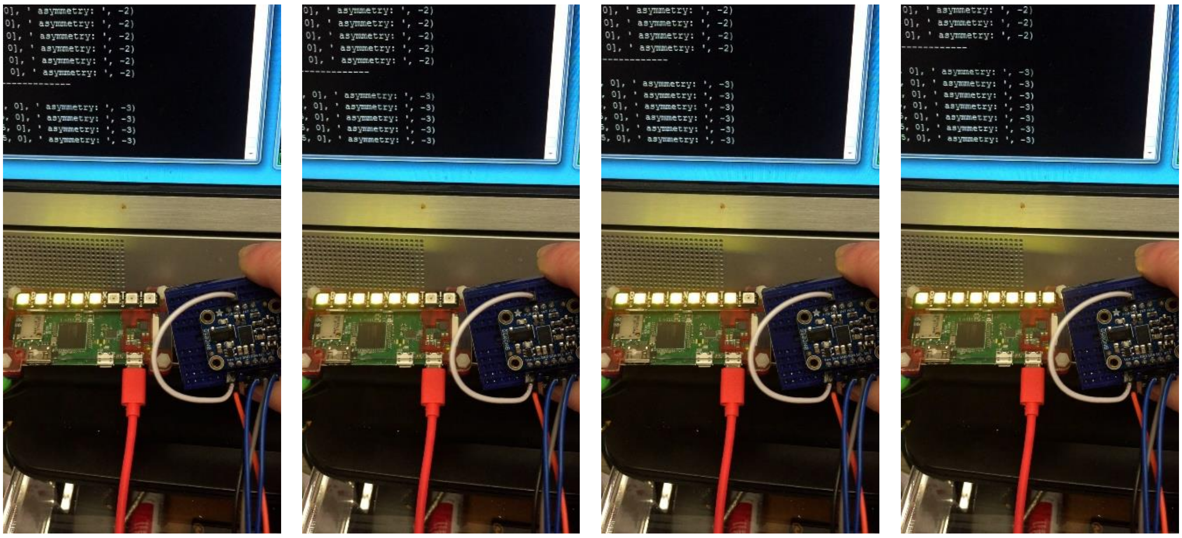
Figure 8.1. Python function to display LED-CORRECTION visualisation.

Green Zone. Within symmetrical range.

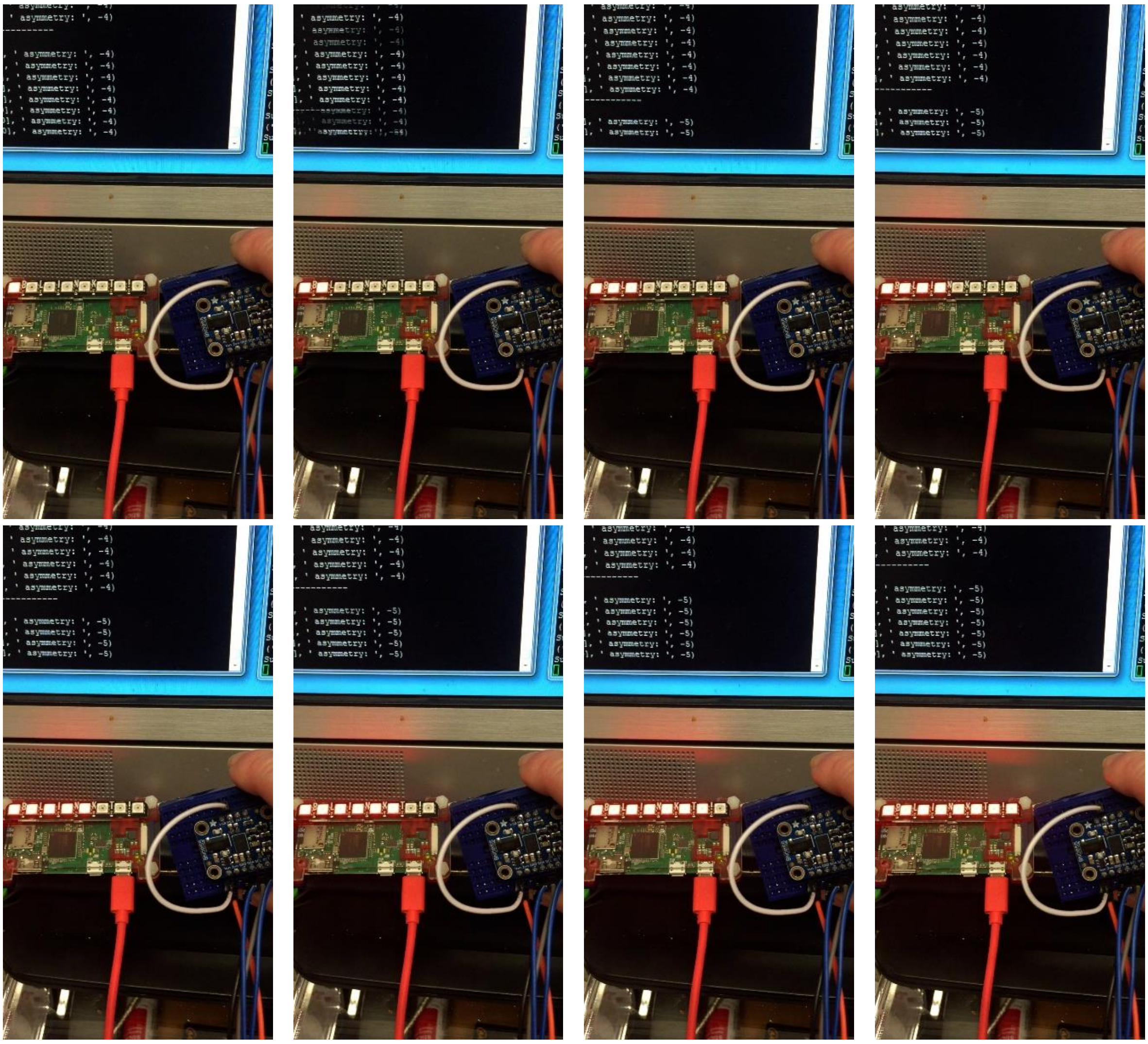


Amber Zone. Asymmetry within correction range (scrolling directional feedback), in this example, rider is asymmetrical to left and correction is indicated by scrolling from left to right. Colour indicates amount of asymmetry (changes from green through orange to red).

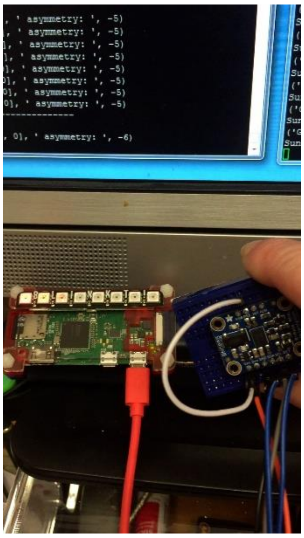





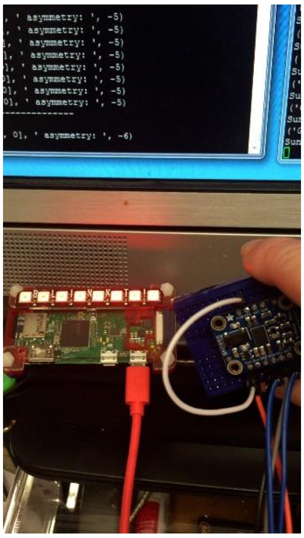


Amber Zone. Increased asymmetry within correction range. Colour is closer to red.



Red zone. Asymmetry beyond feedback range (all LEDs flashing red)



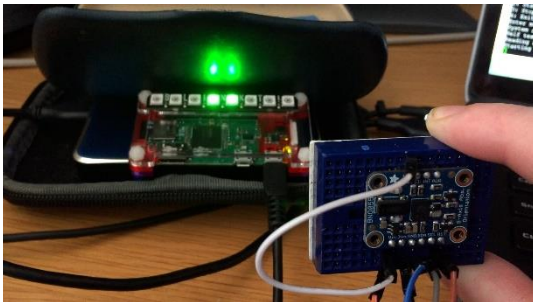


Appendix F. Visualisation Interface for LED-FEEDBACK

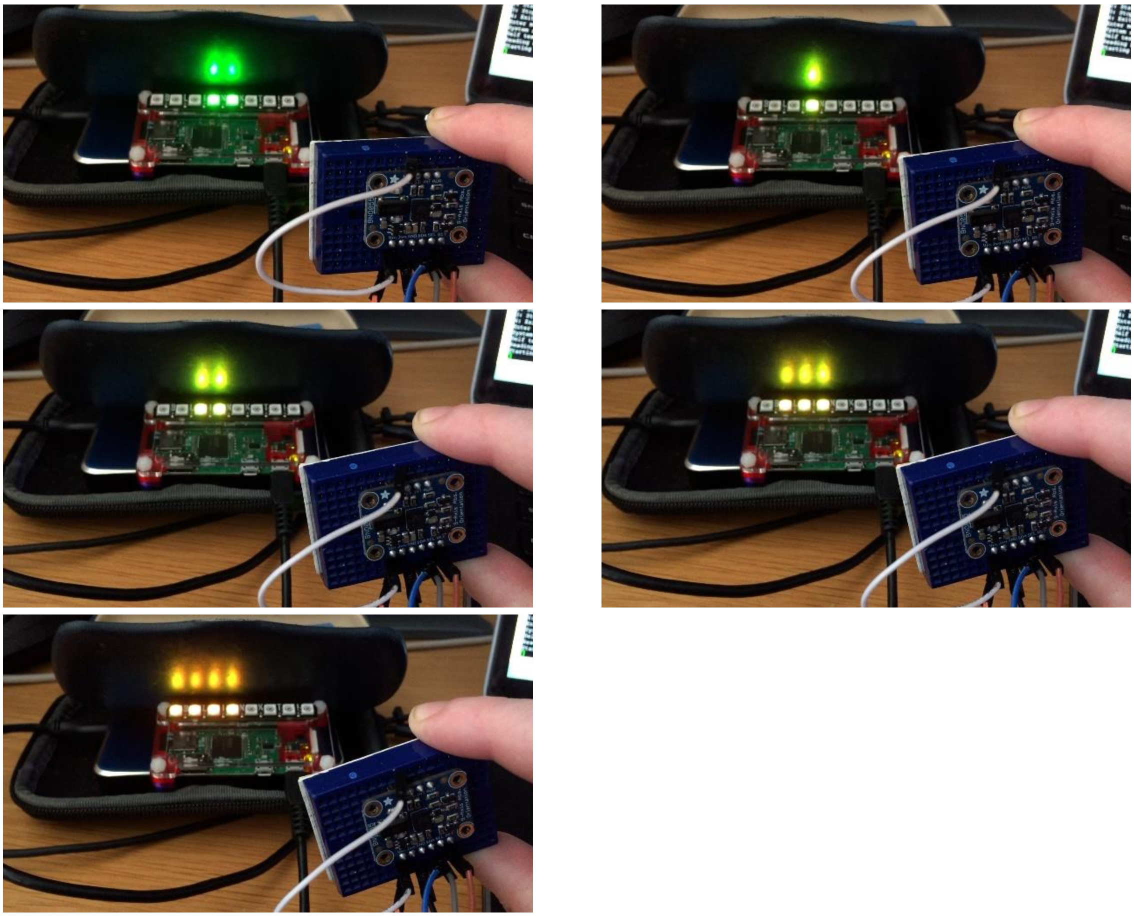
```
def ShowMultiFixedLED(asymVal, rollVal, RGB, LEDCount):
    # set LED brightness
    brightness = 0
    if LED_Count == 8:
        brightness = 0.05
    elif LED_Count == 28:
        brightness = 1

    LEDstrip.set_brightness(brightness)

    if sign(asymVal) == -1:
        asymStartLED = (LEDCount / 2) - 1
    else:
        asymStartLED = LEDCount / 2

    # clear any previous LED settings
    LEDstrip.clear()

    # Update User Interface to display roll value
    print(GenerateAsymmetryDisplay(asymVal, rollVal, LEDCount))

    # turn on the LEDs according to asymmetry value
    if (asymVal == 0):
        LEDstrip.set_pixel((LEDCount / 2) - 1, RGB[0], RGB[1], RGB[2])
        LEDstrip.set_pixel(LEDCount / 2, RGB[0], RGB[1], RGB[2])

    elif (abs(asymVal) <= LEDCount / 2):
        LEDindex = asymStartLED + asymVal

        # loop through LEDs from centre to current
        for i in range(asymStartLED, LEDindex, sign(asymVal)):
            LEDstrip.set_pixel(i, RGB[0], RGB[1], RGB[2])

    else:
        # pause for 0.5ms to blink LEDs
        LEDstrip.clear()
        LEDstrip.show()
        time.sleep(0.05)

        LEDindex = asymStartLED + (sign(asymVal) * LEDCount / 2)

        # loop through LEDs from centre to current
        for i in range(asymStartLED, LEDindex, sign(asymVal)):
            LEDstrip.set_pixel(i, RGB[0], RGB[1], RGB[2])

    # display LEDs
    LEDstrip.show()

    # pause for 0.5ms
    time.sleep(0.05)
```

Figure 8.2. Python function to display LED-FEEDBACK visualisation.

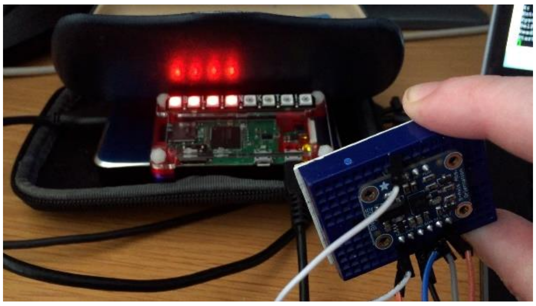
Green Zone. Within symmetrical range.

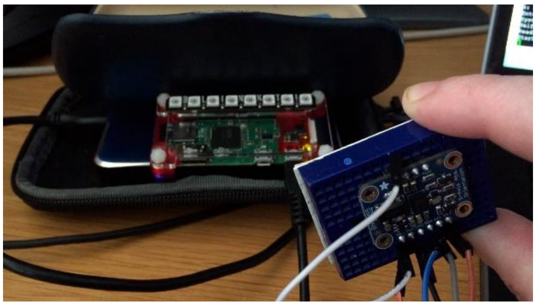


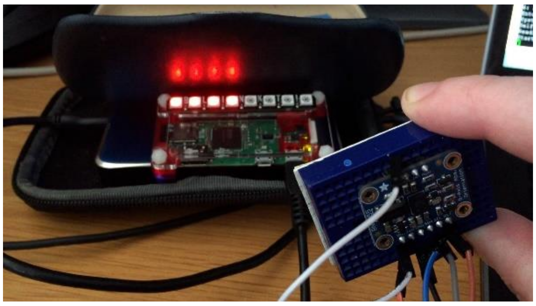
Amber Zone. Asymmetry within feedback range (colour changes and increased number of LEDs indicates amount of asymmetry)



Red zone. Asymmetry beyond feedback range (flashing red LEDs on side of asymmetry)







Appendix G. Software Development Sprints

Sprint 1

- Basic system to provide single function – scrolling LED

Sprint 1 Black Box Test Plan

Test	Description	Expected Outcome	Actual Outcome	Result
T1.1	Scrolling LED-CORRECTION works	LED-CORRECTION interface displayed on horse device	LED-CORRECTION interface displayed	✓

Sprint 2

- Server menu providing on/off IMU polling and exit options
- LED provides 3 alternative functions – scrolling, fixed single light, fixed multi lights
- LED reads IP address from config.txt

Sprint 2 Black Box Test Plan

Test	Description	Expected Outcome	Actual Outcome	Result
T2.1	Check menu for polling on works	Polling works without crashing	Polling works without crashing	✓
T2.2	Check menu for polling off works	Polling stops without crashing	Polling stops without crashing	✓
T2.3	Check IP address is read successfully from configuration file	Polling works	Polling works	✓

Sprint 3

- Calibration menu item coded. Standing calibration takes mean value over 5 seconds and deducts this from roll value before processing.
- LED provides 3 alternative functions – scrolling, fixed single light, fixed multi lights. Configured by 1, 2 or 3 in second line read from config.txt.
- Polling thread started before menu. Threads checked before closing.

Sprint 3 Black Box Test Plan

Test	Description	Expected Outcome	Actual Outcome	Result
T3.1	Check calibration	Calibration correct for values recorded	Correct calibration offset calculated	✓

Test	Description	Expected Outcome	Actual Outcome	Result
T3.2	Check config file option 1 displays LED-CORRECTION	LED-CORRECTION interface displayed on horse device	LED-CORRECTION interface displayed	✓
T3.3	Check config file option 2 displays LED-FEEDBACK single light interface	LED-FEEDBACK single light interface displayed on horse device	LED-FEEDBACK single light interface displayed	✓
T3.4	Check config file option 2 displays LED-FEEDBACK multi light interface	LED-FEEDBACK multi light interface displayed on horse device	LED-FEEDBACK multi light interface displayed	✓
T3.5	Check polling thread starts correctly	Polling works without crashing	Polling works without crashing	✓
T3.6	System closes all threads cleanly	Threads closed (check pi threads not running after closing application)	No threads running after closing application	✓

Sprint 4

- Splitlines used when reading config file to avoid problems with CRLF characters. This enables editing of config file now possible on mobile
- Adjust for vertical calibration when calibrating IMU

Sprint 4 Black Box Test Plan

Test	Description	Expected Outcome	Actual Outcome	Result
T4.1	Check editing of config file on mobile and PC	System runs	System runs	✓
T4.2	Check calibration	Calibration correct for values recorded	Correct calibration offset calculated	✓

Sprint 5

- Menu item added to set LED range:

  1 = 12-16,

  2 = 8-12

  3 = 4-8

  4 = enter min/max values

- Add exception handling when binding to socket to catch and exit with error message when port is in use
- Add menu validation to main menu and calibration range
- LED user interface improved to show roll value with left/right asymmetry indicators as scrolling display.
- LED functions improved with more efficient and consistent calculations for identifying LEDs to turn on
- Improved server messages on startup of IMU
- Added decimal places and use of. format on menu items
- Add 1 to calculation of asymVal to ensure first LED comes on as soon as lower limit is reached
- Change IMU calibration so that LED range is equivalent to values within asymmetry range i.e. min-max asymmetry

Sprint 5 Black Box Test Plan

Test	Description	Expected Outcome	Actual Outcome	Result
T5.1	Menu item range 1 for LED-CORRECTION	LEDs correctly provide correction in range 12-16 degrees	Correction in range 12-16 degrees	✓
T5.2	Menu item range 1 for LED-FEEDBACK	LEDs correctly provide feedback in range 12-16 degrees	Feedback in range 12-16 degrees	✓
T5.3	Menu item range 2 for LED-CORRECTION	LEDs correctly provide correction in range 8-12 degrees	Correction in range 8-12 degrees	✓
T5.4	Menu item range 2 for LED-FEEDBACK	LEDs correctly provide feedback in range 8-12 degrees	Feedback in range 8-12 degrees	✓
T5.5	Menu item range 3 for LED-CORRECTION	LEDs correctly provide correction in range 4-8 degrees	Correction in range 4-8 degrees	✓
T5.6	Menu item range 3 for LED-FEEDBACK	LEDs correctly provide feedback in range 4-8 degrees	Feedback in range 4-8 degrees	✓
T5.7	Menu item range 4 for LED-CORRECTION	LEDs correctly provide correction in range with entered min/max values	Correction in variety of ranges with entered min/max values	✓
T5.8	Menu item range 4 for LED-FEEDBACK	LEDs correctly provide feedback in range with entered min/max values	Correction in variety of ranges with entered min/max values	✓

Test	Description	Expected Outcome	Actual Outcome	Result
T5.9	Abort software then restarts polling to check error message is displayed when socket is already in use	Error message displayed	Error message displayed indicating socket in use	✓
T5.10	Check all validation for all menu options	Correct error messages displayed	Error messages displayed	✓
T5.11	Show interface for controller device on mobile and PC indicating left/right asymmetry for range between 0-90 degrees	Correct new display for values between 0-90 on left and right	Correct display	✓
T5.12	Show LED-CORRECTION for controller device on mobile and PC indicating left/right asymmetry for range between 0-90 degrees	LED-CORRECTION visualisation correctly displays	Correct display	✓
T5.13	Show LED-FEEDBACK for controller device on mobile and PC indicating left/right asymmetry for range between 0-90 degrees	LED-FEEDBACK visualisation correctly displays	Correct display	✓
T5.14	Check server messages on startup	Correct messages	Correct messages	✓
T5.15	Check formatting and decimal places on menu options and messages	Correct formatting and messages	Correct formatting and messages	✓
T5.16	Check first LED comes on as soon as lower limit is reached	First LED comes on as soon as lower limit is reached	First LED comes on as soon as lower limit is reached	✓
T5.17	Check IMU calibration	Correct values	Correct values	✓

Sprint 6

- Fixed error message for threadServer not defined if stop polling or exit is selected before polling
- Recording menu option (7) added with data saved to CSV file in data folder.
- Data format:

dataRecordNum	roll	pitch	LEDMinL	LEDMinR	LEDMaxL	LEDMaxR

- Selection of filename (prompts to replace if file exists)
- Tidying up of menu and string formatting with spacer ================= etc.
- Exit now menu option 8.

- Additional configuration option added to config.txt to determine whether a menu is to be displayed to override the LED display option from the config file.
- Changes to server and menu so that exit works even if LED has not been connected

Sprint 6 Black Box Test Plan

Test	Description	Expected Outcome	Actual Outcome	Result
T6.1	Stop polling selected before polling started	Error message displayed	Error message displayed	✓
T6.2	Exit selected before polling started	Error message displayed	Error message displayed	✓
T6.3	Select menu option 7 and record rotation from 0 to 90 degrees (left and right) for LED-CORRECTION to data file	Data file contains correct values from 0 to 90 degrees	Correct values recorded in data file	✓
T6.4	Select menu option 7 and record rotation from 0 to 90 degrees (left and right) for LED-FEEDBACK to data file	Data file contains correct values from 0 to 90 degrees	Correct values recorded in data file	✓
T6.5	Select filename for file not existing	File created	File created	✓
T6.6	Select filename for file already existing	File overwritten	File overwritten	✓
T6.7	Check menu formatting	Correctly displayed menu	Correctly displayed menu	✓
T6.8	Check menu option 8 for exit	Menu option 8 exits program successfully	Menu option 8 exits program successfully	✓
T6.9	Test configuration file option to display menu option for LED display choice	Menu option displayed and works for both LED visualisations	Menu option displayed and works for both LED visualisations	✓
T6.10	Test configuration file without display menu option for LED display choice	Menu option not included and both visualisations work from configuration file	Menu option not included and both visualisations work from configuration file	✓
T6.11	Test exit works even if LED has not been connected	Program exits without LED connected	Program exits without LED connected	✓

Appendix H. Ethics Paperwork

Study 1: Participant Information Sheet

Research Participant Information Sheet

You are being invited to take part in a research study as part of an investigation into the use of technology in sport. Before you decide whether to participate it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully. Please ask if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

Who will conduct the research?

Elizabeth Gandy, Department of Computing, Engineering & Technology, University of Sunderland. Additional researchers may be involved in the data analysis and reporting phases of the study, under the direction of Elizabeth Gandy.

What is the title of the Research?

Visualising inertial motion sensor data: the design and evaluation of a horse rider assessment interface

What is the aim of the research?

The aim of this research is to investigate the process of rider postural assessment as part of a contextual analysis in order to determine requirements for the development of software to automate the process using 3D motion capture technology.

Why have I been asked to take part?

The study requires data to be collected from a sample of coaches and riders, with sufficient experience levels to be able to perform the required activities.

What will I be asked to do if I take part?

Coach: Carry out a postural assessment of a rider performing free riding in an enclosed arena. It is expected that the assessment will involve observations of the rider at a variety of gaits, riding both straight lines and turns, viewed from a range of positions. You will be required to record your assessment wearing a body-mounted forward-facing video camera, with microphone and the assessment will also be recorded by the researcher to identify your movements within the arena. Following the assessment, you will be required to view the video recordings and discuss the rider assessment that you have carried out. This will be recorded by the researcher.

Rider: Perform free riding in an enclosed arena, whilst being directed and assessed by a coach. You will be observed riding at a variety of gaits, both straight lines and turns, viewed from a range of positions. You will be recorded by the coach, who will be wearing a body-mounted forward-facing video camera, with microphone and the assessment will also be recorded by the researcher to identify the coach's movements within the arena.

Appropriate methods of health and safety management will be adopted, including the use of protective headwear for the rider. You should not experience any pain or discomfort whilst wearing any of the equipment or carrying out the exercises. If you do, then you should stop immediately and inform the researchers.

What will happen to the data collected?

To protect your anonymity, a code will be allocated to any data collected during this study and no personal information will be linked to it. All information collected from you during this study will be considered confidential and used for research and (with additional consent) teaching purposes only.

How will confidentiality be maintained?

Data collected will be anonymised and you will not be identified in any published research-related communications, such as research data, reports or other publications. Identifiable photographic or video images recorded during the study will only be used in publications with your prior permission.

What will happen if I do not want to take part or if I change my mind?

Participation in this study is voluntary and you are under no obligation to take part. If you do decide to take part you will be given this information sheet to keep and asked to sign a consent form. If you decide to take part you are free to withdraw at any time, before or during the study, without giving a reason.

What is the duration of the research?

It is expected that the rider observation will be carried out within a maximum of 10 minutes and the subsequent discussion between the coach and researcher will take up to a further hour.

Where will the research be conducted?

The research will be conducted at a venue pre-arranged with the coach/researcher.

Will the outcomes of the research be published?

It is intended that the outcomes of this study will be submitted for publication in an academic journal. They may also be reported at a conference and included in a postgraduate research thesis. Any personal or identifying information will be removed prior to publication. A copy of any published material resulting from this study will be made available to you if requested.

Who do I contact for further information?

Elizabeth Gandy: liz.gandy@sunderland.ac.uk

Study 2: Participant Information Sheet

Participant Information Sheet (Phase 1 Rider)

You are being invited to take part in a research study. Before you decide whether or not to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully.

Study Title:

Visualising inertial motion sensor data: the design and evaluation of a horse rider assessment interface

What is the purpose of the study?

This research is being conducted as part of a doctoral research programme at the University of Sunderland to investigate the requirements and interface design implications for the presentation of inertial motion sensor (IMU) data to equestrian practitioners.

The current approach to rider postural assessment is primarily observational and is, therefore, highly subjective. Previous research studies have indicated that inertial motion (IMU) technology may enable a more consistent, accurate and objective assessment of the rider to be carried out but current analysis software currently is complex and difficult to interpret by practitioners.

The aim of this study is to determine whether LED technology is an appropriate method of providing feedback within an IMU-based rider assessment tool. In particular, we wish to determine the rider's preference from a choice of two LED feedback interfaces and to evaluate how the tool may be used within a coaching context to provide a rider with postural data feedback.

Why have I been approached?

The study requires data to be collected from a sample of coaches and riders. You have been chosen to take part because you are either a member of staff or a client of the establishment being used for data collection. Approximately 10 riders and 5 coaches will be asked to participate in the study.

Only consenting adults will be selected as participants. Children and vulnerable adults will be excluded from the study.

To be eligible to take part in the study, riders should be of an experience level equivalent to a minimum standard of British Dressage affiliated novice level. Coaches should be qualified to a minimum level of at least BHSAI or equivalent. Riders will also be familiar with the horse(s) used.

Horses will be either provided by the establishment or owned by the rider and should be healthy, free from disease/injury at time of data collection, in regular work and accustomed to executing movements equivalent to British Dressage affiliated novice level.

