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COGNITION AND SKILL LEARNING IN SINGLE LEG LOADING: THE ROLE OF AUGMENTED VISUAL FEEDBACK ON MOTOR CONTROL PERFORMANCE

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Abstract

Externally provided visual feedback is often delivered to an individual during an activity to provide information on 'performance'. These modes of feedback delivery are termed 'augmented' as it is externally provided to the user, often through wearables, practitioners, or coaches. However, no studies have examined the effect of on-screen visual feedback in conjunction with both within-session single-leg squat 'performance' and musculoskeletal profiling tools. This study aimed to investigate the effect of concurrent and terminal visual feedback on Qualitative Analysis of Single Leg Loading (QASLS) score. The alternative hypothesis (H_1) was that there was at least 'strong' evidence ($BF_{10} \geq 10$) for an effect on QASLS score. Participants (N = 17) completed two single-leg squat trials 1 week apart. Trials were held in a randomised order with participants completing three sets of three repetitions on both limbs. No performance information was provided in the control condition. The experimental condition included administering visual feedback (identification of 'movement strategies') using two 84" Philips™ monitors placed directly in front of participants. Data were analysed using a two-tailed Bayesian paired sample t-test with a Cauchy prior. Mean (SD) QASLS score for the no feedback and feedback conditions were 3.54 (0.78) and 3.02 (0.83), respectively. The effect size (Cohen's *dz*; 95% HDI) for the mean difference was 1.42 (0.72 – 2.16). The BF_{10} was 2340 providing 'extreme' evidence for the alternative hypothesis. The data provide 'extreme' evidence for a 'very large' reduction in QASLS score when using feedback. Consequently, demonstrating within-session motor adaptation in response to altered afferent information, suggesting that the incorporation of visual feedback can enhance short-term motor control performance. Additionally, practitioners could make more informed decisions regarding QASLS results by distinguishing between implicit and explicit task-based compensations. This may reduce the counter-productive nature of unsuitable programs, potentially benefiting the user's long-term performance through appropriate feedback administration. However, the wide credible interval for the mean difference means there is uncertainty in this estimate. As such, the results should be interpreted with caution as the small sample can inflate the effect size, whereby, the 'true' effect of visual feedback on QASLS would require additional studies with larger samples.

Glossary of terms

ACL – Anterior Cruciate Ligament.

AFB – Augmented Feedback.

ASIS – Anterior Superior Iliac Spine.

AuFB – Audible Feedback.

BF – Bayes factor.

BG – Basal Ganglia.

CFB – Concurrent Feedback.

CI – Credible/Confidence Interval.

DKV – Dynamic Knee Valgus.

DLPFC – Dorsolateral Prefrontal Cortex.

EDP – Experience Dependant Plasticity.

EEP – Experience Expectant Plasticity.

EFB – Exteroceptive Feedback.

FA – Fractional Anisotropy.

FMS – Functional Movement Screening.

GTF – Greater Trochanter of Femur.

H_0 – Null hypothesis.

H_1 – Alternative hypothesis.

ICC – Interclass/Intraclass correlation Coefficient.

IQR – Interquartile range.

KP/R - Knowledge of Performance/Results.

MAD – Median Absolute Deviation.

M1 – Primary Motor Cortex.

MVF – Mirror Visual Feedback.

PMA – Pre-Motor Area.

PPC – Posterior Parietal Cortex.

Pre-SMA – Pre-Supplementary Motor Area.

PFPS – Patellofemoral Pain Syndrome.

QASLS – Qualitative Analysis of Single Leg Squat.

RAMP – Raise, Activate & Mobilise, Potentiate.

ROPE – Region of practical equivalence.

SD – Standard Deviation.

SLDD – Single Leg Drop Down.

SLHD – Single Leg Hop for Distance.

SMA – Supplementary Motor Area.

SLS – Single Leg Squat.

TFB – Terminal Feedback.

TMS – Transcranial Magnetic Stimulation.

V1 – Primary Visual Cortex.

WB – Weight Bearing.

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1.0 Chapter 1: Introduction

The improvement of athletic performance can be achieved in several ways and performance does not necessarily mean faster or stronger but coordinated and controlled (Almasbakk & Hoff, 1996). Within this study, performance enhancement will be discussed in terms of (1) injury prevention, (2) motor control, learning, and development, and (3) feedback techniques to augment skill learning for improved neuromuscular function.

1.1 Research background

The measurement of isolated single leg movements through qualitative analysis of single leg squats (QASLS; Herrington et al., 2013) has demonstrated high validity and reliability (Parry, 2021; Parry et al., 2023) to identify functional movement deficiencies, asymmetries (Gribble et al., 2013), and individual athletic capacity along the kinetic chain when used in a clinical and sport setting. Additionally, Functional Movement Screening (FMS) is an assessment tool to evaluate dynamic movement and functional capacity asymmetries. It provides valuable insights into an individual's ability to perform various movements and helps identify limitations (Cook et al., 2006a). These single-leg tasks are multi-joint load-bearing activities that require an appropriate level of motor control (Nascimento et al., 2023) to be completed without risk of musculoskeletal injury. The use of QASLS, a dichotomous scoring tool, provides clinicians with a tool to subjectively analyse movement kinematics to evaluate neuromuscular coordination and stability identified through movement asymmetries. The identification and correction of deficits often rely on feedback, a crucial component in cognition and skill learning (Sigrist et al., 2013b).

In both sports and clinical settings, external feedback (provided from an outside source) is provided to acknowledge the performance of an individual (Chen, 2001). This can be as concurrent (during a performance) or terminal (after a performance) and is commonly labelled as knowledge of performance or results, depending on the administration style (Lauber & Keller, 2014). For instance, information to inform the subject of their movement quality during an activity, or when running, their

current speed, would be considered as knowledge of performance. Information regarding a specific criterion, either pass or fail or when running, average speed throughout the exercise, would be considered knowledge of results (Lauber & Keller, 2014; Schmidt & Wrisberg, 2008). Within clinical settings, an example of external visual feedback would be using video analysis to provide the individual with prescriptive feedback for error modification, thus, supplementing implicit feedback (i.e. proprioception), leading to enhancements in overall performance during the initial stages of cognitive skill learning (Chen, 2001). However, for external feedback to be effective, administration must be appropriate for the task to maximise learning outcomes (Walsh et al., 2009). This is a result of concurrent feedback being highly effective at reducing interference during initial skill acquisition. Yet, this becomes detrimental to learning through the degradation of retention due to the limitation of implicit feedback. Therefore, terminal increases late-stage retention as the subjects utilise internalisation and interoceptive feedback, forcing them to process previously made errors (Huet et al., 2009; Sigrist et al., 2008b). The underlying mechanisms also contribute to the execution of motor skills.

Motor control is the planning, perception, and cognition of movement (Utley & Astill, 2008; Willingham, 1998) involving both gross and fine motor skills for large and small muscle groups, respectively. A sub-factor is skill learning, improving performance with practice through methods of implicit and explicit learning (AKA, off-task, and on-task learning, respectively). Learning involves varying levels of awareness to either develop or adapt to movement changes from training or goal-oriented intentions via alternative practice methods, motor sequencing or differential learning, for example. These styles are influenced by neurological requirements and regional brain activity, including neural pathways such as the cortico-striatal and cortico-cerebellar. These pathways play crucial roles in motor control and learning, contributing to the differences observed in task-dependent regional activity (Dahms et al., 2019; Kleynen et al., 2014).

Motor control and skill learning, as discussed, are not only essential for performing simple and complex tasks but also have a significant role in the brain's anatomy and function. This underscores the importance of neuroplasticity (Galvan, 2010; Lin et al., 2021). Skill learning in training influences plasticity such as increasing myelination, neural cell bodies, and synaptic pathways (Dayan & Cohen,

2011; Sampaio-Baptista-Berge, 2017). In exercise, neuroplasticity is the reorganisational process of the brain's neurons to increase efficiency by strengthening nerve cell function or altering neural pathways (Costandi, 2016; Demarnin et al., 2014). This is termed functional (experience-dependent) plasticity as the brain responds to environmental changes; therefore, functional plasticity is task-dependent (Galvan, 2010). For example, learning to juggle increases occipito-parietal activity, leading to microstructural changes within the brain's white matter (Scholz et al., 2009). Existing literature provides evidence for neuroplastic responses to visual stimuli. Namely mirror feedback, where the observation of actions enhances motor-evoked potentials, facilitating corticocortical interactions (Adamovich et al., 2009). Visuomotor responses and increasing excitability whilst reducing cognitive demand (Beets et al., 2015) are also demonstrated while keeping the primary motor cortex engaged (Kumru et al., 2016) and eliciting neuron pruning.

1.1.1 Problem statement & justification for research

The use of QASLS to identify functional movement deficiencies correctly identifies areas for improvement, providing a critical approach to injury prevention. However, the current training approach often focuses on strength enhancement and “spot-fixing” problem areas, typically requiring 4-8 weeks depending on the training regime. However, this approach overlooks the importance of coordination and cognitive learning.

There is a substantial body of research dedicated to musculoskeletal training, thus continuously increasing the research gap for cognitive learning and performance (Kafri & Atun-Einy, 2019; Maestroni et al., 2020; Ngo et al., 2024; Paravlic et al., 2023). The new tool, QASLS, is frequently used as an outcome measure for patient performance to monitor either improvements or regressions, yet the potential for this tool to be used as a training parameter for cognition has not been utilised. This research proposes the integration of cognition and skill learning for single-leg loading tasks (monitored through QASLS) and the use of external visual feedback due to its role in enhancing motor control performance. This approach seeks to bridge the gap in cognition and skill learning by measuring intrasession motor control performance and the influence of visual stimuli. This also has the potential to provide an alternative evidence-based approach to provide practitioners with a greater understanding of cognitive

learning in functional movement training. Potentially leading to more effective training regimens and improved patient outcomes by ensuring the appropriateness of interventions; which will conceivably benefit (1) performance, (2) motor competence, and (3) rehabilitation progression while mitigating (re)injury risk, particularly for 'low-skilled', novice, and recreationally active individuals of whom meet the UK physical activity aerobic guidelines.

1.2 Aims & objectives

Building on the existing literature, this study aims to address the current research gap in cognitive learning, the use of external feedback, and the use of QASLS as a scoring and feedback aid. The central research question to guide this study is: What is the influence of augmented visual feedback on motor control performance during isolated single-leg loading tasks?

Therefore, the research aims are to:

- Investigate the role of augmented visual feedback on motor control performance during a single leg loading task, 'Single leg squat.'
- To administer concurrent feedback (experimental condition) during a single-leg loading task by displaying the frontal and sagittal plane (of the weight-bearing limb) on monitors placed directly in front of the subjects.
- To administer terminal feedback during participant rest times to highlight potential movement errors made.

Objective:

- To compare the effect of visual feedback on single-leg loading performance by measuring changes between control (no feedback) and experimental (feedback) conditions.

Confirmatory analyses:

H_0: There is at least 'strong' evidence (Bayes Factor [BF], $BF_{01} \geq 10$) for no effect of visual feedback on QASLS score; The null hypothesis states that visual feedback does not affect or increases QASLS scores.

H_1: There is at least 'strong' evidence ($BF_{10} \geq 10$) for an effect of visual feedback on QASLS score; The alternative hypothesis states that visual feedback reduces or improves QASLS scores

2.0 Chapter 2: Literature review

2.1 Movement screening in sport, health, and exercise

Movement is the coordinated interaction of anatomy to move the body or part of the body, controlled through the nervous system (Lu & Chang, 2012) while screening as acknowledged by Parry (2021) is medical terminology to distinguish healthy individuals from those at-risk or predisposed to a specific condition by assessing an individual's functional capability (Dorrel et al., 2018; NHS, 2021).

Movement screening is a process that provides clinicians with a battery of tests to screen the functional movement of athletes, the general population, and post-rehabilitative patients (Teyhen et al., 2012). Functional movement screening (FMS^{TM}) is predominantly used as an evaluation tool of movement quality to assess asymmetries in dynamic movement and functional capacity (Cook et al., 2006a). This provides the clinician(s) with the ability to identify functional deficiencies such as mobility, stability, neuromuscular coordination, and muscle weaknesses and imbalance (Cook et al., 2006b; Hotta et al., 2015). Functional movement screening presents auxiliary uses when used in conjunction with qualitative assessment scoring as variations of testing parameters isolate imbalances along the kinetic chain (Cook et al., 2006a). These findings suggest the implementation of movement screening may be used to identify movement errors as a pre-indicator for a non-contact injury in asymptomatic individuals, providing a directional approach to athletic training to remedy deficits in functional capabilities (Cook et al., 2006a).

For clinicians to screen the functional capabilities of a human being, a battery of tests is utilised. Examples of these tests conducted by Cook et al., (2006a; 2006b) are: Deep squat, Hurdle step, In-line lunge, Shoulder mobility, Active straight leg raise, Trunk stability push-up, and Rotary stability. These tests are scored zero to three (individually) with zero indicating reports of pain during the screening process, and three indicating complete movement without error. These scores are combined for a potential total of twenty-one. Individual studies specify differences in cut-off scores to determine the risk of injury, as differences in age, weight, and fitness level vary among participants, sports, and

population samples. An example of this is a total score ≤ 13.5 indicates a risk of injury for participants with a history of previous injuries (Huang & Liu, 2022). However, preliminary literature contradicts the nature of FMS as a predictor for injury risk stating there are no correlations between FMS score and injury prediction accuracy (Bardenett et al., 2015; Dorrel et al., 2018).

Additionally, a musculoskeletal profiling tool, Qualitative analysis of single-leg loading (QASLS), is a recent tool developed with an evaluation scale which utilises a dichotomous scoring system (Herrington et al., 2013; Parry, 2021). This system is a zero-to-ten scoring system where each "movement error" is recorded as a point. This movement screening tool calculates the quality of movement during two prospective tests, single-leg squat and single-leg land. During this process, an individual will be scored based on bodily segmentation, specifically foot, knee, thigh, pelvis, trunk, and arms (Parry, 2021) which focuses on movement errors in kinematics such as limb position and can be used alongside FMS as seen within Cook et al., (2006a; 2006b) publications or as a singular test.

2.1.1 Validity of movement screening

Validity within the field of academia and research depends on whether researchers effectively address their intended research questions. A study is credible and accurate when it aligns with its stated objectives (George et al., 2003). For example, both internal and external validity are imperative within research – internal validity ensures the study design assures the fidelity of the results by demonstrating a causal link between two variables, whereas external validity represents the accurate generalisation of the population and applies to larger populations, settings, and experiments (Andrade, 2018). However, the confidence of the validity of any test or study must have credible reliability with both inter and intra-rater reliability being appraised to improve the validity of a study. Having credible reliability ensures consistency, and validity confirms its accuracy, as such, having reliable results in a study provides a sturdy platform needed to evaluate validity. This process ensures that the results are consistent and repeatable, thereby reinforcing confidence in the study's findings (Nae et al., 2017).

Assessing the validity of a qualitative assessment strategy for screening the functional movement capabilities of an individual has been previously validated regarding lower limb alignment

control. Herrington & Munro (2014) investigated the criterion validity of QASLS by assessing the movement quality of 5 participants (male, n = 3. Female, n = 2; mean age 20.6 ± 1.3 years; height 1.7 ± 0.1m; weight 78± 7kg) during single-leg landing and single leg squat tasks. These tasks were analysed by a 12-camera OQUS 3D motion capture system (Qualisys, Gothenburg, Sweden) and a qualitative scoring system for a comparative measure. Participants were instructed to perform a single leg squat on a force plate with 45° – 60° of knee flexion. This study identified a strong correlation between the kinematic data collected through 3D motion capture and qualitative assessment scoring. Therefore, this would offer a cost-effective alternative for clinicians, avoiding cost-related barriers to assessment. For instance, a 3D camera, Arqus (Versions A5-A26; Qualisys, Gothenburg, Sweden), costs between €7000-€13000 per camera, providing a median twelve camera set up cost of €120,000 (Qualisys, 2023). However, due to the small sample size (n = 5), there is insufficient evidence to suggest an effective alternative for clinicians which puts the construct validity into question. Consequently, more research in comparing movement screening analysis strategies must be conducted with a larger sample size.

The validity of FMS as an effective tool to identify individuals with a predisposition to injury, muscle imbalance, and deficits in neuromuscular coordination and movement capabilities has been investigated between 2015-2022 (Bardenett et al., 2015; Dorrel et al., 2018; Huang & Liu, 2022; Wright et al., 2015). Since FMS became a popular tool in screening predisposed athletes and the general population, Wright et al., (2015) implemented a four-week movement training scheme on twenty-two adolescents (mean age = 13.4) with a focus on dynamic movement principles while coaching movement quality with the training intervention including the use of resistance bands and body-weight exercises. Movement screening was tested in a randomised order and was assessed using video cameras in both sagittal and frontal planes. However, this study does not specify camera height or distance from the participants, lowering the study's replicability. As such, differing camera height or distance will change the field of view and perspective; additionally, standardising participant positioning relative to the plane being observed would enhance methodological repeatability. If the camera and participant positions are not standardised, the cameras may capture movement differently due to perspective error. This can lead

to inconsistent measurements across trials or studies. Nevertheless, data analysis was conducted after a four-week washout period, improving rater reliability by reducing bias. The result of this study indicated that short-term interventions do not affect FMS performance. Furthermore, due to this study being focused on adolescents, there are physiological characteristics to consider for future research, such as maturation, development, and level of motor control (Bardenett et al., 2015). This is crucial because adolescents are at varying stages of physiological and neurocognitive development. Therefore, considering motor control levels will guide future research directions.

This was corroborated by Bardenett et al., (2015) where 185 student-athletes (male, n = 88, female, n = 97; mean age = 15.2) were assessed functionally pre-season and post-season where 39 participants sustained a musculoskeletal injury. The findings of this study indicated a predictive value for college level should not be used for adolescents due to no correlation being recognised. Therefore, these studies highlight the need for further research within the adolescent population while including augmented parameters, and training regimes to address functional deficits while evaluating individual stages of physiological development.

An alternative view on the validity of FMS is found by Huang & Liu, (2022) who investigated the prediction capability of FMS for exercise injury risk, specifically on 165 Chinese police staff (male, n = 82, female, n = 83; aged 23-56). As stated within this study, improving an individual's health does not come from the quantity of exercise alone, but also from the quality of exercise, indicating the importance of FMS within this population. Once testing was complete, scores were totalled and Huang & Liu, (2022) demonstrated the professional application of FMS to be used by healthcare practitioners as a physical examination for Chinese police staff with previous injuries as a potential predictor of injury. As this study provided a positive result for this population this should be considered for use as a pre-exercise screen due to the simplicity of the qualitative analysis. However, even though this study provides promising results for clinical practice in validating FMS for Chinese police staff, the influence of genetics and morphology should be investigated to report external validity. On the other hand, a previous study conducted by Dorrel et al., (2018) investigated the injury prediction accuracy of 257 collegiate athletes (male, n = 176, female, n = 81; aged 18-24), and found no significant relationship

between FMS scores. To conclude, clinicians and members of a multidisciplinary team must remaincautious when using the FMS tool as an injury predictor; however, the use of FMS and QASLS may provide knowledge of functional deficiencies which would provide a directional approach to athletic training and fitness.

2.1.2 Reliability of movement screening

Reliability in scientific literature is when the observed values are compared to the 'true' values across different data sets or participants; high reliability would indicate that the measurement error is low, meaning the measurements are consistent and repeatable (Bruton et al., 2000; Barlett & Frost, 2008). Repeatability refers to the obtainment of consistent measurements under the same conditions, without variation (Barlett & Frost, 2008). For example, within scientific research, rater reliability would be a practitioner/researcher's consistent administration of a specific protocol or measurement device. Within the current literature regarding the reliability of movement screening, inter-rater and intra-rater reliability are the key focal points to determine the reliability of FMS and QASLS.

Previous studies conducted to test the reliability of the movement screening tools have been investigated between 2013-2022 (Almangoush et al., 2014; Epstein et al., 2022; Ressman et al., 2021; Shultz et al., 2013; Smith et al., 2013). These studies had a range of participants (4-39) both male and female (mean, n = 23.8 subjects per study; total, n = 119). Study subjects participated in either the seven fundamental movements (Shultz et al., 2013; Smith et al., 2013), single-leg squat and/or single-leg land (Almangoush et al., 2014; Ressman et al., 2021), or single-leg triple hop (Epstein et al., 2022). Studies conducted by Shultz et al., (2013) and Smith et al., (2013) investigated rater reliability when scoring FMS and results indicated good test-retest reliability for the lead researcher. In particular, the ICC (interclass correlation coefficient) ranged from 0.81-0.91 across four raters, indicating excellent reliability; although, the confidence interval ranges between 0.57-0.96, suggesting uncertainty in the reliability estimate (Smith et al., 2013). Additionally, there was poor to excellent inter-rater agreement between FMS tasks as determined through Krippendorff's alpha, with reliability ranging from 0.10-0.95

(Shultz et al., 2013) However, raters were not of the same profession or level of expertise. To improve inter-rater reliability, using raters from the same/similar professional backgrounds would improve the rater reliability due to the level of understanding of human biomechanics being consistent – one rater was an athletic trainer, while another was an inexperienced physical therapy student. As such, to improve rater reliability between trials or studies, adherence to standardised training (for musculoskeletal [MSK] profiling) and utilising video recordings, while receiving feedback on rating outcomes may provide an initiative-taking approach to standardise minimum rater experience. Therefore, instigating consistent training and providing a feedback loop to raters would help minimise rater differences. Additionally, in the case of Smith et al., (2013) scoring of FMS was completed during (live administration), this may inherently reduce rater reliability as raters could not evaluate performance from sagittal and frontal concomitantly as Gribble et al. (2013) reported high intra-rater reliability when testing both planes. As a result, raters would be unable to identify movement errors made in a separate plane. Therefore, 2D video analysis should be conducted for review during movement screening tests to reduce testing time with the additional benefit of training raters as live-versus-video ICC being 0.60 and 0.92 respectively (Shultz et al., 2013).

Research studies conducted to evaluate the intra-rater reliability during single-leg loading tasks (Almangoush et al., 2014; Epstein et al., 2022; Ressman et al., 2021) all show support for the ability to identify movement errors and functional deficiencies when screening participants qualitatively regardless of rater experience. To conclude, inter-rater reliability for FMS and QASLS has varying results depending on the research methodology, specifically the procedure and method of analysis. Consequently, altering the reliability of each study. Conversely, the reliability of QASLS remains consistent, which may be a factor of simplicity of administration. As such, the reliability of a study is increased when specific practices are put in place to ensure guidelines are met. Intra-rater reliability remains high when following specific methodological criteria, such as utilising video recordings and set camera positioning, to maintain consistency. This provides the rater with the same conditions between trials or participants. Inter-rater reliability is improved when raters are from similar professional backgrounds or follow standardised training to ensure a homogenous rating capacity.

2.1.2.1 Objective measurements in subjective assessments

Functional movement screening (FMS) and QASLS-based assessments are typically evaluated subjectively by professionals in their respective fields. These assessments can be conducted 'live' (in person) or later via video recordings (Shultz et al., 2013). However, the subjective nature of screening tools is inherently biased and prone to measurement errors (Whelan et al., 2017) because clinicians need to obtain 'data' from multiple sources simultaneously, which may reduce the accuracy of the subjective manual scoring (Whiteside et al., 2016).

Studies by Di Paolo et al. (2021), Whelan et al. (2017) and Whiteside et al. (2014) evaluated the differences in scoring movement tasks subjectively and with quantitative input. Both Whelan et al. (2017) and Whiteside et al. (2014) utilised Inertial Measurement Units (IMUs) to test agreement and accuracy between conditions. Whelan et al. (2017) instructed 83 participants (Male, n = 60, Female, n = 23; Age = 26.68 ± 4.91) to perform the single-leg squat (SLS) which was rated by a Chartered Physiotherapist and an IMU system. Whelan et al. (2017) indicated the measurements obtained from the IMU can evaluate SLS performance with moderate accuracy, sensitivity, and specificity (65-76%, 60-80%, and 61-77%, respectively). Whiteside et al. (2014) evaluated the performance of 11 Division 1 women's basketball players (age = 19.7 ± 1.5) during an FMS assessment by a certified FMS assessor and IMU system which captured 'full body' kinematics. The agreement between rating systems was scored according to a weighted Kappa statistic (K_w), with agreement scores ranging from poor to moderate. The lowest agreement (rotary stability) was scored as $K_w = 0.05$ and the highest agreement (left hurdle step) was scored as $K_w = 0.52$. The results of this study suggest that there is a systematic measurement error with subjective scoring. This may lead to a diminished value of the FMS as the inaccurate screening (compared to objective data) may lead to inaccurate test scores. Additionally, Di Paolo et al. (2021) successfully validated the use of 2D scoring during a qualitative deceleration assessment; 3D analysis was used to capture motion kinematics while determining the associations between the 'gold standard' and the 2D alternative. Thirty-four recreational and elite footballers (Male, n = 18, Female, n = 16; age = 22.8 ± 4.1) completed the multi-movement deceleration task with the

evaluation of both frontal and sagittal biomechanics. Results from this study provided an inter-and-intra-rater ICC > 0.94 (found as excellent reliability) indicating the usefulness of 2D analysis during clinical screening.

As such, the literature provides a unique progressive standpoint – objective data and biomechanical tools can be used in conjunction with subjective manual scoring to provide additional input and improve accuracy by reducing systematic measurement error. Therefore, the use of quantitative measures during qualitative assessments are warranted.

2.1.3 Single leg loading tasks in sport, health, exercise, and daily living

Single-leg loading tasks are multi-joint load-bearing activities that require core strength (Ugalde et al., 2015), and an appropriate level of motor control (Nascimento et al., 2023) to complete without risk of injury. Limb asymmetry due to differences caused by sport, leg dominance, and muscular imbalance has been identified as a factor in injury predisposition (Nakahira et al., 2022). Nakahira et al., (2022) explored the kinematic differences between leg dominance during a single leg drop vertical jump in 64 female high school and collegiate soccer players (mean age 16.6, age range 15-22). Participants performed 3-5 practice trials when jumping off a 30cm box with an immediate vertical jump when the participants touched the floor. However, there may have been an unfair learning advantage due to the discrepancy of practice trials between each participant; Additionally, participants within this study were given rest time to prevent fatigue, yet there is no mention of a specific length of time for each participant, thus decreasing the repeatability of this study as methodological parameters are not clearly defined. The result of this study indicated a kinematic difference between dominant and non-dominant legs, where the degree of dynamic knee valgus (DKV) with non-dominant kinematics had a greater DKV during the initial ground contact. However, participants only completed the test trial once, potentially lowering data reliability as a single trial may not capture the full capabilities of the participant due to individual variability. Therefore, increasing the number of trials per participant would have provided intrapersonal differences to be evident within the results. Considering the results, these

kinematic differences were also seen in a preliminary study by Herrington (2014) who investigated the differences in DKV angle during a single leg squat and landing within female patients (asymptomatic, n = 30; unilateral patellofemoral pain, n = 12). The results indicated the degree of knee valgus was greater in the patellofemoral pain limb than in the contralateral leg and asymptomatic patients. These consistent patterns among studies emphasise the importance of understanding kinematic differences for single-leg loading tasks.