Do I have to take part?

Participation is entirely voluntary and you should take time to read this participant information sheet before deciding whether they agree to or decline participation. If you do decide to take part, you will be given this information sheet to keep and be asked to sign a consent form before the start of data collection. You will have the opportunity to ask any questions you may have and will also be asked to complete a questionnaire giving details of your previous and current riding and (if you are a coach) coaching experience.

What will happen if I don't want to carry on with the study?

If you decide to take part you have the right to change your mind and withdraw from the study at any time, without giving a reason and without incurring any penalties.

If you wish to withdraw at any point during the data collection you should stop the activity and inform the researcher who will immediately stop collecting data. If you wish to withdraw after participation in the study then you should contact the researcher using the details at the end of this information sheet.

All data collected up to the point of withdrawal will be immediately destroyed.

What will happen to me if I take part?

Data collection will take place at Washington Riding Centre. Data collection is expected to take no more than 45 minutes, of which approximately 20 minutes will be spent carrying out the ridden activities.

Horses will be provided by the riding centre or riders may use your own, provided it meets the eligibility criteria listed above.

You will be asked to wear a small IMU device, which will be strapped to your pelvis, back or head, on top of the usual clothing that you would wear for riding. An LED light strip will be attached to either the front of the saddle or to the horse's neck in a suitable position for you to be able to view it clearly while you are riding.

After a short period of self-selected warm-up for yourself and the horse, data collection will commence. You will be directed by the researcher to perform a series of ridden dressage movements at halt, walk and trot, including circles and transitions. Data collection will initially take place without the LED feedback interface, with the IMU tool used, under the control of the researcher, to assess your natural riding posture and identify any asymmetries. You will then be asked to repeat the movements whilst viewing each of two LED feedback interfaces, using these to attempt to improve your posture as necessary. The data collection will be video recorded for analysis purposes.

After the ridden part of the data collection is complete you will be asked to take part in a recorded interview, where you will be asked questions relating to your experience of using the tool and your preferred choice of feedback interface. You will also be asked to complete a short questionnaire containing questions relating to your riding level and experience.

What are the possible disadvantages and risks of taking part?

Riding is a risk sport and any interaction with horses does pose a potential risk to health and safety but the data collection protocol has been designed to minimise this risk as far as possible.

The riding centre used will have accident procedures, first aid cover (for both human and horses) and fire safety procedures in place with appropriate signage posted within the venue, as required by their licence to trade as a riding establishment. This means that a first aider will be present on the premises at all times and a first aid kit will be located within or adjacent to the riding arena. In addition, as a requirement of their British Horse Society accreditation, all participant coaches will have received first aid and safeguarding training.

All persons involved in the data collection will be experienced with horses and familiar with safe practices for their handling.

Data collection will be carried out within the confines of an indoor or outdoor riding arena, the required riding movements will be limited to walk and trot; and the horse will be familiarised with the equipment before the rider mounts. The horse will be wearing its normal tack and participants will be able to wear their normal riding clothing and footwear, which should include a British Standard safety approved riding hat at all times when mounted on the horse.

If at any point during the data collection you experience any problems or you are uncomfortable with any activity you are asked to carry out then you should tell the researcher immediately and they will do what they can to resolve the issue and/or will stop the data collection if necessary.

What are the possible benefits of taking part?

Participation in the study will help to increase knowledge in the topic area. During the course of the data collection you will receive feedback on your riding posture via the feedback tool, which you may find of benefit to your riding development.

What if something goes wrong?

If you are unhappy with the conduct of this study please contact the researcher Elizabeth Gandy, supervisor Dr Sharon McDonald or the Chair of the University of Sunderland Research Ethics Group Dr John Fulton. Contact details are included at the end of this sheet.

How will my information be kept confidential?

All participant information (data) will be treated in accordance with the terms of the General Data Protection Regulation (GDPR), 2018.

All information collected about you during the course of the study will be treated in the strictest confidence. We will not pass on any personal information to anyone outside of the research team, and no individually-identifiable information will be published. All individually-identifiable data from the study will be destroyed within 10 years following the completion of the study.

Due to the use of video and audio recordings, some personal identifying information will be collected. Personal identifying information will be kept in a secure place (e.g., locked cabinet, password protected computer or secure cloud storage facility). Participant responses (e.g., transcripts of audio-/video-recordings or any other response data) will be pseudo-anonymized using participant codes and kept separately from personal identifying information. The real names of individuals will not be used in reports and/or stored with the data.

Completely anonymised data from the project may be shared with other researchers and/or used for teaching purposes.

The data may be looked at by staff authorised by the University of Sunderland for audit and quality assurance purposes.

What will happen to the results of this study?

Results will be written-up in project reports for educational qualifications, and/or may be published in academic journals, and/or presented at academic conferences.

Who is organising and funding the research?

The research is organised by Elizabeth Gandy, who is a doctoral student at the University of Sunderland, Faculty of Technology, School of Computer Science.

This project is not externally funded.

Who has reviewed the study?

The study has been reviewed and approved by the University of Sunderland Research Ethics Group.

Further information and contact details

Elizabeth Gandy
Email: liz.gandy@sunderland.ac.uk
Phone: 0191 515 3543

Dr Sharon McDonald (Research Supervisor)
Email: sharon.mcdonald@sunderland.ac.uk
Phone: 0191 515 3278

Dr John Fulton (Chair of the University of Sunderland Research Ethics Group)
Email: john.fulton@sunderland.ac.uk
Phone: 0191 515 2529

Thank you for taking time to read the information sheet

Study 1 & 2: Participant Information Sheet

Research Study Participant Consent Form

Visualising inertial motion sensor data: the design and evaluation of a horse rider assessment interface

The participant should complete the whole of this sheet himself/herself. Please cross out as necessary

- I have read and understood the participant information sheet YES/NO
- I have had the opportunity to ask questions and discuss the study YES/NO
- I have received satisfactory answers to all my questions YES/NO
- I have received enough information about the study YES/NO
- I understand that I am free to withdraw from the study
  - at any time YES/NO
  - without having to give a reason YES/NO
- I agree to photographic/video images, which may potentially identify me, being used in publications resulting from this research YES/NO
- I agree to the data collected being incorporated into teaching materials YES/NO
- I agree to take part in the study as outlined to me YES/NO

"This study has been explained to me to my satisfaction, and I agree to take part. I understand that I am free to withdraw at any time."

Signature of the Participant: ___________________________ _____________- Date: _____________

Name (in block capitals): ____

I have explained the study to the above participant and he/she has agreed to take part.

Signature of researcher: ____ Date: _____________

Name (in block capitals): ____

Appendix I. Risk Assessment

Copy of risk assessment form (hard copy signed version retained).

University of Sunderland

Faculty of Technology

Risk Assessment and Scheme of Work

Note: There is a legal requirement under the Management of Health & Safety at Work Regulations to undertake risk assessments. The absence of any risk assessment is a clear indication of legal non-compliance and inadequate safety management. In conjunction with the legal requirement, the University policy states that 'all managers and supervisors are required, so far as is reasonably practicable, to ensure that all workplace activities are subject to an adequate risk assessment and are planned and controlled so as to be safe and free from risks to the health or safety of persons, or harm to the environment, so far as is reasonably practicable', and 'that all persons are informed of any hazards to their health and safety, or to the environment, which may be inherent in the equipment, substances or work activities and are advised of the precautions to be taken'.

Name:	**Tel Num**:	**Date of Assessment**:	**Date for Review**:
Venue: Washington Riding Centre, Stephenson Rd, Washington NE37 3HR	**Activity Title**: Visualising inertial motion sensor data: the design and evaluation of a horse rider assessment interface	**Activity Overview**: Data collection for a PhD research study. Rider participants will be required to carry out a series of exercises riding a horse, whilst posture is recorded using an inertial motion sensor (IMU) tool and feedback is providing using a set of LED lights. Coach participants will be required to provide a coaching session for the rider, using the above tool. The session will be recorded (audio and video) and participants will take part in a semi-structured interview after the riding session.	

Assessors Name:	**Assessors Signature:**	**Date:**	**Contact Telephone Number:**
Elizabeth A. Gandy			0191 515 3543

Additional Competent Persons Name:	**Additional Competent Persons Signature:**	**Date:**	**Contact Telephone Number:**
David Wilson			0191 515 2546

What are the hazards? *Use the accompanying Prompt List as a guide for identifying some of the potential hazards and controls	**Who might be harmed, and how?**	**What controls are currently in place to prevent harm?**	**What additional controls do you need to manage this risk?**	**What is the overall level of risk?** *Use the accompanying risk matrix to identify the level of risk
Slips, trips and falls	Participant riders, coaches, researcher. Risk of falling from horse or being trampled/kicked/bitten	All persons involved will be familiar with safe practices for handling and riding horses and will wear appropriate clothing and footwear, including a British Standard safety approved riding hat at all times when mounted on the horse. Data collection will take place in an enclosed riding arena and will involve only walk and trot to minimise the risk of falls. Appropriate padding will be provided around the IMU/LED equipment to be attached to riders/horses. Horses will be accustomed to the equipment to be worn prior to the rider mounting.	N/A	Medium
Electrical hazards	Participant riders, coaches, researchers and horses. Use of computer equipment, including cables and batteries (causing burns and electrocution)	Pre-use checks of electrical equipment. Cables will be secured where necessary and will not be positioned where the horse could stand on them. Instructions on safe use of equipment will be provided.	N/A	Low

Page 1 of 4

Fire	Participant riders, coaches, researchers and horses. Fire related injury	Fire evacuation procedures are in place at the venue with appropriate signage.	N/A	Low
Improper use of equipment causing physical injury	Participants. Unfamiliarity with sensor/LED equipment resulting in injury	Full instruction on the operation and limitations of the equipment being used will be provided by the researcher before the start of the data collection session.	N/A	Medium
Physical activity involving horse riding, affecting pre-existing health condition or injury risk through level of exertion	Participant riders and horses. Physical exertion during activity could lead to injury or exacerbation of existing health condition	Participants will be familiar with the activities they are required to carry out and will be advised that, if at any point during the data collection they experience any problems or are uncomfortable with any activity they are asked to carry out, they should stop and inform the researcher.	N/A	Medium
Use of tools and equipment (LED lights)	Participants and researchers. Risk of injury or exacerbation of existing health condition due to sensitivity to flashing LED lights.	Full pre-consent will be given and anyone with an existing medical condition that could be affected by flashing LED lights will be excluded from the study. The rate of flashing LED lights will be within published safety guidelines.	N/A	Low

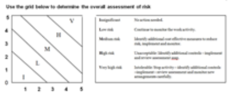
NB: Insert additional rows if required

Additional Information (Complete if required or refer to COSHH form)

General control measures in place:

Emergency Procedures (ie First aid requirements/fire safety/contamination) The riding centres used will have accident procedures, first aid cover (for both human and horses) and fire safety procedures in place with appropriate signage posted within the venue, as required by their licence to trade as a riding establishment. This means that a first aider will be present on the premises at all times and a first aid kit will be located within or adjacent to the riding arena. In addition, as a requirement of their British Horse Society accreditation, all participant coaches will have received first aid and safeguarding training.

Special measures if required (ie chemical spill control/containment/handling/disposal): N/A


Check your Assessment using the information below:

Assessment of Risk

Consequences of Harm (VERT)	Likelihood of Harm Occurring (HORIZ)
1 Minor injury	1 Highly unlikely, not known to occur
2 Over 3 day injury / occupational illness	2 Remote possibility, but known to have occurred
3 Serious injury / Temporary incapacity / occupational disease	3 Can occur, can be reasonably foreseen
4 Loss of limb or eye/ Permanent disability / fire	4 Likely to occur, previous history of such events
5 Fatality / explosion / toxic release	5 Highly likely, quite foreseeable, well known risk

Use the grid below to determine the overall assessment of risk

Insignificant	No action needed.
Low risk	Continue to monitor the work activity.
Medium risk	Identify additional cost effective measures to reduce risk, implement and monitor.
High risk	Unacceptable: Identify additional controls - implement and review assessment asap.
Very high risk	Intolerable: Stop activity - identify additional controls - implement - review assessment and monitor new arrangements carefully.

Prompt List:
Note: Those hazards marked *** require more specific assessment documentation. See your Faculty / Service ASHEC (Area Safety, Health & Environment Co-ordinator) for details.

Hazard Checklist		Who?	Possible controls
Slips, trips and falls	Movement of people	Staff (academic, technical, clerical, manual, professional)	Information and instruction
Use of tools and equipment	Obstructed means of access / egress	Other staff	Staff / student training
Electrical hazards	Overcrowding	Students (Undergraduate, postgraduate)	Safe system of work (specify)
Sources of heat or ignition	Lack of instruction	Others (Contractors, visitors, members of the public)	Personal protective equipment (specific)
Use of hazardous substances***	Lack of supervision		Safety technology (RCD, guarding, sensors,...)
Noise***	Stress		Local exhaust ventilation, fume cupboards
Dust and fumes	Use of sharps / glassware		Planned preventative maintenance
Micro-organisms	Display Screen Equipment***		Inspection and testing regimes
Mechanical Hazards (entanglement, entrapment)	Manual handling operations***		Routine monitoring / supervision

Risk Assessment Scheme of Work

Note: The risk assessment scheme of work is required to provide accompanying information to ensure the planned activity and required resources match the risks assessed for. This will ensure participants of the activities understand where the risks stem from, and also to ensure that the session is set up in an applicable manner to ensure the resources are prepared with the activity description in mind.

Subject Area/Topic	Activity Description	Resources Required
Comparison of LED feedback interfaces	Rider will complete a series of exercises whilst mounted on the horse, initially without the LED feedback interface then repeated whilst viewing (in turn) two alternative LED configurations, using them as a guide to improve their riding posture. This activity is expected to take approximately 20 minutes	IMU/LED feedback equipment. Video recording equipment.
Use of LED feedback interface within a coaching context.	Rider will complete a coaching session of approximately 20 minutes, whilst mounted on the horse, directed by the participant coach who will use the LED feedback interface to assist the rider to improve their riding posture.	IMU/LED feedback equipment. Video recording equipment, including head-mounted GoPro camera attached to the coach
Semi-structured interview	Retrospective Think Aloud (RTA) will be used to enable both coach and rider to provide explanations of their thought processes during the coaching session, to obtain qualitative feedback on their experience of using the proposed tool.	Laptop with screen capture software Video recording equipment (backup recording)

NB: Insert additional rows if required

Page 3 of 4

Signatories:

Note: All staff involved in the delivery or supervision of the practical work outlined above must read and sign the risk assessment as a record of awareness of the potential hazards inherent within the activities. This should include academic and support staff.

Print Name	Signature	Date	Print Name	Signature	Date
Elizabeth A. Gandy		10/01/2019			

Appendix J. Study 2 Rider Information Questionnaire

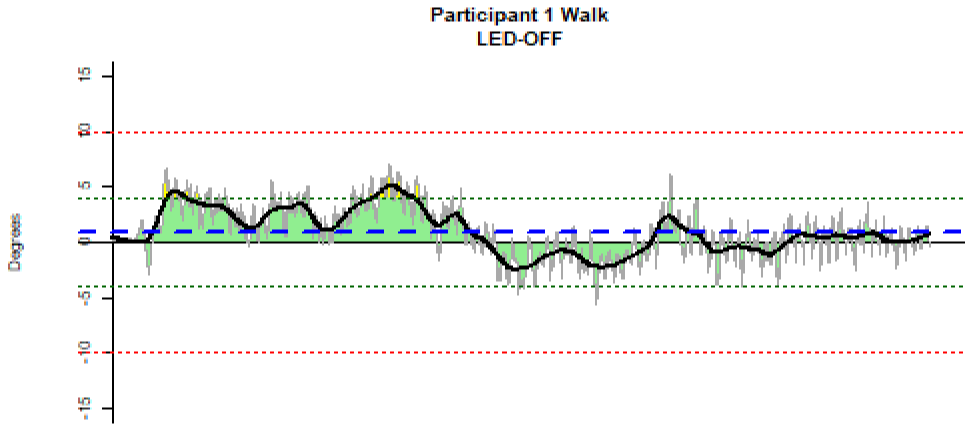
Questions asked at the start of the recorded interview

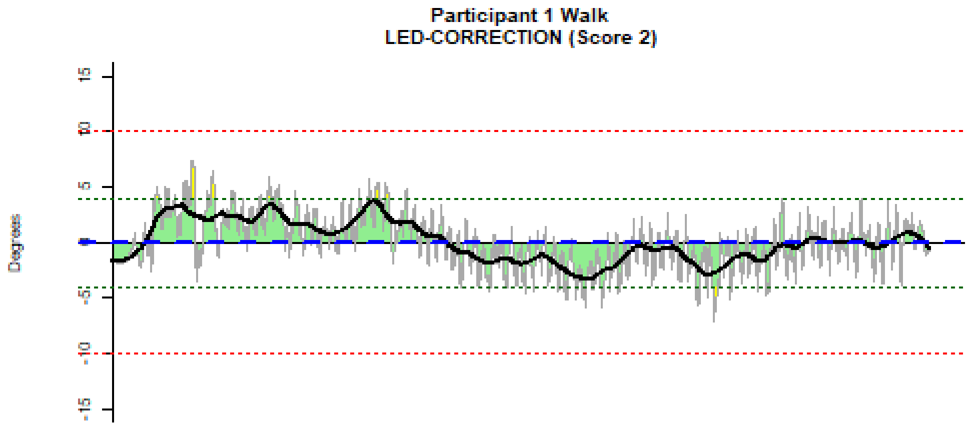
Study 2 – Participant Questionnaire

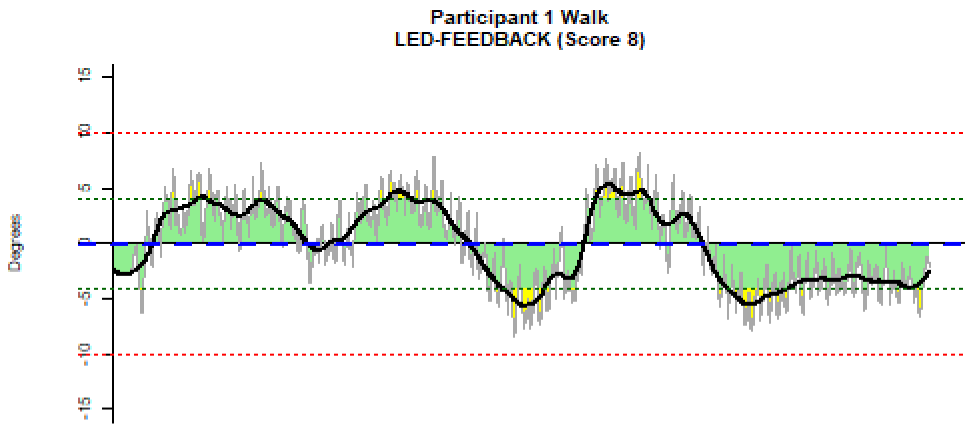
- Age
- Weight
- Height
- Riding experience (number of years)
- Riding qualifications
- How often do you ride?
- What type of riding do you mainly do? (hacking, schooling, lessons etc)
- How often do you have lessons?
- Do you own your own horse/s
- Competition Experience (dressage/eventing): Unaffiliated / Affiliated and Level
- Do you have any conditions/past injuries that affect your posture on the horse?

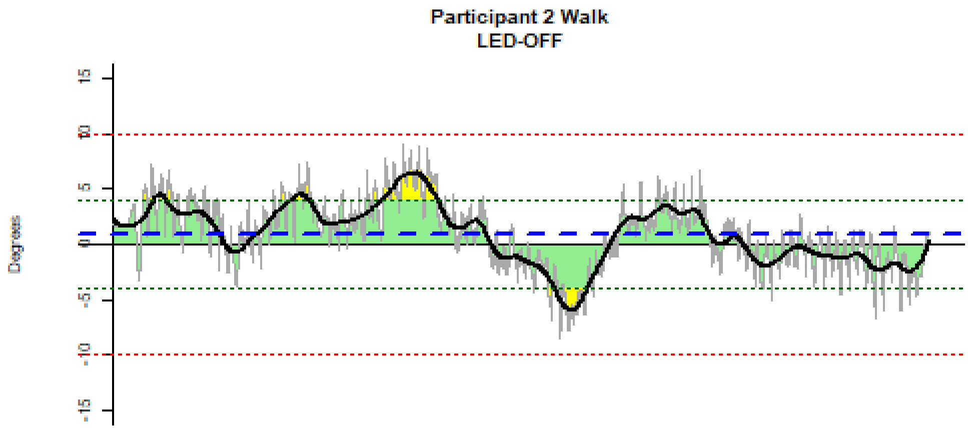
- Do you experience back pain whilst riding?
- Do you experience back pain as a result of riding?
- Do you have any condition that affects your eyesight?
- Do you wear glasses for reading/driving/all the time?
- Do you wear glasses when riding?
- Do you have a condition such as Dyslexia or Dyspraxia that could affect your interpretation of the plots?
- Technology experience level:
    - Limited (no smartphone and avoid use of technology)
    - Basic (email, internet, social media, smartphone apps)
    - Proficient (word processing, spreadsheets, software packages for finance etc)

Appendix K. Study 2 Line Plots

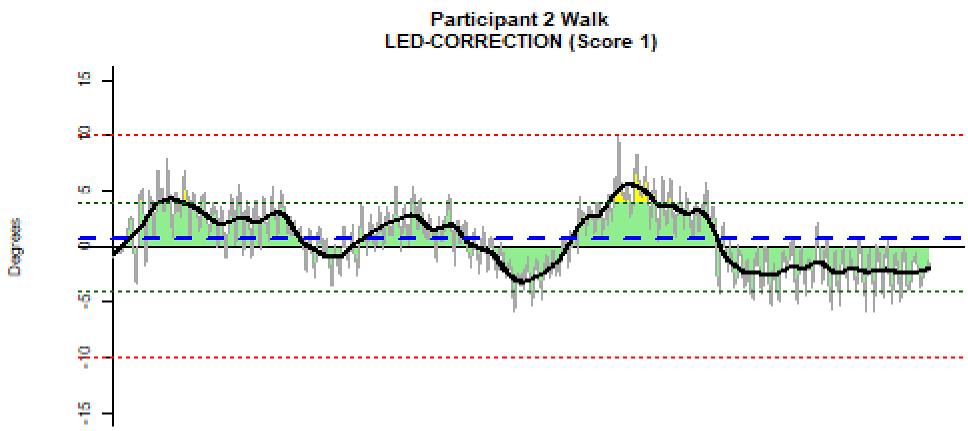




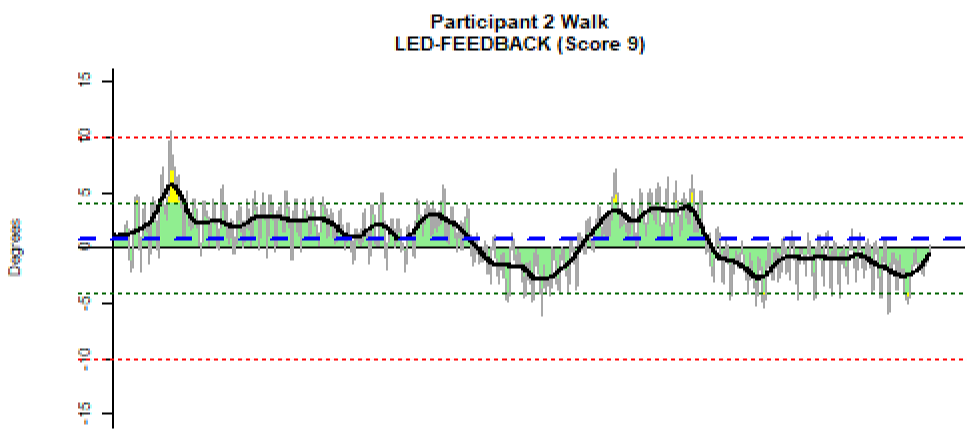




Participant 2 Walk
LED-OFF
Degrees

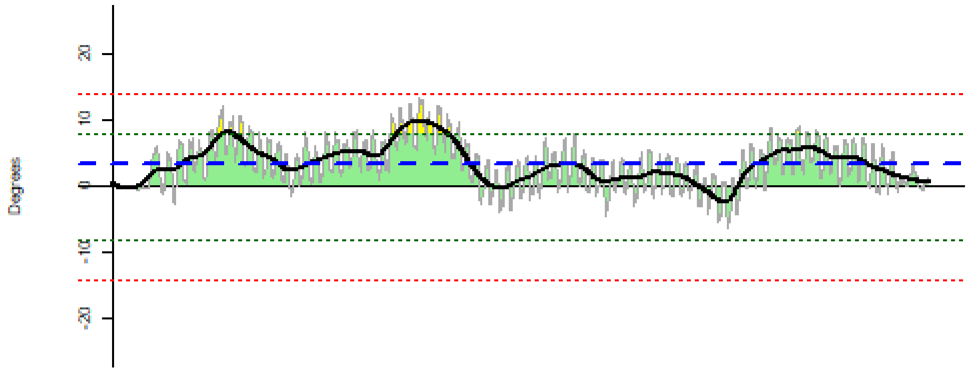


Participant 2 Walk
LED-CORRECTION (Score 1)
Degrees

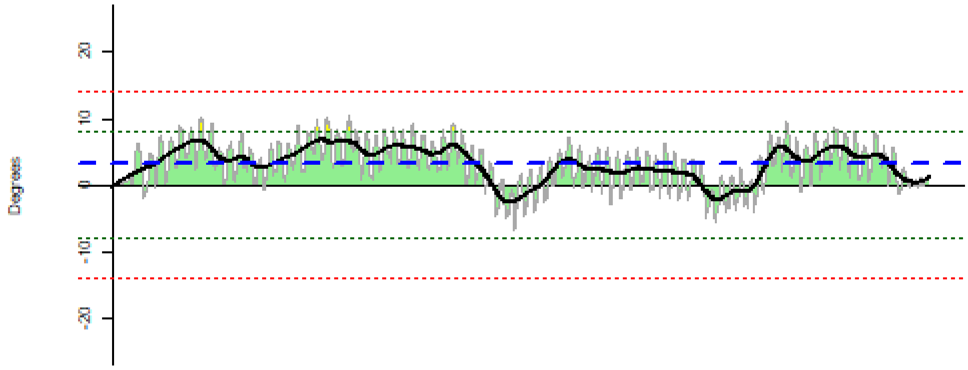


Participant 2 Walk
LED-FEEDBACK (Score 9)
Degrees

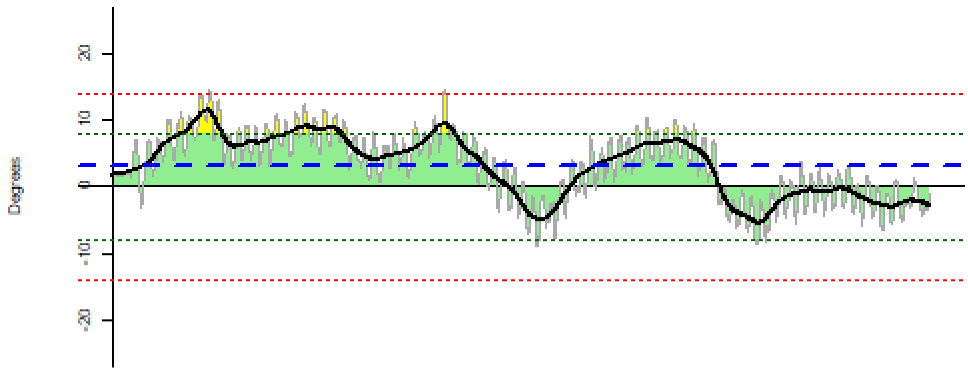
Participant 3 Walk
LED-OFF



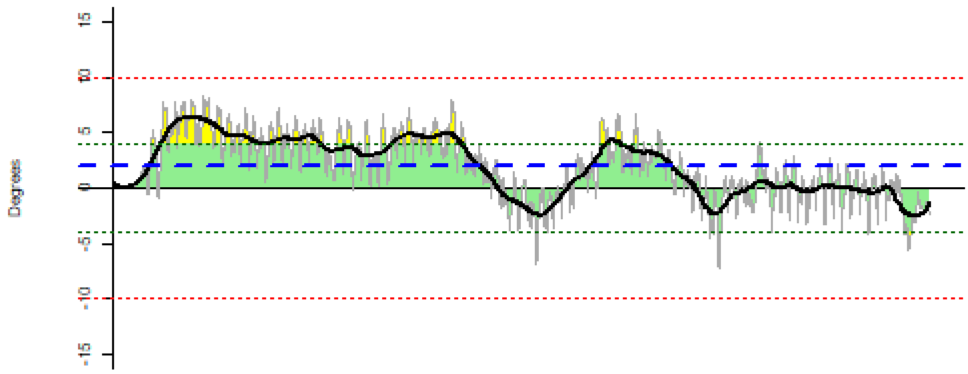
Participant 3 Walk
LED-CORRECTION (Score 1)