Furthermore, an interesting study depicting the differences in single-leg movement patterns by altering the position of the non-stance leg was investigated by Khuu et al. (2016) to identify movement errors and kinematic patterns for the trunk, pelvis, and lower extremities in 16 females (mean age 23.1). Three non-stance leg positions were used for this study: 1 – the non-stance leg was positioned anteriorly similar to a "pistol-squat" (with less degree of knee flexion), 2 – the non-stance leg was positioned in line with the stance leg with some degree of knee flexion with the none weight bearing foot being raised to ankle height of the weight bearing limb, 3 – the non-stance knee was flexed to 90°. The results indicated the observational differences between non-stance positions and kinematic demands were evident between the stance 1 and stance 3 positions for pelvic anterior tilt and pelvic drop. Concluding pelvic kinematics are affected by differences in non-stance leg position. However, improvements to be made to make this data more applicable for a larger populous would be by including male participants. Yet, data validity is appropriate for this sample population as reported p-values for kinematic differences between non-stance limb positions were < 0.05, indicating how the study met the research objectives. Future research should meet the inclusion of male participants with a larger age bracket to represent a larger population value.

2.1.4 Anatomical relevance

In single-leg loading tasks, such as the SLS, the order of muscular activation varies depending on individual well-being. Factors such as biomechanics, neuromuscular coordination, and muscular function play a key role in the SLS (see Table 1). Mirzaie et al. (2019) identified differences in patella

alignment and order of muscular activation and activity using Bipolar Ag-AgCI surface electrodes tomeasure EMG activity following the SENIAM (surface EMG for a non-invasive assessment of muscles) placement instructions. Outcomes from this study displayed an earlier activation of the vastus lateralis for male patients with patellofemoral pain due to reduced or delayed muscular activity of the vastus medialis oblique resulting in maltracking of the patella leading to patellofemoral pain; however, maltracking was a theoretical explanation due to the impaired alignment of the femur, with no direct measures taken for joint positioning. Additionally, the excessive frontal plane motion of the knee joint (valgus torque) has been shown to increase the risk of an anterior cruciate ligament (ACL) injury from the associated rotational movements of the hip, femur, and tibia (Shirey et al., 2012).

Table 1. *Anatomy involved in single leg movements.*

Anatomy	**Function**	**Origin & insertion**	**Nerve innervation**	**Blood supply**
Erector spinae	Provides stability and aids in maintaining posture through the provision of an erector moment.	In erector spinae aponeurosis, the superficial portion inserts into the lower 10 ribs with the deep portion inserted through transverse T4-L4.	Lateral posterior rami.	Intercostal arteries.
Quadratus lumborum	Provides ipsilateral stability during contralateral lateral flexion. Acts as a stabiliser during frontal plane movement.	Iliac crest and inserting onto the 12th rib and transverse L1-L4	Subcostal T12 cutaneous, and anterior rami (iliohypogastric & ilioinguinal) nerves.	Lumbar arteries.
Transverse abdominis	Aids in lumbopelvic stabilisation and increases intra-abdominal pressure.	Originates from the iliac crest and lateral inguinal ligament and inserts in an aponeurotic manner onto the rectus sheath.	T7-L1 thoracolumbar nerves, subcostal (T12), and ilioinguinal, iliohypogastric (L1).	Deep circumflex iliac artery.
Lumbar Multifidus	Provides intersegmental stability and aids in maintaining posture through the provision of an erector moment.	Lumbar mammillary processes, posterior sacrum, and posterior superior iliac spine and insert into the spinous processes above (2-4 spinal levels above origin)	Medial lumbar dorsal rami.	Lumbar arteries.
External & internal oblique	Trunk rotation, postural support, and increases intra-abdominal pressure.	External – originates from the lower eight ribs and inserts at the linea alba, inguinal ligament, and pubic crest. Internal – originates from the iliac crest and lateral inguinal	External – ventral rami T7-T-12 Internal – ventral rami T7-L1	Deep circumflex iliac artery.

		ligament and inserts onto the lower 4 ribs and pubic crest.		
Iliopsoas	Primarily acts as a hip flexor with a secondary function of femoral rotation while stabilising the lumbo-pelvis region.	Psoas major – originates from the transverse processes of T12-L5. Iliacus – originates from the iliac crest, superior iliac fossa, and sacral ala. Both insert onto the lesser trochanter.	Ventral rami (L1-3) and femoral nerve (L2-L3) for the iliacus portion.	Iliac and femoral artery.
Gluteus maximus	Propel body forward from 45°- 65° of hip flexion.	Sacro-tuberous ligament, posterior lateral aspect of the sacrum/coccyx and the gluteal surface of the ilium and inserted onto the iliotibial band and linear aspera of the femur.	Inferior gluteal nerve (L5-S2)	Superior & inferior gluteal artery.
Gluteus medius	Stabilise the hip and generate lateral movement.	Superior ilium and inserting onto the lateral greater trochanter of the femur.	Superior gluteal nerve (L4-S1)	Superior gluteal artery.
Gluteus minimus	Hip Abduction, rotation, and flexion.	External ilium and inserts onto the greater trochanter.	Superior gluteal nerve (L4-S1)	Superior gluteal artery.
Vastus lateralis	Aid in knee extension.	Greater trochanter of the femur and inserted into the tibial tuberosity via the patella tendon.	Femoral nerve (L2-L4)	Descending branch of the lateral femoral circumflex artery.
Vastus intermedius	Extends the knee.	The anterolateral aspect of the femur and inserted into the tibial tuberosity via the patella tendon.	Femoral nerve (L2-L4)	Lateral femoral circumflex artery.
Vastus medialis	Aid in knee extension and provide stability to the patella through prevention of lateral patella maltracking.	Linea Aspera of the femur and inserted into the tibial tuberosity via the patella tendon.	Femoral nerve (L2-L4)	Descending genicular artery.
Rectus femoris	Knee extension and hip flexion.	Originates from the anterior inferior iliac spine and superior lateral acetabulum.	Femoral nerve (L2-L4)	Lateral femoral circumflex artery.
Gastrocnemius	Plantarflexion and aids in knee flexion.	The medial head originates from the popliteal surface of the femur while the lateral head arises from the posterolateral aspect of the lateral femoral condyle. Then inserting onto the posterior surface of the calcaneus via the Achilles tendon.	Tibial nerve (S1-S2)	Sural branches of the popliteal artery.
Soleus	Plantarflexion.	Originates from the medial border of the tibia and posterior head of the fibula. Inserting onto the posterior surface of the calcaneus via the Achilles tendon.	Tibial nerve (S1-S2)	Posterior tibial artery.
Tibialis anterior	Dorsiflexion and inversion.	Lateral condyle of the tibia and lateral surface of the tibial shaft. Inserting onto the first metatarsal and medial cuneiform.	Deep peroneal nerve (L4-S1)	Anterior tibial artery.
Tibialis posterior	Plantarflexion.	Posterolateral tibia and posteromedial fibula and insert onto the navicular tubercle.	Tibial nerve (S1-S2)	Posterior tibial artery.

Biceps femoris	Knee flexion, Hip extension, and lateral rotation.	Ischial tuberosity and linea aspera of the femur. Inserting onto the head of the fibula and lateral condyle of the tibia.	Sciatic nerve (long head, S1-S3; short head, L5-S2)	Deep femoral artery.
Semitendinosus	Knee flexion, Hip extension, and medial rotation.	Ischial tuberosity and inserts onto the proximomedial tibial condyle.	Sciatic nerve (L5-S2)	Deep femoral artery.
Semimembranosus	Knee flexion, Hip extension, and medial rotation.	Ischial tuberosity and inserts onto the posterior medial tibial condyle.	Sciatic nerve (L5-S2)	Deep femoral artery.

Note. Adapted from (Akita et al., 1993; Anderson, 2016; Andrikoula et al., 2006; Beck et al., 2000; Kibler et al., 2006; Bordoni & Varacallo, 2023; Bustami, 1986; Castanov et al., 2019; Dasenbrock et al., 2011; Doral et al., 2010; El Zawawy & El Sekily, 2012; Grevious et al., 2006; Guelfi et al., 2017; Gupta et al., 2019; Hofste et al., 2020; Kim et al., 2005; Lenhart et al., 2014; Loh et al., 2003; Martini et al., 2018; Mawston & Boocock, 2015; Nene et al., 2004; Park et al., 2012; Phillips et al., 2008; Reiman et al., 2012; Revenaugh et al., 2012; Richardson et al., 2002; Ryan et al., 2014; Sahinis & Kellis, 2021; Shah & Bordoni, 2023; Thiranagama, 1990; Tsai et al., 2017; Varghese & Bianchi, 2014; Whiteside, 2014; Wilson et al., 2019; Wu et al., 2021; Yoshida et al., 2017; Zheng et al., 2008).

2.1.5 Injury predisposition, epidemiology, and prevalence

Predisposing factors for lower limb non-contact injuries can be identified through movement deficiencies among FMS and QASLS during single-leg loading tasks. For example, patellofemoral pain syndrome (PFPS) and ACL injuries have been identified in preliminary literature due to changes in biomechanics, neuromuscular coordination, and reduction in gluteal strength. Resulting in poor limb alignment, medial collapse, and excessive knee movement within the frontal plane leading to DKV (Acevedo et al., 2014; Wilczyński et al., 2020). Wilczyński et al., (2020) identified the reduction in neuromuscular coordination inhibited the function of mechanoreceptors responsible for the reflex function and positioning of the limbs (Golgi tendon organ and muscle spindles) contributed to ACL injury while increasing stress of the patellofemoral joint and retinaculum due to maltracking of the patella.

Previous studies have compiled data on the incidence rate and prevalence with the main findings from the UK and US populations. Within the UK and USA, knee MSK injuries are the second most prevalent with patellofemoral pain being highlighted as the most prevalent with a citation rate of 15% - 45% (Smith et al., 2018).

The incidence rate for a non-contact ACL injury was seen to be 0.25 per 10,000 hours of athletic exposure gained from training and matches (for athletes) with the USA totalling 120,000 ACL injuries annually with 41% being non-contact with the mean incidence rate of 68.6 per 100,000 per year; 70% - 80% of these cases arising from a non-contact mechanism (Acevedo et al., 2014; Kaeding et al., 2017; Montalvo et al., 2019; Sanders et al., 2016). The incidence rate of PFPS within the UK between 2000 – 2005 was 25% with separate reports also stating a rate of 3-40% (Callaghan & Selfe, 2007); with 1 in 10 military recruits and 1 in 5 individuals from the general population suffering at any one time where female patients being twice as likely for this pathology (Smith et al., 2018). However, the incidence rate and prevalence of ACL and PFPS have not been reviewed in detail within the past 5 years. Public records within the UK of incidence rate and prevalence are not accessible, to the author's knowledge, with a shortage of available full-text copies making the precise estimation difficult. An area for future research would be to review and update the current rates to provide more reliable data for research purposes.

2.2 Feedback in sport and active daily living

Recognising and rectifying movement deficiencies often rely on the use of feedback provided by a practitioner or coach. Within sports, athletic and occupational training, and daily living, there are an abundance of feedback techniques available, both psychological and physiological. Augmented feedback presents information about a result from an external source (Sigrist et al., 2013b). Within sport and clinical settings, feedback can be delivered in a variety of ways as internal (AKA inherent), exteroceptive feedback (EFB) and augmented (externally provided [see figure 1]). An example of *external* feedback is to provide an individual with knowledge of performance (KP) where the

information provided informs the subject(s) about the quality of movement (Schmidt & Wrisberg, 2008) or knowledge of results (KR) which consists of information regarding a specific goal (Lauber & Keller, 2014) such as pass/fail or completion criteria. Augmented feedback (AFB) can be broken down into sub-categories as identified by Schmidt & Wrisberg (2008) and applied to training to enhance performance in neuromuscular coordination and skill learning (Sigrist et al, 2013a). Examples include kinematic, parameter, descriptive, and reinforcement – additional information found on pages 283-294 of *motor learning and performance* (Schmidt & Wrisberg, 2008).

In sports and active daily living, feedback can be provided through wearable devices such as a smartwatch, as visual data from on-screen results or haptics from vibrations. Coaches and practitioners (external sources) can provide verbal encouragement, prescriptive feedback focusing on error modification, or video analysis. Therefore, supplementing implicit (internal) feedback provides an individual with KR or KP, leading to enhancements in the performance of a specific skill during the initial cognitive stage of skill development (Chen, 2001). However, AFB can become detrimental to individuals in the long term due to dependency on feedback for task completion which inhibits the use of intrinsic mechanisms (Petancevski et al., 2022) such as interoceptive information. Fortunately, this can be avoided by altering the admission of feedback during training (relative feedback frequency) such as reducing feedback once the individual becomes skilled; and changing the parameters from practitioner-controlled to subject-controlled feedback (Chen, 2001) which provides the user with feedback when necessary. An additional approach would be to utilise bandwidth feedback which provides the user with information once an error becomes unacceptable (Schmidt & Wrisberg, 2008); therefore, the individual would rely on inherent proprioceptive feedback in conjunction with AFB. For example, if a practitioner instructed an individual to squat to 90° of knee flexion and provided an acceptable degree range, i.e., 88° - 92° of knee flexion. If the individual went outside of this range, they would receive AFB to correct their movement. Feedback techniques can also be altered by the timing of delivery such as during an activity which is classified as concurrent feedback (CFB) or after an activity, terminal feedback (TFB) – reviewed in the next section.

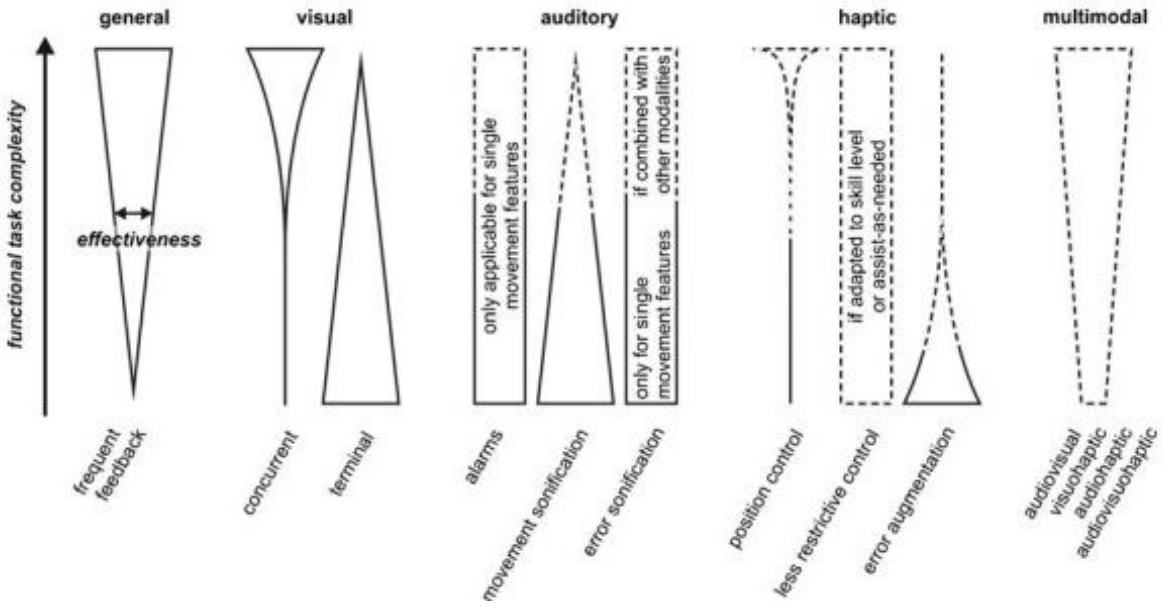


Figure 1. Effectiveness of feedback strategies on functional task complexity.

Note. Taken from *'Augmented visual, auditory, haptic, and multimodal feedback in motor learning: A review'* by Sigrist et al. (2013a).

2.2.1 Concurrent and Terminal feedback styles

For the augmentation of feedback to be effective, deliverance must be appropriate to the task to maximise learning outcomes without the degradation of skill retention or limiting sensory mechanisms gained from intrinsic feedback due to the dependence on augmented factors (Walsh et al., 2009). A balance between concurrent and terminal feedback needs to be facilitated. Previous research has provided literature on the benefits and problems with timing AFB for both simple and complex skill learning. Ferris et al., (2022) evaluated the effectiveness of feedback timings with a visual aid on balance training in older age adults (n = 19, mean age = 70); this study implemented concurrent and terminal visual feedback (experimenter-controlled) during a balancing task with participants standing on a foam pad (Airex AG, Sins, Switzerland) which displayed movement displacement – mediolateral and anteroposterior. Eye-level on-screen feedback was displayed 10ft' away, with concurrent feedback being displayed as an on-screen cursor while terminal displayed the cursor path taken throughout the test. The purpose of this test was to evaluate the effectiveness of balance training with feedback on the

elderly population to provide a cost-effective alternative and implementation of mobile devices as a substitute for expert supervisory testing. Results of this study indicated that feedback reduced movement sway with terminal having greater benefits regarding the retention of a performance increase after testing – the mean sway velocity decreased significantly ($P < 0.001$) during training after receiving terminal feedback; additionally, the 95% CI estimate is lower in the terminal condition over the concurrent (-0.179, -0.065 and –0.159, -.0.063 respectively). However, this research concludes with the use of smartphone devices being the optimal cost-effective device for the assessment of balance training. Yet, no comparison of smartphone visual feedback was compared against the devices used in this experiment. Therefore, future research should compare the reliability of data reported by these devices to draw an accurate conclusion. Additionally, an unreliable conclusion, to the author's sentiment, was made in a study by Yamamoto et al., (2019) due to nonoptimal feedback parameters for the given task. Within this study, 64 (n male = 32, n female = 32) participants received visual feedback during a left lower limb loading task using a force plate (Kistler instruments AG, Winterthur, Switzerland) with instructions to adjust weight distribution to a set goal. Participants received visual KP using a colour-coded "traffic light" system to display correct and incorrect weight distributions with a bandwidth feedback parameter of $\pm$ 2%. However, results indicated no noticeable improvement in the performance of lower limb loading; therefore, future research should use more appropriate visual feedback to display KP/KR to provide data to participants instead of using lights that do not specify data/data range – such as displaying the distribution percentage as providing feedback as light does not provide sufficient instruction to the participant as to increase or decrease their weight distribution.

To conclude, one of the pivotal findings in research on feedback, as corroborated by Huet et al., (2009); and Sigrist et al., (2013b), is that CFB is more effective during skill learning in reducing cognitive interference by guiding an individual through a movement/task while TFB provides increased rates of skill retention as an individual utilises internalisation and interoceptive feedback such as proprioception as they are forced to process previously made movement errors. As a result, a combination of feedback techniques with modified parameters should be implemented within training.

2.2.2 Concurrent visual feedback techniques

Concurrent visual feedback can be delivered variously. In a study by Sewall et al., (1988), Eighteen college-aged male participants were instructed to perform a power clean using an instructional videotape and a mirror. Performance was scored out of 10, with points deducted for errors (U.S. Weightlifting Federation). Two groups were made, the experimental group were instructed to look at a mirror placed 45° to the sagittal plane during each lift as the instructional videotape was also recorded from this angle. Participants performed 24 practice trials followed by 3 repetitions without the mirror and a final 3 repetitions with a mirror (after 2 minutes rest). Findings from this study indicated that performance increased only when the mirror remained in place, and performance reduced without the mirror in the experimental group following skill retention repetitions. However, scores with a mirror were higher (mean with mirror = 20; mean without mirror = 18.7). Yet, retention was performed on the same day which may not offer optimal time for skill consolidation and adaptation. Therefore, future research should implement an appropriate schedule for skill retention testing with the inclusion of female participants to improve study validity for an increased population size. Furthermore, Steinberg et al., (2016) explored cross-education via the cross-activation model (Hubbard et al., 2011) in 80 right-handed participants (male, n = 39; female, n = 41; mean age = 24.87) to understand whether mirrored feedback (MFB) influences inter-manual transfer in sport-specific tasks. This was completed using a 120x50cm mirror (for a visual aid see Steinberg et al, 2016; page 3 Figure 1) while dribbling a basketball with both hands without feedback and then dribbling the ball with the right hand with MFB. Participants then completed a transfer task by dribbling through pylons. Participants were divided into non-experienced and experienced groups during the task. Results concluded that MFB facilitates inter-manual transfer. However, these results were only prevalent in experienced participants (of whom participated in basketball or handball). Therefore, introducing how skill levels among athletes affected the outcome of using a MFB technique for skill acquisition. Future studies should explore the same hypothesis with different sport-specific skills.

Concurrent visual feedback can also be displayed to subjects using visual data graphs. Marco-Ahullo et al., (2019) presented visual data comprised of an x-y graph displaying time (x-axis) and centre

of pressure in anteroposterior directions (y-axis); displayed 1.5m away at eye level during a continuous balancing task on a seesaw using 30 adolescent participants aged 13-14. This aimed to determine the optimal relative feedback frequency for motor skill learning with feedback frequencies of 100% and 67% during a 30-second trial. Results indicated that both feedback frequencies were equally effective in aiding balance. However, the outcome may not remain consistent with a different sample population i.e., adult athletes and the elderly; greater improvements could be made if the feedback technique was more suitable for the population. An example of a variable feedback technique would be to use a semi-transparent avatar to display the correct posture throughout the trial instead of a graph.

Furthermore, a prime example of effective visual CFB being used to boost athletic performance was demonstrated by Szczepan et al., (2016) where 20 expert swimmers (mean age = 19.3) were guided to maintain an optimal training swimming speed using a LED relay along the bottom of the pool with swimming speed being transmitted via a leader device (Kuca Ltd., PL). Optimal training speed was obtained by adding 10 seconds to the participants' personal best (100m distance) to moderate swimming intensity. Swimmers would complete the test distance first without feedback and then again with feedback by following the LED along the swimming pool. Resulting in swimming times being completed to the desired intensity when using CFB as time trials remained consistent. This style of feedback would provide an effective practical application for training within this sport and should be explored in future research to determine its effectiveness in different sports settings. As such, CFB is an effective technique when administered appropriately to improve motor learning and sports performance/economy.

2.2.3 Terminal visual feedback techniques

Terminal feedback (TFB) is a technique to provide an individual with KR (Liu & Wrisberg, 1997) in response to a sport-specific task or movement outcome. Garcia-Ramos et al., (2023) used on-screen feedback to display jump height performance for 16 participants (male, n = 10 [mean age = 26.4]; female, n = 6 [mean age = 24.5]) during a vertical jump trial. During the trials, environmental conditions

remained the same (22°c & 60% humidity). Trials consisted of 6 jumps performed at an individually chosen knee angle and again at an experimenter-controlled 90° knee angle, with four trials being completed over two weeks. Sessions were executed with a relative feedback frequency of 50% and results indicated that KR is an effective modality to increase vertical jump performance regardless of knee angle. Moreover, Chiviacowsky & Wulf, (2007); Chiviacowsky et al., (2008); Chiviacowsky et al., (2009) completed studies with three populations; adolescents (n = 26, mean age = 10.5), students (n = 24, mean age 21.1), and older aged females (n = 22, mean age = 65.9) to examine how KR may enhance motor learning. Participants completed 6 trials with a relative feedback frequency of 50%, trials consisted of a beanbag (100g) toss on a target (100cm radius) 3m away using their non-dominant arm. The target was segmented from 100-10 with 100 being a bullseye. Zero points were awarded if the participant missed the target. The target was also sectioned into four for directional feedback. Visual TFB was displayed on a board for 15 seconds after 50% of attempts, i.e., right 50. Sixty practice trials took place with ten retention tests taking place one day later (three days later for the older population). Results for displaying TFB of KR expressed an improvement in accuracy performance during practice and retention stages of testing. However, TFB administration varied among studies with experimenter-controlled feedback being used during the 2007 & 2009 studies. Whereas, for adolescents (2008 study), one group obtained experimenter-controlled feedback, the experimental group used a subject-controlled feedback protocol where participants were allowed to choose when to receive feedback. Task and apparatus remained the same with improvements being made in all sample populations. Yet, differences in feedback administration create an unintentional gap in the research, to the author's sentiment, which could have been avoided. Additionally, the reasoning for using only female participants in the 2009 study is not specified. Validity of results would improve if male participants were to be included.

Terminal feedback is effective at improving performance, specifically motor control, during the retention stages of testing. Future research regarding the above studies should include increased population samples; however, the current literature on the administration of KR after sport-specific

tasks and motor learning is reliable yet limited. Future research is needed to reduce gaps in TFB in numerous sports and daily activities.

2.2.4 Psychophysiological effects of visual feedback in sport

An important factor to note for individuals during exercise is the psychological impact of visual feedback on the physiological state. Areas highlighted within the literature are attentional focus toward the task, physical enjoyment, perceived exertion, competitiveness, mood, hedonic tone, and exercise arousal. These areas of interest have been shown to change depending on the task and style of feedback administration, leading to enhanced physical performance, behavioural adjustments, and changes in intrinsic/extrinsic motivation (Trewick et al., 2022; Wilson et al., 2017). The role of using a virtual environment when training, displayed using a projected screen, to provide visual feedback (pedal speed and heart rate) to participants on a stationary bike was conducted by Mestre et al. (2011). This study used a Tacx Trainer VR software which controlled a virtual avatar of the participants (n = 6; aged 19-25). This software recorded participant pedalling speed which translated to the environment for avatar speed displacement. Three conditions were explored; condition 1 – no feedback (control), condition 2 – visual feedback, and condition 3 – visual feedback with a virtual coach (acting as a virtual "pacer" calculated through practice trial speeds [average]). Questionnaires were used before and after testing to calculate changes in perceived exertion (Borg scale), physical exertion (PACES scale) and attentional focus (association-dissociation scale). Results from this study expressed a change in attentional focus with mean scores of 3.47, 6.97, and 8.04 – changes in enjoyment; 3.54, 4.97, and 5.45 respective to the condition, showing the positive effects of visual feedback on psychology. However, within this study there were no mention of sex; therefore, test repeatability would not be accurate. Future research should increase the sample size and provide a factual representation of sex. Otherwise, this study provides an interesting insight into the individuals' perception of visual feedback, potentially being used as a distraction from internal mechanisms i.e., fatigue. Yet, this could potentially impact implicit factors in different tasks such as interoceptive feedback as participants may become reliant on AFB.