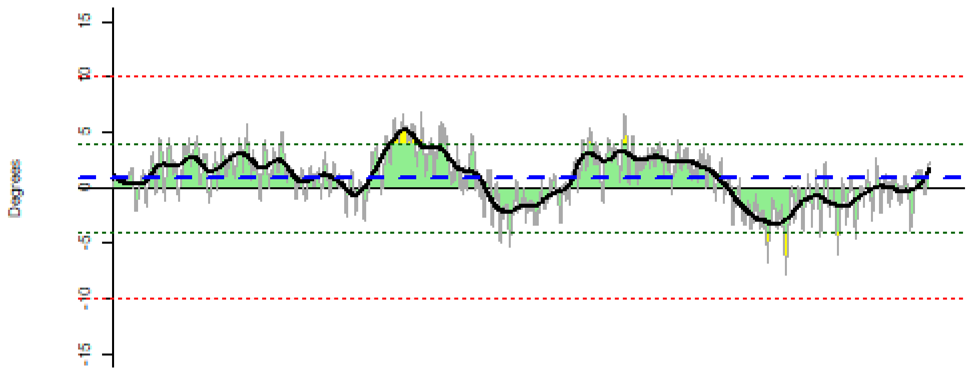
Participant 3 Walk
LED-FEEDBACK (Score 9)



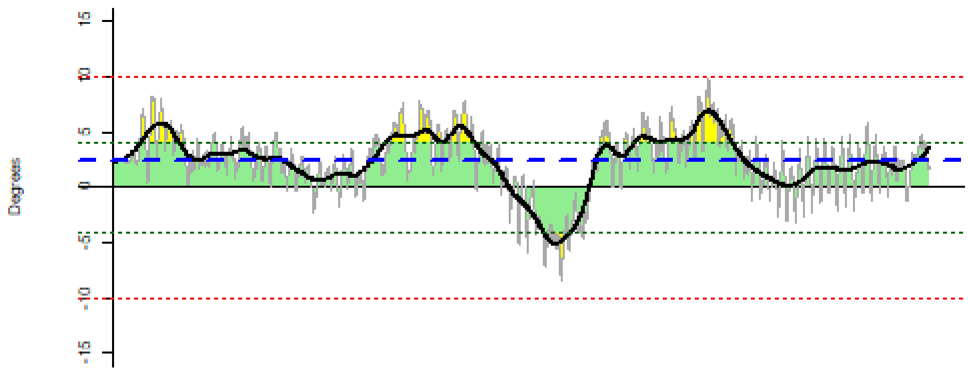
Participant 4 Walk
LED-OFF



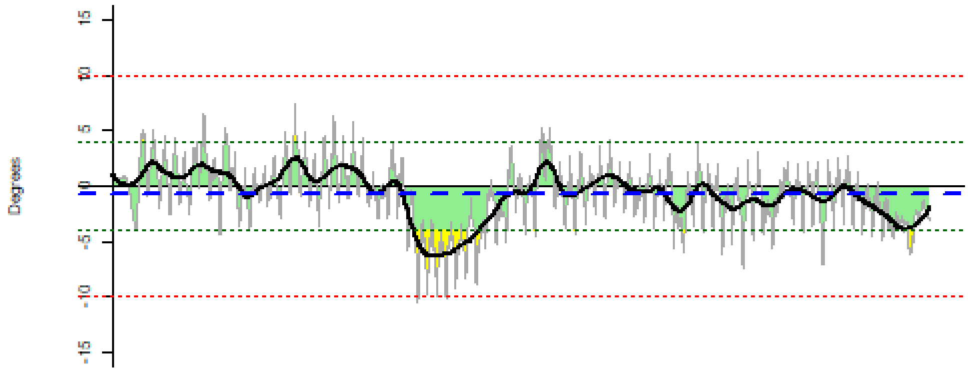
Participant 4 Walk
LED-CORRECTION (Score 8)



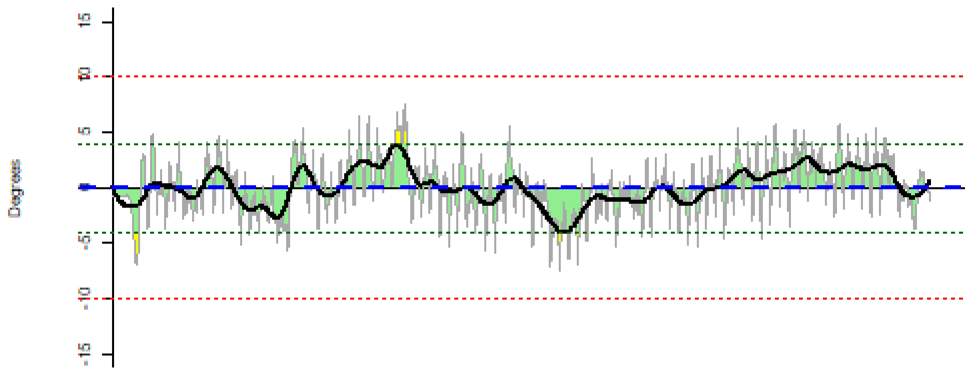
Participant 4 Walk
LED-FEEDBACK (Score 2)



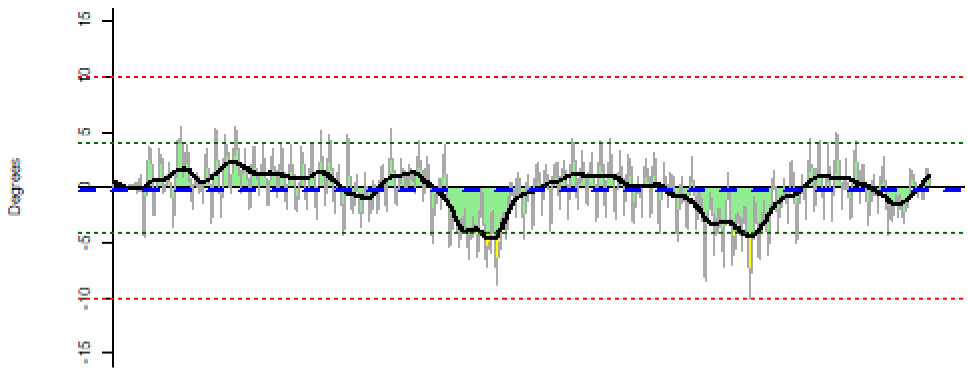
Participant 5 Walk
LED-OFF

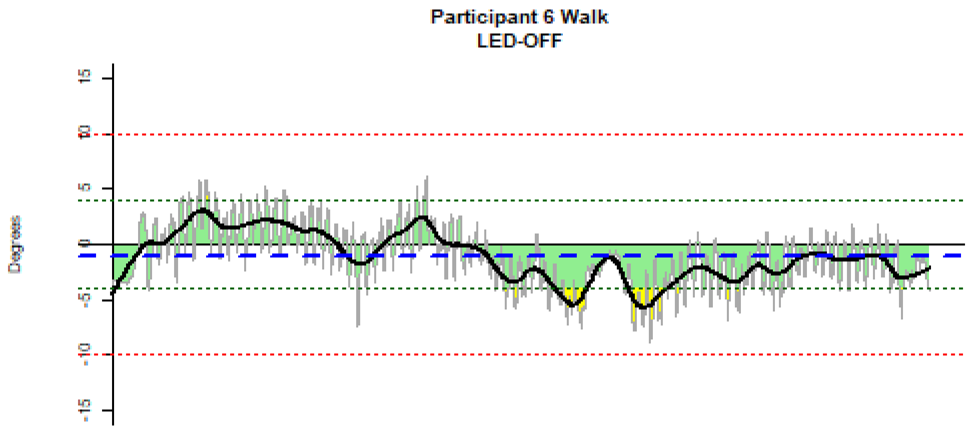


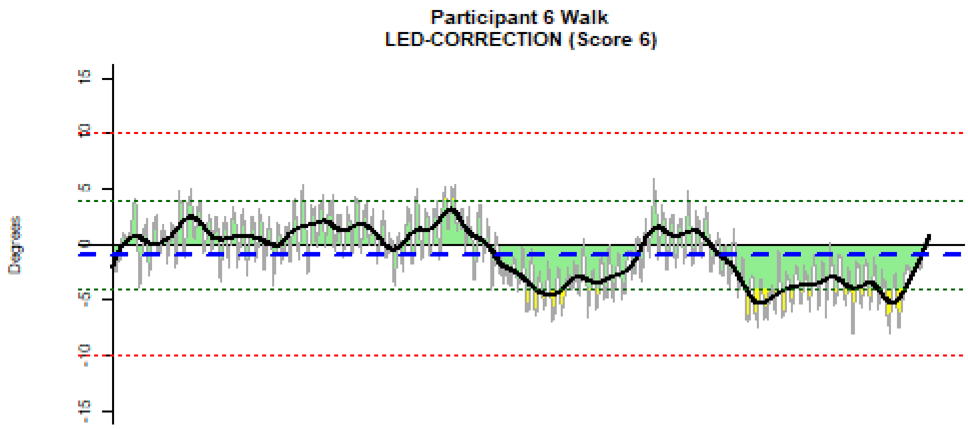
Participant 5 Walk
LED-CORRECTION (Score 6)

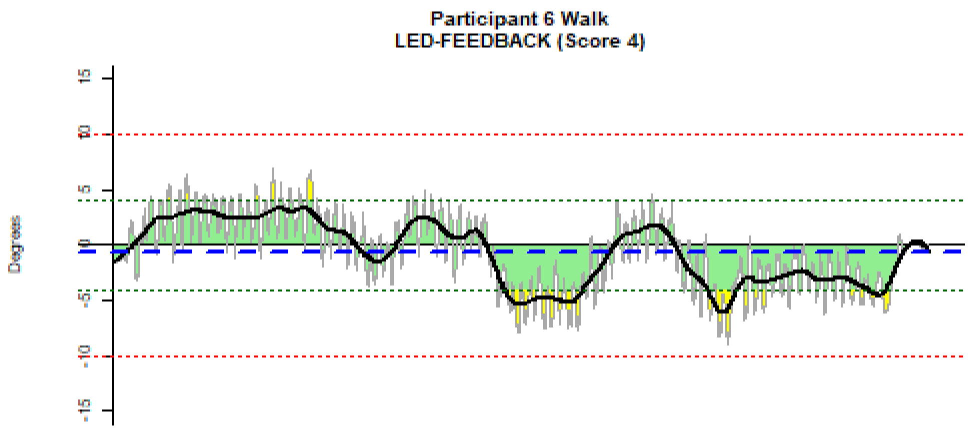


Participant 5 Walk
LED-FEEDBACK (Score 4)

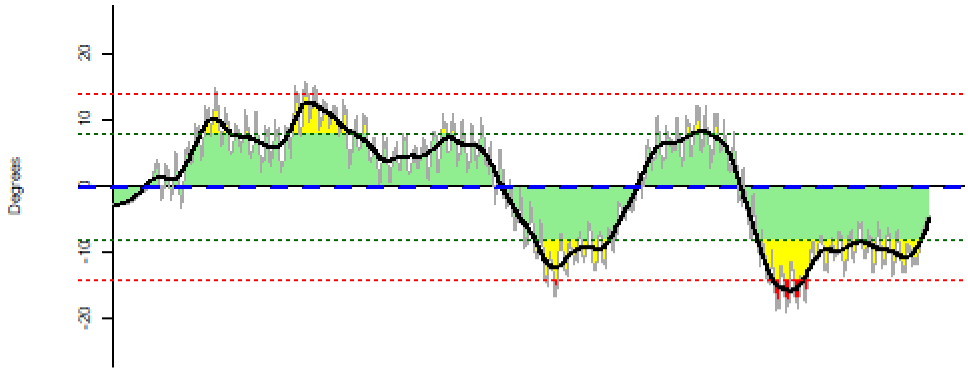



Participant 6 Walk
LED-OFF
Degrees
15
10
5
0
-5
-10
-15

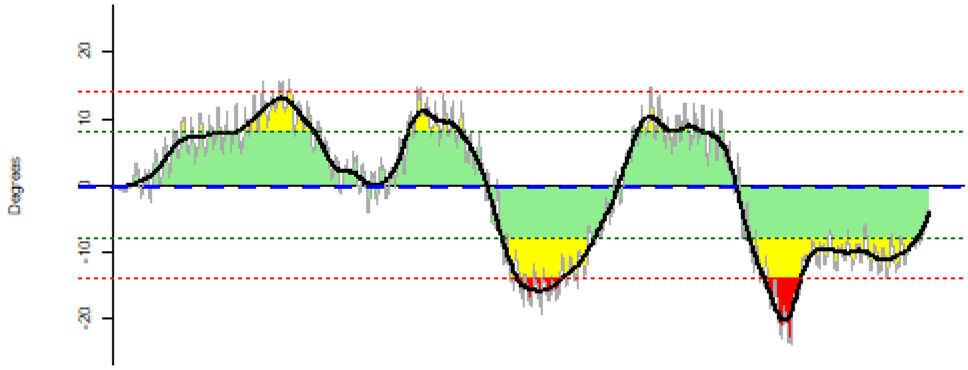

Participant 6 Walk
LED-CORRECTION (Score 6)
Degrees
15
10
5
0
-5
-10
-15


Participant 6 Walk
LED-FEEDBACK (Score 4)
Degrees
15
10
5
0
-5
-10
-15

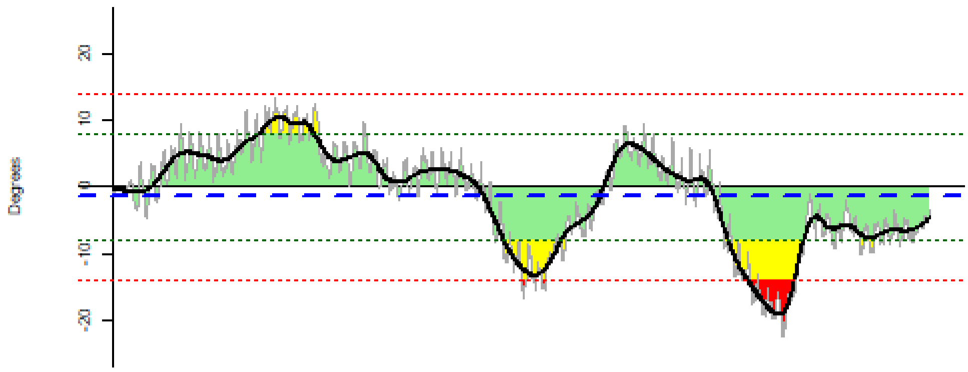
Participant 7 Walk
LED-OFF

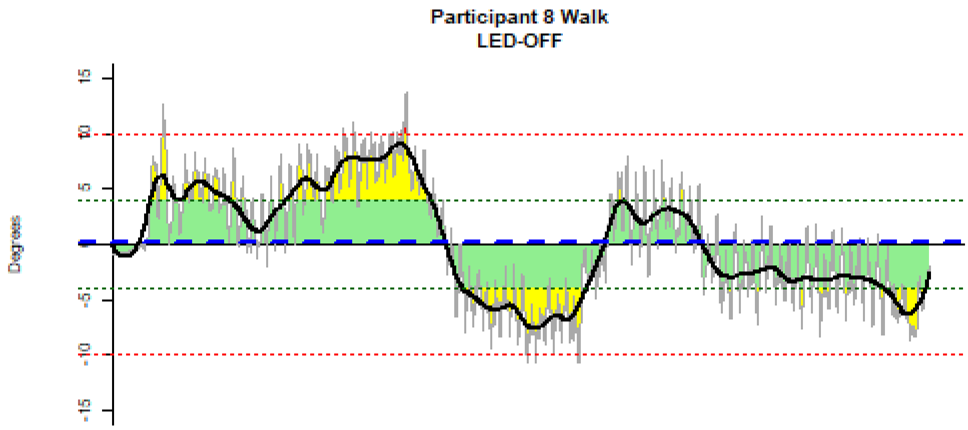


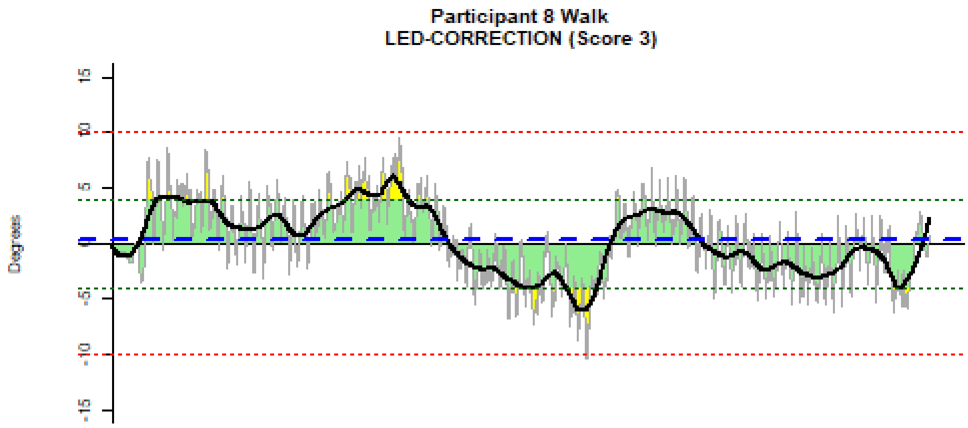
Participant 7 Walk
LED-CORRECTION (Score 4)

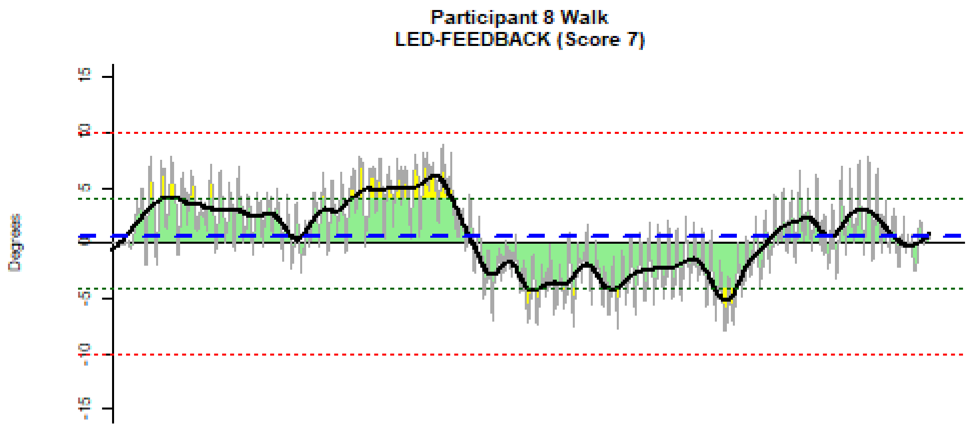


Participant 7 Walk
LED-FEEDBACK (Score 6)

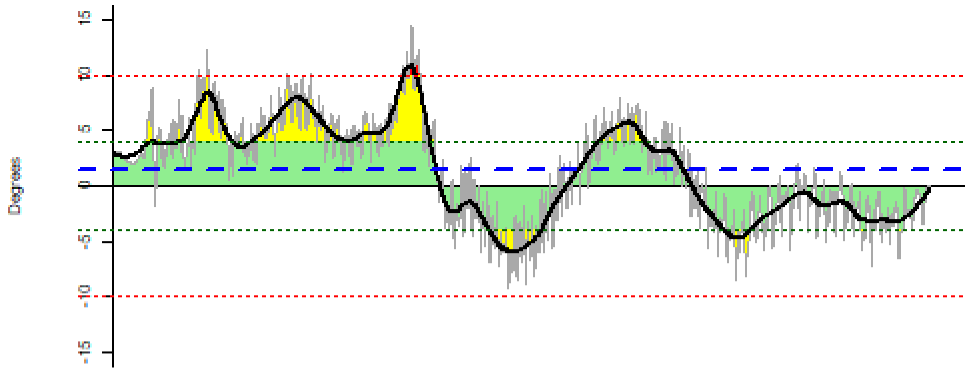



Participant 8 Walk
LED-OFF
Degrees
15
10
5
0
-5
-10
-15

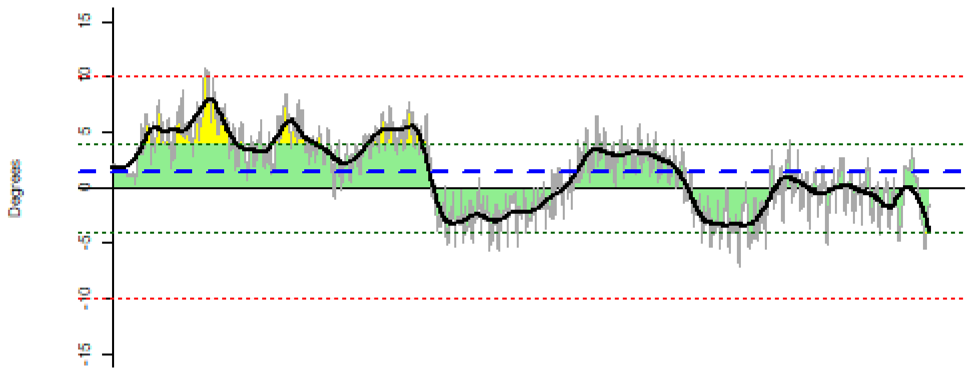

Participant 8 Walk
LED-CORRECTION (Score 3)
Degrees
15
10
5
0
-5
-10
-15


Participant 8 Walk
LED-FEEDBACK (Score 7)
Degrees
15
10
5
0
-5
-10
-15

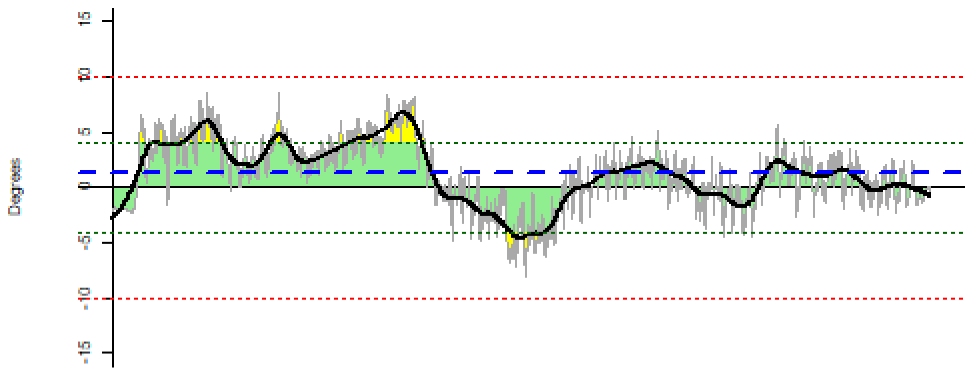
Participant 9 Walk
LED-OFF



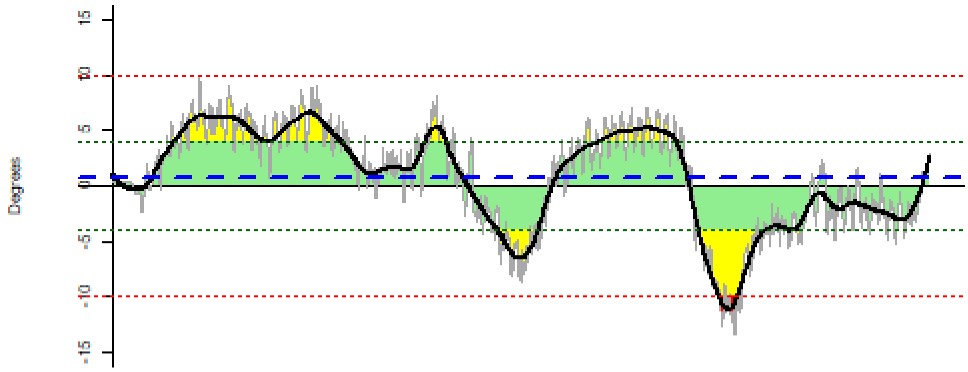
Participant 9 Walk
LED-CORRECTION (Score 4)



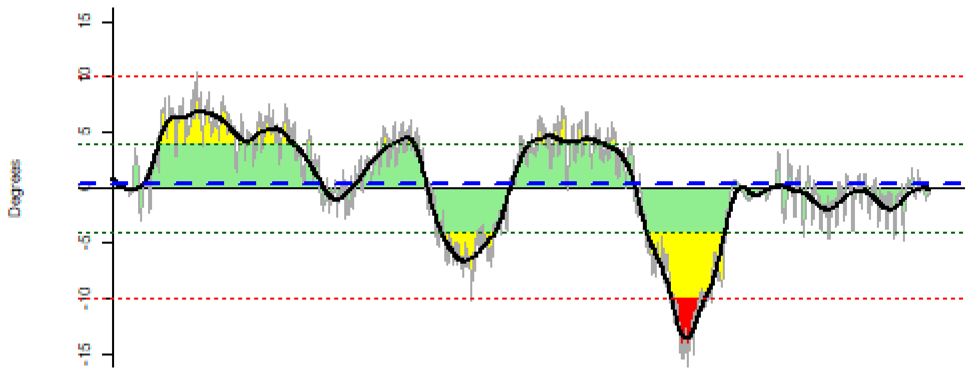
Participant 9 Walk
LED-FEEDBACK (Score 6)



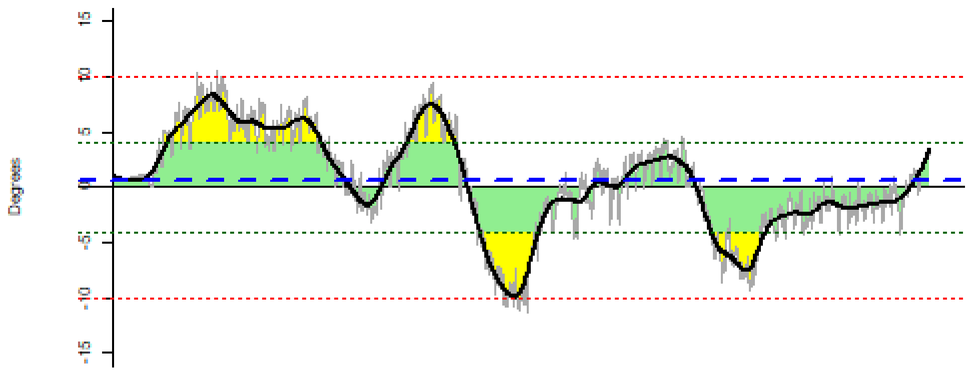
Participant 10 Walk
LED-OFF

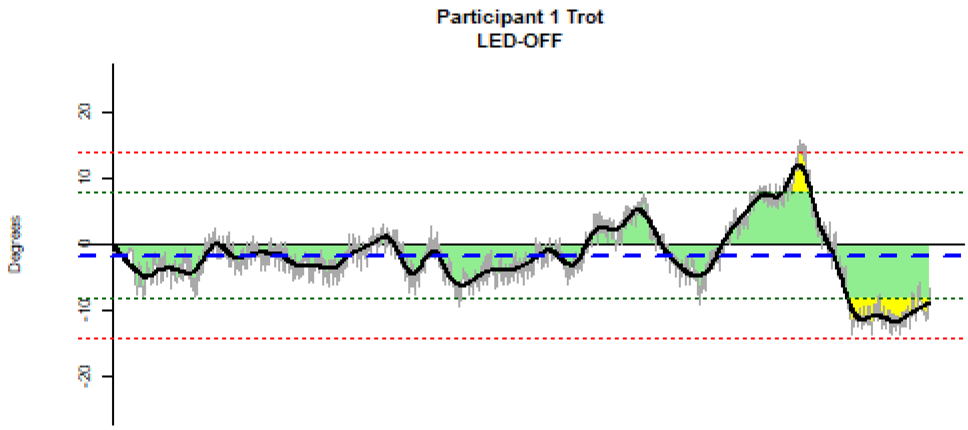


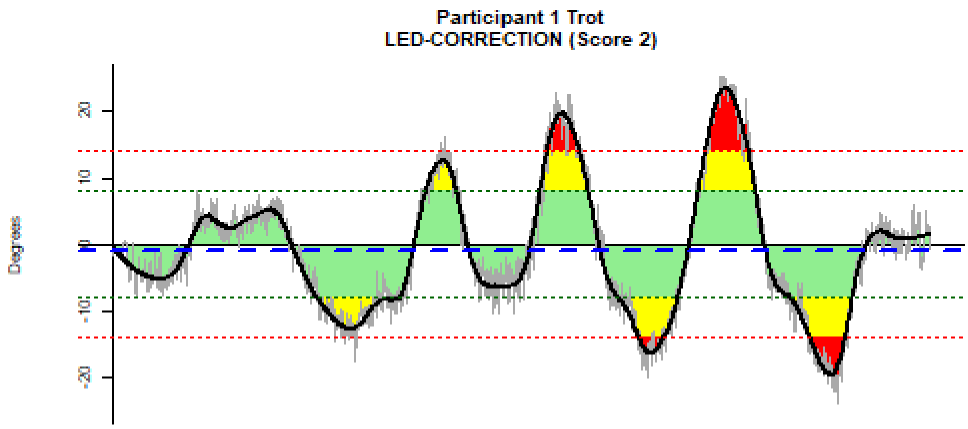
Participant 10 Walk
LED-CORRECTION (Score 3)

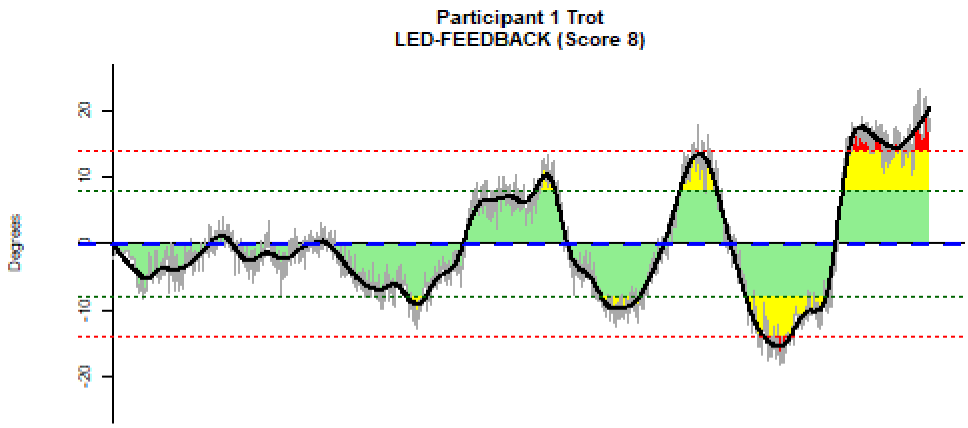


Participant 10 Walk
LED-FEEDBACK (Score 7)

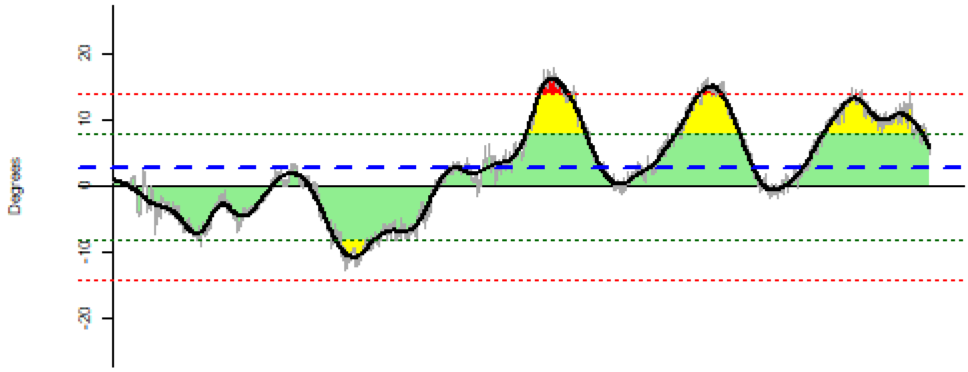



Participant 1 Trot
LED-OFF
Degrees
20
10
0
-10
-20

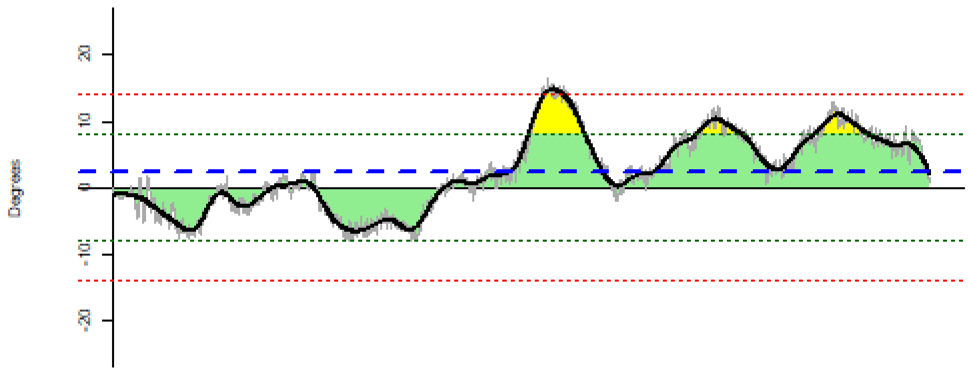

Participant 1 Trot
LED-CORRECTION (Score 2)
Degrees
20
10
0
-10
-20


Participant 1 Trot
LED-FEEDBACK (Score 8)
Degrees
20
10
0
-10
-20

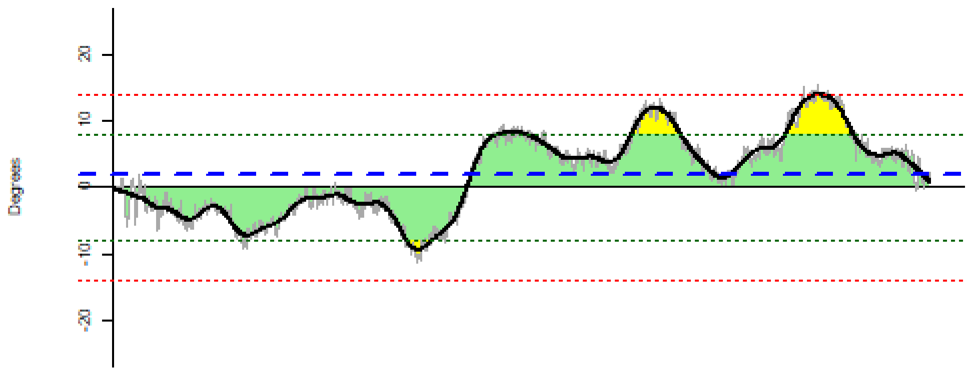
Participant 2 Trot
LED-OFF

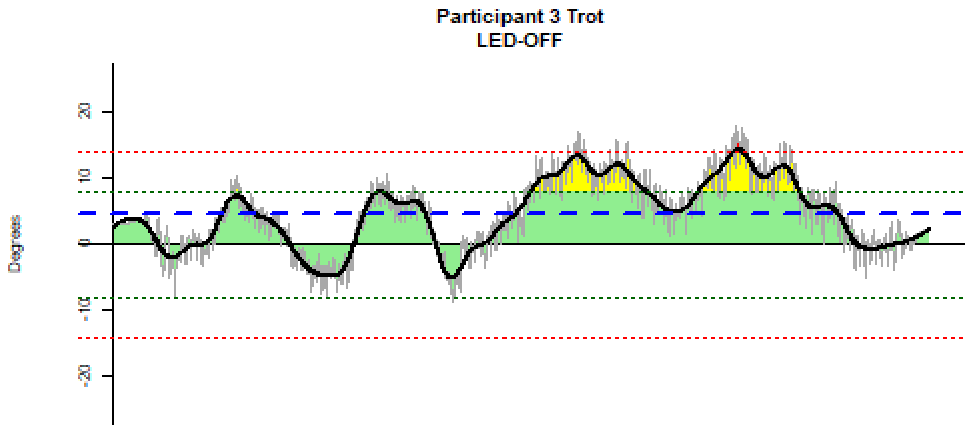


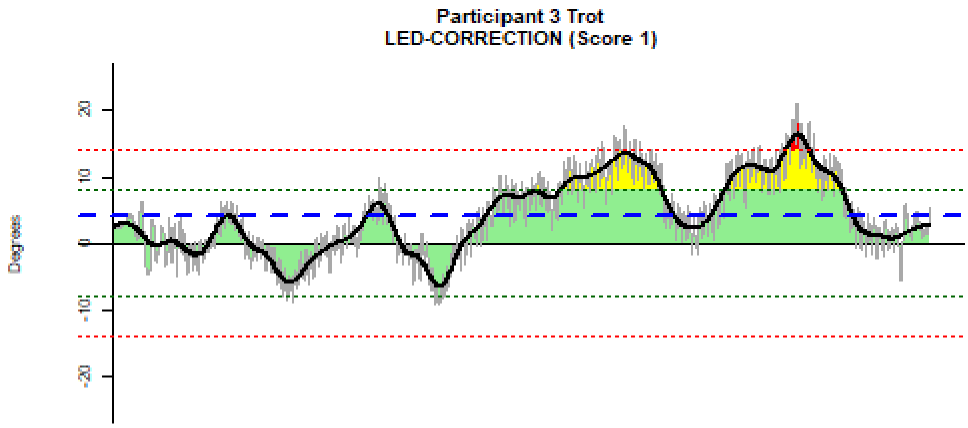
Participant 2 Trot
LED-CORRECTION (Score 1)

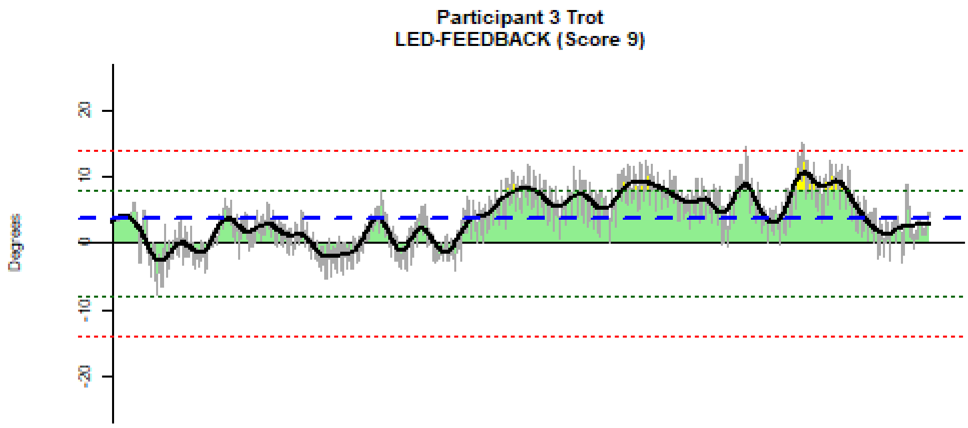


Participant 2 Trot
LED-FEEDBACK (Score 9)

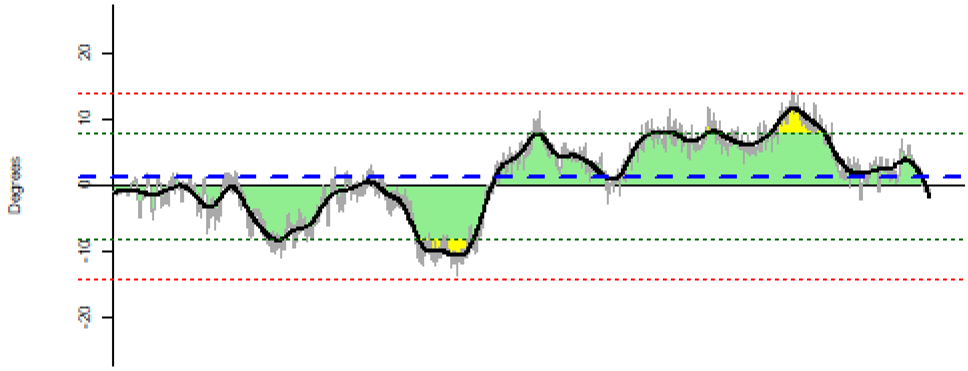



Participant 3 Trot
LED-OFF
Degrees
20
10
0
-10
-20


Participant 3 Trot
LED-CORRECTION (Score 1)
Degrees
20
10
0
-10
-20


Participant 3 Trot
LED-FEEDBACK (Score 9)
Degrees
20
10
0
-10
-20

Participant 4 Trot
LED-OFF



Participant 4 Trot
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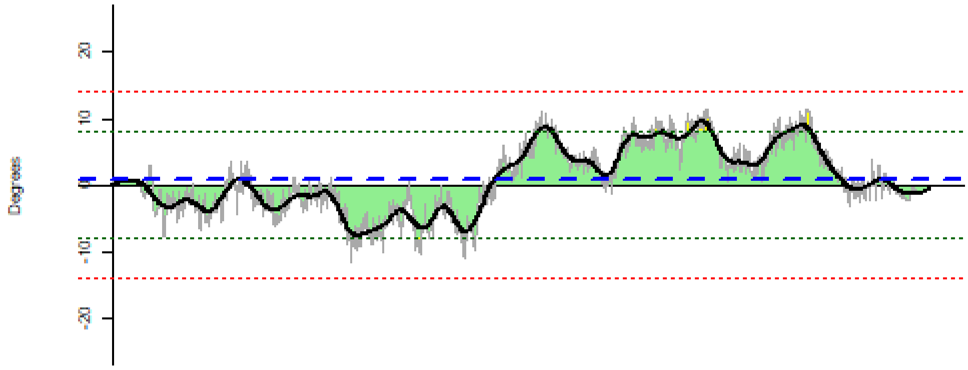
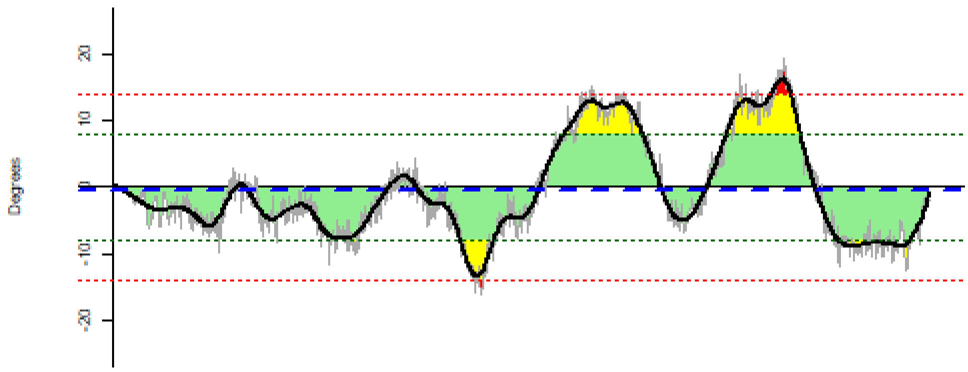
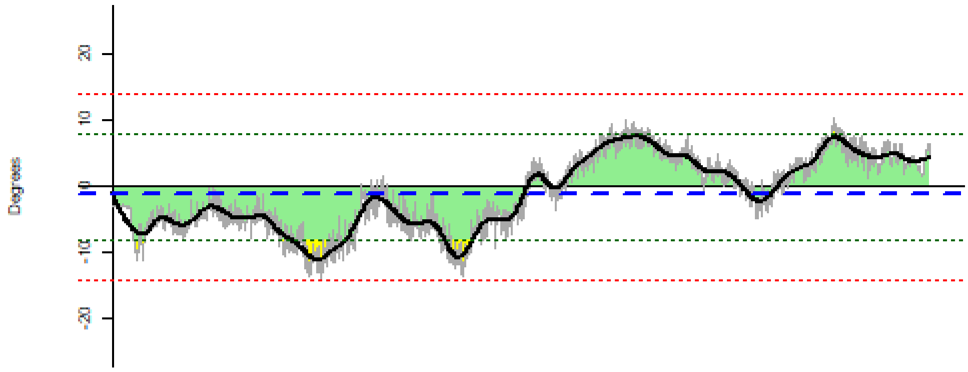


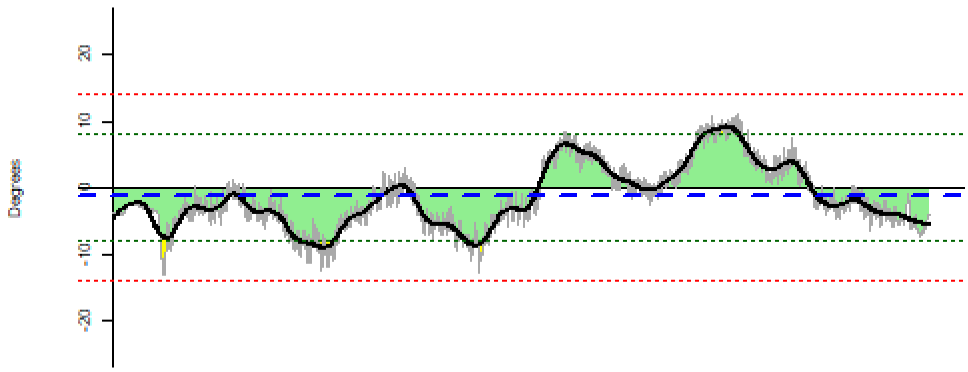
Participant 4 Trot
LED-FEEDBACK (Score 2)



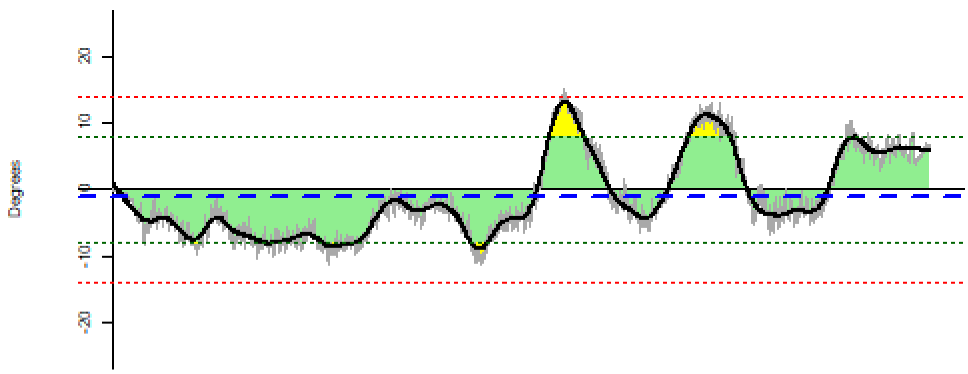
Participant 5 Trot
LED-OFF



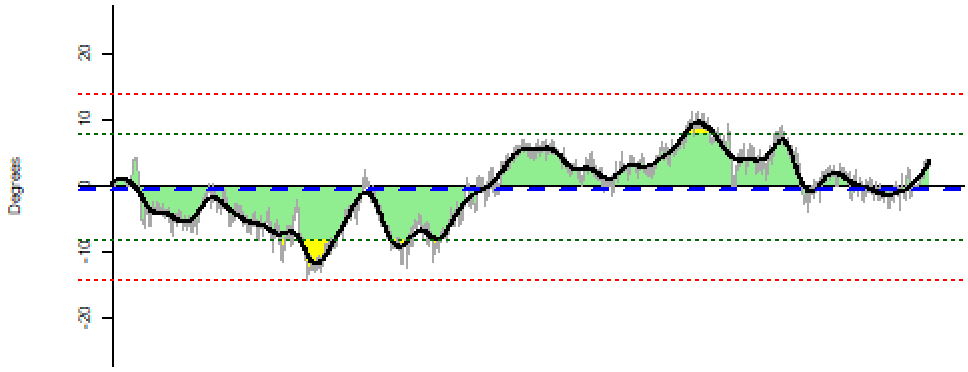
Participant 5 Trot
LED-CORRECTION (Score 6)



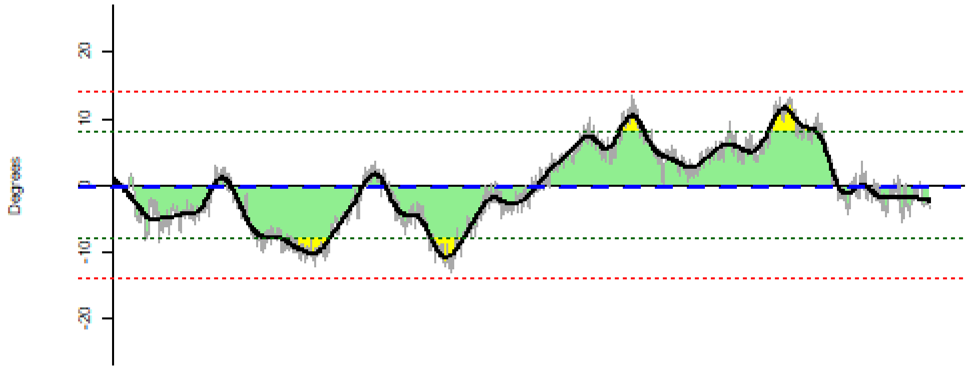
Participant 5 Trot
LED-FEEDBACK (Score 4)



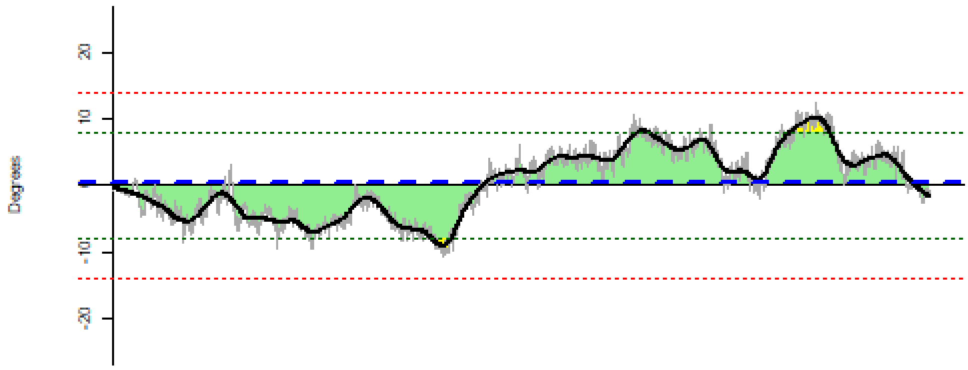
Participant 6 Trot
LED-OFF



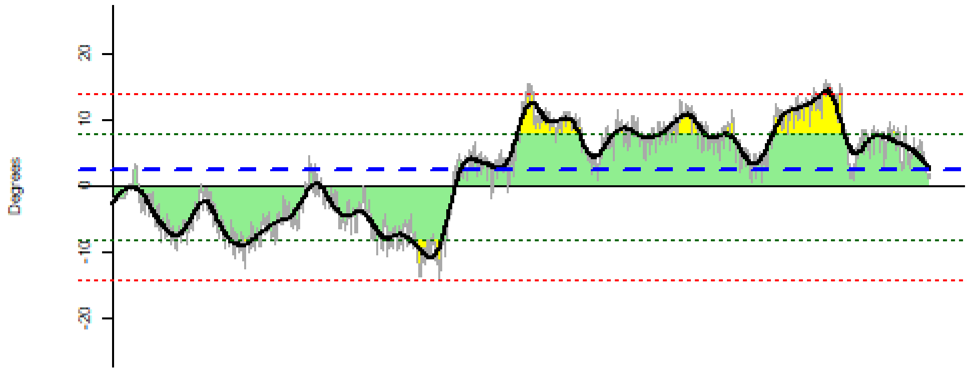
Participant 6 Trot
LED-CORRECTION (Score 6)



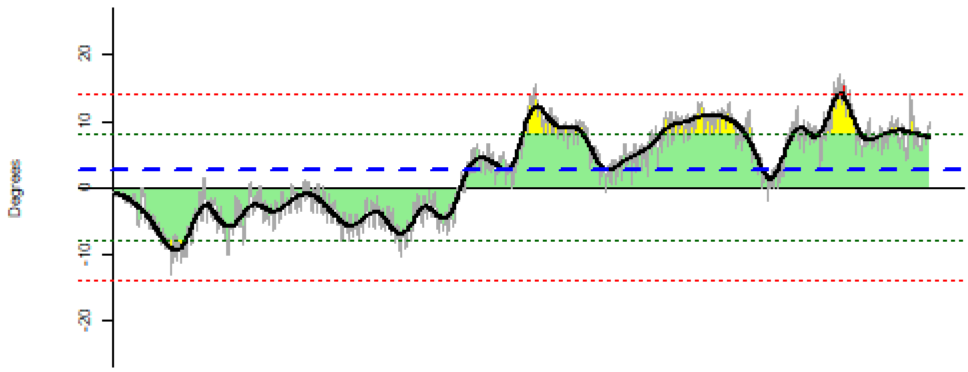
Participant 6 Trot
LED-FEEDBACK (Score 4)