Additionally, Campenella et al. (2000) performed isokinetic testing using a dynamometer (Biodex Medical Systems, Shirley, NY) on 30 participants (male, n = 15; female, n = 15; mean age =

25.4) and displayed visual feedback (torque curve) on a monitor at eye level to the participant. Isokinetic testing focused on quadricep and hamstring peak torque. Results displayed improvements made in the experimental group with a mean of 17.16 (male quadriceps) and 8.48 (female quadriceps), 4.72 (male hamstrings), and 4.89 (female hamstrings) with the experimenter stating improvements made due to individual characteristics relating to competitiveness, effort, and motivation; expressing that male subjects are more extrinsically motivated. Demonstrating how feedback can be used to improve psychophysiological performance (Wilson et al., 2018). Thus, psychological, and behavioural factors can be modified with the administration of visual feedback while enhancing physical performance. However, the administration of feedback as a distraction may become detrimental to skill learning if used inappropriately.

2.3 Motor control & cognitive neuroscience

Motor control is the study of action, planning, perception, execution, and cognition of movement (Utley & Astill, 2008; Willingham, 1998) which focuses on the control of physical movement and stability (Rosenbaum, 2010). Motor control has additional sub-factors that define different stages such as motor skill learning – which refers to "the increasing spatial and temporal accuracy of movements with practice" (Willingham, 1998). For example, in physics, this would refer to an individual learning how to use momentum in sports to maximise force on a ball (Rosenbaum, 2010). There are two classifications of motor skills used within the literature: gross and fine motor skills. Gross motor skills involve utilising large muscle groups to perform a task (lifting an object) whereas fine motor skills refer to using smaller muscle groups to perform finer actions such as using utensils or typing on a keyboard (Utley & Astill, 2008). This involves a predetermined sequence of motor actions which is done with varying levels of conscious awareness such as implicit (unconscious) and explicit (conscious) learning which requires active attention to complete a task (Dahms et al., 2019; Kleynen et al., 2014). This leads to motor learning and development which is an individual's ability to learn a skill and adapt to changes in movement which can arise from training or an individual's intention to achieve a goal, thus, motor behaviour (Utley & Astill, 2008).

Furthermore, motor control involves different stages during the development of a new skill which requires different neurological processes. Stages can be broken down into four components owing to the control-based learning theory which consists of (1) strategic, (2) sequencing, (3) perceptual-motor integration, and (4) dynamic processes (Willingham, 1998). However, postliminary studies have concluded that motor learning occurs over three stages (see Figure 2). (1), the cortico-striatal loop (associative circuit) which is comprised of the dorsolateral prefrontal cortex (DLPFC), posterior parietal cortex (PPC), and anterior basal ganglia (BG) is engaged. This is identified as an important factor in motor learning, due to impairments found in individuals with neurological dysfunctions such as Parkinson's disease (Obeso et al., 2000), to acquire new motor sequences effectively for skill learning. The cortico-striatal loop works in conjunction with the cortico-cerebellar loop which works to calculate future movements. (2), newly learnt motor actions are consolidated, known as information chunking. This is owed to the pre-supplementary motor area (pre-SMA), supplementary motor area (SMA), and BG. (3) is the retention phase of learning a motor skill, during this stage motor skills (actions aimed to achieve a goal), actions (goal-specific movement), and movements (behavioural characteristics required to complete an action) (Utley & Astill, 2008), become autonomous and physical performance will become optimal. During this stage, the PPC, pre-motor area (PMA), and the primary motor cortex (M1) are the most active to create "motor maps" for precise movements (Dahms et al., 2019). The stages of motor learning will be discussed in the next sections.

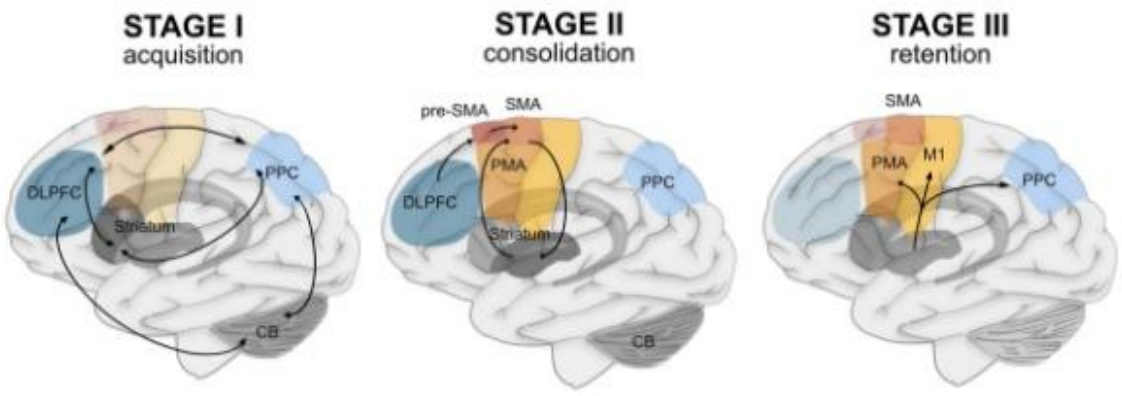


Figure 2. Representation of neural anatomy involved in stages of motor learning.

Note. Taken from *'the importance of different learning stages for motor sequence learning after stroke,'* by Dahms et al. (2019)

2.3.1 Cognitive stage

The cognitive stage also referred to as skill acquisition, is the initial stage where a learner focuses on a specific task, understanding the demands, and determining an appropriate sequence of steps involved to accomplish the task – either implicitly or explicitly (Fitts & Posner, 1967; Taylor & Ivry, 2012; Utley & Astill, 2008). During the first stage, adopted from the three-stage model (Fitts & Posner, 1967), cortico-striatal and cortico-cerebellar systems are highly active (Doyon et al., 2003) with the activity of the cortico-cerebellar system reducing during memory consolidation, yet the cortico-striatal loop remains active during later stages (Doyon et al., 2009). Doyon et al. (2003) evaluated the contribution of cortical systems in the development of a learnt skill by evaluating existing literature. For example, a study using a keyboard and mouse where individuals completed a timed motor sequence with the control group reproducing a random pattern, and the experimental group reproducing a learned sequence. Results from this study indicated changes in cerebellar activity. Extensive activity on the first day and decreased activity on day five with increased activity in the BG and the medial frontal lobe, involved both directly and indirectly in motor skill learning (Schoenberg & Scott, 2011). During retention testing four weeks later, negligible activity was seen in the cerebellum and BG. However, this study specifically focused on neuronal activity during fine motor skill learning, yet the activity during gross motor skills is not determined. Furthermore, this study produced evidence of increased activity of striatal or cerebellar systems dependent on task complexity and style, such as motor sequence learning (see Figure 3). Nonetheless, this either contradicts previously thought conclusions regarding the location of neuronal activity during motor skill learning and motor adaptation or there is some discrepancy in terminology. As examined by Doyon et al. (2003), motor sequence learning activates the striatal circuit, the previous study examined the activity of the cerebellum. Therefore, dated studies suggest cortical circuits work independently on the type of task being learnt. However, new research using EEG devices during the cognitive stage of motor learning shows how both cortical circuits are

important for the cognitive phase of learning (Dahms et al., 2019). Future research should investigate imaging processes during a large study on implicit versus explicit learning to demonstrate how brain activity may change during gross and fine motor skill acquisition during both sequence and differential learning (motor adaptive process) followed through to retention.

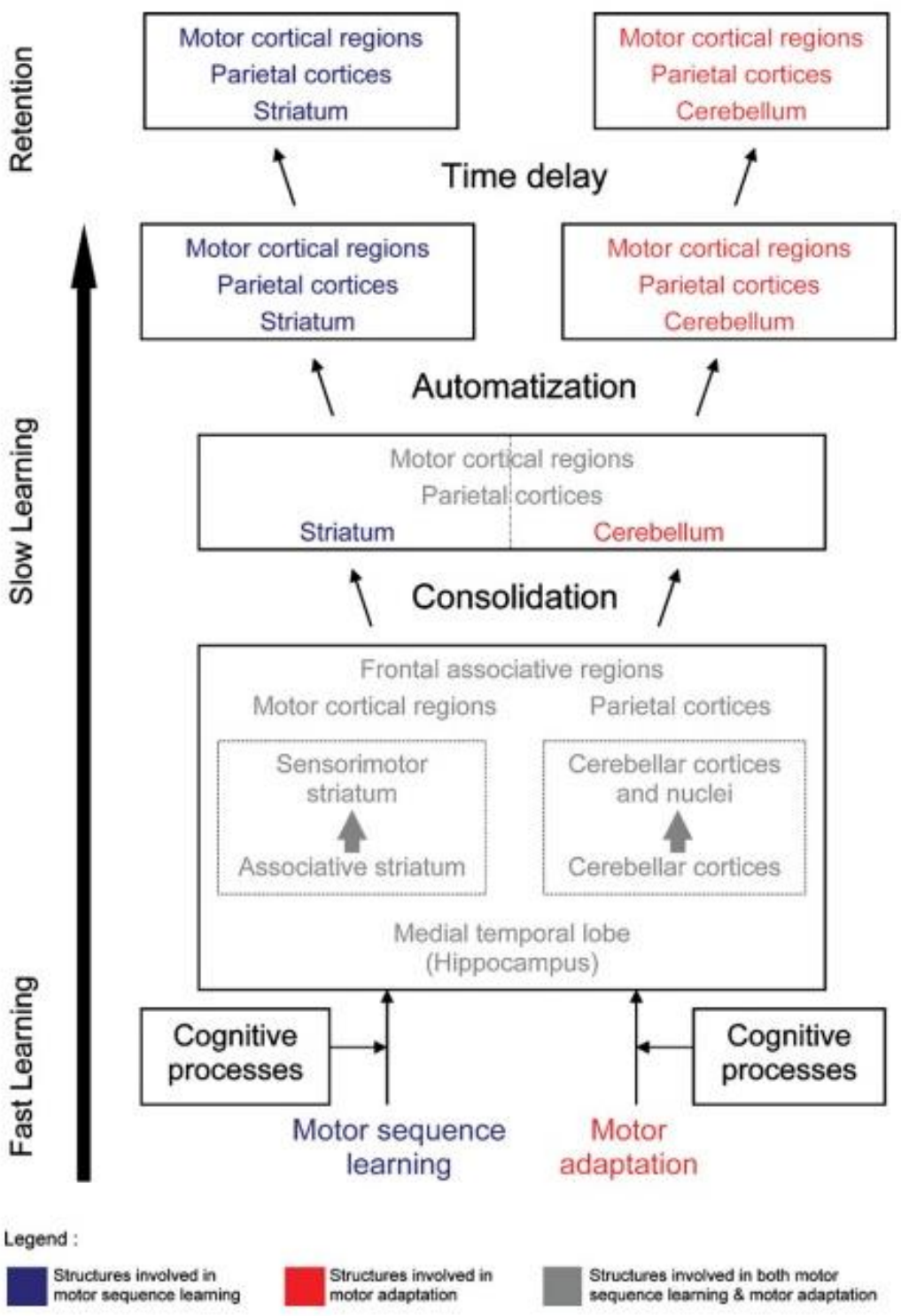


Figure 3. Process of motor learning and brain activity during motor sequence learning and adaptation.

Note. Taken from the *Distinct contribution of the cortico-striatal and cortico-cerebellar systems to motor skill learning*, by Doyon et al. (2009).

2.3.2 Associative stage

The associative stage of motor learning, commonly referred to as the consolidation phase, is the stage at which a learner can adequately perform a learnt skill and is focused on developing an efficient movement sequence as performance stabilises (Fitts & Posner, 1967; Utley & Astill, 2008). An example of this is the reduction of attentional focus on sequence learning, thus, providing the learner with the opportunity to focus on movement adjustments such as adapting to the environment. In a sports setting, a learner may have learned to throw a ball effectively; however, the task demands will have reduced therefore the learner can focus on throwing the ball with increased accuracy (Coker, 2021). Additionally, during this stage of learning, a learner undergoes memory consolidation or "information chunking" which occurs after a training session. This form of memory consolidation can happen in two ways; one of which is during sleep, known as "off-line enhancement" which typically follows motor sequence learning performed explicitly; the second can occur during the day (typically 4+ hours after training) and sleep, following implicit learning (Song, 2009).

The style of training can also affect the process of skill consolidation as examined by Henz & Schöllhorn. (2016) which analysed the differences between repetition-based learning and differential learning. Repetition-based learning simply involves numerous repetitions of the same movement without any variability, whereas differential learning involves completing a task which varies to meet the learner's needs. As a result of these differences, Henz & Schöllhorn. (2016) identified during a precision-based task of kicking a ball, the differential learning group had an increased rate of learning as this group were more precise in comparison to the control (repetition-based learning) group, which could only kick the ball the same way each time. As a result, this study may be a key identifier to differentiate between learning a sequence and responding to environmental changes (motor adaptation), highlighting the role of the cortico-cerebellar circuit and the associated feedforward mechanism (Dahms et al., 2019). This is due to the response to environmental changes, while the repetition-based learning group cannot respond owing to an unchanged movement pattern. This was further evaluated with 24 semi-professional badminton players (mean age = 25.3; males, n = 16; females, n = 8) who performed

60 trials with an EEG device recording brain activity (serving a shuttlecock diagonally toward the left service court whilst standing on the right service court 8.4m away from the service line). Participants were divided into repetition and differential groups; the repetition-based performed serves without variation, while the differential group could alter their serving style – specifics are not stated to the author's knowledge, making reproducibility difficult. Results indicated differences in neuron activation patterns with increased theta activity (frequency oscillation found in the medial temporal lobe) relating to increased activity of the hippocampus, which plays a significant role in memory consolidation (Schapiro et al., 2019). Thus, implying the formation of motor memory in the differential learning group. Furthermore, Rieth et al. (2010) investigated the role of sleep (mean sleep time = 59.9 minutes) and rest (listening to instrumental music for 90 minutes) after explicit and implicit learning following a circular red target on a computer screen with a cursor (using the non-dominant hand) with a repeating and non-repeating trajectory. Eighty-one participants completed the trial study with training beginning at 9 am, rest periods starting 4 hours later and retesting 3 hours 30 minutes later. Results indicated there were no benefits from sleep when compared to rest on performance. However, results from this study indicate sleep and rest do not offer additional benefits in implicit/explicit learning consolidation a few hours after a training period. Therefore, modifying testing parameters, rest times, and time between testing and rest periods need to be investigated further. Additionally, this study cannot confirm with certainty that neuronal activity did not change during rest periods, i.e., increased theta activity, as this study specifically examined pre-rest post-rest performance, and did not examine the effect of testing parameters on brain activity during testing and resting to identify changes in activity in addition to performance changes. Future studies should include the use of either an EEG device or PSG device when studying the consolidation stage of motor learning.

2.3.3 Autonomous stage

The autonomous stage, as the final phase of motor learning, is characterised by the learner's ability to perform actions or movements autonomously with minimal conscious awareness (Fitts & Posner, 1967; Utley & Astill, 2008). During this period, actions can be performed proficiently with

focus being directed at correcting potential errors. The M1 develops motor maps (discussed in greater detail in section 2.4) by storing use-dependent muscle synergies for coordination associated with the control of movement, making the learner's movements optimal (Coker, 2021; Dahms et al., 2019; Taylor & Ivry, 2012).

Mendes et al. (2012) investigated the effects of virtual-reality-based training on skill learning and retention in healthy individuals (11 elderly, mean age 68.7) and patients with Parkinson's disease (16, mean age 68.6) using various Wii Fit games due to the differences in cognitive and motor demands. Example games used – obstacle course, single leg extension, and basic run. Testing involves 14 twice weekly sessions with 2 practice sessions per game and 2 attempts. Retention testing was completed 60 days after the final session. Results from this study indicated that patients with Parkinson's disease had similar performance compared to the elderly (both learning and retention) in games such as single leg extension. However, those with Parkinson's disease showed no improvements during training i.e., motor learning, during games such as obstacle course. Concluding how individuals with motor difficulties have impaired performance in some games. This is further corroborated by Dahms et al. (2019) as the striatum is linked to long-term memory, thus, reiterating why individuals with a striatal dysfunction will have impaired learning and retention of skills. Additionally, Coxon et al. (2014) evaluated the difference between repetitive-based practice and interleaved practice in motor learning and retention with 24 participants (male, n = 12; female, n = 12; mean age 22.9) using transcranial magnetic stimulation (TMS). Trials consisted of participants performing a finger and thumb squeeze on a transducer to move an on-screen cursor horizontally. Participants were timed on the time taken to move the cursor to the given target. During the motor learning phase, participants completed 16 blocks of 15 trials where 5 sequences were selected and randomised from trial to trial (interleaved), whilst the repetitive group had the same sequence each trial with changes only occurring between each block. Retention was evaluated 7-9 days after skill acquisition (5 blocks of 15 trials). Results from these trials indicated a negligible difference between groups in performance (force production) and retention. However, TMS results indicate that repetitive practice leads to an increase in cortico-motor excitability and inhibition. This practice may enhance neural connections during the initial learning stage.

Furthermore, a higher rate of disinhibition during motor retention is observed with repetitive practice. As a result, this study provides additional evidence to suggest that repetitive sequence learning is critical to the retention of skill learning in comparison to an interleaved structure, which may involve an implicit learning focus with adaptative processes. This is supported by Cataldi et al. (2022); Dahms et al. (2019); and Mendes et al. (2012) where the striatum is a highly active region during repetitive practice and a primary indicator of motor memory with the dorsolateral striatum aiding in the facilitation of autonomy. However, studies do suggest the importance of the cerebellum for motor memory and adaption (error recognition). Therefore, both cortical systems are vital to skill learning and the activity of these regions is dependent. The cooperative nature of these systems is identified as a key factor for autonomy and retention with results by Mendes et al. (2012) providing evidence to show the performance (retention score) of a healthy individual is greater than those with a striatal dysfunction. Further research is needed to provide evidence of regional brain activity for a battery of tasks to validate this view.

2.4 Neuroplasticity & skill learning

Neuroplasticity in sport, training, and skill acquisition is the reorganisational process of the brain neurons when learning new movements to execute actions proficiently by strengthening nerve cell function or forming new neural pathways (Costandi, 2016; Demarnin et al., 2014). Skill learning in sports and rehabilitation influences plasticity within the brain white matter microstructure, such as an increase in myelination and gray matter density, increasing neural cell bodies and synaptic pathways (Dayan & Cohen, 2011; Sampaio-Baptista & Johansen-Berg, 2017; Spinalcord.com, 2020).

2.4.1 Structural & Functional neuroplasticity in White and Gray matter

Neuroplasticity can often be broken into experience-expectant (EEP) and experience-dependent (EDP) changes within the brain as a response to the external environment or internal changes caused by injury to the nervous system. Structural changes are predominantly seen during early child development which is often linked with neurogenesis and neuronal morphology within the brain gray matter, while functional plasticity developed in response to skill learning, shows axonal changes (change in diameter,

number, and density), and myelination (May, 2011; Scholz et al., 2009; Zatorre et al., 2012). There is evidence for neurogenesis within adults; however, there is a limited number of studies involving humans. Zatorre et al. (2012) found increased vascular volume in the cerebral cortex, indicating neurogenic changes after exercise, yet this was in monkeys. Therefore, further MRI testing should be conducted on adult humans. Additionally, Galvan (2010) categorised EEP as a structural anatomical change, while EDP as a functional response to exercise. These changes are dependent on regional requirements; for example, learning to juggle increases in activity within the occipito-parietal region, leading to microstructural changes within white matter due to an increase in fractional anisotropy (FA) value (Scholz et al., 2009). As a result, regional plasticity is task-dependent. This is further evidenced by Chang (2014) where increased gray matter volume in the frontal lobe and prefrontal cortex was found to be extensively higher in elite judo athletes in comparison to a control sample. To conclude, regional plasticity in white and gray matter as a response to the environment and exercise requirements is dependent on the regional brain anatomy needed. Further studies involving FA in MRI testing need to be conducted in adult humans during skill learning and motor behaviour.

2.4.2 Neuroplastic response to visual stimuli

Neuroplasticity is task and experience dependant as discussed in the previous section; therefore, neuroplastic changes in response to visual stimuli correspond with the relevant anatomical regions, evident in an animal study where exposure to visual stimuli resulted in functional plasticity of the primary visual cortex (V1) after an off-line period, i.e., stage 2 of motor learning (Montgomery et al., 2022). Additionally, sensorimotor reorganisation may be predetermined through the alteration of motor cortices such as the adjustment of premotor and parietal neurons in response to visual information. Furthermore, repetitive practice or the observation of actions can enhance motor-evoked potentials, facilitating corticocortical interactions within motor cortices (Adamovich et al., 2009).

Three studies highlight the impact of visual feedback on neural activity and peripheral coordination. Beets et al. (2015) conducted a study with 26 participants (aged 21.6) performing

bimanual coordination tasks with and without visual feedback. MRI scans revealed neural activation differences between feedback conditions. In the absence of feedback, areas responsible for decision-making were more active, resulting in a visuomotor response in the feedback condition, with increased cognitive demand in the no-feedback group. Kumru et al. (2016) involved 11 participants performing sequential unilateral movements with their dominant hand under three conditions: direct, mirror, and blocked visual feedback. The primary finding resulted in increased excitability of the ipsilateral corticospinal tract during the feedback condition - mirror visual feedback (MFB) enhanced engagement of the primary motor cortex. Lin et al. (2021) involved 16 participants (aged 23.44) performing finger flexion and extension with and without MFB. The study found that MFB increased M1 activity while pruning neural networks between V1 and associated perceptuo-motor regions. This suggests that MFB can be implemented effectively to promote neuroplasticity. These studies collectively emphasise the significant role of visual feedback in modulating neuroplasticity and its potential applications in promoting motor learning. However, these studies use small sample sizes with an estimated mean age of 22.52, implicating these findings' applicability to a larger population value and age range. Moreover, these studies recruit healthy individuals, future studies would need a more diverse sample population to validate these results.

3.0 Chapter 3: Method

3.1 Study design

This study used a randomised repeated measures crossover design to compare data from non-feedback and feedback conditions, conducted one week apart. The rationale for a randomised design was to compare the potential influence of augmented visual feedback on motor control performance during a single leg loading task while mitigating the learning effect of a repetitive-based practice between sessions. Approval was granted by the University of Hull ethics committee (see Appendix 8.1.8).

The study was preregistered on the Open Science Framework (https://osf.io/v2fec) prior to data collection. The preregistration included *a priori* statements outlining hypotheses, methods of data collection, and a statistical plan. Deviations from any of the information stated in the preregistration are highlighted in the methods. The study was preregistered prior to data collection to minimise several questionable research practices that are common across research disciplines, including our own (Abt et al., 2020; Caldwell et al., 2020; Nosek et al., 2018).

3.2 Participant recruitment

Participants were recruited from the local community through recruitment posters (see Appendix 8.3) placed within the University of Hull campus and through appropriate postings on social media. Individuals who expressed an interest in participation through email or personal request were provided with an email detailing their involvement, process of informed consent, and participation requirements outlining exercise protocol, medical history, and data protection (Participant information sheet, Informed consent document, and medical questionnaire; see Appendix 8.1.4 – 8.1.6). Additionally, once complete, medical forms were screened to identify those who met the inclusion/exclusion criteria.

3.2.1 Inclusion

Participants included were those ≥ 18 years of age, and adults who met the UK physical activity aerobic guidelines (HM Government, 2019). Eligibility was assessed using self-reported chronological age and the score from the self-administered International Physical Activity Questionnaire short form (IPAQ-SF) (Craig et al., 2003; physio-pedia, 2002). Those with a score of "category 2" (completing a minimum of 600 MET-min/week [physio-pedia, 2004]) and above were defined as meeting the guidelines.

3.2.2 Exclusion

Participants excluded were those under the age of 18, and adults with neurological and cognitive conditions impacting motor skill learning, such as Parkinson's disease, post-stroke, or mild cognitive impairment. Participants were excluded if they were of a semi-professional/professional athletic level as there is good evidence that there is a significant contrast in motor control precision and efficiency when compared to amateur athletes and the general population (Li & Smith, 2021). Additionally, those with a current musculoskeletal injury(s), grade 1 or 2 musculoskeletal injuries less the 3 months before testing (Bahr, 2012), individuals who have ever had a grade 3 musculoskeletal injury or a lower limb surgical intervention, and individuals with severe cardiorespiratory conditions were excluded for health and safety reasons.

3.3 Test space set-up

During the control condition, one iPhone SE (3rd Gen, model A2783; Apple Inc., One Apple Park Way, Cupertino, CA, 95014 USA) was placed 2 metres in front of the participant to record their effort from the frontal plane at a 1.2-metre height. A second iPhone SE was placed 2 metres to the side of the participant (same height) to record the sagittal plane of the stance leg. When the participant performed the task on the contralateral limb, the sagittal iPhone was re-positioned to the sagittal plane of the stance leg in a pre-marked position on the floor. The same set-up applied to the experimental condition, however, two 84-inch Philips™ monitors (Model BLD8470EU/00, Prins Bernhardplein 200, 1097 JB Amsterdam, Netherlands) were positioned in front of the participant to display concurrent

feedback. This feedback was displayed on the monitors using two Veho Muvi™ cameras (Veho, Southhampton, England). These cameras were positioned next to the iPhones to display the frontal and sagittal planes of the participant. No calibration object was used; measurements from the horizontal and vertical planes would have been superfluous, as Kinovea™ annotations were used solely as a visual scoring aid with no kinematic data being utilised for quantitative purposes.

3.4 Protocol

Participants were familiarised with procedures before experimental testing began. Operational definitions for the SLS familiarisation test are outlined below:

1. A minimum knee flexion angle of 45° was preset using a goniometer. The participant was then asked to demonstrate a double leg squat to find their individual hip height at 45° of knee flexion. This height was recorded with the participant being instructed to perform a SLS to a comfortably challenging depth which is greater than the minimum of 45° knee flexion. This is to reduce tensile forces applied on the ACL, as maximum anterior shear forces peak between 15° - 30° knee flexion (decreasing above 30°) (Schoenfeld, 2010). Reaching a comfortable depth allows for individual mobility differences.
2. Range/depth was measured using a bubble inclinometer placed on the mid-thigh. Mid-thigh was located halfway between the greater trochanter of the femur and the lateral femoral condyle (Charlton et al., 2015).
3. To allow for uncertainty in the measurement and measurement error, a region of practical equivalence (ROPE) was created, with 5° on either side (10° error margin) (Alenezi et al., 2014).
4. The participant performed 3 consecutive repetitions within the ROPE to be deemed familiarised.