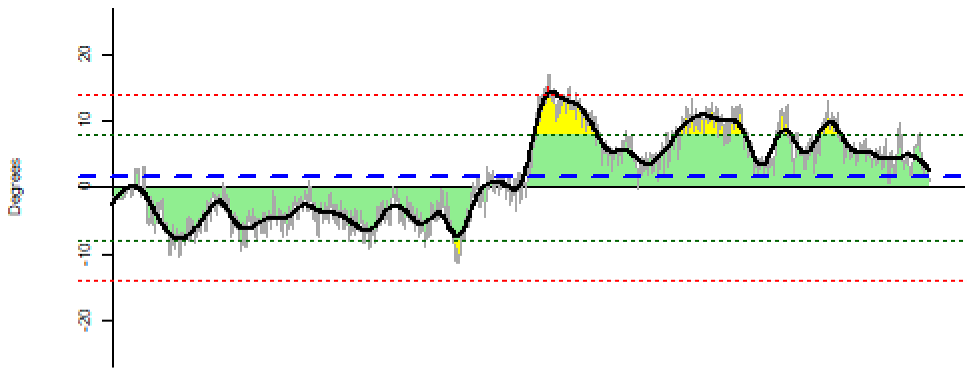
Participant 7 Trot
LED-OFF

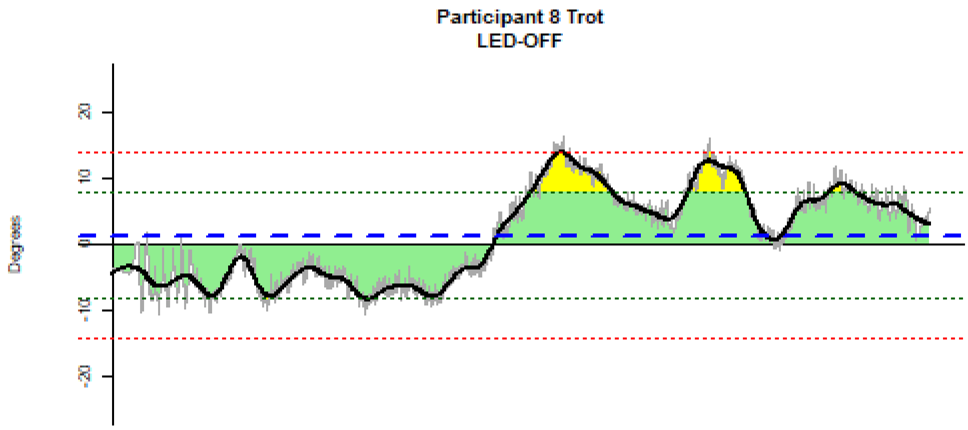


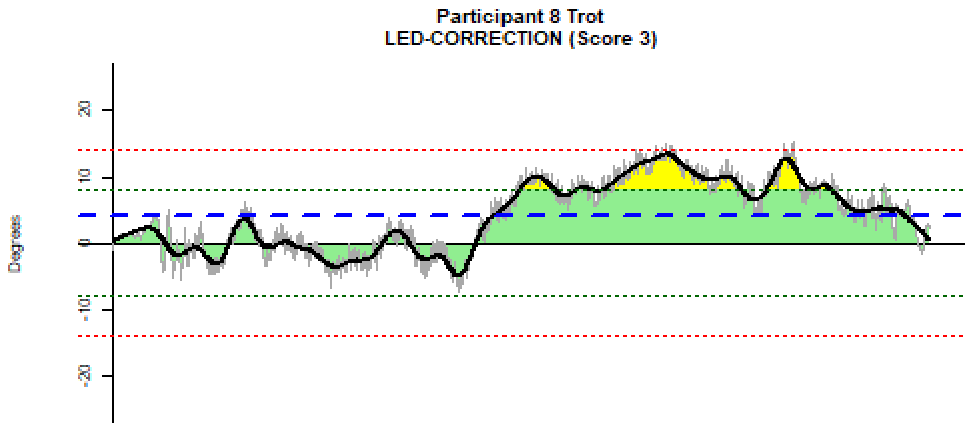
Participant 7 Trot
LED-CORRECTION (Score 4)

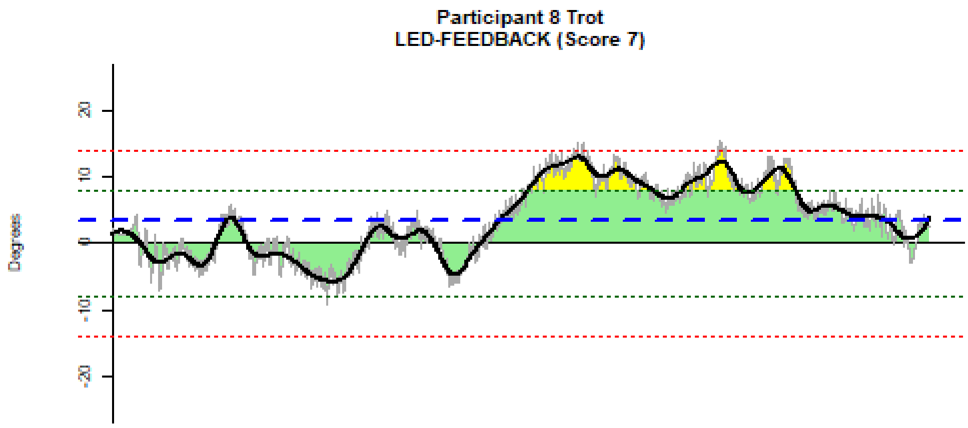


Participant 7 Trot
LED-FEEDBACK (Score 6)

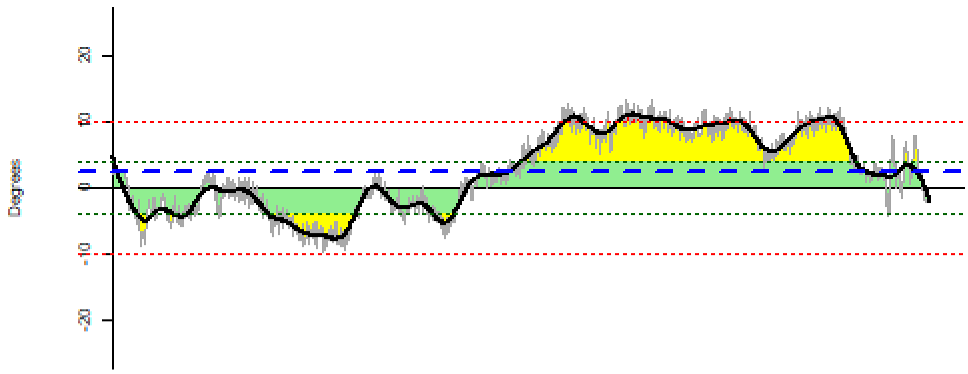



Participant 8 Trot
LED-OFF
Degrees
20
10
0
-10
-20

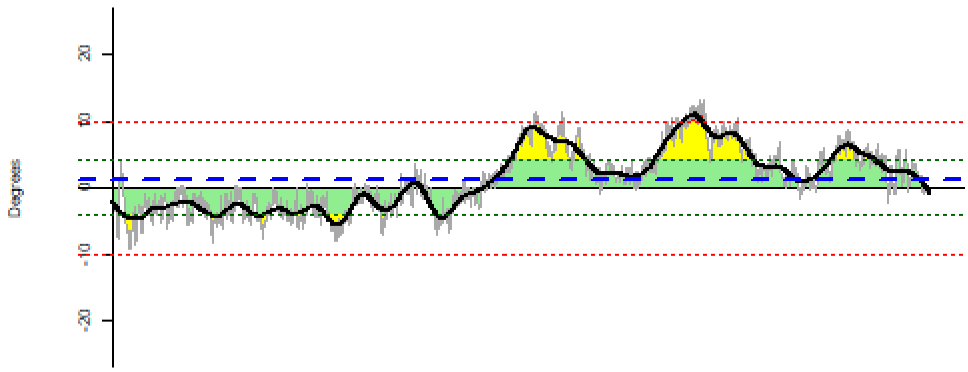

Participant 8 Trot
LED-CORRECTION (Score 3)
Degrees
20
10
0
-10
-20


Participant 8 Trot
LED-FEEDBACK (Score 7)
Degrees
20
10
0
-10
-20

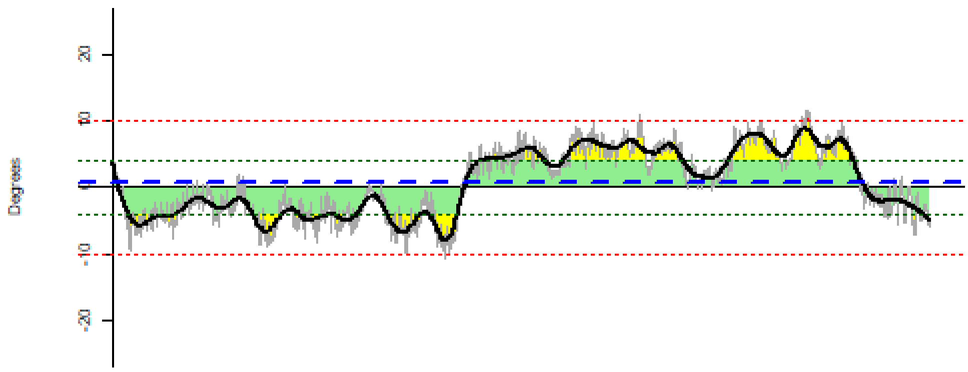
Participant 9 Trot
LED-OFF

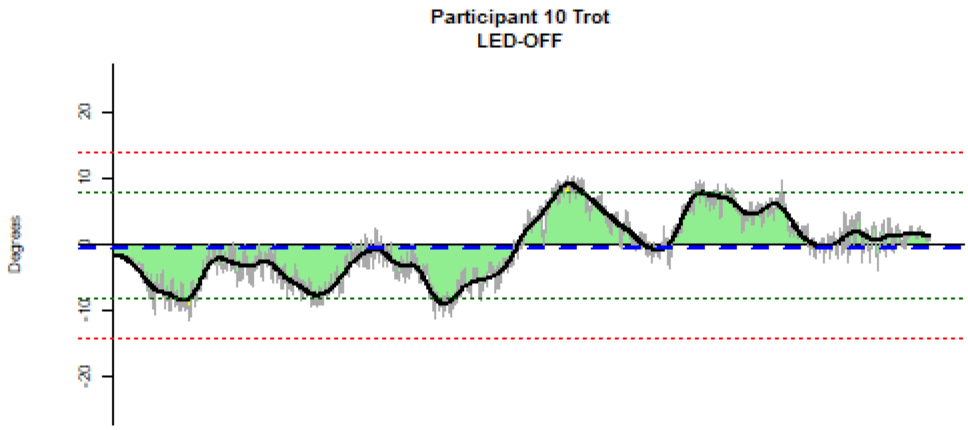


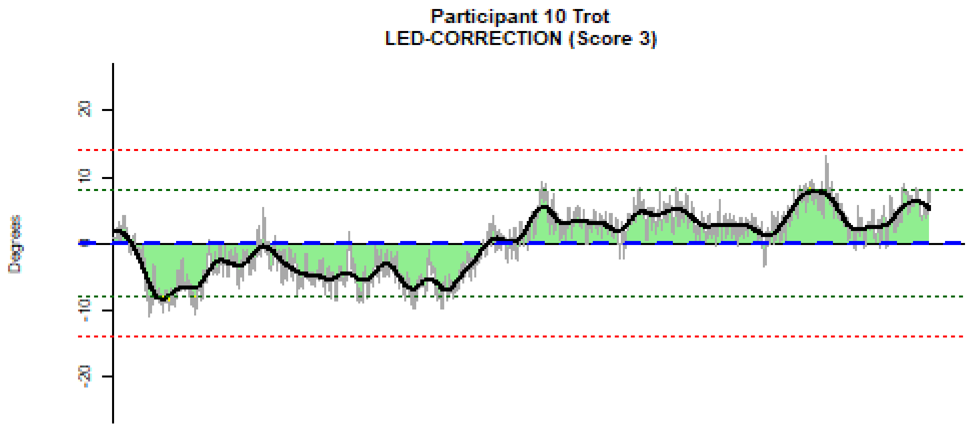
Participant 9 Trot
LED-CORRECTION (Score 4)

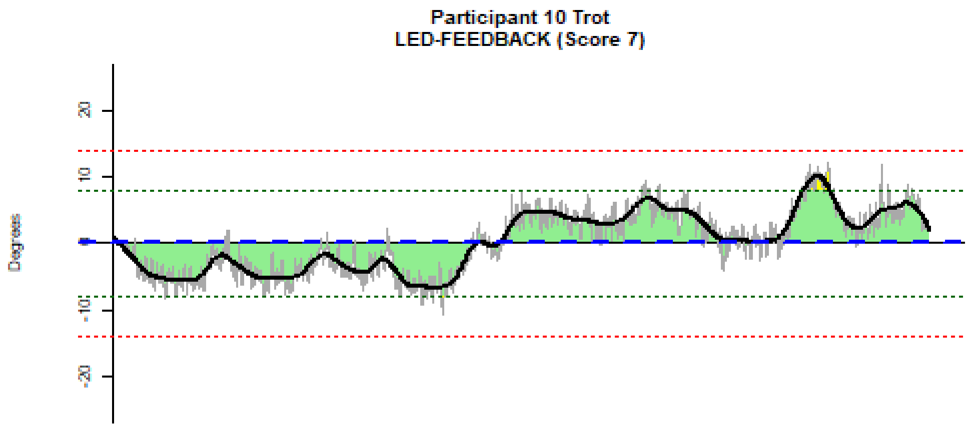


Participant 9 Trot
LED-FEEDBACK (Score 6)

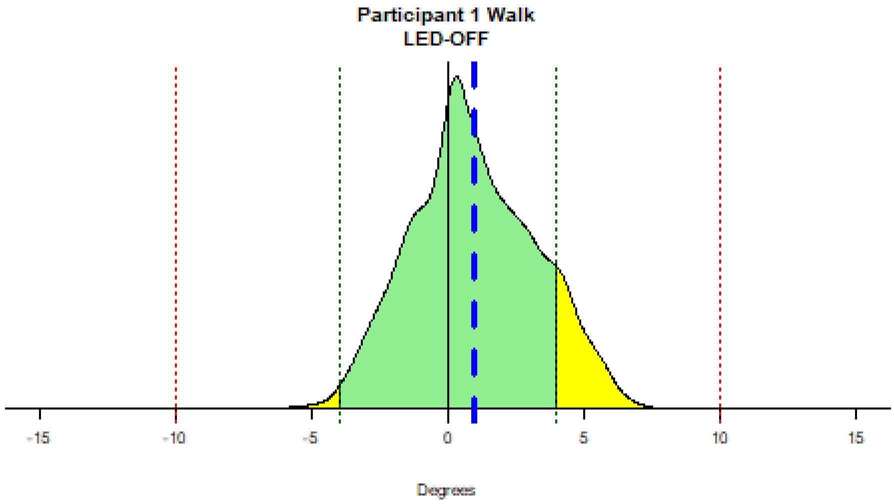


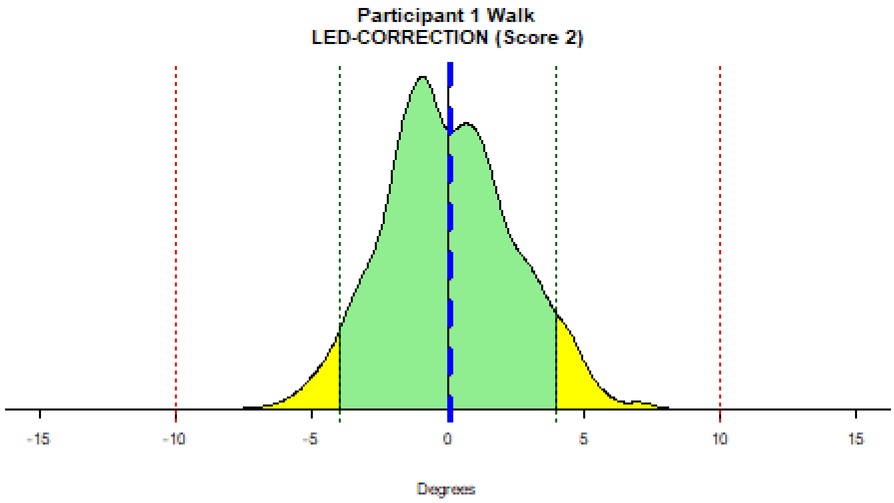

Participant 10 Trot
LED-OFF
Degrees
20
10
0
-10
-20

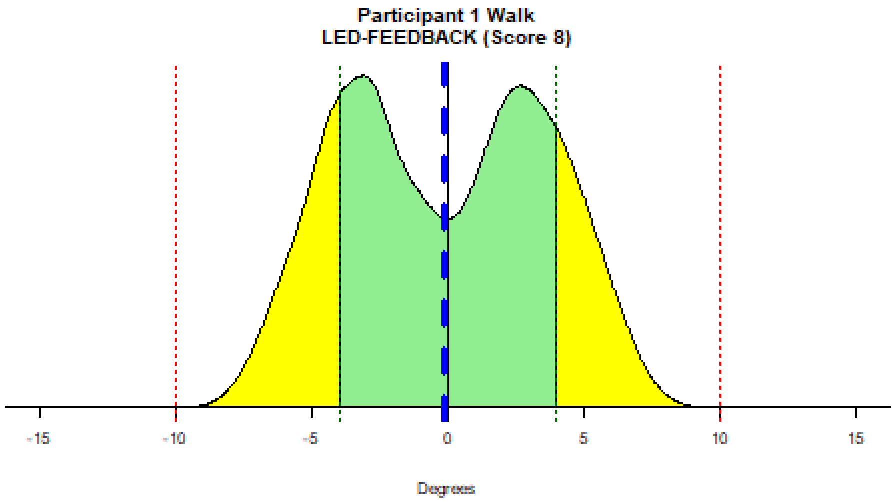

Participant 10 Trot
LED-CORRECTION (Score 3)
Degrees
20
10
0
-10
-20

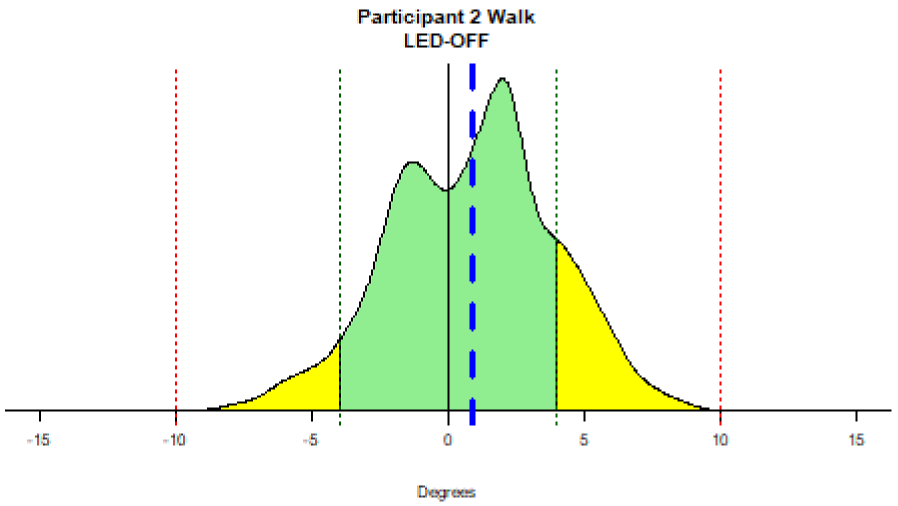

Participant 10 Trot
LED-FEEDBACK (Score 7)
Degrees
20
10
0
-10
-20

Appendix L. Study 2 Density Plots

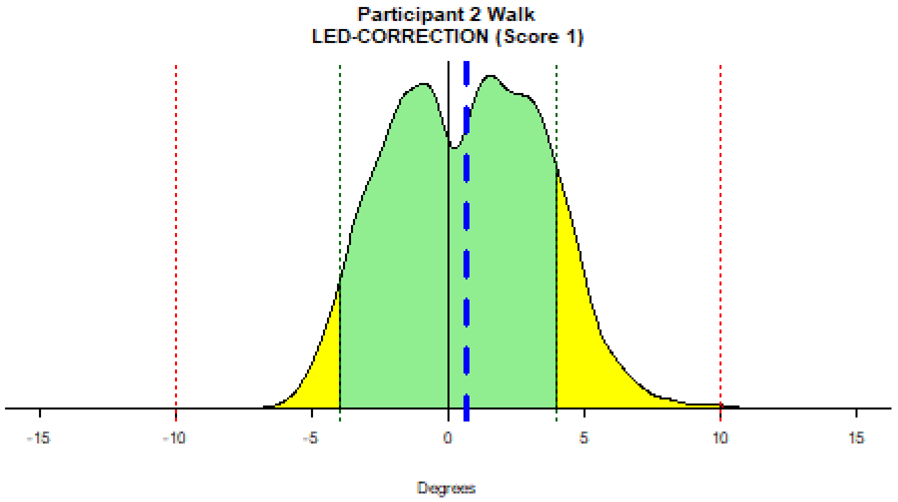




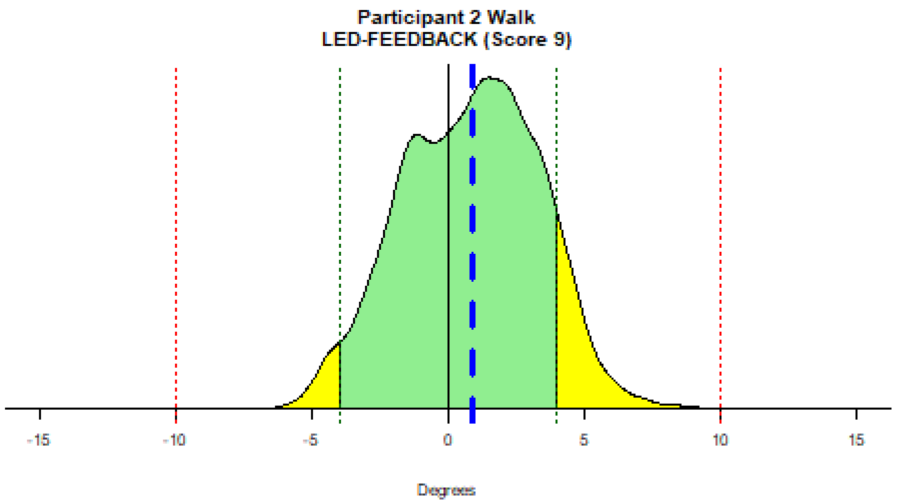




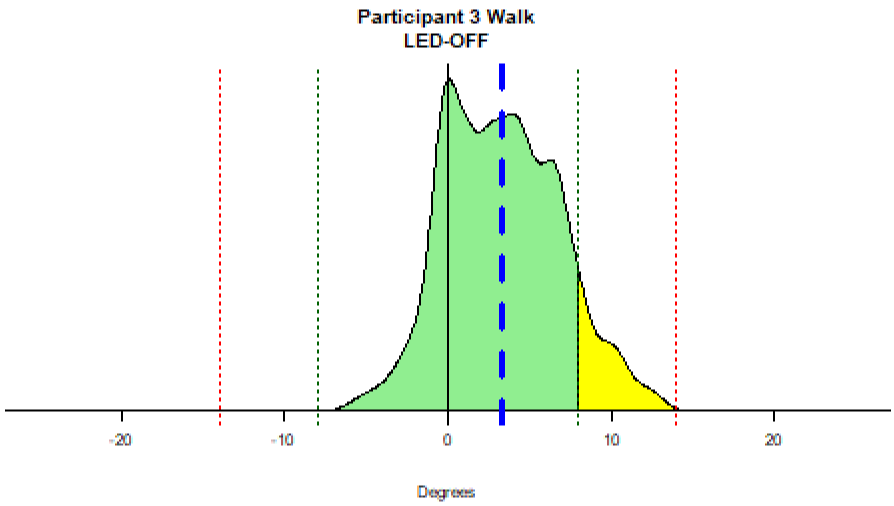
Participant 2 Walk
LED-OFF
-15
-10
-5
0
5
10
15
Degrees

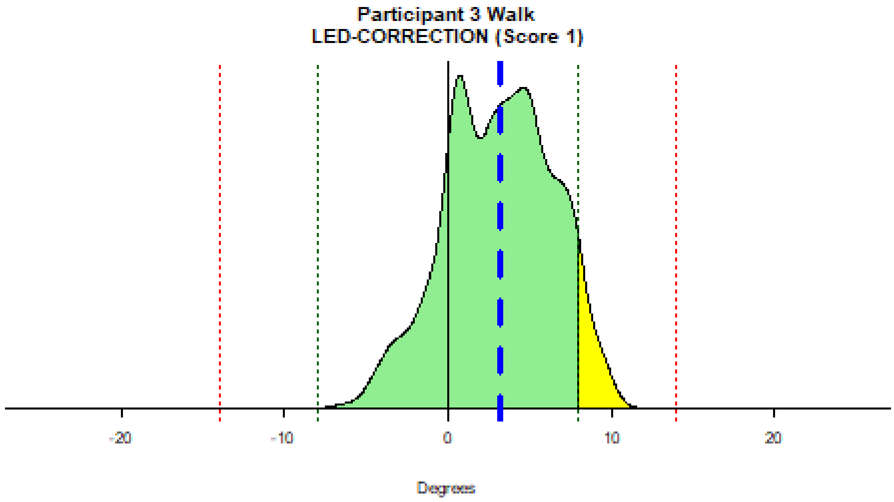


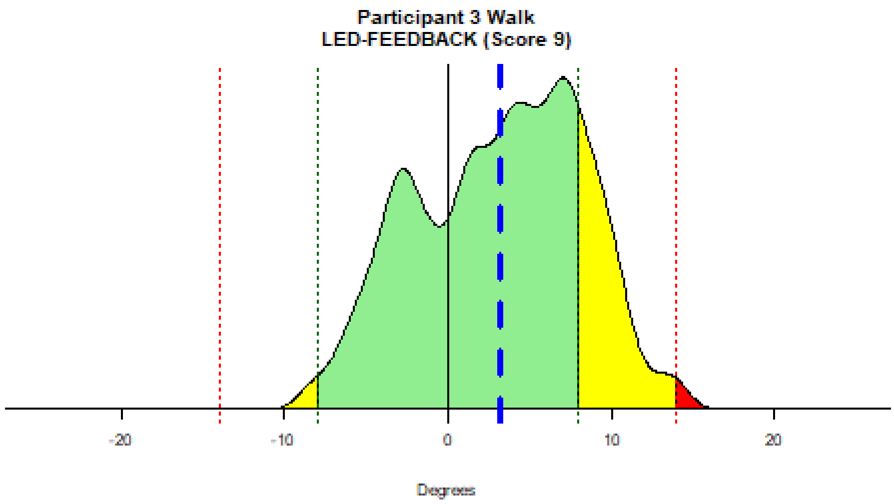
Participant 2 Walk
LED-CORRECTION (Score 1)
-15
-10
-5
0
5
10
15
Degrees

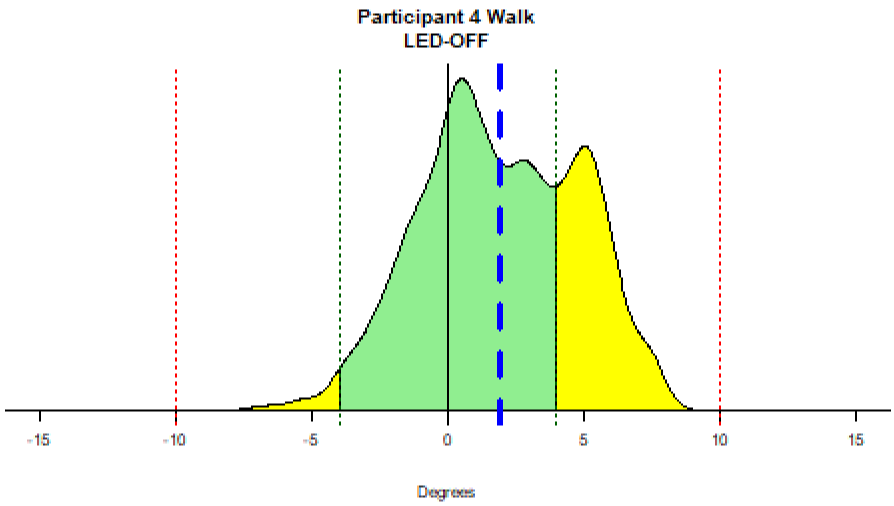


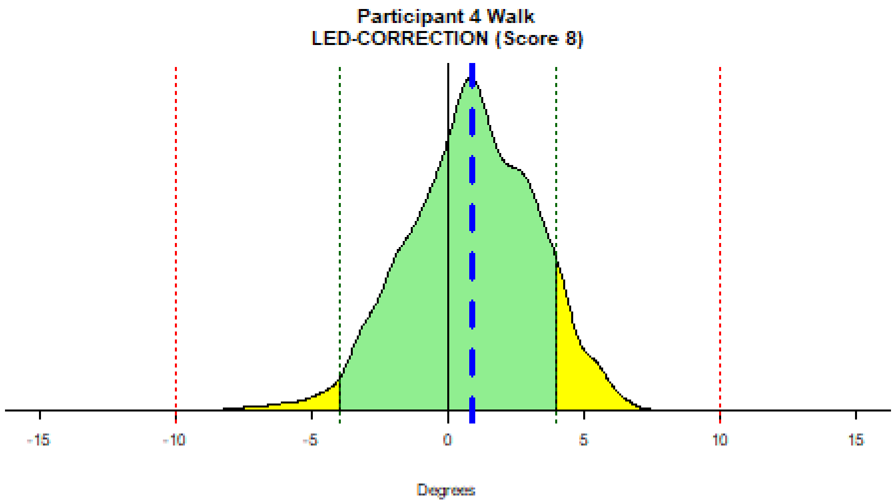
Participant 2 Walk
LED-FEEDBACK (Score 9)
-15
-10
-5
0
5
10
15
Degrees