Participants were involved in two trials, held 7 days apart. These trials consisted of non-feedback and feedback conditions conducted in a randomised order. Randomisation was performed using Research Randomizer (Version 4.0; Urbaniak & Plous, 2024). In the non-feedback condition, participants completed the movement task in three sets (per limb). Each set consisted of three repetitions

with three minutes of rest between each set. Repetitions were recorded from the frontal and sagittal planes for analysis and scoring. During the feedback condition, the same structure was followed. However, concurrent visual feedback (knowledge of performance provided during the activity) was provided by two monitors placed directly in front of the participant and acting as a mirror, displaying the frontal plane and sagittal plane of the standing leg. Between each set and during rest time, participants received terminal visual feedback (knowledge of results provided after the activity) to highlight any errors made during each repetition.

3.4.1 Movement task

Single leg squat (SLS): Participants performed the SLS with their hands down by their sides, shoulders, and head in an anatomically neutral position, with their non-stance leg at 90° of knee flexion. Participants were instructed to perform the SLS movement to a comfortably challenging depth beyond 45° of knee flexion and then return to the starting position.

3.4.2 2D analysis

Two digital cameras (3rd Gen, model A2783; Apple Inc., Cupertino, CA, 95014 USA) recorded participant movements for 2D movement biomechanics which was saved to a secure OneDrive folder for later analysis. Analysis was completed using Kinovea™ (Version 0.9.5; Charmant & Contributors, 2021), which is a tool designed for movement analysis (Charmant, 2021). Movement angles were highlighted by placing protruding retroreflective markers (Qualisys, Gothenburg, Sweden) on key anatomical landmarks for enhanced visibility in all planes; bilateral acromioclavicular joint (ACJ), mid-sternal body, cubital fossa, lateral epicondyle, anterior superior iliac spine (ASIS), greater trochanter of the femur, patella, lateral knee joint line, lateral malleoli, anterior ankle joint line, and the dorsolateral head of the 5th metatarsal (Parry, 2021) (see Figures 4a and 4b) to test for potential errors through displaying the projection angle from the starting position to the greatest knee flexion angle (deepest position). For example, when assessing thigh motion in the frontal plane (hip adduction angle), lines were drawn using Kinovea™ from the weight-bearing to non-weight-bearing anterior superior iliac spine (ASIS) (Parry, 2021), and then a line was drawn from the weight bearing ASIS to the ipsilateral superior anterior patella to create an adduction angle. Additionally, when assessing trunk alignment in

the sagittal plane (leaning anteriorly/posteriorly) lines were drawn using Kinovea™ from the weight-bearing greater trochanter of the femur to the sternum (Brouwer et al., 2021), and then a vertical line was drawn from the greater trochanter of the femur to a known fixed position in the testing site. Additionally, "track paths" were positioned over each moving retroreflective marker to display movement pathways to highlight potential movement strategies throughout the task.

Figures 4a and 4b. Frontal marker placement (left) and sagittal marker placement (right).

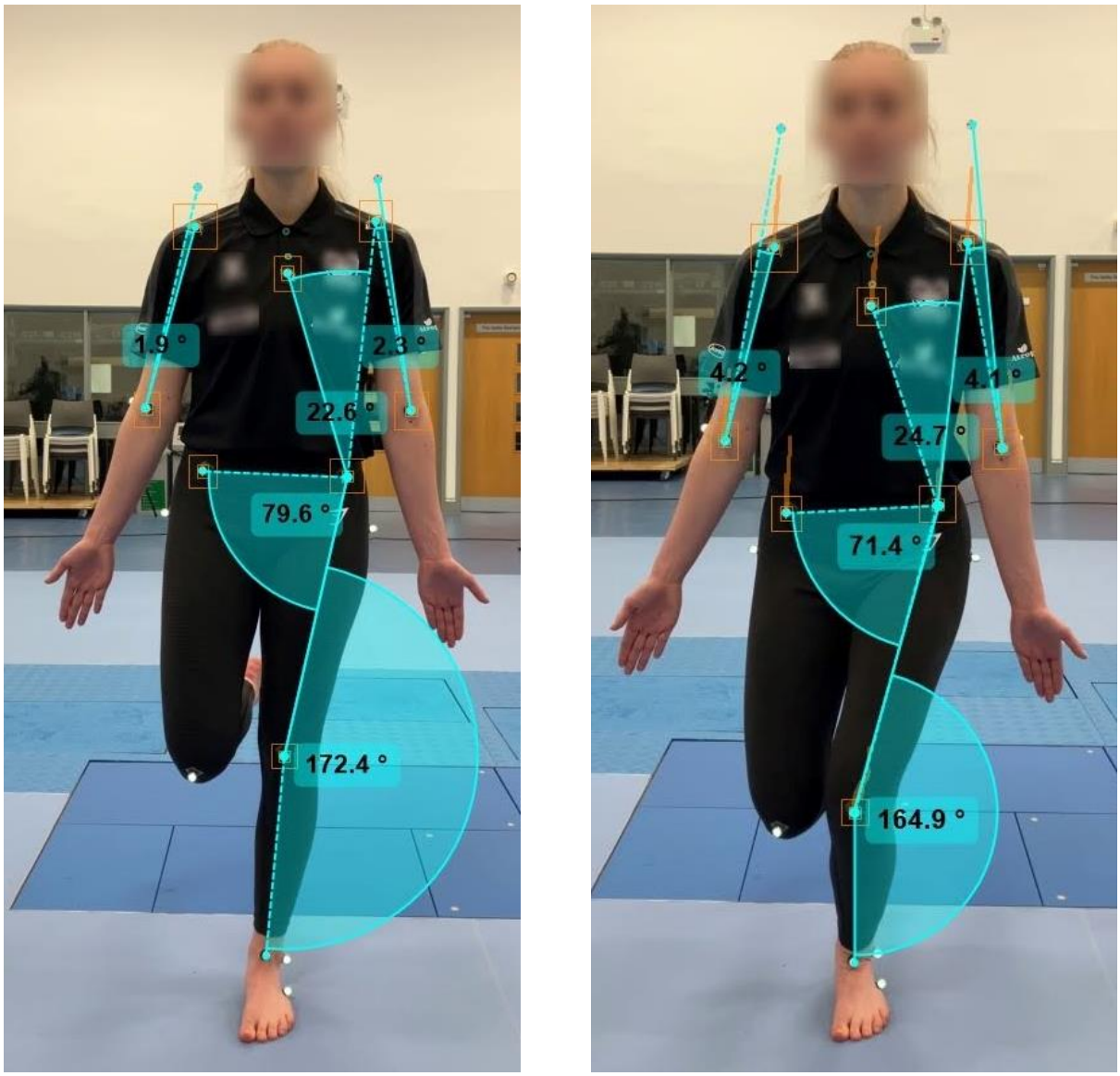
Note: Marker placement images were used with participant consent.

3.4.3 Movement scoring

Movement scoring was completed by comparing annotated videos (edited videos with drawn-on projection angles as seen in Figures 5 and 6) of participants at 0.25% speed (or frame-by-frame if needed for extra precision). Use of annotations were used in the QASLS scoring process due to the limited literature validating the use of the subjective tool (Parry, 2021; Parry et al., 2023); as such annotations acted purely as a visual scoring aid with no data being taken from the projections, yet the additional input from the biomechanical tool (Kinovea™) provided a visual guide to mitigate subjective measurement error, as seen in previous literature (see section 2.1.2.1). Annotated videos from both control and experimental conditions were used. Movement strategies were marked down as a movement error, such as excessive arm movement or the non-weight bearing thigh moving away from the neutral position, using the Qualitative Analysis of Single Leg Loading scale (QASLS), a 0-10 dichotomous scoring tool (QASLS; Herrington et al, 2013; see Appendix 8.4). QASLS has been validated with excellent reliability in both adolescent and adult populations (Parry, 2021; Parry et al., 2023) and is used primarily as a musculoskeletal profiling tool for unilateral functional capacity during a SLS or single-leg landing task, identifying potential kinematic compensatory behaviour through 'movement strategies.' When an individual scores highly (closer to 10) that would indicate poor performance, with scores closer to 0 indicating high performance. For an outline of potential movement strategies used, see Appendix 8.4. Scoring of participant performance was taken after a participant had performed three sets of three repetitions on both legs. Participants were recorded from both the frontal and sagittal planes of the stance leg, which was then annotated in Kinovea™ before scoring began. Once the participant recordings were annotated (see sections 3.4.4 and 3.4.5), participants were scored by one rater. Each repetition was viewed once at 0.25 speed or frame-by-frame if there were any ambiguities in the participants' movement strategies used.

3.4.4 The frontal plane

Frontal plane movements were analysed using Kinovea™ software by tracking the projection angles gathered (see Figures 5a and 5b). Retroreflective markers were placed on key anatomical landmarks for easy identification during analysis.

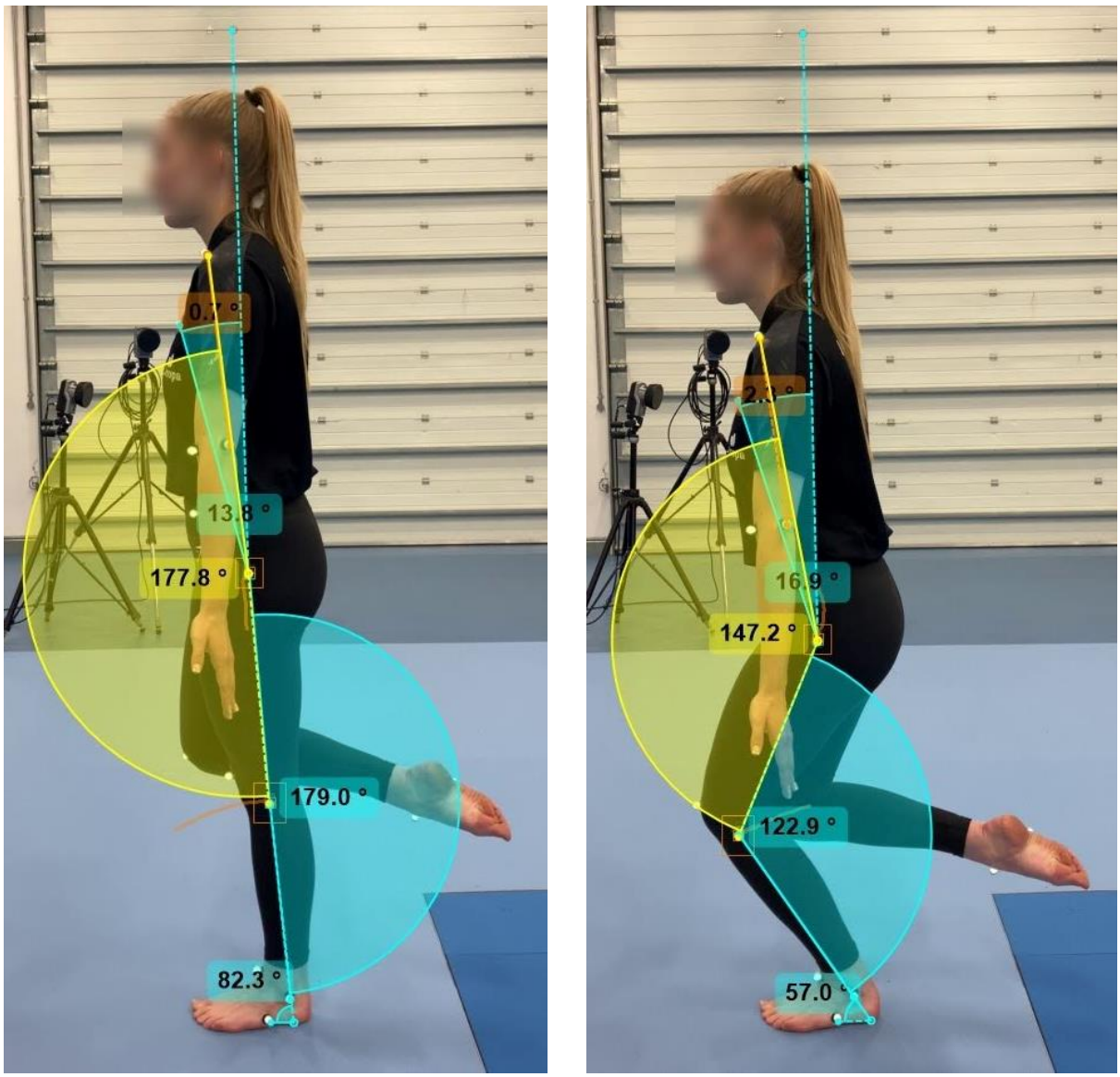


Figures 5a and 5b. Frontal 2D angle placement in the upright (left) and mid-repetition (right) positions.

Note. Frontal angle placement images were used with participant consent. Angle placement was adapted from *The Reliability and Validity Development of an MSK Profiling Tool and Its Value in Youth Athletes and Prospective Injury Risk* (Parry, 2021). Angle legend: Arms = shoulder abduction angle, torso = lateral trunk lean, hip = hip adduction angle, leg = frontal plane projection angle.

3.4.5 The sagittal plane

Equivalent to the frontal plane, retroreflective markers were placed on key anatomical landmarks seen within the sagittal plane for easy identification during analysis (see Figures 6a and 6b).



Figures 6a and 6b. Sagittal 2D angle placement in the upright (left) and mid-repetition (right) positions.

Note. Sagittal angle placement images were used with participant consent. Angle placement was adapted from *The Reliability and Validity Development of an MSK Profiling Tool and Its Value in Youth Athletes and Prospective Injury Risk* (Parry, 2021). Angle legend: Ankle = angle of dorsiflexion, leg = knee flexion angle, hip = hip flexion angle, torso = trunk flexion angle, arm = shoulder flexion and extension angle.

3.4.6 Health, safety, and risk management

Before each trial, a risk assessment of the biomechanics laboratory took place, which consisted of identifying and removing any potential obstacles in the participant's and investigator's vicinity, pre-exercise screening, and equipment checks ensuring safe use. Additionally, participants completed an appropriate RAMP (Raise, Activate & Mobilise, Potentiate; Jeffreys, 2007) warm-up to prepare the participants physically for the task.

Raise: During this phase, participants were instructed to complete 2 minutes on a Watt bike on level 5 resistance at 70 RPM.

Activate & Mobilise: During this phase, participants were instructed to complete two sets of five repetitions of body weight squats, walking lunges, glute bridges, heel raises, and leg swings (sagittal plane). Each exercise was performed consecutively, and once complete, three minutes of rest was provided between each set.

Potentiate: During this phase, participants were instructed to complete three sets of alternating double to single leg wall sit at 60° hip flexion for 15 seconds each set. Hip flexion was measured using a goniometer and double-leg squat jumps at 90 BPM. Forty-five seconds of rest was provided between each set.

Finally, confidential participant information, such as participant names, was coded using Randomizer App™ (Version 10.0.0; V Team, 2020) to provide anonymity for those involved following GDPR guidelines (Data Protection Act, 2018).

3.5 Statistical analysis

3.5.1 Sequential testing and inference criteria

This study used a randomised repeated measures design to examine the role of the independent variable (visual feedback) on the dependent variable (QASLS score). Rather than estimate a sample size *a priori* using estimates of effect size, sequential testing was used with the aim of reaching an evidence 'threshold' (a certain Bayes factor). Sequential testing with a stopping rule based on an *a priori* defined Bayes factor is an accepted method for evidence accumulation and establishment of inference criteria (Lakens, 2014; Schönbrodt et al., 2017). As outlined in the preregistration, data collection would cease when BF_{10} or BF_{01} reached ≥ 10. A Bayes factor of 10 would mean that the data were 10 times more likely under the alternative hypothesis compared to the null if using BF_{10}, or the opposite if using BF_{01}. The preregistration states that a minimum sample size of 20 would be used, after which the first inferential analysis would be performed. If a Bayes factor ≥ 10 was not achieved, then a further five participants would be recruited and then the inferential analysis would be conducted again. This process would continue until the *a priori* Bayes factor criteria of ≥ 10 was achieved.

3.5.2 Confirmatory Hypothesis Analysis

Following a descriptive analysis and confirmation that the data residuals were normally distributed (using QQ plots and histograms), an inferential analysis of the mean QASLS score was completed using the statistical package JASP (JASP team, 2023; version 0.18.3 [computer software]). To compare the means of the two groups, a Bayesian paired sample t-test was used. Bayesian analysis is an updating process, so starts with defining a distribution prior to seeing the data, which logically is called the prior. For this analysis, a Cauchy prior (scale 0.707) was used, which is a distribution like the

normal distribution but with slightly more mass assigned to the tails (Wagenmakers et al., 2018). The effect of the chosen prior was examined using a Bayes factor robustness check, which highlights the differences (if any) in Bayes factor when using different priors. The results using the Cauchy prior were not changed when using a range of other priors, highlighting the appropriateness of using the Cauchy prior. Results are presented showing the Bayes factor (BF_{10}) (quantifying the relative likelihood of the alternative hypothesis compared to the null hypothesis), the median Cohen's *dz* (the middle value of the Cohen's *dz* posterior distribution), and the 95% credible interval (the middle 95% of the posterior distribution). To evaluate the Bayes factor, the classification scheme of Lee and Wagenmakers (2013) was used, with a Bayes factor between 1 and 3 considered as anecdotal evidence, between 3 and 10 as moderate evidence, between 10 and 30 as strong evidence, between 30 and 100 as very strong evidence, and >100 as extreme evidence.

3.5.3 Intra-observer Reliability

Three weeks after individual trials were complete, the annotated recordings (with the inclusion of joint angles and track paths) were re-scored against QASLS to test scoring reliability. Intra-observer reliability was examined using Bland-Altman limits of agreement (Bland & Altman, 1999; Nevill & Atkinson, 1997) and intra-class correlation (Weir, 2005). This is a deviation from the preregistration, where we stated that video recordings were to be re-annotated for joint angles with (1) 95% limits of agreement within +2.5° and -2.5° degrees, (2) mean bias not statistically different from zero as assessed using a one-sample t-test, and (3) no heteroskedasticity as assessed using linear regression. This deviation was made for simplicity, with the ICC seen as easily interpretable and understood.

4.0 Chapter 4: Results

4.1 Descriptive statistics

Seventeen participants (Female, n = 11; Male, n = 6) were recruited and completed both experimental conditions, as seen in Table 2. This is a deviation from the preregistration, where it was stated that a minimum of 20 participants would be recruited (see Discussion for further information).

Table 2. *Participant characteristics.*

	MASS (KG)	HEIGHT (CM)	AGE (YEARS)
VALID	17	17	17
MEAN (SD)	81.61 (18.96)	168.18 (10.42)	34.18 (14.54)
MINIMUM	51	154	19
MAXIMUM	120	193	71

The descriptive results for both control and experimental groups are displayed in Table 3. As can be seen, the mean and median are reasonably close to each other, suggesting that the distributions for each group are symmetrical and follow a normal distribution. This is confirmed by both the Shapiro-Wilk test (P = > 0.9 for both groups), the histograms (Figures 7a and 7b), box plots (Figures 8a and 8b), and Q-Q plots (Figures 9a and 9b). All these figures would suggest that the data residuals are normally distributed.

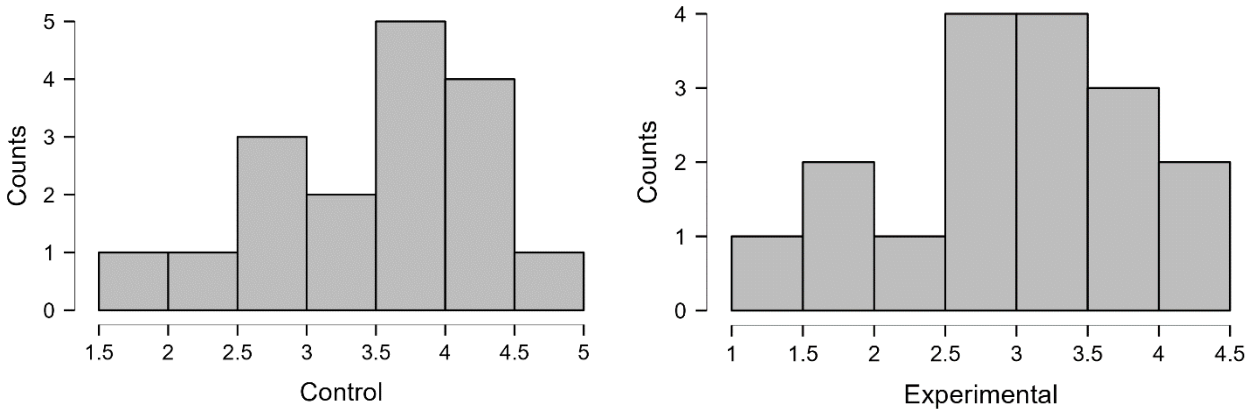
Table 3. *Descriptive values related to central tendency, variability, normality testing, and range.*

	Control	Experimental
Valid	17	17
Median	3.610	3.060
Mean (SD)	3.536 (0.776)	3.024 (0.828)
MAD robust	0.741	0.993
Shapiro-Wilk	0.964	0.993
P-value of Shapiro-Wilk	0.712	0.834
Minimum	1.840	1.390
Maximum	4.780	4.280

Note. Median and Mean (SD) correspond to participant QASLS scores.

All participants (N = 17) completed the control (non-feedback) and experimental (feedback) conditions in a randomised order. As displayed in Table 3, both the median and mean are lower in the experimental condition by 0.55 and 0.51, respectively. The Median Absolute Deviation (MAD robust) provides a robust measure of the distribution around the median where the experimental condition has a wider dispersion (0.252 units greater). The standard deviation (SD) quantifies variability around the mean, with the experimental condition having an SD of 0.052 units greater than the control. Thus, the overall variability is greater in the experimental condition. Yet, the experimental MAD robust is closer to 1 indicating greater stability against outliers. The normality of the data (Shapiro-Wilk) suggests that a t-test is appropriate for comparing mean values as both groups provide a p-value greater than 0.05, indicating that the data are not different from a normal distribution. The QASLS score range of the data for the control and experimental are 2.94 and 2.89, respectively.

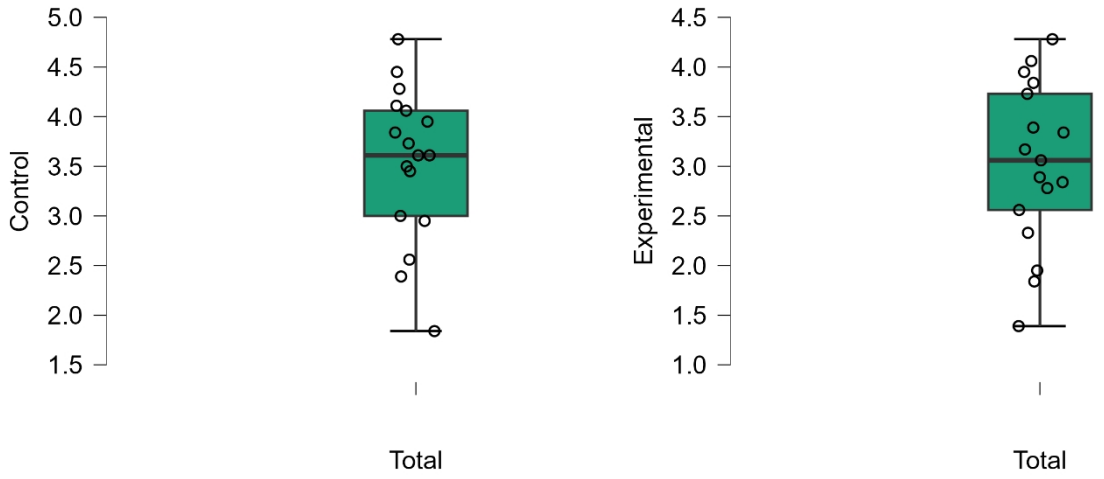
4.1.1 Histogram plots



Figures 7a and 7b. Histograms showing the frequency of QASLS scores

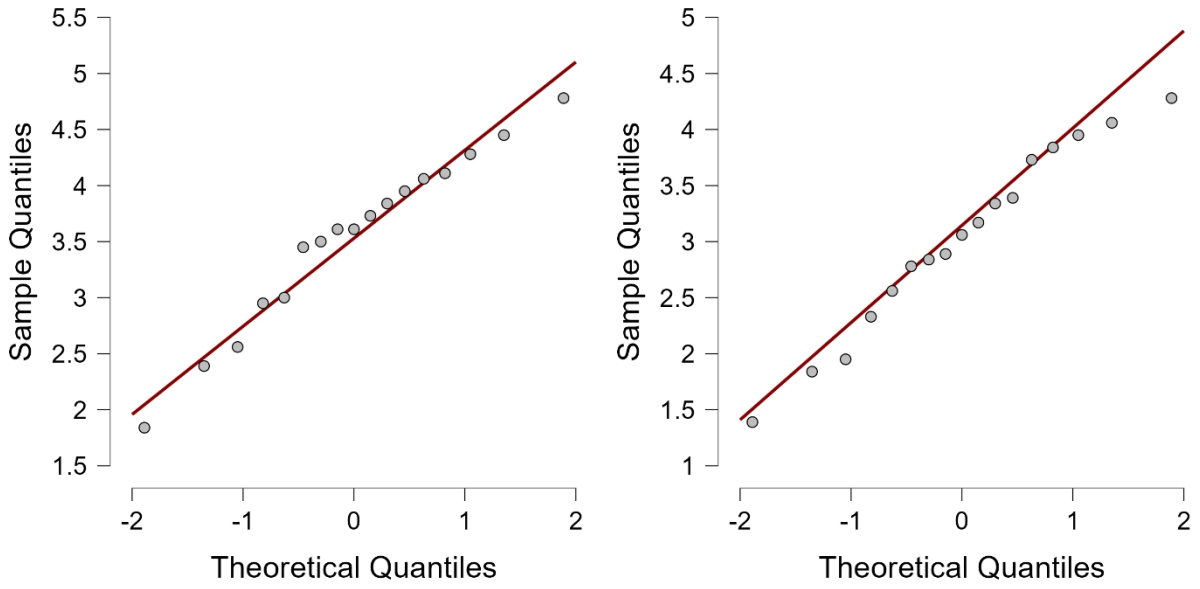
Note. Counts refer to the frequency of participants scoring within a 0.5 (mean) boundary in QASLS.