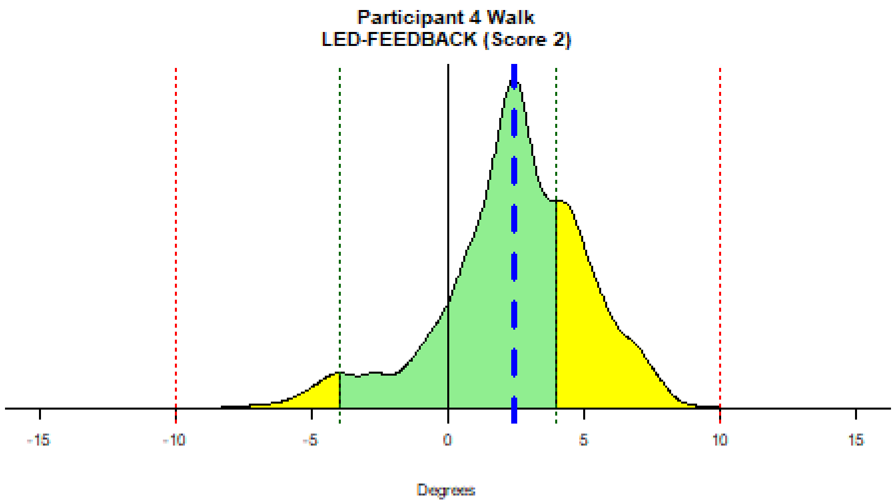

Participant 3 Walk
LED-OFF
-20
-10
0
10
20
Degrees

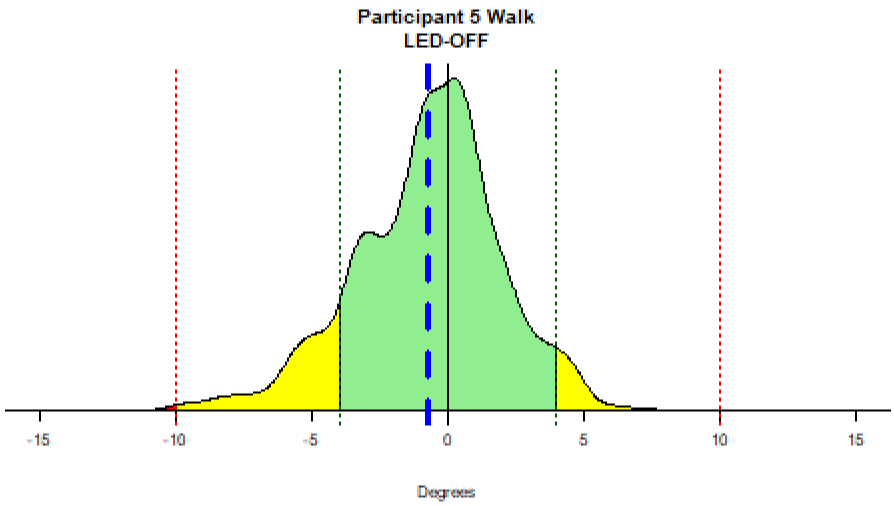

Participant 3 Walk
LED-CORRECTION (Score 1)
-20
-10
0
10
20
Degrees

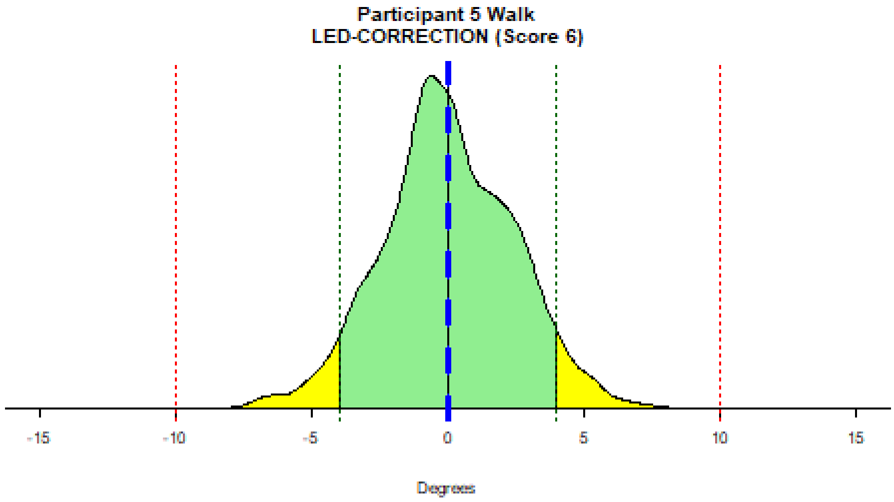

Participant 3 Walk
LED-FEEDBACK (Score 9)
-20
-10
0
10
20
Degrees

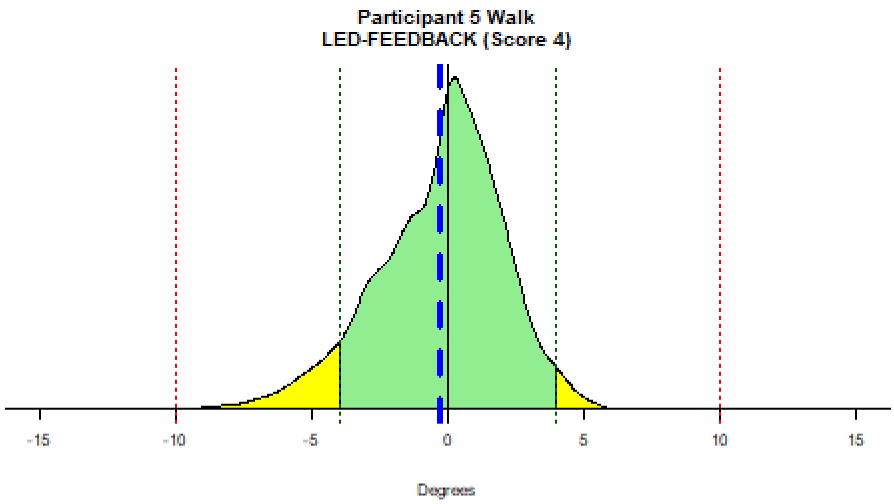

Participant 4 Walk
LED-OFF
-15
-10
-5
0
5
10
15
Degrees

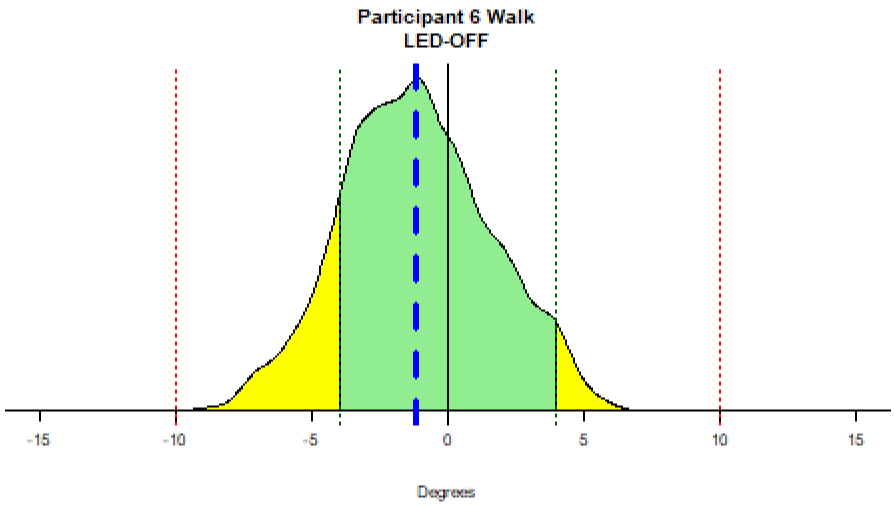

Participant 4 Walk
LED-CORRECTION (Score 8)
-15
-10
-5
0
5
10
15
Degrees


Participant 4 Walk
LED-FEEDBACK (Score 2)
-15
-10
-5
0
5
10
15
Degrees

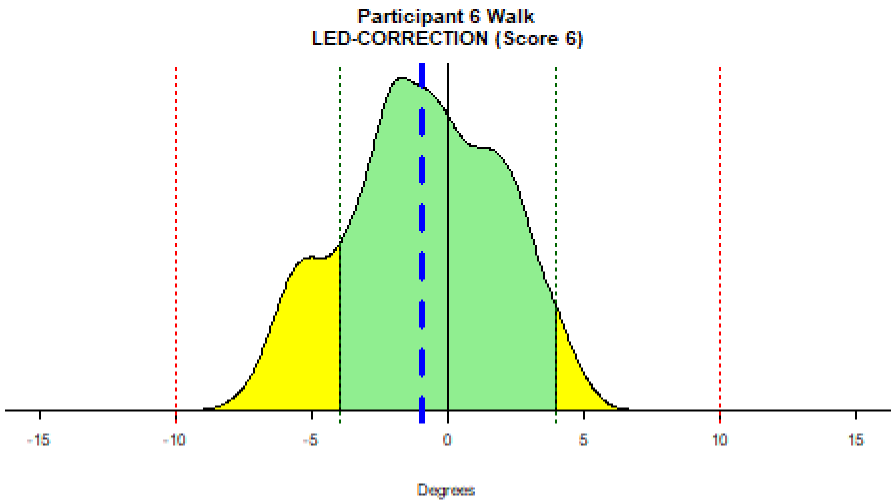

Participant 5 Walk
LED-OFF
-15
-10
-5
0
5
10
15
Degrees


Participant 5 Walk
LED-CORRECTION (Score 6)
-15
-10
-5
0
5
10
15
Degrees

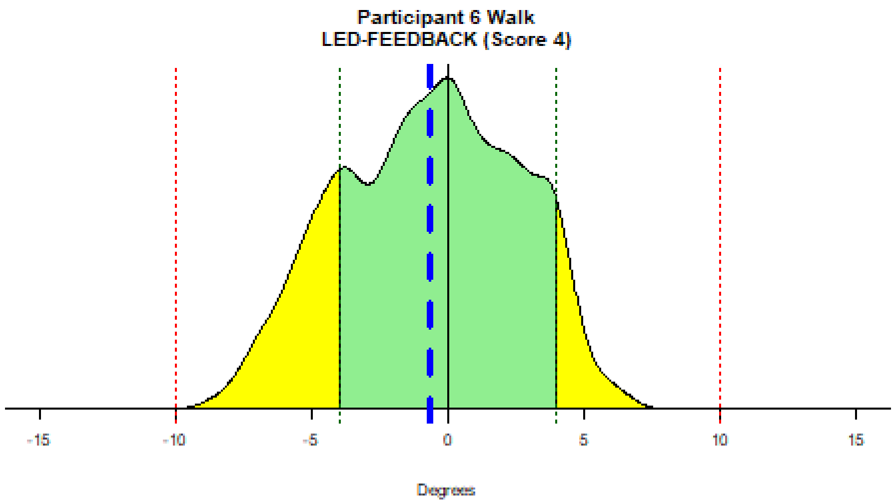

Participant 5 Walk
LED-FEEDBACK (Score 4)
-15
-10
-5
0
5
10
15
Degrees



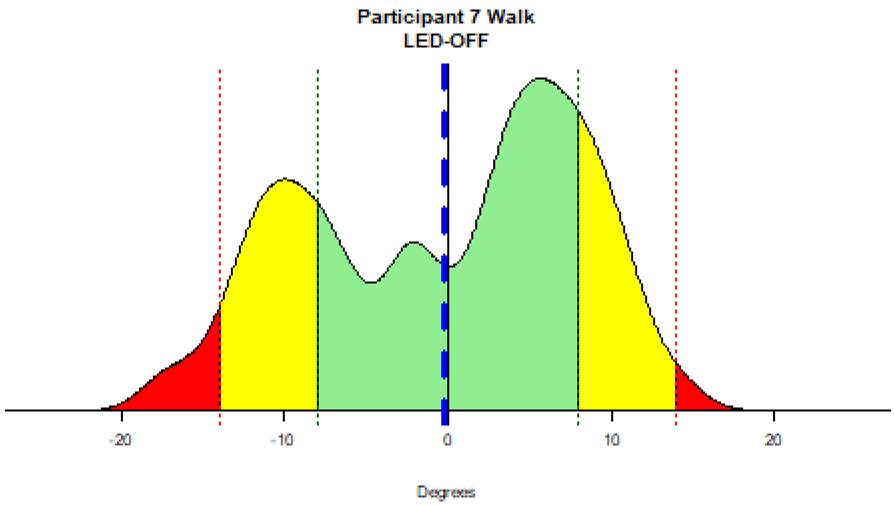
Participant 6 Walk
LED-OFF
-15
-10
-5
0
5
10
15
Degrees

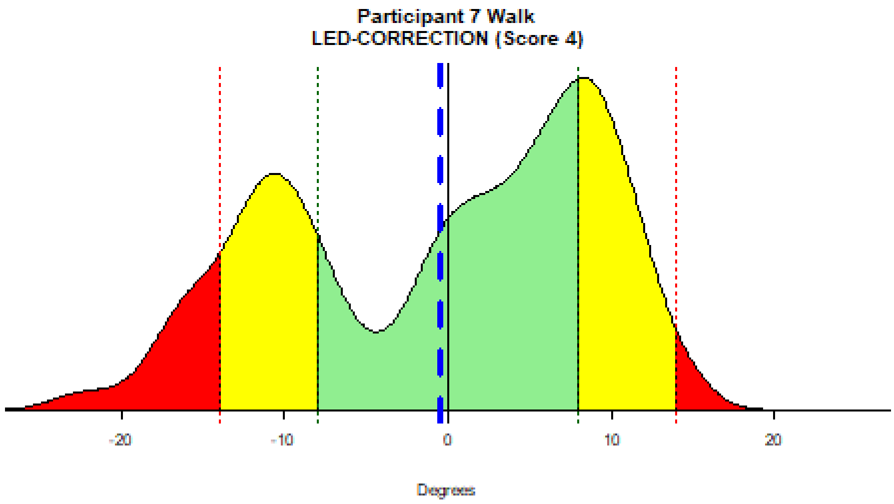


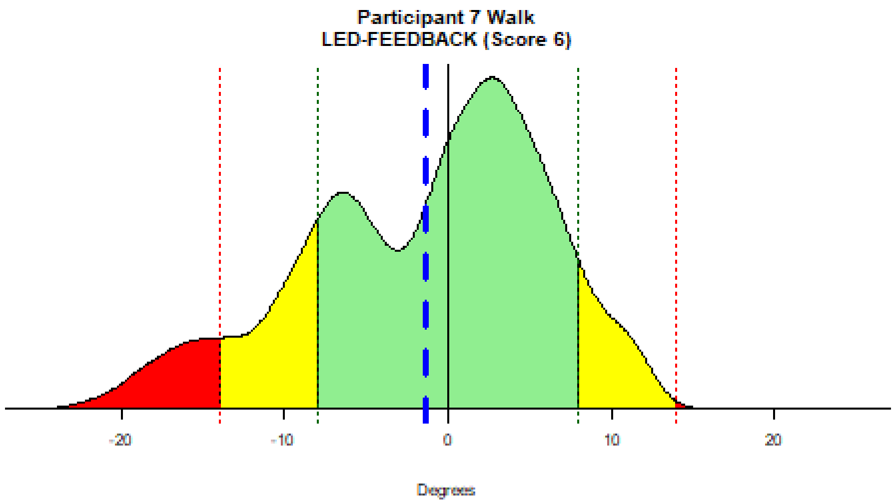
Participant 6 Walk
LED-CORRECTION (Score 6)
-15
-10
-5
0
5
10
15
Degrees

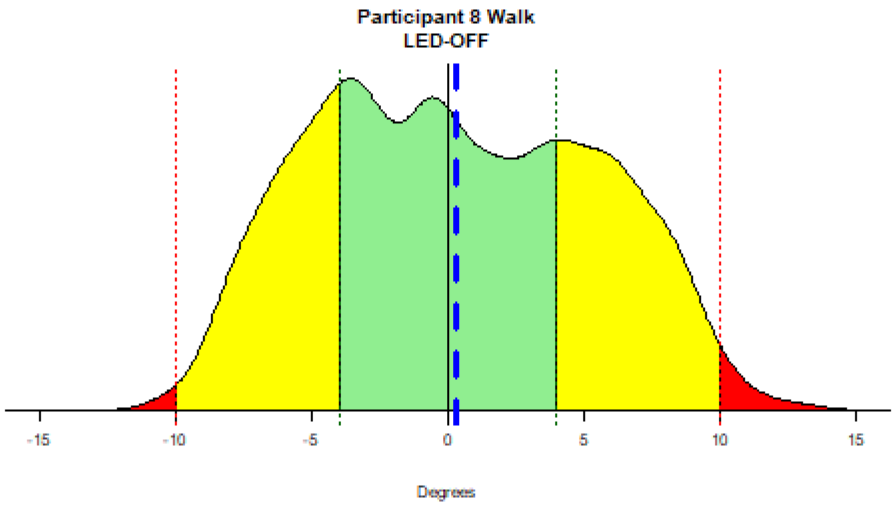


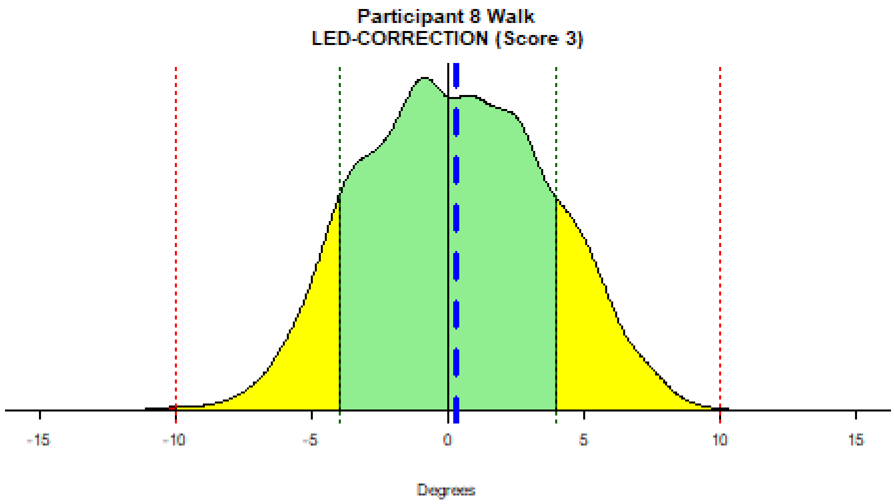
Participant 6 Walk
LED-FEEDBACK (Score 4)
-15
-10
-5
0
5
10
15
Degrees