4.1.2 Box plots



Figures 8a and 8b. Boxplots show the interquartile range (green box), median (black horizontal line), minimum/maximum (whiskers), and individual data points for each condition.

As displayed in Figures 8a and 8b, the interquartile range (IQR) of the experimental condition is 'lower' than the control condition. This indicates the middle 50% of data (QASLS scores) falls in a lower range. Additionally, the median (solid horizontal line within the box) is lower in the experimental condition. Neither condition has any outliers.



Figures 9a and 9b. Q-Q plots for the control (left panel) and experimental (right panel) conditions.

Note. The red reference line indicates agreement between the sampled values and the predicted, which would indicate that the residuals are normally distributed.

As displayed in Figures 9a and 9b, the distribution of data residuals in both conditions appears to follow a 'normal' distribution. Additionally, tests less sensitive to outliers such as a MAD robust suggest the stability of the data.

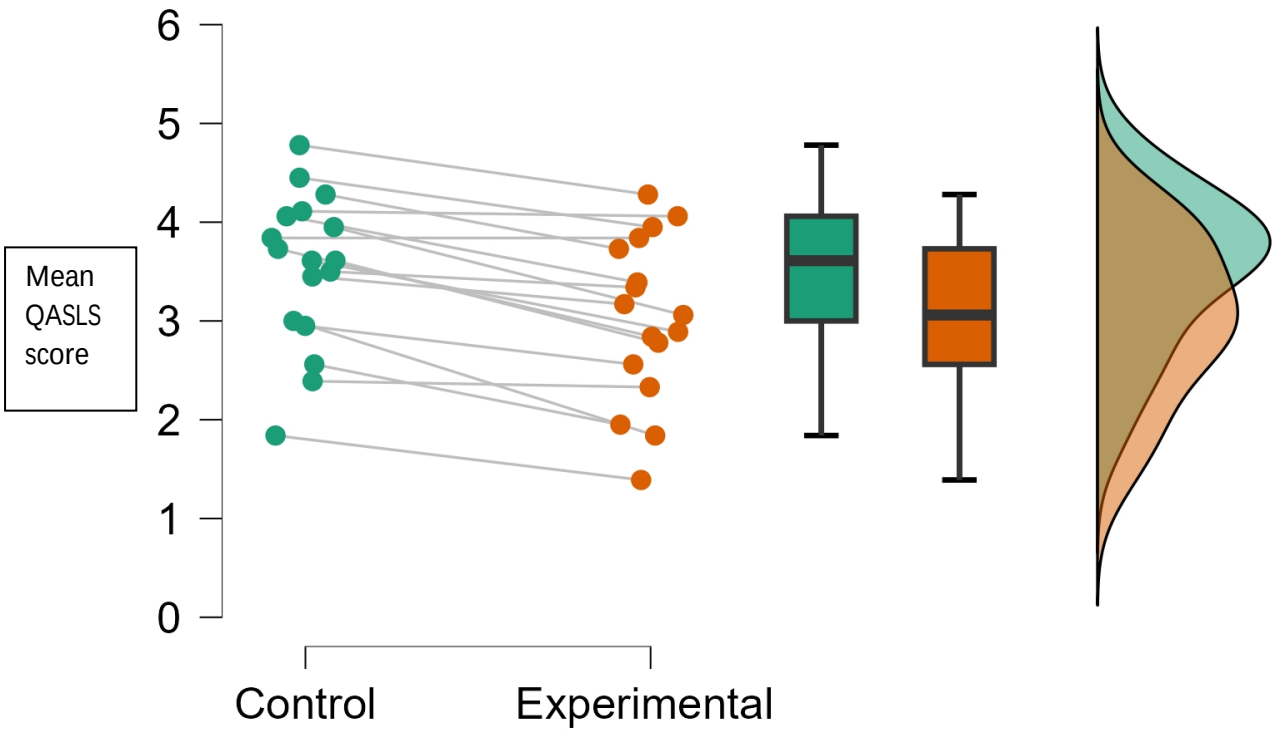


Figure 10. Raincloud plot shows the individual participant data, box plots, and distributions.

As displayed in Figure 10, the scatter plot (left) shows the difference between the control and experimental data where the experimental has lower QASLS scores. The box plot (centre) shows the differences in IQR, median, and min/max scores where the experimental condition's middle 50% of the data and the median are lower. The density plot (right) shows the differences in the density and distribution of data in both groups, indicating where most values are concentrated. As seen in the density plot, the control condition's data are centred at a higher value than the experimental with a pronounced 'peak,' stipulating how the data are concentrated. However, the experimental data does not have a strict 'peak' and the data is more evenly distributed.

4.2 Inferential statistics - Bayesian paired samples t-test

4.2.1 Prior and posterior plot

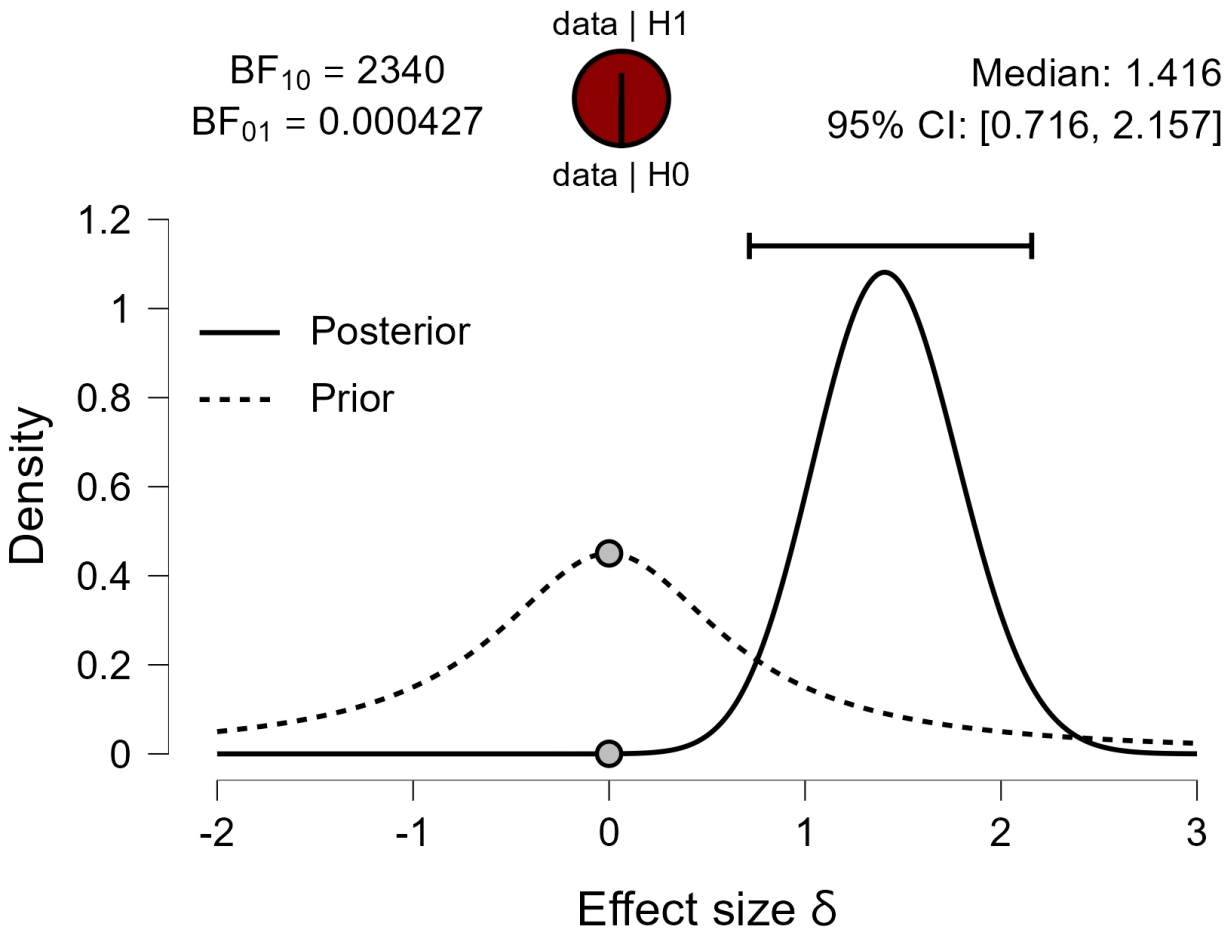


Figure 11. Prior and posterior distributions, the median effect size with 95% credible interval, and the Bayes factor.

Note. BF_{10} shows evidence for the alternative (H_1) hypothesis relative to the null hypothesis. BF_{01} shows evidence for the null (H_0) hypothesis relative to the alternative hypothesis (one is simply the reciprocal of the other). CI shows a 95% credible interval.

As displayed in Figure 11, the Bayes Factor (BF), which indicates how much the data favours one hypothesis over another, shows that there is extreme evidence ($BF_{10} > 100$) for the alternative hypothesis (H_1). A BF_{10} of 2340 suggests that the data are 2340 times more likely under the alternative hypothesis compared to the null hypothesis. The prior (dotted line) shows a two-tailed distribution and represents an assumption before seeing the data; the posterior (solid line) represents an updated assumption (the effect of feedback on QASLS scores) after seeing the data. In this case, the posterior

has shifted to the right which indicates that the estimation of the population effect has shifted since seeing the data. The posterior provided a median effect of ~ 1.4 (very large effect), but the 95% credible interval (horizontal line above the posterior) shows that there is large uncertainty in the effect size (moderate to extreme effect).

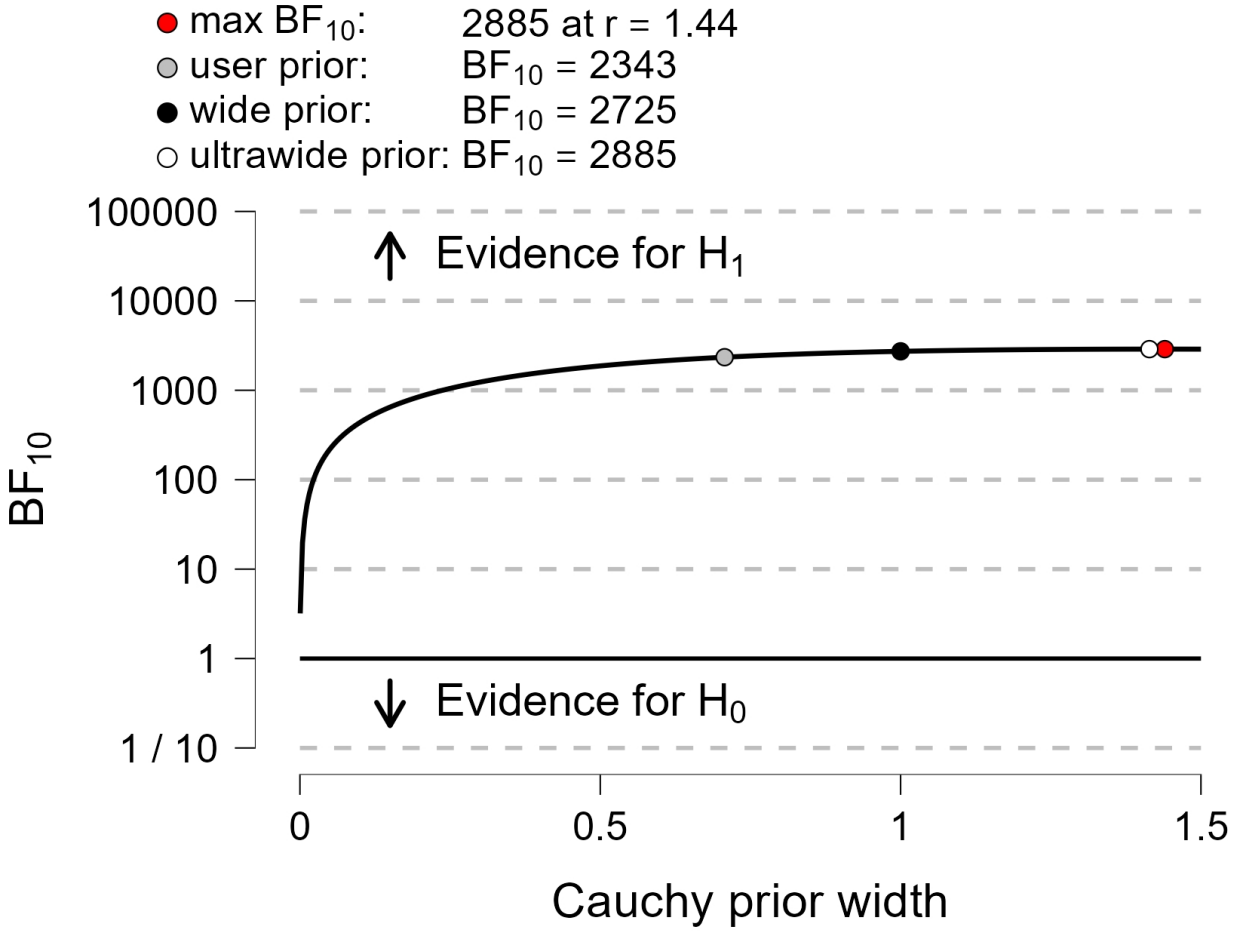


Figure 12. Bayes factor robustness check.

Note. Displays the stability of the Bayes Factor under different prior specifications.

As displayed in Figure 12, the robustness check demonstrates how the Bayes Factor remains stable across different prior widths against values like the user prior (JASP default 0.707) indicating the robustness of the data in favour of H_1 regardless of prior choice.

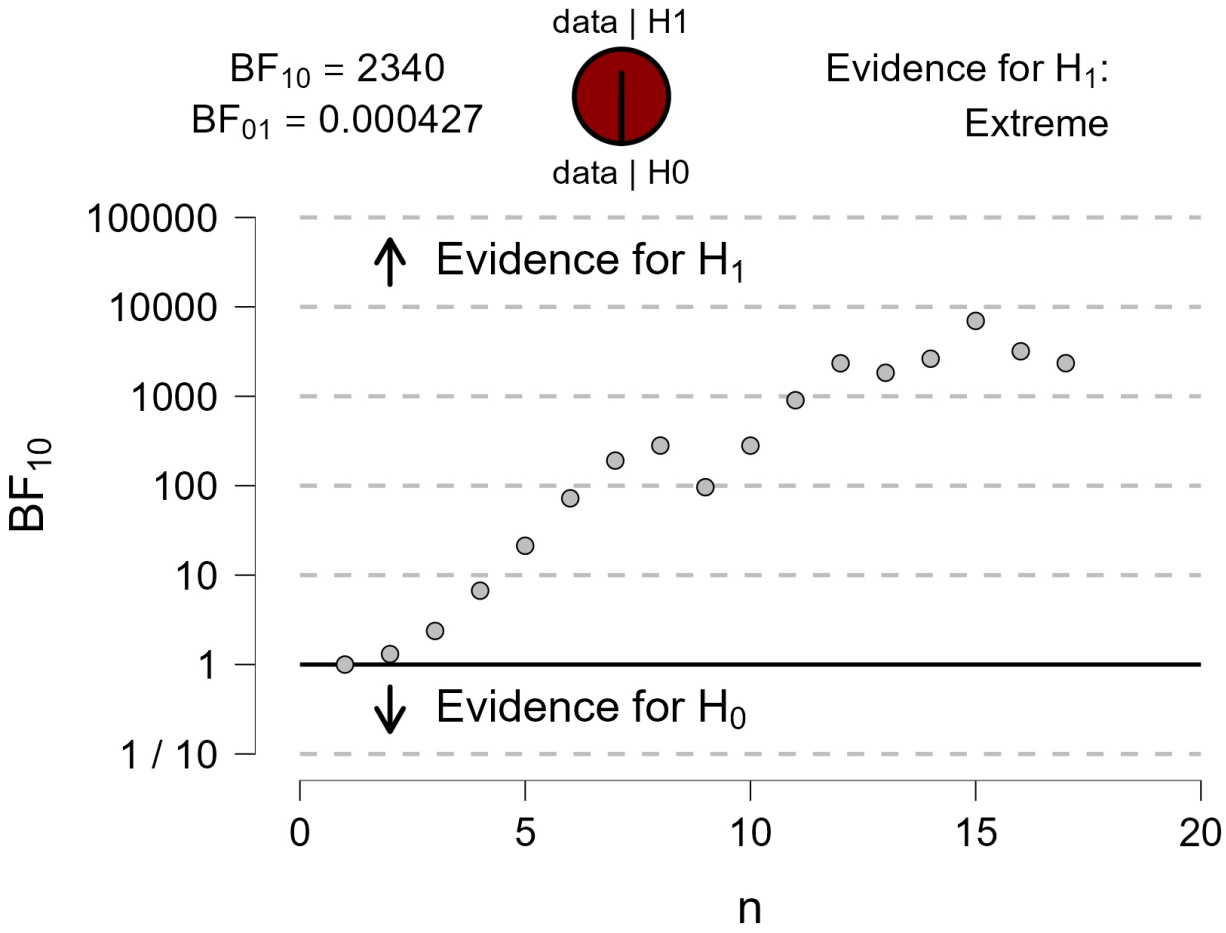


Figure 13. Sequential analysis.

Note. Each plot corresponds to participant data where the y-axis demonstrates the favour of the hypothesis.

As displayed in Figure 13, with each participant, the data is continuously in favour of H_1 with a nonlinear relationship between 'n' and the Bayes Factor indicating the mounting evidence in favour of H_1 as the sample size increases. The nonlinear progression and data fluctuations suggest increasing the sample size will aid the progression to 'taper' and increase the statistical precision of the data.

4.3 Intra-observer reliability

4.3.1 Intraclass correlation

Table 4. *Intraclass correlation for both control and experimental conditions.*

	Type	Point estimate	Lower 95% CI	Upper 95% CI
Control	ICC3, k	0.998	0.996	0.999
Experimental	ICC3, k	0.999	0.997	1.000

Note. 17 subjects and 2 raters/measurements. Intraclass Correlation Coefficient (ICC) type as referenced by Shrout & Fleiss (1979).

The ICC3, k identifies the reliability and consistency of measurements between raters or methods. As seen in Table 4, the reliability is excellent (> 0.9) for the measurements made over repeated assessments (a condition with a rescore 3 weeks later) by the same observer.

4.3.2 Bland-Altman plots

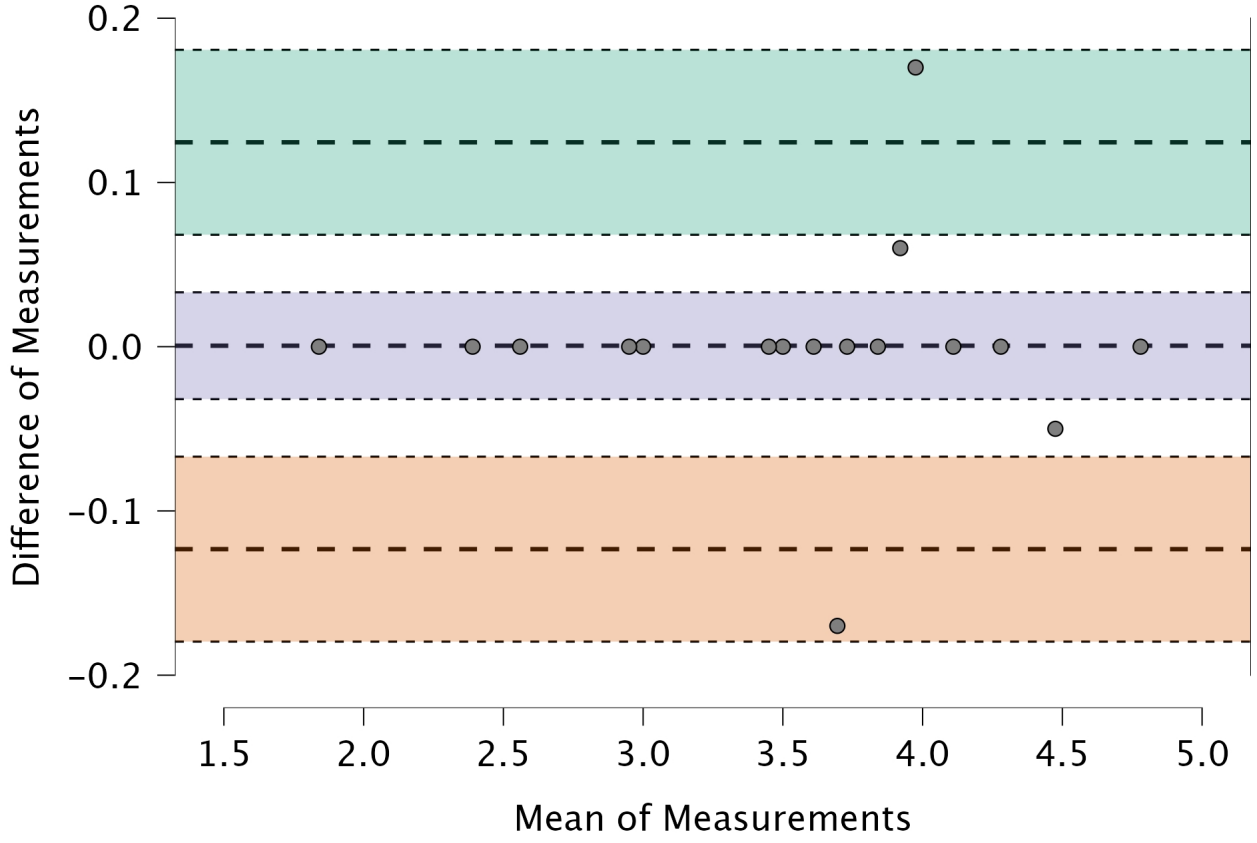


Figure 14. Control – Intra-observer Reliability Control.

Note. The Central line shows the bias (mean difference) between measurements. The upper and lower limits show the upper/lower bound of the CI for the mean difference.

As seen in Figure 14, the mean bias is close to 0, and the limits of agreement remain 'narrow.' This suggests good agreement between both measurements.

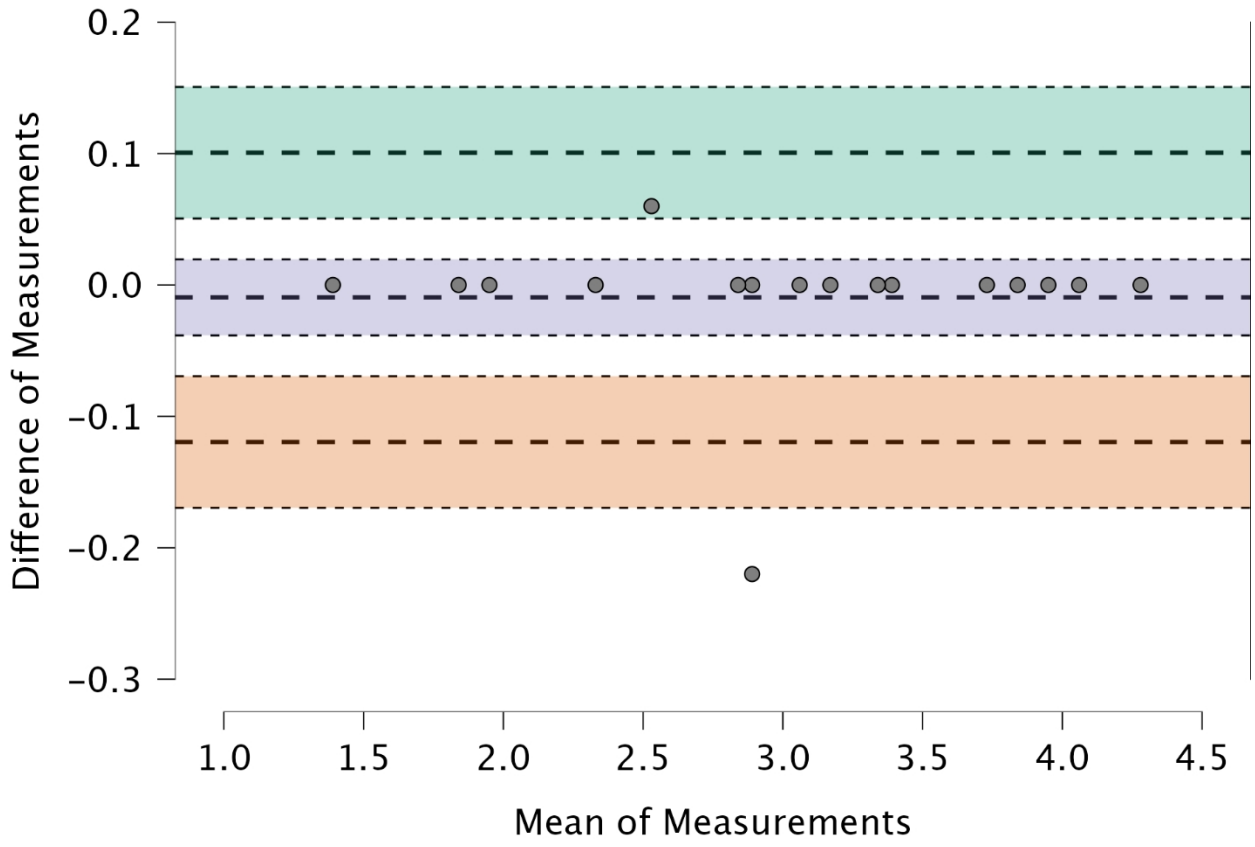


Figure 15. Experimental – Intra-observer Reliability Experimental.

Note. The Central line shows the bias (mean difference) between measurements. The upper and lower limits show the upper/lower bound of the CI for the average difference.

As seen in Figure 15, the mean bias is close to 0 indicating minimal bias. The limits of agreement remain 'narrow,' suggesting good agreement between both measurements. However, there appears to be a data residual outside the limits of agreement. Yet, as seen in Table 6, the results maintain a 'narrow' range.

4.3.3 Bland-Altman tables

Table 5. *Control – Intra-observer Reliability Control.*

Bias & Limits	Point Value	Lower 95% CI	Upper 95% CI
Mean difference + 1.96 SD	0.124	0.068	0.181
Mean difference	5.882×10^{-4}	-0.032	0.033
Mean difference – 1.96 SD	-0.123	-0.180	-0.067

Note. The point value shows the true measurement obtained with the SD indicating the mean difference ± 1.96 and the CI shows the range around the point value.

The mean difference, as seen in Table 5, is extremely close to 0 indicating excellent reliability between measurements within the control condition. Additionally, the small deviation (SD) and narrow 95% CI suggest robust reliability.

Table 6. *Experimental – Intra-observer Reliability Experimental.*

Bias & Limits	Point Value	Lower 95% CI	Upper 95% CI
Mean difference + 1.96 SD	0.101	0.051	0.151
Mean difference	-0.009	-0.038	0.019
Mean difference – 1.96 SD	-0.120	-0.170	-0.069

Note. The point value shows the true measurement obtained with the SD indicating the mean difference ± 1.96 and the CI shows the range around the point value.

The mean difference, as seen in Table 5, is close to 0 indicating excellent reliability between measurements within the experimental condition. Additionally, the small deviation (SD) and narrow 95% CI suggest robust reliability.

5.0 Chapter 5: Discussion

The current study results are to be treated in a 'confirmatory' manner as the Bayes Factor (BF_{10} = 2340) provides 'extreme' evidence (BF_{10} > 100) for the alternative hypothesis (H_1). The prespecified alternative hypothesis (OSF preregistration, https://doi.org/10.17605/OSF.IO/V2FEC) of $BF_{10} \geq 10$, can be accepted.

5.1 Reviewing the results

The study research question was "What is the influence of augmented visual feedback on motor control performance during isolated single-leg loading tasks?" The current training approach in clinical and sporting environments often focuses on strength enhancement and 'spot-fixing' problematic areas; this overlooks the importance of neurocognitive training (Dawson & Herrington, 2015). This results from expecting a specific level of performance from an individual when they may not be lacking in strength (for example), they may be lacking the desired neuromuscular coordination (lack of skill). Thus, reiterating the importance of skill-based training. Consequently, this study aimed to improve the performance of a desired skill using an appropriate intervention proven in preliminary research (Huet et al., 2009; Lin et al., 2021; Schmidt & Wrisberg, 2008; Sigrist et al., 2013a; Sigrist et al., 2013b) to aid motor control performance. Therefore, motor control performance was evaluated following kinematic, subjective, and statistical analysis. As such, the descriptive results provide evidence of a 'Gaussian' distribution, as seen in Table 3, Figures 7, 8, and 9, indicating a normally distributed numerical difference between the control and experimental conditions. This shows a reduction in QASLS score in the experimental condition, suggesting a positive influence of augmented visual feedback. Clinically, the decrease in QASLS will determine the significance of an external focus in verifying whether an individual is skill-deficient or functionally deficient. Differences in QASLS score with no additional training, just a single-session change in the independent variable, demonstrate the causal link in neural function between implicit and explicitly focused training environments (Doyon et al., 2003; Doyon et al., 2009; Fitts & Posner, 1967; Taylor & Ivry, 2012; Utley & Astill, 2008). This

may be the result of within-session motor adaptation (a short-term performance change), see section 5.1.1.

Due to the nature of QASLS being scored from 0-10, a single point difference between conditions (per participant) may not appear visually meaningful. However, when utilising standardised effect size, a 'minor' numerical difference (one point) is a 'very large' effect. Therefore, the 'very large' effect will encourage changes in clinical practice through the evidenced differences in QASLS performance between conditions; thereby, providing an incentive to utilise external tools to augment short-term performance.

Though the results display a statistical and numerical difference for mean participant QASLS score between conditions, a reduction by one 'point' (a single movement strategy [see Figure 10]) may not be clinically meaningful for this population regarding injury mitigation or long-term performance. This may be the result of a 'ceiling effect' within this population which can be identified with the low starting QASLS scores. Testing this population with the introduction of a cognitive challenge, interference, or with a more demanding task, such as the single leg drop-down, will increase task complexity (Sigrist et al., 2013a) and may help identify the individual differences due to feedback more accurately. However, this approach may still benefit those of a low skill level, and from the clinical perspective, be beneficial to those with neuro-musculoskeletal injuries. These individuals may exhibit changes in plasticity, causing them to become 'novice' or 'low-skilled' (this remains theoretical at this stage). Nonetheless, clinicians and coaches will be able to differentiate between intrinsic and extrinsic compensatory behaviour through the administration of an augmented source of afferent information.

Furthermore, the Bayesian paired sample t-tests inferential plots demonstrate the overall 'influence' of feedback by providing 'extreme' evidence for a very large effect (Figure 11) under H_1. The robustness (Figure 12) shows how the user prior (JASP default, 0.707) remains stable and the sequential analysis (Figure 13) is continuously in favour of H_1 as the sample size increases. This demonstrates the appropriateness of the feedback intervention on physically active, healthy adults, used within this study. Current literature has identified differences in feedback administration and their practical use for athletic disciplines and motor competence, for example, the method of feedback

delivery or type (Visual, Audible, or Haptic) as seen in Figure 1 (Sigrist et al, 2013a). With the current data, it is possible to suggest that augmented visual feedback positively affects skill learning within a population of healthy, physically active adults. However, due to differences in maturation, motor competence, and efficiency in specific age brackets and athletic levels, the administration of feedback type, frequency, and mode must be appropriate for each population (Chiviacowsky & Wulf, 2007; Chiviacowsky et al., 2008; Chiviacowsky et al., 2009; Liu & Wrisberg, 1997; Steinberg et al., 2016). This feedback style would need further testing on a much more diverse population, including participants of variable age, sex, ethnicity, and divergent populations (including adolescents, elderly, and clinical) to confirm or deny its generalisability.

However, even though the results are extremely positive for H_1, the results should be interpreted with caution as the small sample size (n = 17) can inflate the effect size (Abt et al., 2020). Therefore the 'true' effect would require a larger sample to estimate the precise effect to generalise to the wider populous. Additionally, as seen in Figure 11, the 95% credible interval is very wide, indicating uncertainty in the effect size estimate. Yet, because the effect size estimation has shifted a considerable amount to the right (away from 0) and has a high 'moderate' to 'extreme' effect, the substantial effect may allow for the wide credible interval to be disregarded. Although, even as the median effect size is more likely, we cannot discount the lower and upper bounds of the credible interval. As a result, the credible interval may show uncertainty, but the substantial effect size, including the lower/upper bounds, supports the research findings. Furthermore, the intra-observer reliability is excellent (ICC ≥ 0.9), as seen in Table 4, and the Bland-Altman limits of agreement suggest robust reliability with the mean difference being close to 0 (Table 5 and Table 6).

To summarise, the current study answers the research question and the alternative hypothesis ($BF_{10} \geq 10$) as there is unambiguous evidence ($BF_{10} = 2340$; median Cohen's *dz* ~ 1.4) of improved performance with the administration of concurrent and terminal feedback on physically active adults within the general population. This is shown by the reduction in mean QASLS score by reducing the number of 'movement strategies' used when performing the gross motor skill, 'single leg squat.' Ergo indicated an improvement in performance because of visual feedback.

5.1.1 Interpretation and Implications

The results indicate that QASLS can assess an individual's neuromuscular performance and this performance can be improved using augmented visual feedback. This may be an indicator that the use of QASLS as a screening tool and 'outcome' measure for rehabilitation progression/regression is being limited due to its common implicit targeting. This would not utilise the explicit portion of training, which is seen to improve performance, with augmented interventions being a part of training and everyday life (Schmidt & Wrisberg, 2008). Therefore, the results ascertain the use of feedback during movement screening tasks (scored with QASLS) as individuals will gain the neurocognitive benefits of visual stimuli, consistent with preliminary literature that identifies differences between regional brain activity and individual performance when exposed to visual feedback (Adamovich et al., 2009; Beets et al., 2015; Kumru et al., 2016; Lauber & Keller, 2014). While literature underlines the subjective and observational variations in response to visual stimuli thereby providing a correlational relationship to the current findings, further research employing the current studies' methodological approach with musculoskeletal profiling tools is warranted. This should include more rigorous observational and objective measures such as non-invasive EEG or FMRI neuroimaging techniques to effectively corroborate subjective findings. Furthermore, this may potentially aid the ruling out of deficits in neurocognitive and neuromuscular function, such as lower limb coordination as the clear intrasession improvement would highlight changes in motor control due to a motor adaptive response (Doyon et al., 2003; Doyon et al., 2009: Taylor & Ivry 2012); possibly indicating there is a skill issue, not something along the kinetic chain such as a strength deficit (Dawson & Herrington, 2015). This study demonstrates a correlation between concurrent and terminal feedback techniques on motor control performance as previously illustrated in the literature. As such, the analysis supports the theory that augmented feedback influences intrasession single-leg squat 'performance.'

The practical implications of the study demonstrate the practicality of feedback interventions as an external focus to elicit (1) a motor adaptive response, and (2) rather than use QASLS to 'pinpoint' potential kinematic compensatory behaviour which may be misjudged as a lack of strength, QASLS

can instead, with the aid of feedback, help understand the performance change, highlighting neural compensations during the implicit task. Concurrent augmented feedback acts as the primary source of afferent information, reducing the reliance on interoceptive mechanisms such as proprioception (Sigrist et al., 2013b), thus improved within-session performance would imply a deficit in the neuromuscular ability within the control condition. Therefore, these results would adjust the current perception and refine assessments, using 'outcome' measures, in a clinical and sporting environment. Consequently, improving patient outcomes because of more effective training regimens; the differentiation between implicit and explicit task-based compensations will guide clinicians and coaches to design prescriptive interventions tailored to individual needs, ensuring long-term performance gains by mitigating the counter-productive nature of unsuitable programs.

5.2 Limitations

A limitation which impacted kinematic analysis and consequently, the QASLS scoring procedure, was participant movement strategies causing certain anatomical retroreflective markers to become obscured. This made use of kinematic analysis as an aid for scoring, less effective and more challenging due to imprecise angle projection placement. Markers were obscured in three places: (1) at the head of the femur by the forearm, (2) at the lateral knee joint line by the hand, and (3) at the ASIS due to excessive hip flexion. Additionally, markers on the anterior patella and lateral malleolus would fall off during assessment, potentially due to the type of fabric worn by the participant and excess sweat reducing the adhesive qualities of the marker tape. The issues surrounding the marker adhesiveness could have been mitigated by instructing participants to wear a specific fabric or use fabric-friendly adhesive tape (on areas with clothing) and having all participants wear shorts to improve the tape-to-skin adhesive quality. Additionally, the placement of markers on clothing would not be biomechanically optimal when viewing joint angles, future studies would follow a stricter dress code, ensuring markers remain in the correct position relative to the joints being assessed. However, movement strategies which obscure a marker may be unavoidable in most cases (dependent on the individual).

Another limitation was problems with technology such as camera/battery failure or technical difficulties with the monitors used to deliver feedback. These problems caused delays in testing and showed unpreparedness to the participant which could have been avoided with better planning, communication with the technicians, and personal time management to solve any problems before the participant arrived. Additionally, having replacement equipment would have been beneficial in the event of short-notice technical difficulties.

A final limitation of the study which impacted the results was participant withdrawals from the study and cancellations with short notice or on the day of testing. This resulted in a smaller sample size than outlined in the preregistration, impeding the precision (narrowing) of the 95% credible interval that occurs with increased sample sizes (Cumming & Calin-Jageman, 2016). However, given the extreme evidence (BF_{10} > 100) provided for the alternative hypothesis, reaching a minimum sample size of 20 as outlined in the preregistration would probably not have made a meaningful impact on the result. In fact, given the direction of effect shown in the sequential analysis (Figure 13) a greater sample size would have increased the BF_{10} even more. To avoid this repetition in the future, increasing the data collection duration in anticipation of potential cancellations will provide ample time to meet and surpass the minimum sample size.

5.2.1 Recommendations & future research directions

To begin, this study provides a great insight into the use of feedback during screening tasks but would benefit from a larger sample, thus should be treated as a 'pilot.' Therefore, the completion of a replication study on the role of feedback on single-leg squat performance should be done. Increasing the scale of the project as part of a Doctorate (PhD) would provide the time required to complete a longitudinal study and a more comprehensive investigation with an increased sample size. This should provide a reliable and 'narrower' credible interval. However, during the replication study, changes will be made to improve efficiency while providing more data, and a greater understanding of the role of

feedback on skill acquisition and retention. The kinematic analysis process will be amended by altering the number of movement projection angles measured (annotated) as the angle projections are there to aid the QASLS scoring process, with angles not being observed frequently or beneficial. Their removal will speed up the analysis process while providing the same level of scoring aid. Moreover, a replication study with a larger sample would be followed by a training study where participants will complete a training protocol such as a 6-week skill acquisition plan with laboratory testing taking place at intervals and a retention test on week 12 (6 weeks after the training has ended). This will provide a greater amount of participant data between conditions while mitigating the effects of participant lifestyle (e.g. lack of sleep, changes in nutrition, and behaviour) on their intrasession performance due to the process of functional plasticity.

To summarise, recommendations for future practice are to increase the sample size and make methodological adjustments to improve the robustness of the study.

6.0 Chapter 6: Conclusion

While the role of augmented feedback techniques as an aid for improving motor control performance is known, preliminary research fails to identify the role of feedback in recognising differences in motor control performance in conjunction with musculoskeletal screening tools. As such, the evidence is clear that externally provided visual feedback can enhance the performance of an individual during a single-leg loading assessment. Therefore, screening tools that primarily assess for deficits in musculoskeletal function and target the implicit portion of the activity, can benefit from the explicit feedback due to the external focus placed on the individual which will aid in identifying neural compensations. This approach to administering feedback during screening assessments provides practitioners with the opportunity to clinically reason training interventions. By identifying differences in physiological and neural compensations, practitioners can make more informed decisions. The interplay between these factors becomes more apparent, allowing for targeted training interventions. Wherefore, practitioners would be able to assess the function of an individual and compare it with a repeated measures assessment with feedback for comparison; the differentiation between implicit and explicit task-based compensations will guide clinicians and coaches to design prescriptive interventions, ensuring long-term performance gains by mitigating the counter-productive nature of unsuitable programs. However, the feedback must be appropriate for the individual as differences in athletic capabilities and age will play a significant role in determining the style of feedback used. As such, future directions are to conduct a comprehensive investigation as part of a longitudinal study to further understand the ramifications of external interventions on training with a larger sample size for greater generalisation to the wider population.

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8.0 Chapter 8: Appendices

Appendix A

8.1 Ethics documentation

8.1.1 Research Ethics Form A1 (V1.9.1 20.06.2022)

FHS RESEARCH ETHICS COMMITTEE

SUBMISSION CHECKLIST

Applications by members of Staff:

I have completed the Research Integrity module on the e learning portal **Yes/No**

Indicate with 'X' the documents that have been included with this application.

Fully completed application form	x
Completed risk assessment (see section B4, form available on FHS Sharepoint	x
Recruitment materials – with date and version number) (e.g. poster or email used to invite people to participate)	
Information sheet(s) – with date and version number (different version for each group of participants)	x
Consent form(s) – with date and version number (different version for each group of participants)	x
Letter or email seeking permission from gatekeeper/host	

Questionnaire(s) – with date and version number	
If conducting a student survey, confirm that it fits with University policy	
Interview questions / topic guide – with date and version number	
Data management plan (see section F2)	x

Supporting documents should be saved with a meaningful file name and version control (e.g. 'Participant Information Sheet v1.0').

Wherever possible, please ensure that the research title used on consent forms, information sheets, and other supporting documentation is consistent. The title should make clear (where appropriate) what the research is about.

RESEARCH ETHICS COMMITTEE

FORM A – New Application

(Involving human participants, subjects or material)

It is essential that you are familiar with the University Code of Good Research Practice, Research Ethics Policy and the Procedures for Granting Ethical Approval before you complete this form that can be found here. Please confirm that you have read and understood these documents:

x	Yes		No

Please read each question carefully, taking note of instructions and completing all parts. If a question is not applicable please indicate so. Where a question asks for information which you have previously provided in answer to another question, please refer to your earlier answer rather than repeating information.

Ethics reference number (for office use):	
WorkTribe project URL	

PART A: SUMMARY	
A.1 Title of the research Cognition and skill learning in single-leg loading: The role of augmented visual feedback on motor control performance.	
A.2 Principal investigator's contact details	
Name *(Title, first name, surname)*	Mr Kai Duke
Position	Student
Faculty/School	Faculty of Health Sciences
Telephone number	07786 813 906

University of Hull email address	KAI.DUKE-2020@hull.ac.uk
A.3 To be completed by students only	
Qualification working towards (e.g. Masters, PhD, ClinPsyD)	Masters by thesis
Student number	202019072
Supervisor's name (Title, first name, surname)	Mr Jonty Ashton
Faculty/ School	FHS/Sport, Exercise and Rehabilitation Science
Supervisor's telephone number	n/a
Supervisor's email address	Jonty.ashton@hull.ac.uk
A.4 Other relevant members of the research team (e.g. co-investigators, co-supervisors)	
Name *(Title, first name, surname)*	Dr Ben Oliver
Position	Lecturer in Sport Rehabilitation
Faculty/ School	FHS/Sport, Exercise and Rehabilitation Science
Telephone number	n/a
Institution	University of Hull
Email address	b.oliver@hull.ac.uk
Name (Title, first name, surname)	Professor Grant Abt
Position	Professor of Exercise Physiology
Faculty/ School	FHS/Sport, Exercise and Rehabilitation Science
Telephone number	+44 01482 463397
Email address	g.abt@hull.ac.uk

A.5 Select from the list below to describe your research: (Mark with X all that apply)

- [x] Research on or with human participants
- [x] Research working with data of human participants
- [ ] New data collected by qualitative methods
- [x] New data collected by quantitative methods
- [x] New data collected from observing individuals or populations
- [x] Routinely collected data or secondary data
- [ ] Research working with aggregated or population data
- [ ] Research using already published data or data in the public domain
- [x] Research taking direct measurements from individuals e.g. physiology
- [ ] Research working with human tissue samples
- [ ] Research involving any invasive techniques including administering substances, food (other than refreshments), vitamins or supplements.
- [ ] Research involving discussion of sensitive topics or topics that could be considered sensitive
- [ ] Research involving discussion of culturally sensitive issues
- [ ] Prolonged or frequent participant involvement
- [x] Research involving members of the public in a research capacity (participant research)
- [ ] Research conducted outside the UK
- [ ] Research involving accessing social media sites
- [ ] Research involving accessing or encountering security sensitive material
- [ ] Research involving accessing websites or material associated with extreme or terrorist communities
- [ ] Research involving storing or transmitting any material that could be interpreted as sympathetic, endorsing or promoting terrorist acts
- [ ] Research involving financial inducements for participants (other than reasonable expenses and compensation for time)

A.6 If you are an employee of the university, are you employed under an academic contract? ***(applicable to University staff only)***

	Yes		No

If not, please explain very briefly why the research is required / permitted and provide evidence of permission to conduct the research from your line manager and any other appropriate party.

A.7 Will this study be pre-registered with an online registry (such as https://osf.io/, or AsPredicted.org)

x	Yes		No

If yes, please give the name of the registry. If the study has already been pre-registered, you should also provide the URL and/or study ID.

The study will be preregistered at the Open Science Framework prior to data collection.

A.8 Will this study be considered by any Ethics Committees external to the Faculty of Health Sciences?

	Yes	x	No

If yes, please identity the external committee:

PART B: THE RESEARCH

B.1 Give a short summary of the research (max 300 words)

Feedback techniques are used frequently in active daily living, sport, and training. For example, visual feedback such as distance or mean speed could be administered via a wearable device (e.g., Apple Watch) when running.

However, there is little evidence to support the use of visual feedback when performing an isolated single-leg movement. This information is important because single leg loading tasks are commonly used in sport and clinical settings as an outcome measure to identify functional movement deficiencies such as poor neuromuscular coordination and there is evidence of improvements in coordination because of visual feedback administration. This study aims to highlight the influence of feedback on movement 'quality'. The current study uses a repeated-measures crossover design with two conditions – visual feedback and control (no visual feedback). Participants will be randomly assigned to the first condition and then crossover to the alternative condition. In both conditions participants' movement 'quality' will be measured during 20 repeats of a single leg

loading movement. Movement 'quality' will be quantified using a 0-10 scoring tool where each point away from zero reflects a movement error such as waving arms to regain balance. In the visual feedback condition, visual feedback will be displayed in real-time using large monitors to the front of the participant. Summary feedback will also be shown to the participant after 5 repetitions to highlight any errors made. No visual feedback will be provided in the control condition. In both conditions all 20 single-leg movements will be video recorded. This information will be later analysed using video analyses software to determine differences in movement 'quality' between conditions. The primary research question is how does visual feedback impact single leg loading movement 'quality'?

B.2 Proposed study dates and duration

Research start date (DD/MM/YY): __01/09/2023___ Research end date (DD/MM/YY): _01/05/2024_____

Fieldwork start date (DD/MM/YY): _01/02/2024_____ Fieldwork end date (DD/MM/YY): __14/04/2024_____

B.3 Where will the research be undertaken? (i.e. in the street, on University of Hull premises, in schools, on-line etc.)

University of Hull biomechanics laboratory.

Do you have permission to conduct the research on the premises?

If no, please describe how this will be addressed.

B.4 Does the research involve any risks to the researchers themselves, or people not directly involved in the research? *E.g. lone working*

	Yes		x	No

If yes, please describe and say how these will be addressed (include reference to relevant lone working policies): _____

If yes, please include a copy of your completed risk assessment form with your application.

NB: If you are unsure whether a risk assessment is required visit the Health and Safety SharePoint site. Risk assessments are required for all fieldwork taking place off campus.

B.5 What are the main ethical issues with the research and how will these be addressed?

Indicate any issues on which you would welcome advice from the ethics committee

Data protection/privacy of participants. This will be addressed by storing all data/documents on a multi-factor password protected University of Hull OneDrive account. Personal details such as name used to identify participants will be coded/pseudonyms used to protect the identity of the participant.

B.6 Does the research involve an international collaborator or research conducted overseas:

	Yes		x	No

If yes, describe any ethical review procedures that you will need to comply with in that country:

Describe the measures you have taken to comply with these:

Include copies of any ethical approval letters/ certificates with your application.

PART C: HUMAN PARTCIPANTS AND SUBJECTS

C.1 Are the participants expected to be from any of the following groups? (Mark with X as appropriate)

Include in Section D5 details of extra steps taken to assure their protection.

Does your research require you to have a DBS check?

	Yes		x	No

It is the researcher's responsibility to check whether a DBS check (or equivalent) is required and to obtain one if it is needed. See also http://www.homeoffice.gov.uk/agencies-public-bodies/dbs

C.2 What are the potential benefits and/ or risks for research participants in both the short and medium-term?

Risks may include health and safety, physical harm and emotional well-being

Potential risks include musculoskeletal/soft tissue injury.

What will be done to avoid or minimise the risks?

Pre-exercise screening/medical history checks of participants and excluding those at risk. Providing an appropriate warm up before testing.

C.3 Is there a potential for criminal or other disclosures to the researcher requiring action to take place during the research? (e.g. during interviews/group discussions, or use of screen tests for drugs?)

	Yes		x	No

If yes, please describe and say how these will be addressed:

C.4 What will participants be asked to do in the study? *(e.g. number of visits, time involved, travel required, interviews)*

Prior to the main trials, participants will be measured for motor competency using a screening tool. The outcome of this screening process will determine the complexity of the task assigned to each participant during the main trials (see Movement Tasks section later). This screening process is a combination of the results from the pre-exercise medical questionnaire and a subjective score provided from the screening tool using a 0-10 scoring sheet (QASLS: adapted from Herrington et al., 2013). Participants will be instructed to complete the single leg squat (least challenging) for "live" scoring to determine their motor competency. Participants who score higher on the screening tool will be assigned a more complex (harder) movement to complete during the main trials. If screening indicates a high motor competency, participants will be instructed to perform the single leg drop down task. If motor competency remains high, participants will then be assessed during the single leg hop-for-distance. This screening 'triage' is being used because of the inevitable variation in athletic capacity and therefore potential for learning between participants.

Following the initial screening process, participants will be randomly assigned to one of two conditions – visual feedback or control (no visual feedback). In both conditions, participants will complete the movement task in four blocks (per limb), with each block consisting of five repetitions and blocks separated by three minutes of rest. Each movement will be video recorded from the frontal

and sagittal plane for later scoring and analysis. During the visual feedback condition only, concurrent visual feedback will be provided by two monitors placed directly in front of the participant to act as a mirror, displaying the frontal plane and sagittal plane of the standing leg. During each rest period, participants will also receive terminal visual feedback to highlight any errors made during each repetition.

Movement Tasks

Single leg squat (SLS): Participants will perform the SLS with their hands down by their sides, shoulders, and head in an anatomically neutral position, with their none-stance leg at 90° knee flexion. Participants will be instructed to perform the SLS movement to a comfortably challenging depth, then return to the starting position.

Single leg drop-down (SLDD): Participants will perform the SLDD on a box (20-30cm in height), and will be instructed to take a step forward and land on the contralateral limb then hold the landing for three seconds.

Single leg hop-for-distance (SLHD): Starting in the same position as SLS, participants will perform the SLHD by performing a partial SLS behind a marked line placed on the floor, then hopping as far as possible then hold the landing for three seconds.

Trials will last approximately 60 minutes each, totalling 120 minutes.

PART D: RECRUITMENT & CONSENT PROCESSES

How participants are recruited is important to ensure that they are not induced or coerced into participation. The way participants are identified may have a bearing on whether the results can be generalised. Explain each point and give details for subgroups separately if appropriate. Also say who will identify, approach and recruit participants. Remember to include all advertising material (posters, emails etc) as part of your application.

D.1 Describe <u>how</u> potential participants in the study be identified, approached and recruited and <u>who</u> will do this:

(i) identified:

Inclusion criteria

Those above the age of 18 with no injuries or recent injuries (less than 3 months prior to testing).

Exclusion criteria

1. Neurological conditions such as Parkinson's disease.
2. Semi-professional/professional athletic level.

(ii) approached:

Through personal approach, social media postings, and posters on the University of Hull campus.

(iii) recruited:

Participants will be recruited once they meet all inclusion criteria, have been informed on their requirements, and have completed a consent form.

D.2 Will you be excluding any groups of people, and if so what is the rationale for that?

Excluding certain groups of people, intentionally or unintentionally may be unethical in some circumstances. It may be wholly appropriate to exclude groups of people in other cases

As outlined in the exclusion criteria listed in section D1. The rationale for this is to avoid putting those at risk under stressful conditions, and this study is aimed at adult amateur level athletes and the healthy general population.

D.3 How many participants will be recruited and how was the number decided upon?

It is important to ensure that enough participants are recruited to be able to answer the aims of the research. The number of participants should be sufficient to achieve worthwhile results but should not be so high as to involve unnecessary recruitment and burdens for participants. This is especially pertinent in research which involves an element of risk. Describe here how many participants will be recruited, and whether this will be enough to answer the research question.