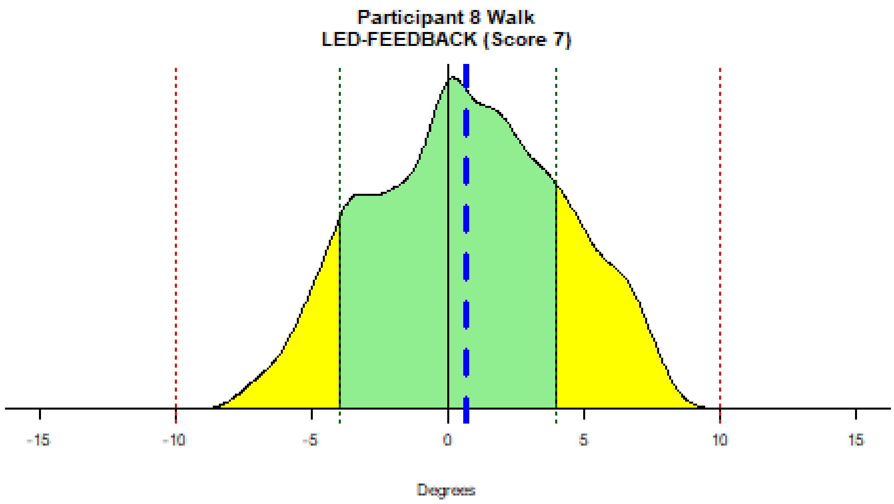

Participant 7 Walk
LED-OFF
-20
-10
0
10
20
Degrees

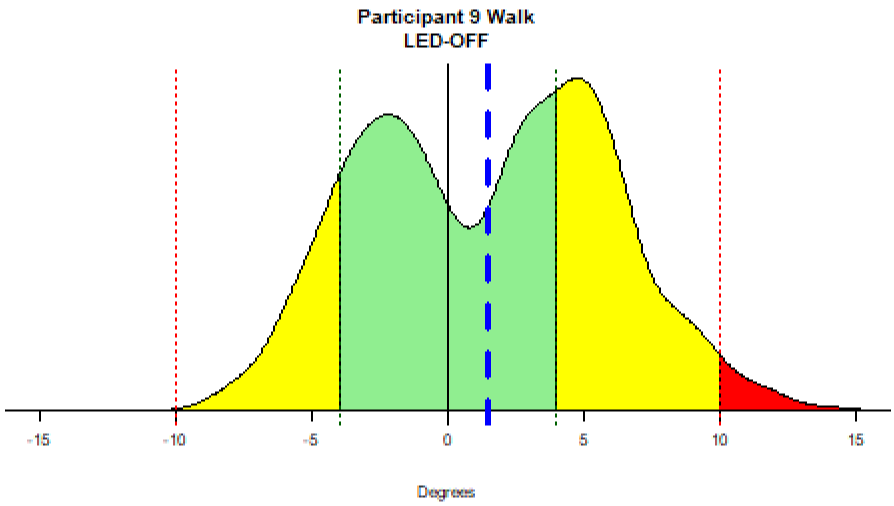

Participant 7 Walk
LED-CORRECTION (Score 4)
-20
-10
0
10
20
Degrees

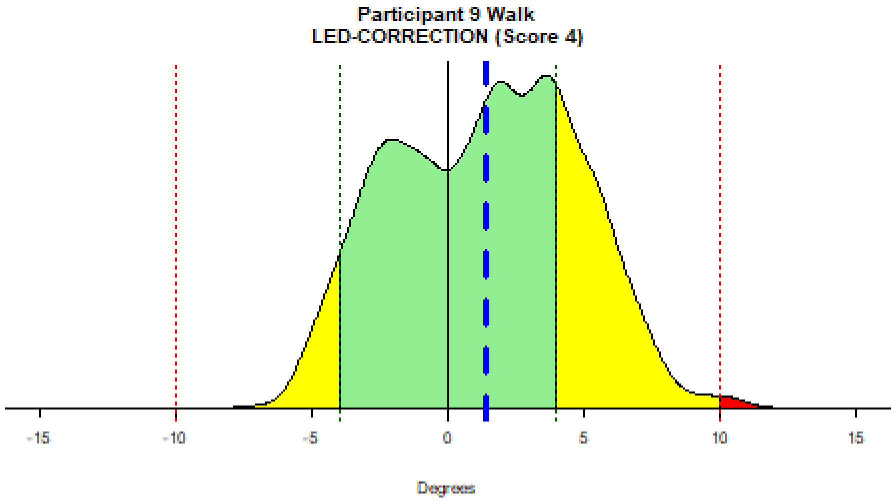

Participant 7 Walk
LED-FEEDBACK (Score 6)
-20
-10
0
10
20
Degrees

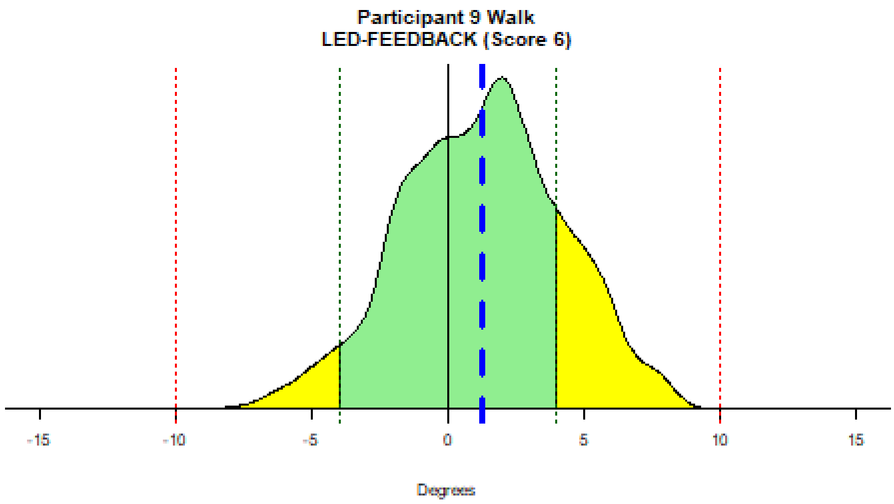

Participant 8 Walk
LED-OFF
-15
-10
-5
0
5
10
15
Degrees

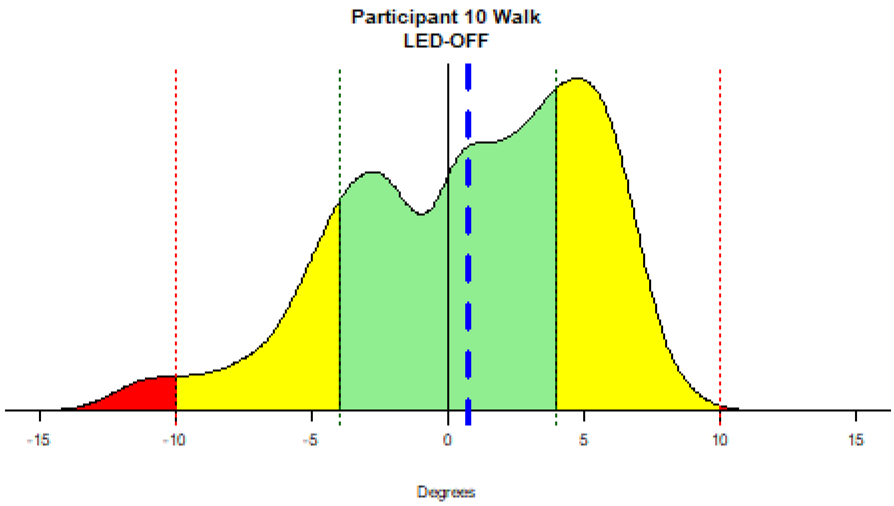

Participant 8 Walk
LED-CORRECTION (Score 3)
-15
-10
-5
0
5
10
15
Degrees

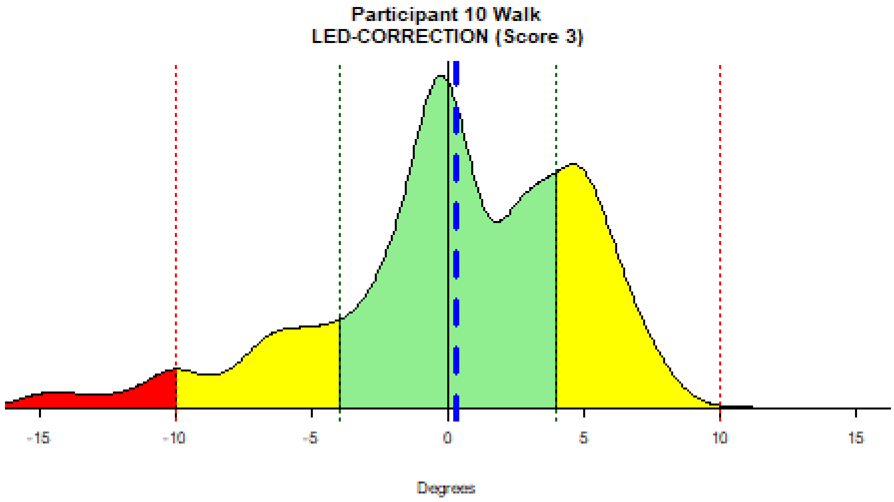

Participant 8 Walk
LED-FEEDBACK (Score 7)
-15
-10
-5
0
5
10
15
Degrees

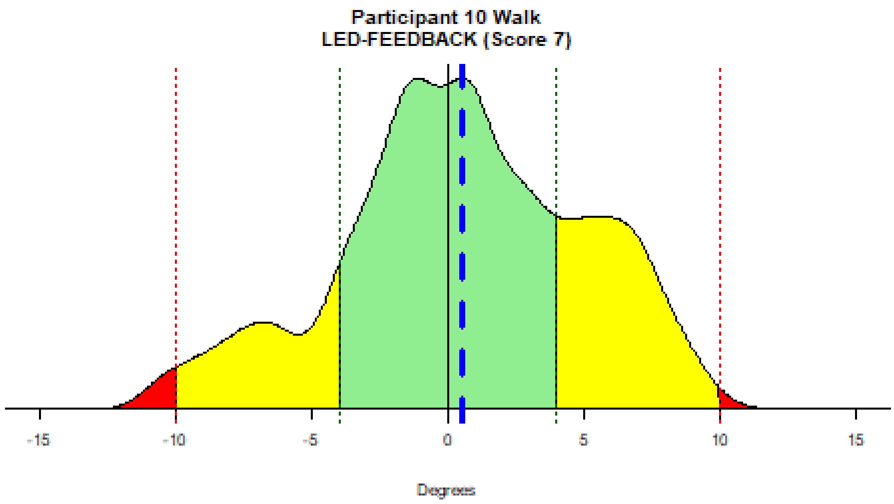

Participant 9 Walk
LED-OFF
-15
-10
-5
0
5
10
15
Degrees

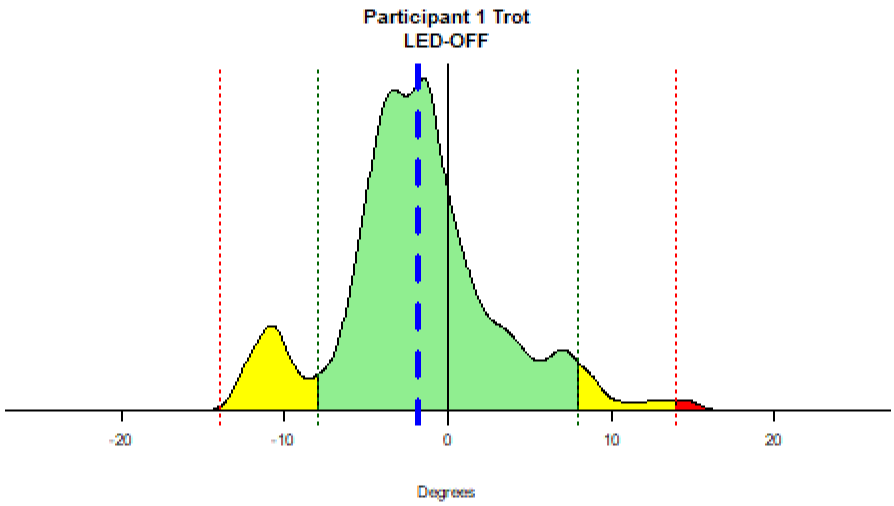

Participant 9 Walk
LED-CORRECTION (Score 4)
-15
-10
-5
0
5
10
15
Degrees

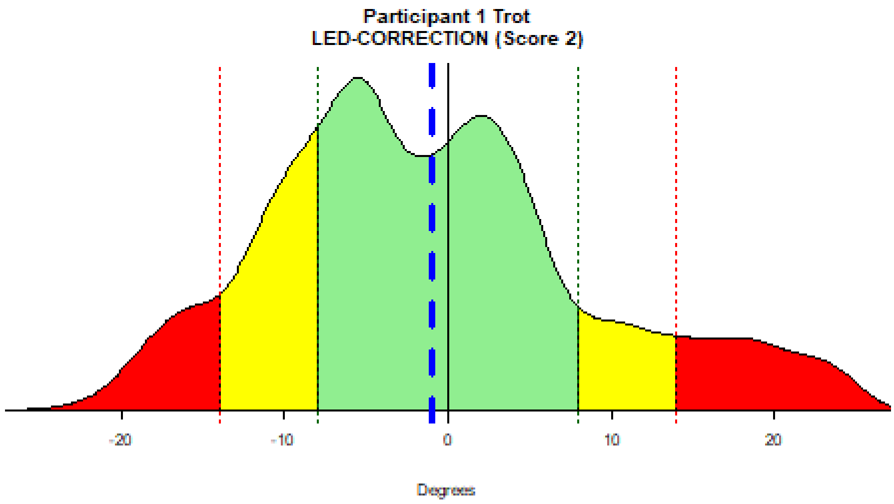

Participant 9 Walk
LED-FEEDBACK (Score 6)
-15
-10
-5
0
5
10
15
Degrees

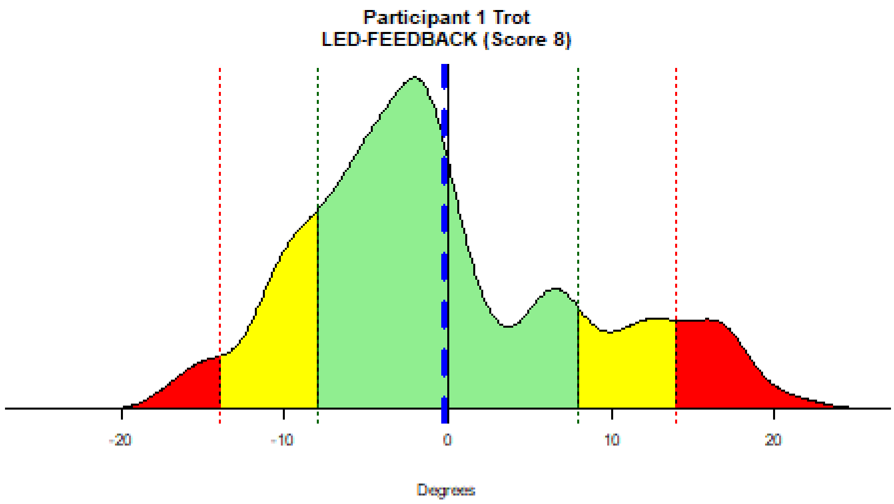

Participant 10 Walk
LED-OFF
-15
-10
-5
0
5
10
15
Degrees

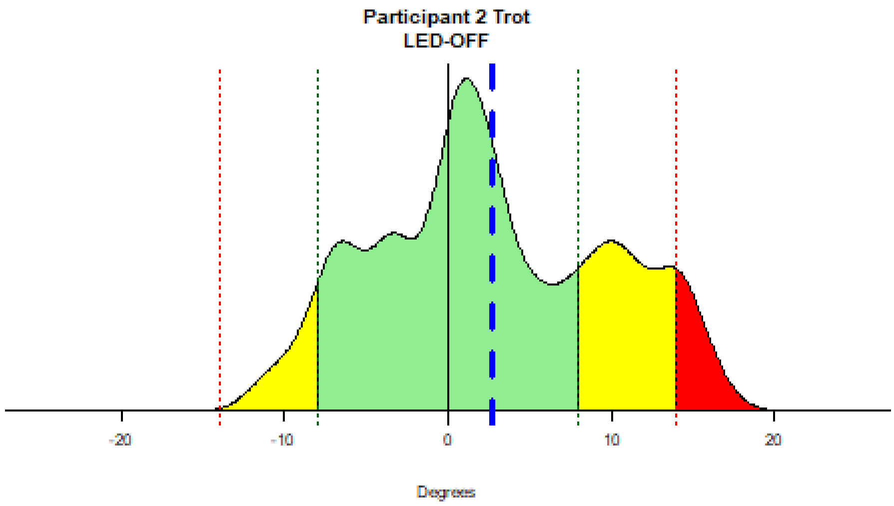

Participant 10 Walk
LED-CORRECTION (Score 3)
-15
-10
-5
0
5
10
15
Degrees

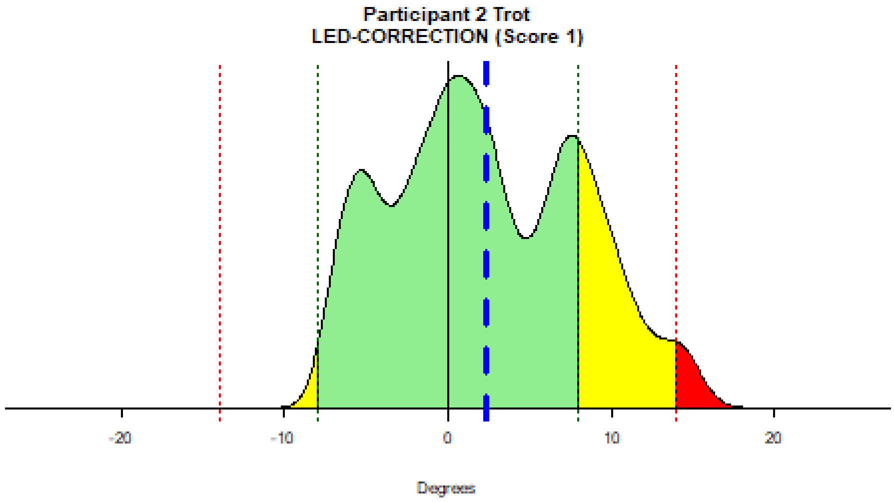

Participant 10 Walk
LED-FEEDBACK (Score 7)
-15
-10
-5
0
5
10
15
Degrees

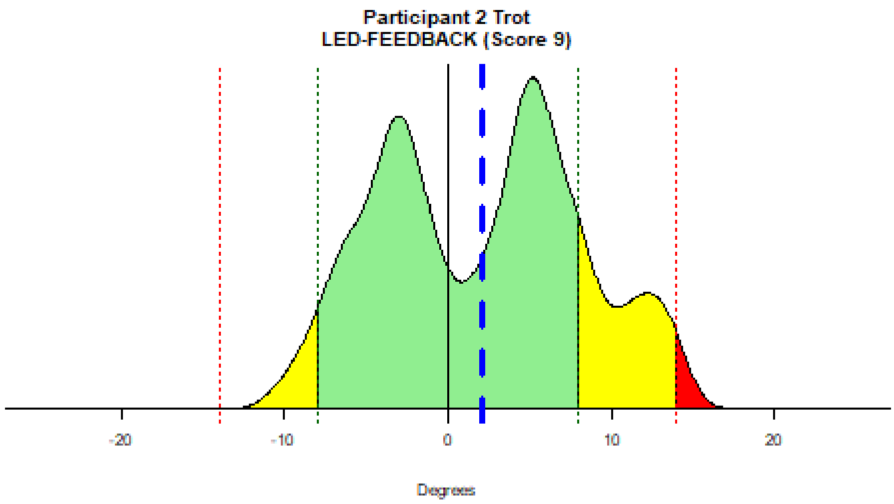

Participant 1 Trot
LED-OFF
-20
-10
0
10
20
Degrees

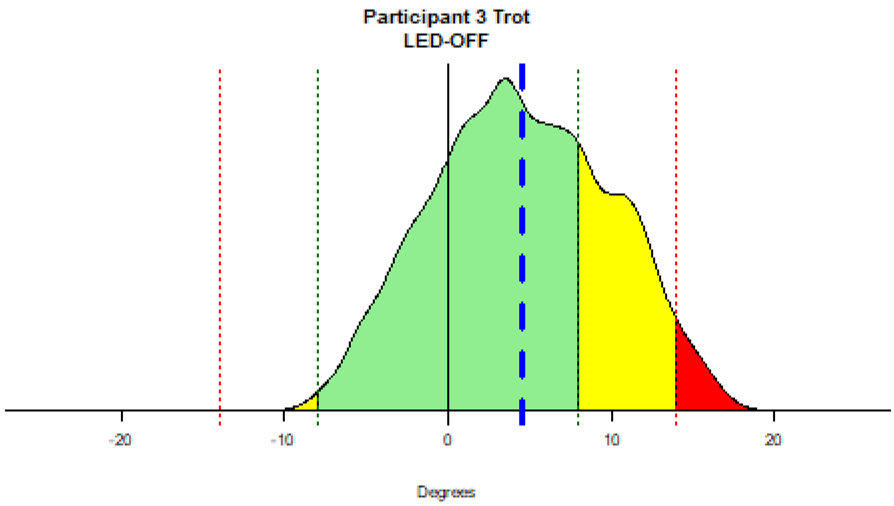

Participant 1 Trot
LED-CORRECTION (Score 2)
-20
-10
0
10
20
Degrees

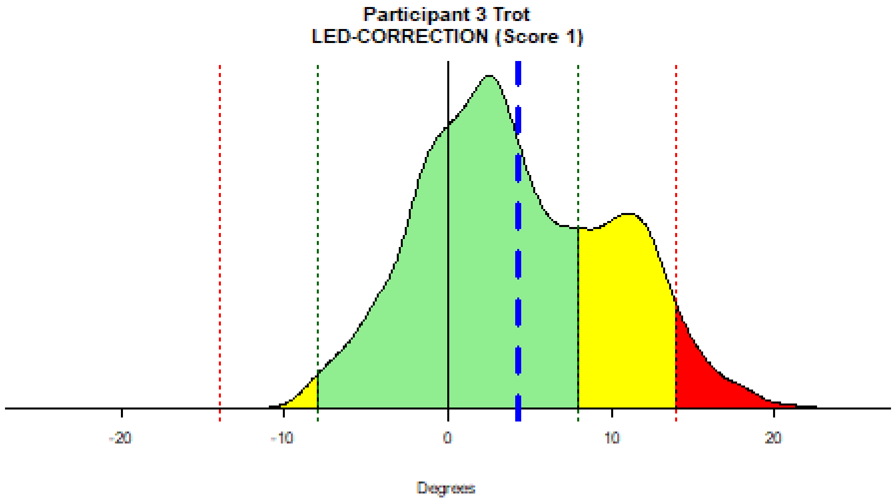

Participant 1 Trot
LED-FEEDBACK (Score 8)
-20
-10
0
10
20
Degrees

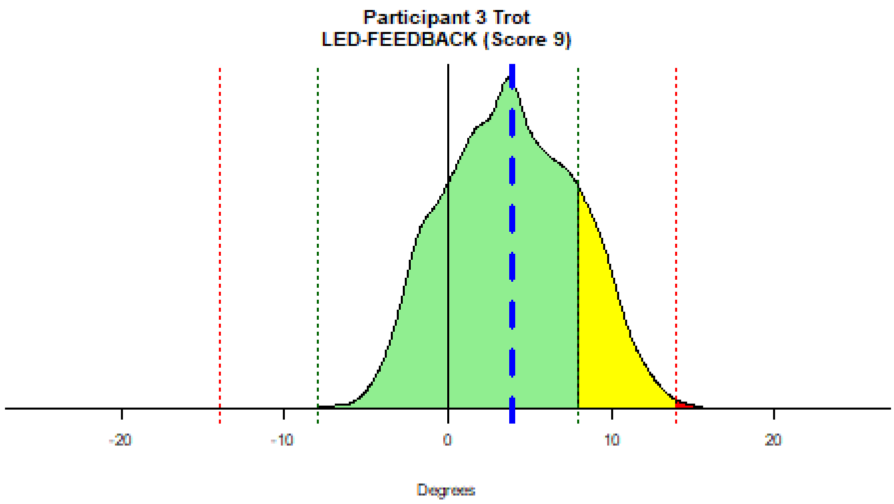

Participant 2 Trot
LED-OFF
-20
-10
0
10
20
Degrees

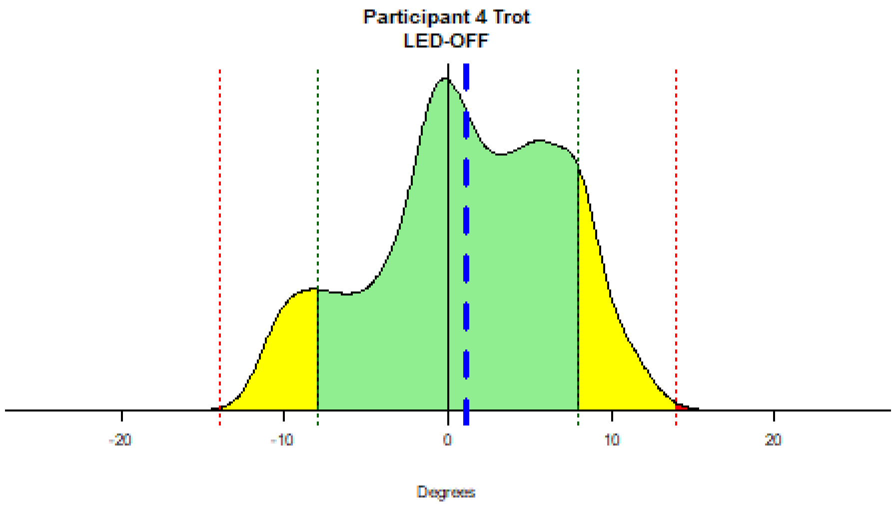

Participant 2 Trot
LED-CORRECTION (Score 1)
-20
-10
0
10
20
Degrees

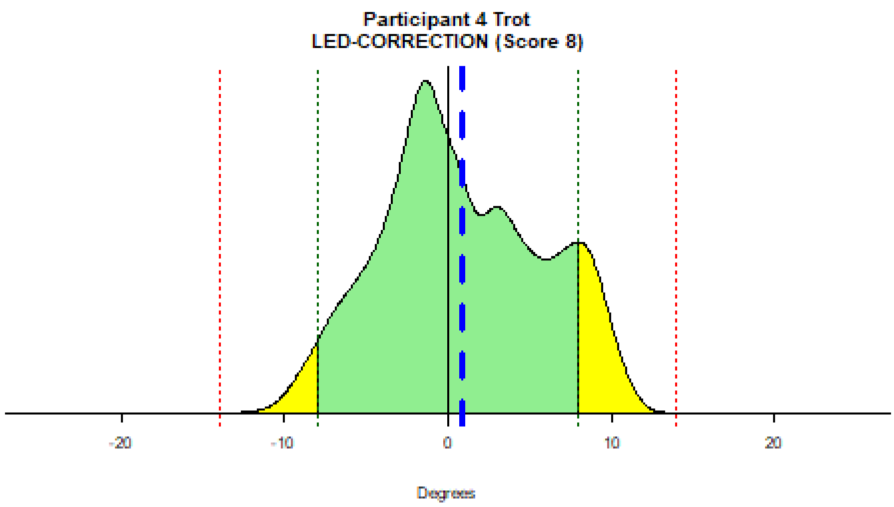

Participant 2 Trot
LED-FEEDBACK (Score 9)
-20
-10
0
10
20
Degrees

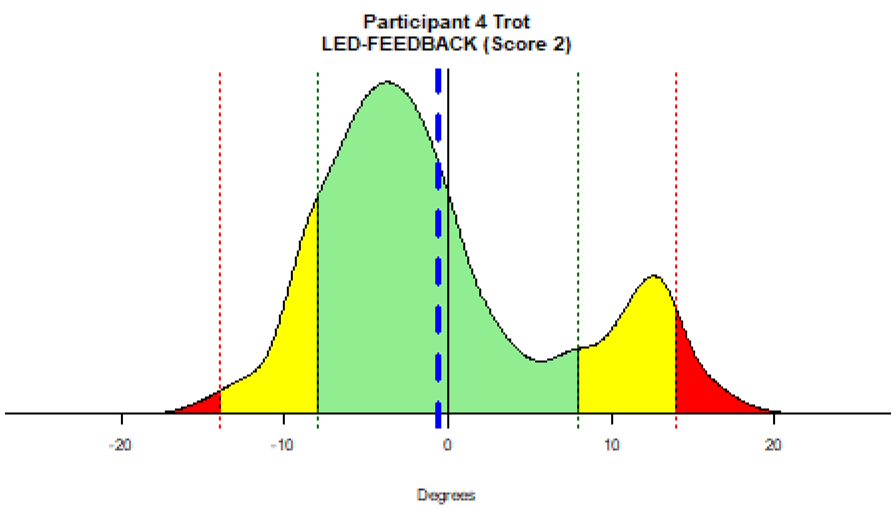

Participant 3 Trot
LED-OFF
-20
-10
0
10
20
Degrees

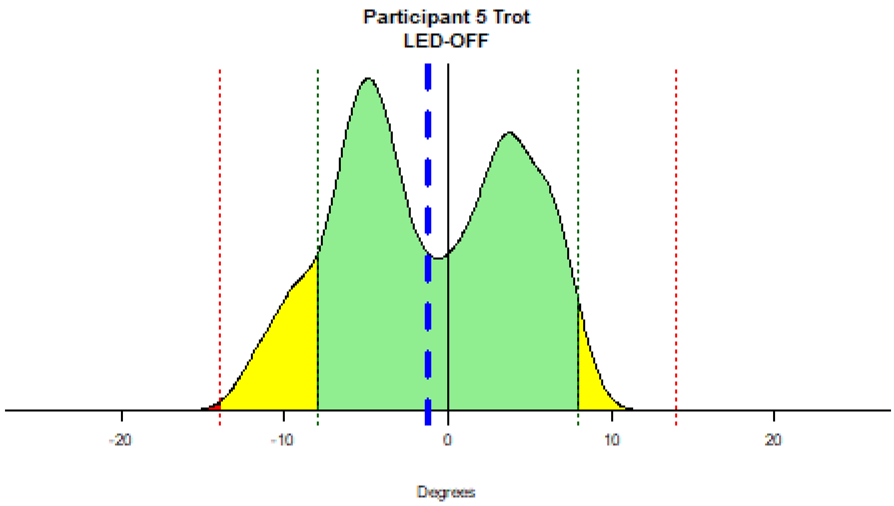

Participant 3 Trot
LED-CORRECTION (Score 1)
-20
-10
0
10
20
Degrees

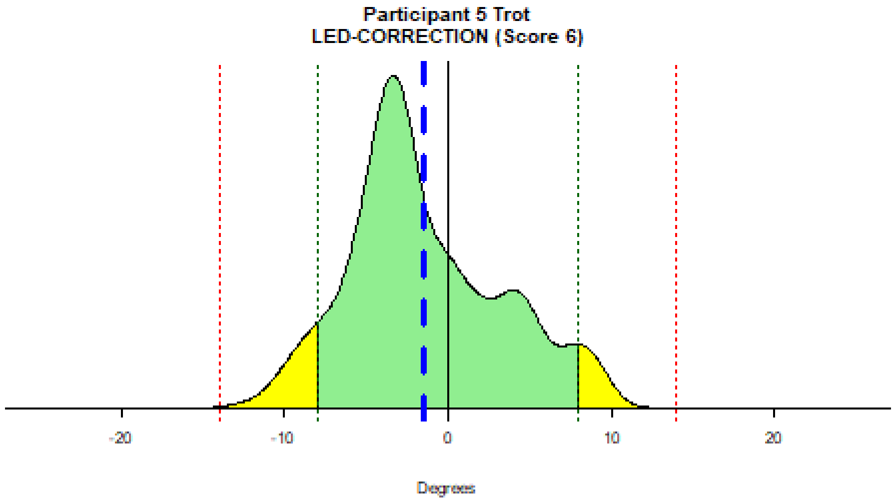

Participant 3 Trot
LED-FEEDBACK (Score 9)
-20
-10
0
10
20
Degrees

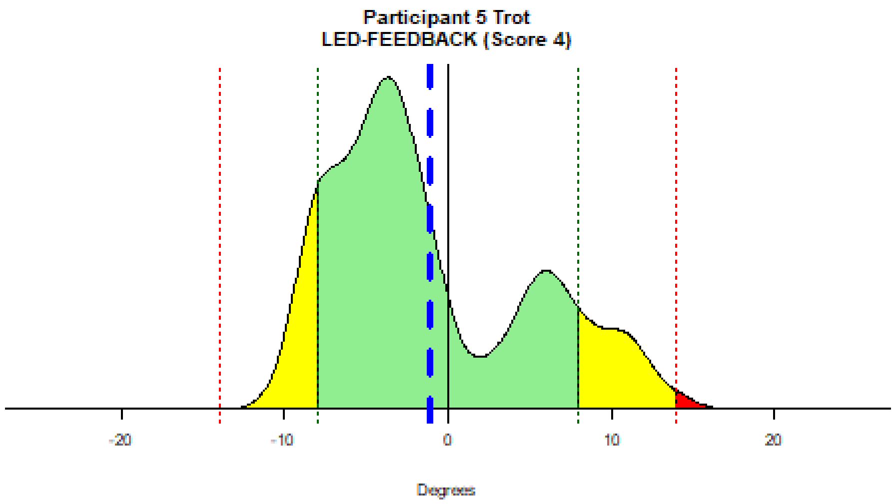

Participant 4 Trot
LED-OFF
-20
-10
0
10
20
Degrees

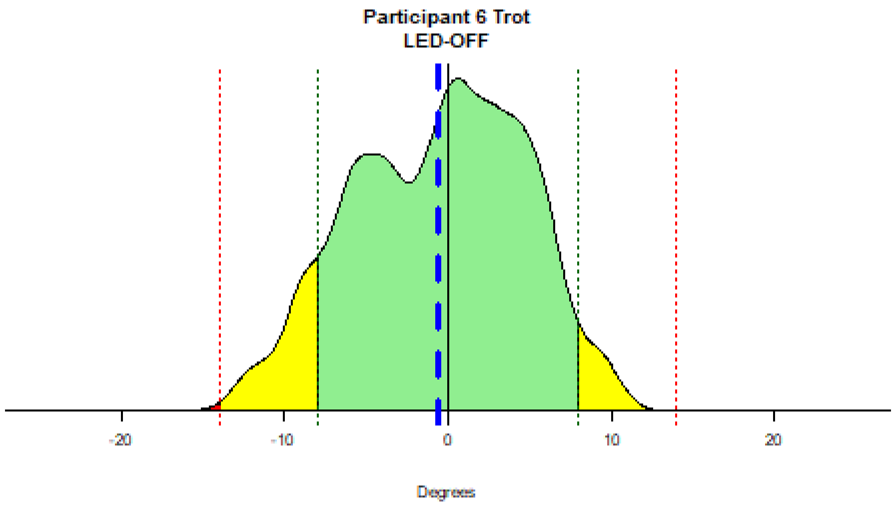

Participant 4 Trot
LED-CORRECTION (Score 8)
-20
-10
0
10
20
Degrees

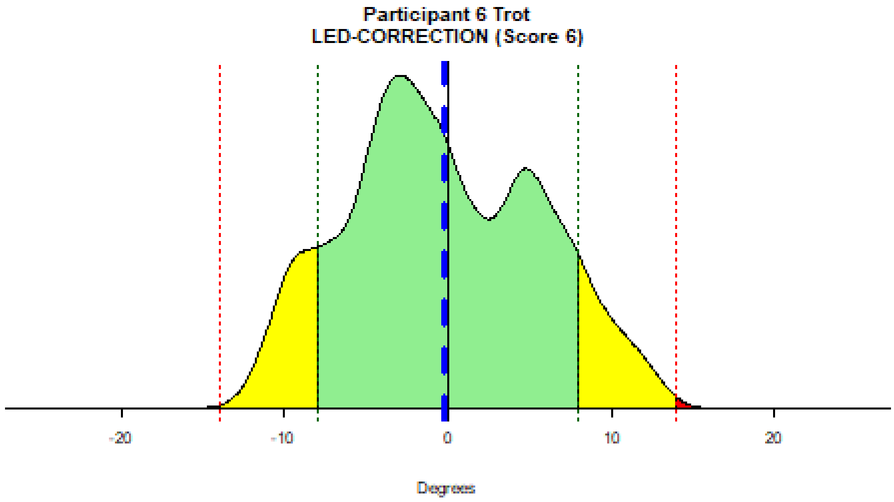

Participant 4 Trot
LED-FEEDBACK (Score 2)
-20
-10
0
10
20
Degrees

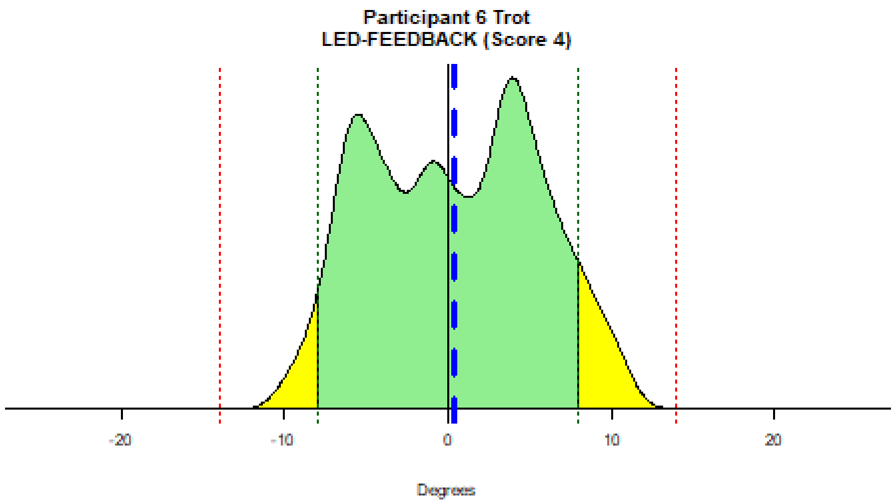

Participant 5 Trot
LED-OFF
-20
-10
0
10
20
Degrees

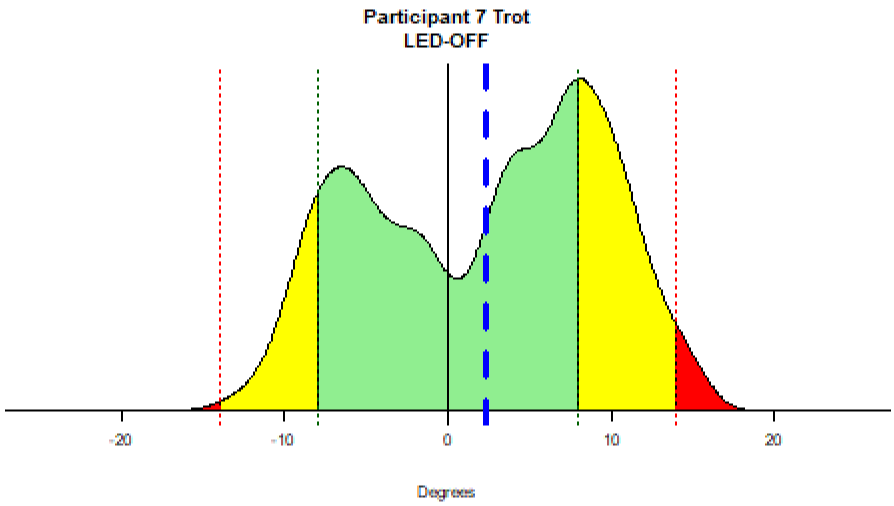

Participant 5 Trot
LED-CORRECTION (Score 6)
-20
-10
0
10
20
Degrees

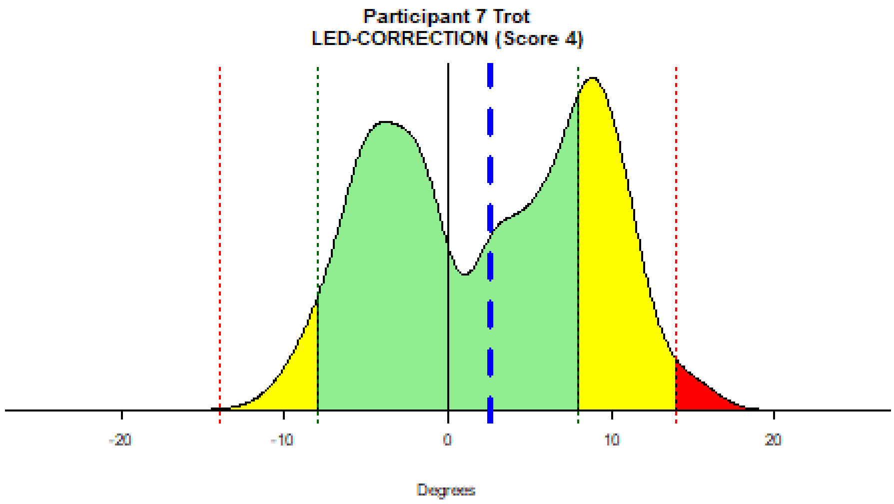

Participant 5 Trot
LED-FEEDBACK (Score 4)
-20
-10
0
10
20
Degrees

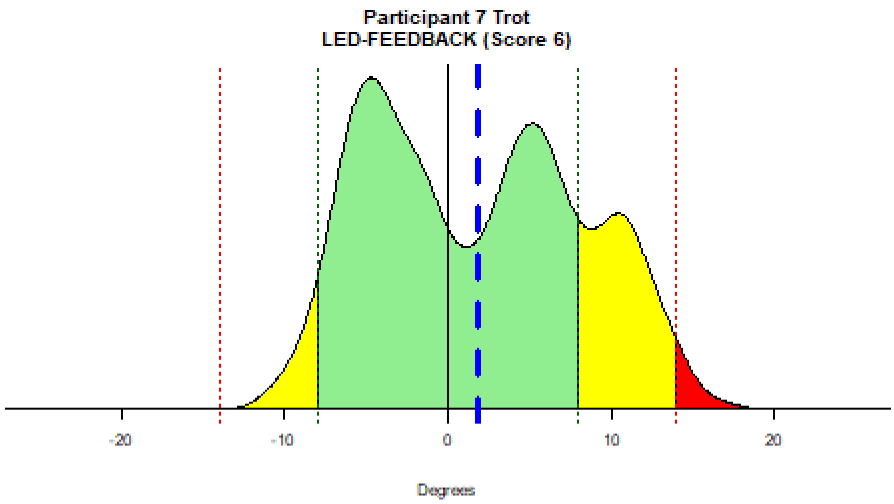

Participant 6 Trot
LED-OFF
-20
-10
0
10
20
Degrees

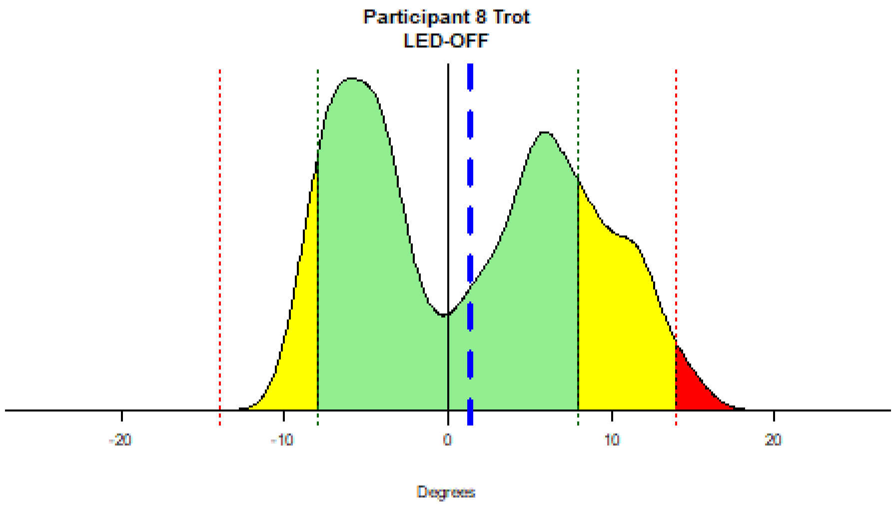

Participant 6 Trot
LED-CORRECTION (Score 6)
-20
-10
0
10
20
Degrees

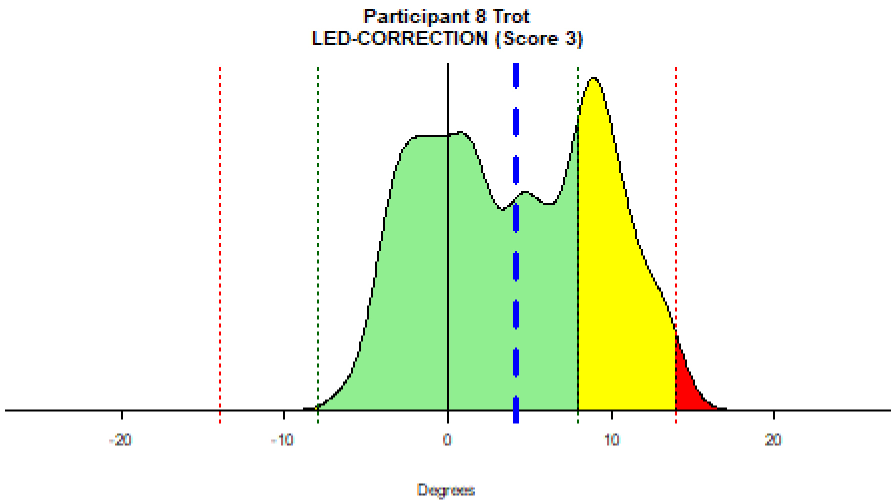

Participant 6 Trot
LED-FEEDBACK (Score 4)
-20
-10
0
10
20
Degrees


Participant 7 Trot
LED-OFF
-20
-10
0
10
20
Degrees


Participant 7 Trot
LED-CORRECTION (Score 4)
-20
-10
0
10
20
Degrees


Participant 7 Trot
LED-FEEDBACK (Score 6)
-20
-10
0
10
20
Degrees


Participant 8 Trot
LED-OFF
-20
-10
0
10
20
Degrees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LED-CORRECTION (Score 3)
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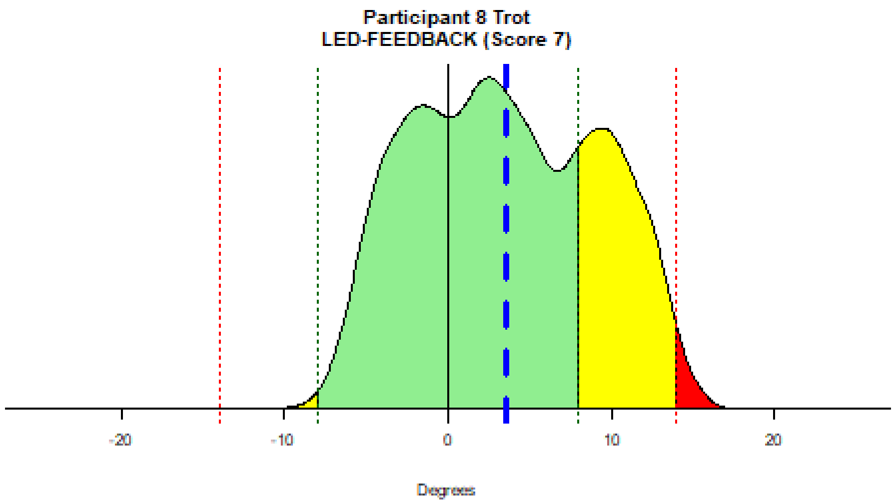
-10
0
10
20
Degrees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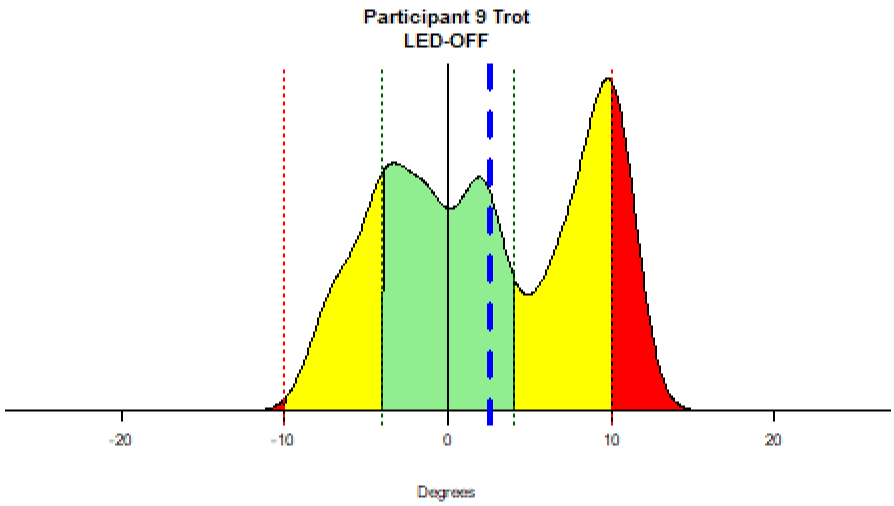
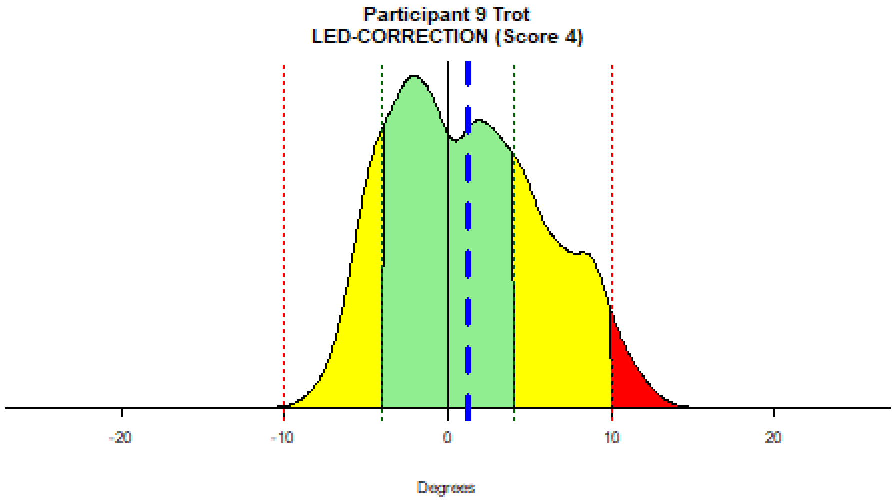
LED-FEEDBACK (Score 7)
-20
-10
0
10
20
Degrees


Participant 9 Trot
LED-OFF
-20
-10
0
10
20
Degrees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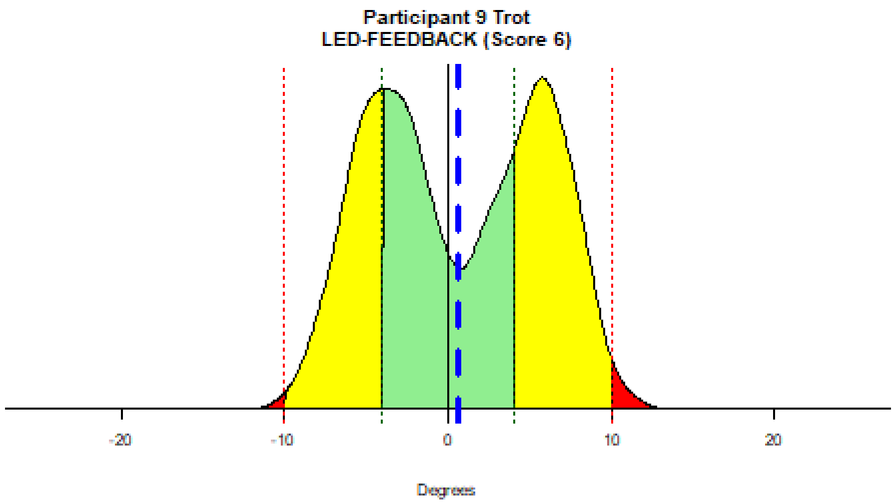
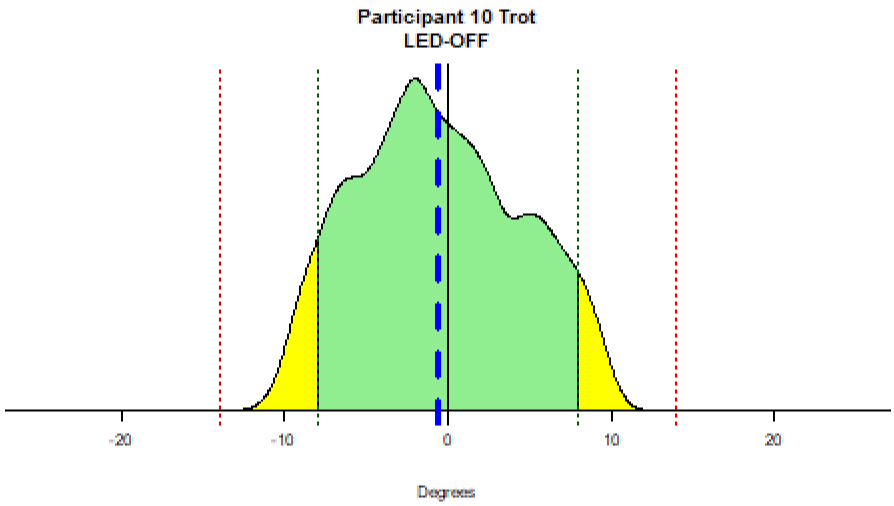
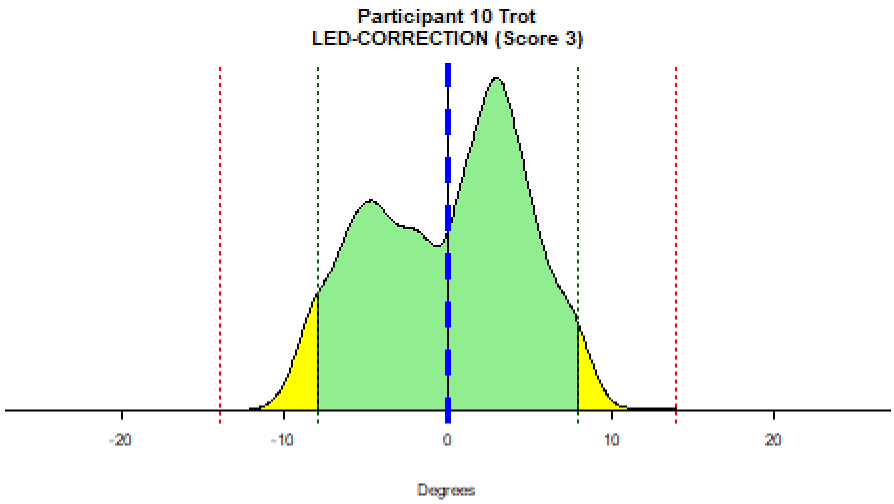
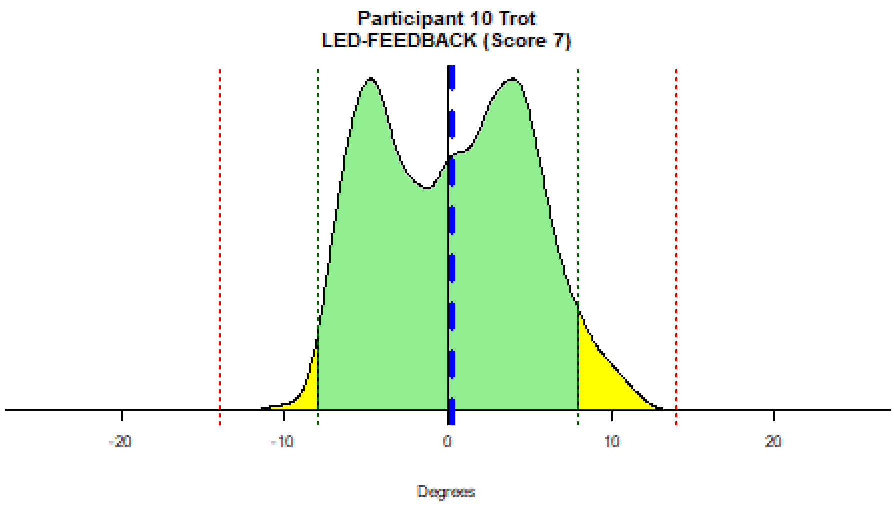
LED-CORRECTION (Score 4)
-20
-10
0
10
20
Degrees


Participant 9 Trot
LED-FEEDBACK (Score 6)
-20
-10
0
10
20
Degrees


Participant 10 Trot
LED-OFF
-20
-10
0
10
20
Degrees


Participant 10 Trot
LED-CORRECTION (Score 3)
-20
-10
0
10
20
Degrees


Participant 10 Trot
LED-FEEDBACK (Score 7)
-20
-10
0
10
20
Degrees

Appendix M. Rider comments on visualisation interfaces

LED- CORRECTION		
	Positive	**Negative**
P2	the minute you moved they showed you what was going on	a bit confusing because wasn't sure which way it wanted me to move back. At the time while you are walking or trotting along, if you look at them and start going that way I wasn't sure if that meant move to the right if they were pointing to the right or if that meant it was me leaning to the right so should I move back to the left so I just found it a little bit confusing as I was going to get my head around which way is it I need to turn, to lean a little bit trickier to follow
P3		scrolling was harder I thought. It was interesting to see the lights change and correct but I didn't know if I was over-correcting or not correcting. Then was I correcting enough. Watching it was a lot harder than trying to see where I was going at the same time. There was so many of them it kind of distracts a little bit to look through his ears and to look where I am going at the same time had to focus on a lot more because you had all the lights going whereas the other one was "you are going this way" and you had to go back so it was easier to correct as you could look down and then back up again rather than thinking "I have to get onto the two lights in the middle"
P4	it gave me an indication; I felt like I made a minor adjustment and it corrected me once I made the adjustment it didn't go to the other side, it stayed central. I felt like it told me to make a minor adjustment rather than a major adjustment I felt like the scrolling lights made me relax; it made things easier to read from the scrolling lights	