We will use a Bayesian sequential analysis approach, with the goals of generating 'strong' evidence for either H_0 or H_1 together with high precision in our population estimates. Bayesians are free to monitor the data as often as they wish as it is being collected (Wagenmakers et al., 2018, Moerbeek, 2021). We therefore do not have a fixed sample size. However, we have set a minimum sample size of 40. We will analyse data after our minimal sample size (40) has been achieved, after

every 5 participants thereafter (i.e., 45, 50), and/or when one of the stopping rules is met.

Given the research design, we will use a Bayesian paired-samples t-test to test for a difference between the two conditions (visual feedback and control). We will conduct this test in JASP 0.18.1 (https://jasp-stats.org/). Evidence in favour of H_1 will be quantified using a Bayes factor, with the 95% HDI (credible interval) used to quantify precision (uncertainty) in the population estimate.

Although we are collecting data that are ordinal in nature, parametric hypothesis tests are extremely robust to deviations from assumptions, such as normally distributed residuals (Norman, 2010).

Stopping rules

Using a Bayesian sequential analysis, and after our minimal sample size (40) has been achieved, we will continue collecting data until one of the following interim stopping rules are met:

1. A BF_{10} (evidence for H_1) for the primary outcome variable is >=10 ('strong' evidence for H_1).
2. A BF_{01} (evidence for H_0) for the primary outcome variable is >=10 ('strong' evidence for H_0).

If one of those criteria have been met, and there is adequate time between this point and the date stopping rule listed at 4, we will continue data collection until:

3. The 95% credible interval for the mean difference is no larger than 2 either side of the mean.

4. We will stop data collection on 12 April 2024.

Wagenmakers, E.-J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., Love, J., Selker, R., Gronau, Q. F., Šmíra, M., Epskamp, S., Matzke, D., Rouder, J. N., & Morey, R. D. (2018). Bayesian inference for psychology. Part I: Theoretical advantages and practical ramifications. Psychonomic Bulletin & Review, 25(1), 35–57. https://doi.org/10.3758/s13423-017-1343-3

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If you have a formal power calculation, please replicate it here.

D.4 Will the research involve any element of deception?

	Yes		x	No

If yes, please describe why this is necessary and whether participants will be informed at the end of the study.

D.5 Will informed consent be obtained from the research participants?

x	Yes			No

If yes, <u>give details</u> of how it will be done. Give details of any particular steps to provide information (in addition to a written information sheet) e.g. videos, interactive material. If you are not going to be obtaining informed consent you will need to justify this.

Participants will be briefed on the study requirements and aims with benefits and risks of involvement; any questions they may have will be answered. Once informed, participants will provide their informed consent.

If participants are to be recruited from any of potentially vulnerable groups, <u>give details of extra steps</u> taken to assure their protection. Describe any arrangements to be made for obtaining consent from a legal representative.

n/a

Copies of any written consent form, written information and all other explanatory material should accompany this application*. The information sheet should make explicit that participants can withdraw from the research at any time, if the research design permits. Remember to use meaningful file names and version control to make it easier to keep track of your documents.*

D.6 Describe whether participants will be able to withdraw from the study, and up to what point (e.g. if data is to be anonymised). If withdrawal is <u>not</u> possible, explain why not.

Any limits to withdrawal, e.g. once the results have been written up or published, should be made clear to participants in advance, preferably by specifying a date after which withdrawal would not be possible. Make sure that the information provided to participants (e.g. information sheets, consent forms) is consistent with the answer to D6.

Prior to submission of the thesis (~31st May 2024), participants are free to withdraw and do not have to provide a reason for withdrawal. Once a participant has withdrawn from the study, all personal information provided, or data gathered from the participant will be destroyed immediately. After submission of the thesis, any experimental data gathered from participants cannot be removed. However, only anonymised testing data will be stored and used. No personal information will be stored.

D.7 How long will the participant have to decide whether to take part in the research?

It may be appropriate to recruit participants on the spot for low risk research; however consideration is usually necessary for riskier projects.

Participants will take as long as necessary, consult family members if they wish to determine their involvement in the study. No coercion will be involved, and participants are not expected to be recruited immediately.

D.8 What arrangements have been made for participants who might have difficulties understanding verbal explanations or written information, or who have particular communication needs that should be taken into account to facilitate their involvement in the research? *Different populations will have different information needs, different communication abilities and different levels of understanding of the research topic. Reasonable efforts should be made to include potential participants who could otherwise be prevented from participating due to disabilities or language barriers.*

Those with neurological disorders will not be included in this study due to differences in cognitive ability. The rationale for this is due to the study aiming to highlight the role of visual feedback on motor control performance in healthy individuals.

If a language barrier is apparent then individuals will be provided with a visual aid to demonstrate what their involvement will consist of. Additionally, an appropriate translator will be sought if needed.

D.9 Will individual or group interviews/ questionnaires discuss any topics or issues that might be sensitive, embarrassing or upsetting, or is it possible that criminal or other disclosures requiring action could take place during the study (e.g. during interviews or group discussions)? *The information sheet should explain under what circumstances action may be taken.*

	Yes	x	No

If yes, give details of procedures in place to deal with these issues.

D.10 Will individual research participants receive any payments, fees, reimbursement of expenses or any other incentives or benefits for taking part in this research?

	Yes	x	No

If Yes, please describe the amount, number and size of incentives and on what basis this was decided.

PART E: RESEARCH INVOLVING HUMAN TISSUES OR MATERIAL (leave blank if not applicable)

E.1 Will the research involve the use of any of the following? (Mark with X as appropriate)

- ☐ Foetal material
- ☐ The recently deceased
- ☐ Cadavers
- ☐ Human bodily fluid
- ☐ Human tissue
- ☐ Human organs
- ☐ Human gametes

Go to Section F if the research does not involve any of the above material.

E.2 Will the material to be accessed be collected as part of this study or 3rd party accessed (E.g. material collected as part of another study or purchased)?

If yes to 3rd party access, please provide details on appropriate consent for this use.

E.3 What type of tissue or material will be collected?

E.4 How will the tissue or material be collected and who will do this?

E.5 How many samples will be collected?

E.6 How long will samples be stored?

E.7 Do you require a regulatory licence to use or store this material?

	Yes		No

All material is expected to be stored in line with the Human Tissue Authority storage expectations.

E.8 Do you have the appropriate Health and Safety procedures in place for the researchers to handle the samples?

	Yes		No

PART F: RESEARCH DATA

F.1 Explain what measures will be put in place to protect personal data. E.g. anonymisation procedures and coding of data. Any potential for re-identification should be made clear to participants in advance.

Personal information (e.g., name) will be stored separately from the data collected during the trials. We will also use codes to represent individuals. Personal data will be stored securely and unable to be accessed to those of the general public and those not involved in the research study.

F2. What security measures are place to ensure secure storage of data at any stage of the research?

Provide details on where personal data will be stored, any of the following: (mark with X all that apply)

X	University approved cloud computing services
x	Other cloud computing services
	Manual files
	Private company computers

	Portable devices
	Home or other personal computers (not recommended; data should be stored on a Unive server such as your G,T, X or Z: drive where it is secure and backed up regularly).

Please complete the simplified DMP by following the link below and attach as a word document in the appendices. Please use the extended DMP if you are submitting an IRAS application.

https://libguides.hull.ac.uk/researchdata/plan

F.3 Who will have access to participant's personal data during the study?

Lead researcher and study supervisors.

F.4 Where will the data generated by the research be analysed and by whom?

Data will be analysed at the home address of the lead researcher.

F.5 Who will have access and act as long term custodian for the research data generated by the study?

The lead researcher.

F.6 Have all researchers that have access to the personal data that will be collected as part of the research study, completed the University (or equivalent) data protection training?

x	Yes		No

It is mandatory that all researchers accessing personal data have completed data protection training prior to commencing the research.

F.7 Will the research involve any of the following activities at any stage (including identification of potential research participants)? (Select all that apply)

	Examination of personal records by those who would not normally have access
	Access to research data on individuals by people from outside the research team

	Electronic surveys, please specify survey tool: _____
	Other electronic transfer of data
x	Use of personal addresses, postcodes, faxes, e-mails or telephone numbers
x	Use of audio/ visual recording devices (NB this should usually be mentioned in the informatio participants)

F.8 Are there any reasons to prevent or delay the publication of this research? E.g. Commercial embargoes, sensitive material.

	Yes	x	No

If yes, provide details:

F.9 Where will the results of this study be disseminated? (Select all that apply)

	Conference presentation
x	Peer reviewed journals
x	Publication as an eThesis in the Institutional repository HYDRA
	Publication on website
x	Public data repository (e.g. the Open Science Framework OSF.org.io)
	Other publication or report, please state: _____
	Submission to regulatory authorities
	Other, please state: _____.
	No plans to report or disseminate the results

F.10 How long will research data from the study be stored?

5	years

F.11 When will the personal data collected during the study be destroyed and how?

Once the study is complete and passed. Personal data will be deleted from electronic software.

Researchers must comply with the General Data Protection Regulations that are live from May 2018.

PART G: CONFLICTS OF INTEREST

G.1 Will any of the researchers or their institutions receive any other benefits or incentives for taking part in this research over and above normal salary or the costs of undertaking the research?

	Yes		x	No

If yes, indicate how much and on what basis this has been decided

G.2 Is there scope for any other conflict of interest? *For example, could the research findings affect any ongoing relationship between any of the individuals or organisations involved and the researcher(s)? Will the research funder have control of publication of research findings?*

	Yes		x	No

If so, please describe this potential conflict of interest, and outline what measures will be taken to address any ethical issues that might arise from the research.

G.3 Does the research involve external funding? (Tick as appropriate)

	Yes		x	No

If yes, what is the source of this funding? _____

PART H: TRAINING
Please provide details of any training required to conduct this research by any member of the research team.

PART I: DECLARATIONS

Declaration by Principal Investigator

1 The information in this form is accurate to the best of my knowledge and belief.

2. I take full responsibility for the information I have supplied in this document.

3. I undertake to abide by the University's ethical and health and safety guidelines, and the ethical principles underlying good practice guidelines appropriate to my discipline.

4. I will seek the relevant School Risk assessment/COSHH approval if required.

5. If the research is approved, I undertake to adhere to the project protocol, the terms of this application and any conditions set out by the Faculty Research Ethics Committee.

6. Before implementing substantial amendments to the protocol, I will submit an amendment request to the Faculty Research Ethics Committee seeking approval.

7. If requested, I will submit progress reports.

8. I am aware of my responsibility to be up to date and comply with the requirements of the law and relevant guidelines relating to security and confidentiality of participants or other personal data, including the need to register when necessary with the appropriate Data Protection Officer.

9. I understand that research records/data may be subject to inspection for audit purposes if required in future.

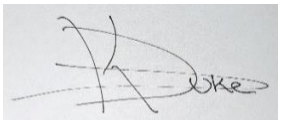
10. I take full responsibility for the actions of the research team and individuals supporting this study, thus all those involved will be given training relevant to their role in the study.

11. By signing the validation I agree that the Faculty Research Ethics Committee, on behalf of the University of Hull, will hold personal data in this application and this will be managed according to the principles established in the Data protection Act (1998).

Sharing information for training purposes: Optional – please mark with X as appropriate:

x	I would be content for members of other Research Ethics Committees to have access to the information in the application in confidence for training purposes. All personal identifiers and references to researchers, funders and research units would be removed.

Principal Investigator

Signature of Principal Investigator: 

(This needs to be an actual signature rather than just typed. Electronic signatures are acceptable)

Print name: .....Kai Duke..... Date: (dd/mm/yyyy): .....14/11/2023.....

Supervisor of student research: I have read, edited and agree with the form above.

Supervisor's signature:.....  .....

(This needs to be an actual signature rather than just typed. Electronic signatures are acceptable)

Print name: ....Jonty Ashton..... Date: (dd/mm/yyyy): .....30/11/2023.....

mailto:**Remember to include any supporting material** such as your participant information sheet, consent form, interview questions and recruitment material with your application. Version control should be adopted to include the version number and date on relevant documents in the appendices.

These should be pasted as Appendices to this form.

Multiple documents will not be accepted.

Please submit your form **by email** to **FHS-ethicssubmissions@hull.ac.uk**

8.1.2 Risk assessment (v1.0 / 27.10.2017)

FHS RESEARCH ETHICS COMMITTEE

RISK ASSESSMENT FORM

Title of the research	Cognition and skill learning in single-leg loading: The role of augmented visual feedback on motor control performance.
Name of Principal Investigator	Kai Duke
Location of research	University of Hull biomechanics laboratory.

Brief description of research activity

Participants will be required to perform 20 repetitions of a single leg squat or single leg landing task depending on their athletic level. This will then be repeated on the opposite limb.

RISK IDENTIFICATION

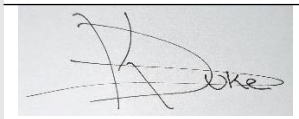
Please identify all risks related to this research and indicate WHO is at risk and the measures that are in place or are required to mitigate these.

RISK(S)	**MEASURES IN PLACE / REQUIRED** *(e.g. alternative work methods, training, supervision, protective equipment)*
Training / supervision: *(e.g. information or training required, level of experience, supervisor's input and oversight)*	Participants will be provided with a visual aid and demonstration on how to complete the movement correctly. Participants will be supervised for the duration of the session to avoid misuse of equipment or injury.
Location: *(e.g. remote area, laboratory, confined space, entry or exit, level of illumination, heating etc.)*	Data collection will take place in an illuminated indoor University of Hull biomechanics laboratory.

Research processes: *(e.g. use of electrical systems, gas, liquids, tissue, potential for contamination, flammability etc.)*	Research will include the use of 2 mobile devices, 2 monitors, and 2 cameras. These devices will only be operated by the lead researcher.
Equipment use: *(e.g. manual handling, operation of emergency controls etc.)*	Equipment will not be used by the participants; equipment will be set up prior to the session by the lead researcher. Potential equipment use includes a step-up box for a single leg drop down task. This will be supervised by the lead researcher. Participants will only be able to use this equipment if they meet the required athletic standard after pre-exercise screening.
Violence / upset / harm: *(e.g. potential for violence, sensitivity of topic, previous incidents etc.)*	No risk of violence or exposure to sensitive topics for both researcher and participant.

CONTINUED…..

Individuals: *(e.g. medical condition, young, inexperienced, disability etc.)*	Potential risk of musculoskeletal or soft tissue injury due to improper technique or loss of balance. Participants will be excluded if an existing injury exist or recent injury less than 3 months prior to testing. Participants will be provided an appropriate warm up and pre-exercise screening will be completed to identify those at risk.
Work patterns: *(e.g. lone working, working out of hours, working off site, isolated or remote location etc.)*	Data collection will be completed on the University of Hull campus.
Other:	n/a

Name of Principal Investigator:	Kai Duke
Signature:	

Date:	07/11/2023
Name of Supervisor (if relevant):	Jonty Ashton
Signature:	
Date:	5/12/2023

8.1.3 Data Management Plan

University of Hull

Data Management Plan

(NB: This form should be completed <u>at the start</u> of all projects where data management is not dealt with otherwise). Shaded areas are considered essential, particularly when a data management plan is required for a grant application.

Date	07/11/2023
Researcher(s)	Kai Duke
Project title	Cognition and skill learning in single-leg loading: The role of augmented visual feedback on motor control performance.
Brief description	This study consists of performance testing participants during single leg loading, such as the single leg squat. Scoring will be made using the dichotomous scoring tool

	(QASLS). Participants will perform 20 repetitions with and without augmented visual feedback (displayed using monitors) in a randomized order – repeated measures design. Visual feedback will be displayed concurrently to the participants with sagittal and frontal plane angles. Terminal feedback will be provided after 5 repetitions. This information will be analyzed using Kinovea software to determine differences in performance between conditions. This study aims to highlight the influence of feedback on motor control performance.

For detailed, updated explanations of the various parts of the document that require completion, please refer to the accompanying Appendices.

This University of Hull History Data Management Plan (HDMP) applies the DCC Checklist for Data Management (v3.0 17 March 2011).

Contents

Section 1: Project Information

A summary of the project details and associated data management requirements

1.1 Project title: Cognition and skill learning in single-leg loading: The role of augmented visual feedback on motor control performance.
1.2 Project duration (01/12/2023-01/04/2024)
1.3 Partners (if applicable)
1.4 Brief description This study consists of performance testing participants during single-leg loading, such as the single-leg squat. Scoring will be made using the dichotomous scoring tool (QASLS). Participants will perform 20 repetitions with and without augmented visual feedback (displayed using monitors) in a randomized order -repeated measures design. Visual feedback will be displayed concurrently to the participant with sagittal and frontal plane angles. Terminal feedback will be provided after 5 repetitions. This information will be analyzed using Kinovea software to determine differences in performance between conditions. This study aims to highlight the influence of feedback on motor control performance.
1.5 Faculty or University requirements for data management As outlined in the following sections.
1.6 Funding body(ies) Self-funded
1.7 Budget (estimate if necessary) n/a
1.8 Funding body requirements for data management N/A

Section 2: Data, Materials, Resource Collection Information

This section is used to more fully describe the data

2.1 Brief description of data being created or compiled Video recordings are collected from participants during the trials. These recordings are then analyzed and scored using a dichotomous scoring tool. These scores will act as the primary data for that participant.
2.2 Data collection process Data will be collected through video recordings of participants performing the movement. Video recordings will be analyzed in Kinovea software to track anatomical landmarks and identify potential movement errors. These errors will be scoring using the dichotomous 0-10 scoring tool (QASLS) where a point indicated a movement error. Scores taken will be placed in Microsoft Excel and once an appropriate amount of data is collected. Scores will be directed to JASP for further analyses.
2.3 Are there existing forms of the data that will be used within this research project, or which will be used as the basis for the research? If so, provide a brief description and citation No data.
2.3 Will data be available in electronic format (if so then state format(s))? Data will be in the form of video recordings, scored, then made available on Excel and stored in OneDrive.
2.4 Will the data be available in non-digital form (if so then state format(s))?

n/a

2.5 Will the data stand alone and be comprehensible to a third party or be accompanied by explanatory documentation (e.g., a data dictionary)?

Data will be comprehensible with a brief description explaining the process of scoring an individual.

2.6 Describe the quality assurance process for data management

The supervisory team will quality assure the data management plan.

Section 3: Ethics, Intellectual Property

This section is used to address issues surrounding relevant ethical and intellectual property issues the research will encounter

3.1 How will the ethical aspects of data storage and subsequent access be addressed? Data will be stored following GDPR guidelines and be stored using a multi-factor password protected University of Hull OneDrive account. This data will then be backed to a separate secure OneDrive account for subsequent access if needed.
3.2 Will the data comply with relevant legislation such as Data Protection Act, Copyright, Design and Patents Act, Freedom of Information Act, etc.? Yes, this will comply with GDPR guidelines/Data Protection Act.
3.3 If several partners are involved how will compliance with 3.1 and 3.2 be assured? Those able to review data are the study supervisor(s) and data is made available through a shared OneDrive folder. This data cannot be shared without the approval of the lead researcher.

Section 4: Access and Use of Information

This section is used to consider if and how you will share the data once it has been created/compiled

4.1 Are you required, or do you intend, to share the data, and with whom? If so, when? Yes, the data will be uploaded to an open access repository, the data file will be anonymized with identifiable information removed.
4.2 If ‘yes’ to 4.1, in what format will data be shared? Data will be shared in a .CVS file format.
4.3 Will the data have to be stored and/or made accessible for a specific period (if so, how long)? 5 years storage on an anonymous OSF and stored on a University of Hull approved OneDrive account for 5 years which is only accessible to the research team.
4.4 Who may need or wish to have access to the data? Research team.

4.5 How do you anticipate the data being used subsequent to the project?

Data will not be used after completion of the study; data will remain in secure storage.

Section 5: Storage and Backup of Data

This section is used to clarify details of how the data will be stored

5.1 Where and how will the data be stored **during the lifespan of the project**? Stored using a multi-factor password protected University of Hull OneDrive account.
5.2 Where and how will the data be stored **on completion of the project**? Upon completion of the study, data will be stored on a University of Hull OneDrive account which is accessible by research supervisors.
5.3 What provision is being made for backup of the data? Data is backed up each time new data is provided.
5.4 Will different versions of the data be stored? If so, what frequency of versioning will be appropriate? Copies of data will be stored in different OneDrive folders both shared and unshared.

Section 6: Archiving and Future Proofing of Information

This section is used to describe long-term, post-project aspects of managing the data

6.1 What is the long-term strategy for future proofing of the data? Data stored is in .CVS file format that can be imported into Excel.
6.2 How will the data be managed after the life of the project, for how long and in what format (NB this section refers to the detail of preservation and archiving actions, not just how it will be stored – this is addressed in section 5.2)? Data will be managed using University of Hull OneDrive with data being in a .CVS file format and managed by study supervisors for 5 years.
6.3 If the data include confidential or sensitive information, how will these data be managed to prevent possible future breaches? No confidential information will be stored long-term.
6.4 If metadata or explanatory information is to be archived, how will this be linked to the data? No metadata. Explanatory information (word document format) and raw anonymized data will be uploaded to the OSF site.

6.5 How will the data be cited? OSF project will have a citable URL.

Section 7: Resourcing of Data Management

This section is used to outline the staffing and financial details of the data management

7.1 List the specific staff who will have access to the data and denote who will have the responsibility for data management. Mr. Jonty Ashton – primary responsibility over data management. Dr Ben Oliver Professor Grant Abt
7.2 How will the data management described in this document be funded? OneDrive will be funded by the University of Hull, OSF is funded by an external body – center for open science Http://www.cos.io/
7.3 How will data storage be funded? OneDrive will be funded by the University of Hull.

Section 8: Review of Data Management process

This section is used to clarify how data management will be an embedded part of the research project

8.1 How will the data management plan be adhered to? Frequent reviews of the data management plan to ensure data management complies with requirements.
8.2 Who will review the data management plan? What is the schedule for this review? Study supervisors will review the data management plan 3 times. Once during the initial development, once half-way through the study, once at the end of the study.

Section 9: Statements and Personnel Details

9.1 Statement of agreement

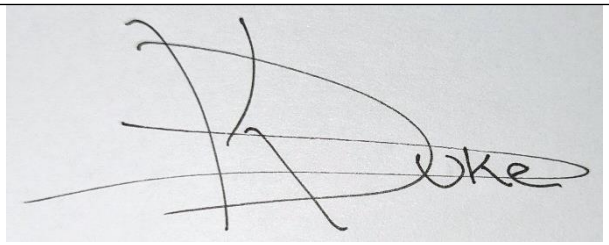
I/we agree to the specific elements of the plan as outlined:

Principal investigator or PhD supervisor

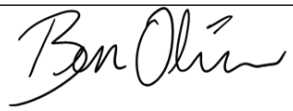
Title	Lecturer in Sport Rehabilitation
Designation	Primary supervisor
Name	Mr. Jonty Ashton, MSc
Date	30/11/23
Signature	

Researcher

Title	Graduate Sport Rehabilitator
Designation	MSc (by research) Sport, Health and Exercise Science post graduate student.

Name	Mr. Kai Duke, BSc
Date	30/11/23
Signature	

Researcher

Title	Programme director for Sport Rehabilitation
Designation	Co-supervisor
Name	Dr Ben Oliver, PhD
Date	30/11/2023
Signature	

Researcher

Title	Professor of Exercise Physiology
Designation	Co-supervisor
Name	Professor Grant Abt, PhD
Date	30/11/23
Signature	

9.2 Expertise of Researchers

Title	Lecturer of Sport Rehabilitation
Name	Mr. Jonty Ashton, MSc
Contact Details	Jonty.ashton@hull.ac.uk
Expertise	Sport rehabilitation Strength and conditioning.

Title	Graduate Sport Rehabilitator
Name	Mr. Kai Duke, BSc
Contact Details	KAI.DUKE-2020@hull.ac.uk
Expertise	Musculoskeletal injury assessment and management.

Title	Programme director for Sport Rehabilitation
Name	Dr Ben Oliver, PhD
Contact Details	b.oliver@hull.ac.uk
Expertise	Musculoskeletal assessment and management of injured populations.

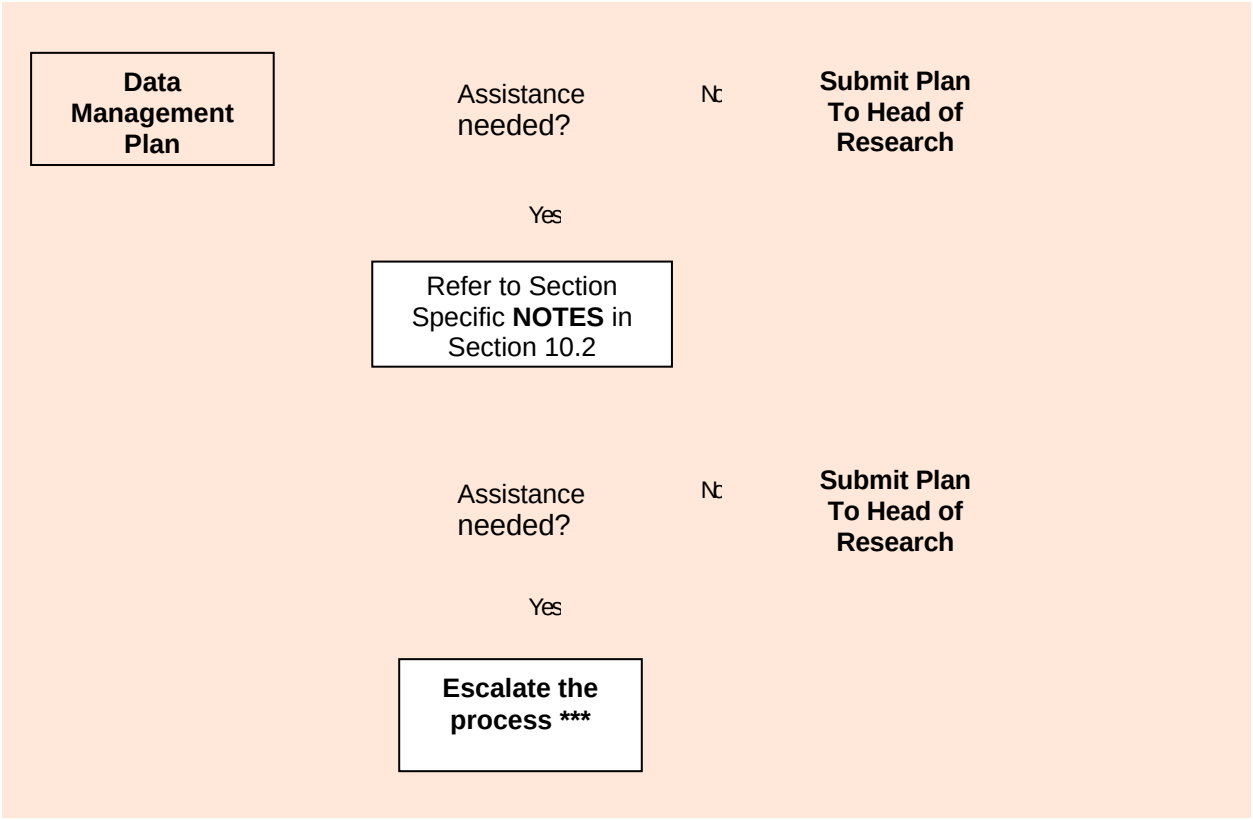
Title	Professor of Exercise Physiology
Name	Professor Grant Abt, PhD
Contact Details	g.abt@hull.ac.uk
Expertise	Research methods and statical analysis.