P5	you can see them better from being on the horse you could see them more. I think they were both just as good but from sitting on the horse you could see the first set of lights better [Asked if this was to do with correcting vs feedback] No, it was more about how I could see them from my point of view	

LED- CORRECTION		
	Positive	**Negative**
	better because my vision is not too good and I could see them better from being on the horse	
P6	they would go on to red much quicker seemed to show up more red in the light outside with the sun the scrolling ones were easier to see. (normally wear glasses but not for riding but should). [Do you think that would come into your decision or would that make no differences?] Probably would if I wore my glasses. Scrolling ones better to see with eyesight, particularly in outdoor school. Truthfully there's not that much in it. I don't know if there's a difference when you are riding indoors	
P7		In walk, when I was (and this is a personal issue with me as I tend to get sea sickness) focusing on the lights I was feeling a bit dizzy. I need to keep looking away in walk. In trot that didn't happen as much probably because I was looking away more. It was mostly the scrolling ones when I was fixed on those it's a bright sunny-ish day, I found those difficult to see in the bright sunlight. In fact, when I raised my sunglasses when the sun was out, I couldn't see them. sometimes by the time you've looked at the scrolling lights and then thought "I need to move" it was almost like the moment has gone
P9	easier to kind of see Easier to correct myself from which way I was leaning	So even though preference initially was for the scrolling I've gone the other way now I think about it. Yes, because I think it's more effective
P10		I get confused with the scrolling lights because it tells you which way to correct yourself but I was like "am I leaning that way" I just got confused as to whether it meant that I was sliding that way or was sat upright

LED-FEEDBACK		
	Positive	**Negative**
P1	Nice reminder when the lights pointed away that not quite as level as thought was it told you where you were. Especially in trot. It was easier to see how far you were so it was easier to adjust back. And because I'm looking for two green lights rather than them moving to set. Personally, it was easier to work out what I had to do the fixed light telling you where you are is easier for me, my personal preference. Adjust where I am rather it pointing and you going "I need to go that way but how far, whereas with the fixed lights you know how far because it tells you and as soon as you get back to the middle you've got the two"	
P2	good because the minute you moved, they did show you straight away that you'd moved Even with practice prefer, found them a lot easier to read because had the two green in the middle and then the flashing one, one/two or one/two/three to show you how much you are leaning whereas the other ones had all the lights on then just started scrolling so these definitely, showed you how much you are leaning and much more you needed to go that way great because I found them really informative, it was easy to correct	
P3	much better, they were easier to read, easier to see because there were just two lights and one changed or the other changed and you didn't have them scrolling. In the walk it was easier to look down and look up to see where I was going. The same with the trot. It was interesting because I was trying to correct myself because I knew where I needed to be but wasn't quite sure so it was playing with my position to get the lights to stay in the middle and that was easier with that than with the other set of lights.	

LED-FEEDBACK		
	Positive	**Negative**
	it was easier to watch, easier to view while I was riding, whereas the other set you had to focus on a lot more because you had all the lights going whereas the other one was "you are going this way" and you had to go back so it was easier to correct as you could look down and then back up again rather than thinking "I have to get onto the two lights in the middle"	
P4		very sensitive, the slightest little movement in myself or having to correct the horse it flared up quite significantly to say to me I'm too far this way, too far that way The smaller lights, the initial ones that moved into the red side, I felt like I was trying to move over too much and going to the other side. I felt like I was going off balance working through the smaller lights Working through both sets of lights helped because at first working through the shorter lights I didn't feel like I was doing enough to make the improvement
P6	Not too sure to be honest because I'm not sure if it is judging how straight you are or when you are going wonky [explanation given]. If you were going off that you would say these are better	Good but I don't know if they weren't as sensitive but they didn't go on red as much
P7	Probably to do with the sunlight and the ability to see them seem to react more slowly, I don’t know whether that’s the case? There was more instant feedback I felt with the two fixed ones	
P8	It seemed a bit more accurate for side to side than the scrolling wanted to but for me visually the other one works a little bit better to go out the side I was actively trying to sort it out and it was really satisfying when you did get the lights into the centre	
P9	Easier to correct especially with just the two lights because I knew I had to work harder to try and keep myself in the middle It’s harder with the two but it probably made it more effective.	It was a lot harder with just the two dots to keep them in the middle because obviously you haven’t got as many lights so it was a lot harder with just the two in both walk and trot

LED-FEEDBACK		
	Positive	**Negative**
	So even though preference initially was for the scrolling I've gone the other way now I think if only allowed one set: I don't know. It's harder with the two but it probably made it more effective.	
P10	much easier and there wasn't so many of them so it was clear to me to know I was going one way then the other	