** More than one Researcher may be involved. Continue on a separate page if necessary.

Section 10: Appendices

10.1 Specific Help with completing the Plan

In certain instances, specific guidance may be required in order to complete this Data Management Plan. Assistance should be sought by following the flow chart below:



Escalate the process by requesting assistance from the Departmental Head of Research. Typically this will entail contacting Departmental or Faculty data managers and/or Library and Learning Innovation and ICTD. Specific assistance may be available through the Research Funding Office as well, particularly in relation to funder requirements for data management.

10.2 Notes

These notes refer to the specified sections and subsections in this document. Any areas not addressed may be referred to the project lead, supervisor, or the Head of Research. Technical issues may be addressed to the HDMP development team in the first instance.

Front Cover

Details are required to ensure the correct future referencing, storage and archiving of the Data Management Plan. There will be strict adherence to applicable law, including the Data Protection Act; this information will not be made available outside of the specific remit of the Faculty of Health and Social Care of the University of Hull.

Section 1: Project Information

1.1 No specific guidance available

1.2 No specific guidance available

1.3 Required for funded projects – this refers to organisations other than the University of Hull

1.4 If necessary, further information may be provided on an attached, clearly labelled **typed** or **printed** sheet. For online forms, the space will automatically be increased to accommodate extra text.

1.5 State what local requirements are in place – details from Head of Research

1.6 Details may be requested from the project Supervisor, or the Head of Research.

1.7 Applies specifically to funded projects. If necessary, further information may be provided on an attached, clearly labelled **typed** or **printed** sheet. For online forms, the space will automatically be increased to accommodate extra text.

1.8 Applies specifically to funded projects. If necessary, further information may be provided on an attached, clearly labelled **typed** or **printed** sheet. For online forms, the space will automatically be increased to accommodate extra text. Details may be requested from the project Supervisor, or the Head of Research.

Section 2: Data, Materials, Resource Collection Information

2.1 If necessary, further information may be provided on an attached, clearly labelled **typed** or **printed** sheet. For online forms, the space will automatically be increased to accommodate extra text. NOTE: details may change as the project evolves; provide a best estimate.

2.2 If necessary, further information may be provided on an attached, clearly labelled **typed** or **printed** sheet. For online forms, the space will automatically be increased to accommodate extra text.

2.3 It is vital that there is a clear understanding of exactly which data types are being discussed in order to plan for future storage, accessibility and integrity. Example data types and formats are available at http://en.wikipedia.org/wiki/List_of_file_formats.

2.4 A great deal of non-digital data may need to be stored securely and/or archived. Various examples of this type of data are:

- Documents: Printed digital, Original artefact, , etc.
- Images: Photographs (size, print type, age), posters, etc.
- Artefacts: Physical model (scale/non-scale, size, availability), archaeological, etc.
- Film: 8/16/32mm, Video, microfilm, negative, etc.
- Other: Live performance, logical model, etc.

2.5 “Standalone” implies a provided information resource that requires no further explanation and may be used “as is” without additional resource. Accompanied implies information that is informed by accompanying documentation or resource(s) which help to understand the resource. For example, a database may need to be accompanied by a “metadata” informative document which explains the purpose, use of specific fields, and instructions for utilisation. Details may be requested from the project Supervisor, or the Head of Research.

2.6 Quality Assurance/Management in this context refers to the concise provision of a breakdown of what will be done to ensure that the project’s progress will be monitored for accuracy, quality of work or research, and timely delivery at regular intervals. Typically, this would be the remit of the Research Supervisor, the Project Lead, or the Head of Department. Details may be requested from the project Supervisor, or the Head of Research.

Section 3: Ethics, Intellectual Property, Citation

3.1 If your research has an impact on the welfare, confidentiality or economic status of any individual or corporate group, this should be clearly stated. If necessary, further information may be provided on an attached, clearly labelled **typed** or **printed** sheet. For online forms, the space will automatically be increased to accommodate extra text. **NOTE**: details may change as the project evolves; provide a best estimate.

3.2 It is vital to comply with applicable law. Provide a brief outline of how relevant legislation and regulations will be complied with where appropriate. Where there is any doubt, the first line of contact is the project Supervisor, or the Head of Research.

3.3 See note 3.2 above. Partners in the project must be held to the same legal and regulatory standards. Partners are also protected by applicable law and may avail themselves of the prospect of legal recourse in the event of any perceived illegality or infringement by any party. This applies to all participants effecting or affected by the research project. Where there is any doubt, the first line of contact is the project Supervisor, or the Head of Research.

Section 4: Access and Use of Information

4.1 Sharing data, i.e. making it publically available, may be a requirement of a funding bid, or of a University research project (e.g. Doctoral thesis or research project). Details may be requested from the project Supervisor, or the Head of Research.

4.2 Provide details of how you intend to share your data (if relevant). This may include several options, such as an online accessible dataset or database, or online images.

It could also be in the form of a paper based document or set of documents. If you are uncertain, or wish to explore this avenue further, the first line of contact is the project Supervisor, or the Head of Research.

4.3 If your data are sensitive (e.g. not suitable for general access until you have completed, or contains personal data or information) you may need to keep the data secure until you are ready to publish – if at all. Similarly, if the project funder requires “mile-stone” releases, this should be indicated. If in doubt, check this with the project Supervisor, or the Head of Research.

4.4 It is vital that you have a clear perspective of who the outcome of your research is intended to reach. Funding bodies may stipulate specific outcomes – e.g. public access, etc.

4.5 Funding bodies will typically require an explanation of the usefulness of your research once completed, and you should be able to provide a clear idea of what will be done with your data once published or released. Certain obvious options should not be overlooked, such as: paper presented at conference for history community, or book chapter published for community and public research/interest, etc.

Section 5: Storage and Backup of Data

5.1 It is vital that the research materials and data are kept *safely at every stage* of the research process lifespan. There may be help available from IT Services, the Library or the Department. If you are uncertain, or wish to explore this avenue further, the first line of contact is the project Supervisor, or the Head of Research.

5.2 As for 5.1 above, it is vital that you have a clear understanding of how, where and when the research materials and data will be maintained after research process lifespan. This is particularly true where funding bodies have specific outcome criteria (e.g. making a public website available, etc.). There may be help available from IT Services, the Library or the Department. If you are uncertain, or wish to explore this avenue further, the first line of contact is the project Supervisor, or the Head of Research.

5.3 Similarly to 5.1 and 5.2 above, it is vital that you have a clear understanding of how, where and when the research materials and data will be backed up and kept safely, both during and after the after the research process lifespan. This is particularly true where funding bodies have specific outcome criteria (e.g. ensuring that online datasets are maintained for a specific period after the end of a project, etc.). There may be help available from IT Services, the Library or the Department. If you are uncertain, or wish to explore this avenue further, the first line of contact is the project Supervisor, or the Head of Research.

5.4 Very often work is added to, revised or altered and older versions are either overwritten, left as they were, or deleted. It may be wise to maintain a clearly labelled and stored set of older versions of current work in order to backtrack if necessary. Itis imperative that a logical and sequenced filing system is used. On computer systems this may be attained by uniquely numbering each version. A useful means of achieving this is by using the current date and time as the unique numbering reference – e.g. “yyyymmdd FHSC Data Management Plan”.

Section 6: Archiving and Future Proofing of Information

6.1 Provide information about how you intend for the project outcome(s) or deliverable(s)

to be maintained after the end of the project. For example, a dataset may be perpetually maintained by the University's online provision. However, this will need to be confirmed. There may be help available from IT Services, the Library or the Department. If you are uncertain, or wish to explore this avenue further, the first line of contact is the project Supervisor, or the Head of Research.

6.2 Any information that is kept after the lifespan of a project will still need to be stored safely, maintained and be provided in a useable format. If specific file formats are used, they may become unusable after a few years as new software replaces the old. Also, media such as DVDs, CDs and diskettes may become unusable after a while. There may be help available from IT Services, the Library or the Department. If you are uncertain, or wish to explore this avenue further, the first line of contact is the project Supervisor, or the Head of Research.

6.3 It is vital that any confidential data (e.g. personal information about any individual who is protected under the terms of the Data Protection Act, or information that may infringe copyright if released, etc.) must be kept and maintained in a secure environment. All reasonable steps should be taken to ensure the safety of such information. This applies to any information that is kept after the lifespan of a project as well. If you are uncertain, or wish to explore this avenue further, the first line of contact is the project Supervisor, or the Head of Research.

6.4 Datasets, databases, standalone documents, and even artefacts may prove useless without explanatory notes (metadata) accompanying them. These materials need to be clearly linked to the materials so that they can adequately inform any future user about the material. For example, a published dataset will typically be accompanied by a metadata document that explains the various fields, their usefulness and summarises the purpose of the dataset in general. These documents will be stored along with the dataset and are accessible in the same manner as the dataset (e.g. online, or download). Examples of such accompanying documentation are available for download. If you wish to explore this avenue further, the first line of contact is the project Supervisor, or the Head of Research.

6.5 Typically, any stored data, materials, artefacts, etc. will need to be cited when accessed and referenced by other researchers. It is useful to provide clear and concise citation information for researchers to access. This can be done via the accompanying documentation (metadata) indicated in 6.4 above. If you wish to explore this avenue further, the first line of contact is the project Supervisor, or the Head of Research.

Section 7: Resourcing of Data Management

7.1 In the event that this is an individual project or piece of research, your own name

should be listed. Include any other staff or assistants are to be involved in the project as well. It may be necessary to include staff from other departments of the University.

If you are uncertain, or wish to explore this avenue further, the first line of contact is the project Supervisor, or the Head of Research.

7.2 Funding strategies are often outlined by funders and will include a data management aspect. The costs of any materials, equipment and specialist knowledge will need to be factored to arrive at a reasonable estimate. Include any materials or equipment that will be funded by the University and/or you. If you are uncertain, or wish to explore this avenue further, the first line of contact is the project Supervisor, or the Head of Research.

7.3 As in 7.2 above, funding strategies are often outlined by funders and will include a data management aspect. Typically the University will support on-going research projects, and assist in facilitating post project maintenance and/or presence of outputs. However, this needs to be confirmed to ensure that the service will be available in the form that is required. If you are uncertain, or wish to explore this avenue further, the first line of contact is the project Supervisor, or the Head of Research.

Section 8: Review of Data Management process

8.1 Funders will need to be informed about how the data management process will be implemented. Provide specific information about how you intend to follow through with the commitments and processes that have been discussed in the rest of this document. Typically, regular reviews, reports and assessments of progress will suffice, but some funders may require specific means of identifying adherence to the plan. If you are uncertain, or wish to explore this avenue further, the first line of contact is the project Supervisor, or the Head of Research.

8.2 Based on 8.1 above, list those who will be carrying out the reviews and subsequent reports or processes necessary to ensure the successful implementation and completion of the data management plan. Typically, in the event of smaller research projects or individual research, the project Supervisor will fill this role. In the event of PhD research, this role will be carried out by the PhD Supervisor(s). If you are uncertain, or wish to explore this avenue further, the first line of contact is the project Supervisor, or the Head of Research.

Section 9: Statements and Personnel Details

9.1 The Statement of Agreement is necessary to clarify the areas of responsibility and work that will be carried out by the various researchers engaged in the project. This information is vital for funding bodies that will require these details.

9.2 As in 9.1 above, the Expertise of Researchers is necessary to clarify the areas of responsibility and work that will be carried out by the various researchers engaged in the project. This information is vital for funding bodies that will require these details in the form of a brief résumé for each researcher.

Section 10: Appendices

10.1 Assistance with completing the Plan; follow the instructions to obtain help specific to each section.

10.2 Follow the guidance for each specific section as necessary.

10.3 This list of Relevant Contacts will be reviewed and altered regularly.

10.3 Relevant Contacts

The following list of contacts should be regularly revised as appropriate for the purposes of your research:

Head of Research	
Library and Learning Innovation	Chris Awre Head of Information Management Phone: +44 (0) 1482 465441 Email: c.awre@hull.ac.uk
ICT Directorate	IT Helpdesk Phone: +44 (0)1482 462010 E-mail: help@hull.ac.uk
Head of Department	
Document Author	Chris Awre Details as above

8.1.4 Participant Information Sheet (PIS)

INFORMATION SHEET FOR PARTICIPANTS

YOU WILL BE GIVEN A COPY OF THIS INFORMATION SHEET

Title of study – Cognition and skill learning in single-leg loading: The role of augmented visual feedback on motor control performance.

I would like to invite you to participate in a research project which forms part of my Masters degree research. The sponsor for this research is the University of Hull. Before you decide whether you want to take part, it is important for you to understand why the research is being done and what your participation will involve. Please take time to read the following information carefully and discuss it with others if you wish. Please ask me if there is anything that is not clear or if you would like more information.

What is the purpose of the study?

The purpose of the study is to understand the role of visual feedback (i.e., video recordings), administered by a practitioner/coach. This will be for single leg exercise performance, such as the single leg squat, to improve training in amateur sports and recreational activity.

Why have I been invited to take part?

You are being invited to participate in this study because you have met the inclusion criteria and are of an appropriate athletic/fitness level.

What will happen if I take part?

If you choose to take part in the study, you will be asked to complete pre-exercise screening to determine your athletic level. Your athletic level will be determined by completing the single leg squat task (least challenging) and this will be marked out of 10 on the day prior to the primary testing. You will complete familiarisation testing with/without visual feedback. Once complete, you will undertake four sets of five repetitions of the single leg squat, or an appropriate single leg landing task depending on your athletic level, then repeat the process on the opposite leg. You will be given 3-minute breaks between each set. When receiving feedback, visual feedback will be displayed throughout the testing period on large monitors placed in front of you, monitors will act as a mirror to display a video of you performing the movement from the front and the side. Additional feedback will be given during rest times to

highlight any errors made. Participation will take place in the University of Hull biomechanics laboratory and directions will be provided. The expected session length is 60 minutes, and you are expected to attend a second session 1 week after the first session. As part of participation, you will be asked to provide a completed informed consent document and completed medical document. Video recording will take place during the session; therefore, your consent to be recorded will be gained on the day of the session. Video recordings will be used to score the movement tasks.

Do I have to take part?

Participation is completely voluntary. You should only take part if you want to and choosing not to take part will not disadvantage you in any way. Once you have read the information sheet, please contact us if you have any questions that will help you decide about taking part. If you decide to take part, we will ask you to sign a consent form and you will be given a copy of this consent form to keep.

What are the possible risks of taking part?

Physical effort is involved in this study. You will experience the usual responses to exercise e.g., elevated heartrate, increased body temperature, and fatigue which are normal responses, other than that they will be no discomfort or harm. The likelihood of sustaining an injury is low however possible. For example, muscular injuries due to improper technique, or soft tissue damage such as scrapes/bruises due to loss of balance is also possible.

What are the possible benefits of taking part?

Possible benefits of taking part include gaining an understanding of a potentially new (to you) feedback technique that you can utilise within your own training/daily activities.

How will we use information about you?

We will need to use information from a completed medical document to determine your inclusion for this research project. This information will include your name, date of birth, physical activity status and past medical history.

People who do not need to know who you are will not be able to see your name or contact details. Your data will have a code number or pseudonym instead.

We will keep all information about you safe and secure.

Once we have finished the study, we will keep some of the data so we can check the results. We will draft our reports in a way that no-one can work out that you took part in the study.

Your data will be processed in accordance with the UK-GDPR and the Data Protection Act 2018.

- During this study, your data will be anonymised, and data will be stored on a multi-factor password protected University of Hull OneDrive account.
- Your personal data will be coded and provided with a pseudonym to avoid identification.
- Data will be stored for 5 years, and personal data will be destroyed once the study has been completed.
- Data will only be accessible to the lead researcher and study supervisor(s).
- Research data will not be shared to external sources; however, publication of results will include data from all participants. Your involvement/personal details will not be shared only scores from testing will be viewable.

What are your choices about how your information is used?

You are free withdraw at any point of the study, without having to give a reason but we will keep information about you that we already have if the study has been submitted (prior to publication – 31st May 2024). This will include your anonymised testing results; no personal information will be stored if you choose to withdraw.

Your rights to access, change or move your information are limited, as we need to manage your information in specific ways for the research to be reliable and accurate. If you withdraw from the study, we will keep the information about you that we have already obtained. To safeguard your rights, we will use the minimum personally identifiable information possible.

Where can you find out more about how your information is used?

You can find out more about how we use your information:

- By asking one of the research team
- By contacting the University of Hull Data Protection Officer by emailing dataprotection@hull.ac.uk or by calling 01482 466594 or by writing to the Data Protection Officer at University of Hull, Cottingham Road, Hull, HU6 7RX
- By reviewing the University of Hull Research Participant privacy notice: https://www.hull.ac.uk/choose-hull/university-and-region/key-documents/docs/quality/research-participant-privacy-notice.pdf

Data Protection Statement

The data controller for this project will be the University of Hull. The University will process your personal data for the purpose of the research outlined above. The legal basis for processing your personal data for research purposes under GDPR is a 'task in the public interest'

If you are not happy with the sponsor's response or believe the sponsor processing your data in a way that is not right or lawful, you can complain to the Information Commissioner's Office (ICO) (www.ico.org.uk or 0303 123 1113).

How is the project being funded?

This study is being self-funded by the lead researcher.

What will happen to the results of the study?

The results of the study will be summarised in a debrief form made available to you once the study is complete. The results will be used as part of a Masters degree thesis and a copy can be made available to you upon request. The results may be published in a scientific journal article.

Who has reviewed this study?

Research studies are reviewed by an independent group of people, called a Research Ethics Committee, to protect your interests. This study has been reviewed and been given a favourable opinion by the Faculty of Health Sciences Ethics Committee, University of Hull.

Who should I contact for further information?

If you have any questions or require more information about this study, please contact me using the following contact details:

KAI.DUKE-2020@hull.ac.uk

What if I have further questions, or if something goes wrong?

If you wish to make a complaint about the conduct of the study, you can contact the University of Hull using the details below for further advice and information:

Mr Jonty Ashton – jonty.ashton@hull.ac.uk

Alternatively, please contact university-secretary@hull.ac.uk

Thank you for reading this information sheet and for considering taking part in this research.

8.1.5 Participant Pre-exercise medical questionnaire

School of Sport, Exercise and Rehabilitation Sciences

UNIVERSITY

Pre-Exercise Medical Questionnaire

The information in this document will be treated as strictly confidential

Name:

Date of Birth: Age: Gender:

Blood pressure: Resting blood pressure:

Height (cm): Weight (Kg):

Please answer the following questions by putting a circle round the appropriate response or filling in the blank.

1. How would you describe your present level of **exercise** activity?

   Sedentary / Moderately-active / Active / Highly active

2. Please outline a typical weeks exercise activity

3. How would you describe your present level of **lifestyle** activity?
Sedentary / Moderately active / Active / Highly active

4. What is your occupation?

5. How would you describe your present level of fitness?
Unfit / Moderately fit / Trained / Highly trained

6. Smoking Habits

Are you currently a smoker?	Yes / No
How many do you smoke	per day
Are you a previous smoker?	Yes / No
How long is it since you stopped?	years
How many did you smoke?	per day

7. Do you drink alcohol? Yes / No

If you answered **Yes** and you are male do you drink more than 28 units a week?
Yes / No

If you answered **Yes** and you are female do you drink more than 21 units a week?
Yes / No

8. Have you had to consult your doctor within the last six months? Yes / No
If you answered **Yes**, Have you been advised **not** to exercise?
Yes / No

9. Are you presently taking any form of medication? Yes / No
If you answered **Yes**, Have you been advised **not** to exercise?
Yes / No

10. Do you have a history of fainting during or following exercise? Yes / No
If **Yes**, please provide details:

11. To the best of your knowledge do you, or have you ever, or have a family history:

a Diabetes?	Yes / No	**b** Asthma?	Yes / No
c Epilepsy?	Yes / No	**d** Bronchitis?	Yes / No
e ✸Any form of heart complaint?	Yes / No	**f** Raynaud's Disease	Yes / No
g ✸Marfan's Syndrome?	Yes / No	**h** ✸Aneurysm / embolism?	Yes / No
I Anaemia	Yes / No		

12. ✸Are you over 45, and with a history of heart disease in your family? Yes / No

13. Do you currently have any form of muscle or joint injury? Yes / No

If you answered **Yes**, please give details

14. Have you had to suspend your normal training in the last two weeks? Yes / No

If the answer is **Yes** please give details

15. ✸ Please read the following questions:

a) Are you suffering from any known serious infection? Yes / No

b) Have you had jaundice within the previous year? Yes / No

c) Have you ever had any form of hepatitis? Yes / No

d) Are you HIV antibody positive Yes / No

e) Have you had unprotected sexual intercourse with any person from an HIV high-risk population? Yes / No

f) Have you ever been involved in intravenous drug use? Yes / No

g) Are you haemophiliac? Yes / No

16. As far as you are aware, is there anything that might prevent you from successfully completing the tests that have been outlined to you? Yes / No.

IF THE ANSWER TO ANY OF THE ABOVE IS YES:

a) Discuss with the test administrators or another appropriate member of the department.

b) Questions indicated by (✱) answered yes: Please obtain written approval from your doctor before taking part in the test.

PLEASE SIGN AND DATE AS INDICATED ON THE NEXT PAGE

Participant Signature Date

Supervising staff member Date

Parent (if minor) Date

THIS SECTION IS ONLY REQUIRED FOR RETURN VISITS!

For any future testing sessions it is necessary to verify that the responses provided above are still valid, or to detail any new information. This is to ensure that you have had no new illness or injury that could unduly increase any risks from participation in the proposed physical exercise.

ANSWER THE FOLLOWING QUESTION AT EACH REPEAT VISIT.

Is the information you provided above still correct, and can you confirm that you have NOT experienced any new injury or illness which could influence your participation in this exercise session?

Repeat 1	Yes / No*	Signature:	Date:
*Additional info required:			
Repeat 2	Yes / No*	Signature:	Date:
*Additional info required:			

8.1.6 Participant Consent form

Version number and date: V1; 05/12/23

CONSENT FORM

Title of study: Cognition and skill learning in single-leg loading: The role of augmented visual feedback on motor control performance.

Name of Researcher: Kai Duke

	Please initial box
1. I confirm that I have read the information sheet dated..... version..... for the above study. I have had the opportunity to consider the information, ask questions and have had any questions answered satisfactorily.	☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason.	☐
3. I understand that my personal data will be kept securely in accordance with data protection guidelines and will only be available to the immediate research team.	☐
4. I give permission for the collection and use of my data to answer the research question in this study.	☐
5. I agree to take part in the above study.	☐

_____	_____	_____
Name of Participant	Date	Signature
_____	_____	_____
Name of Person taking consent	Date	Signature

8.1.7 Participant Debrief form

Participant Debrief

1. Project title	Cognition and skill learning in single-leg loading: The role of augmented visual feedback on motor control performance.
2. Student investigator	**Name**: Kai Duke **Email address**: KAI.DUKE-2020@hull.ac.uk **Contact telephone number**: 07786 813 906

3. What was the purpose of the project?
The purpose of this project was to understand the role of visual feedback (i.e., video recordings), administered by a practitioner/coach, on single leg loading performance to improve training in amateur sports and recreational activity.
4. How will I find out about the results?
You will be informed of the results once the study is complete.
5. What will happen to the information I have provided?
Any information that you have provided will be destroyed upon completion of the study and once the thesis has passed the exam board. Any confidential information will be protected via a password protected service.
6. Have I been deceived in any way during the project?
No.
7. If I change my mind and wish to withdraw the information I have provided, how do I do this?
Contact the student investigator using the contact details provided. You do not need to explain yourself, the information will be destroyed if requested.
8. What if I am unhappy about my participation in the project?
If you have any concerns or worries concerning the way in which this research has been conducted, then please contact the Chair of the Department of Sport, Health and Exercise Ethics (Dr Daniel Fleming / Professor Lee Ingle: SERSethics@hull.ac.uk), who will investigate your complaint.

8.1.8 Ethical Approval Letter

University of Hull
Hull, HU6 7RX
United Kingdom
T: +44 (0)1482 463336 | **E:** Maureen.Twiddy@hyms.ac.uk
w: www.hull.ac.uk

PRIVATE AND CONFIDENTIAL
Kai Duke
Faculty of Health Sciences
University of Hull
Via email

Thursday 4th January 2024

Dear Kai,

FHS 23-24.38 - Cognition and skill learning in single-leg loading: The role of augmented visual feedback on motor control performance.

Thank you for your responses to the points raised by the Faculty of Health Sciences Research Ethics Committee.

Given the information you have provided I confirm approval by Chair's action.

The approval is valid until 1st May 2024. If you require an extension to this end date or you need to report any
further amendments to your study please complete Form C which can be found at Research Ethics (sharepoint.com) for staff and Student Research Ethics (sharepoint.com) for students.

Should an Adverse Event need to be reported, please complete the Adverse Event Form and send it to the Research Ethics Committee FHS ethicssubmissions@hull.ac.uk within 15 days of the Chief Investigator becoming aware of the event.

I wish you every success with your study.

Yours sincerely

Maureen Twiddy

Dr Maureen Twiddy
Chair, FHS Research Ethics Committee

Maureen Twiddy I Senior Lecturer in Applied Health Research Methods I Faculty of Health Sciences
University of Hull
Hull, HU6 7RX, UK
www.hull.ac.uk
Maureen.Twiddy@hyms.ac.uk I 01482 463336
@UniOfHull /UniversityOfHull universityofhull

Appendix B

8.2 Self-administered International Physical Activity Questionnaire Short Form

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE (August 2002)

SHORT LAST 7 DAYS SELF-ADMINISTERED FORMAT

FOR USE WITH YOUNG AND MIDDLE-AGED ADULTS (15-69 years)

The International Physical Activity Questionnaires (IPAQ) comprises a set of 4 questionnaires. Long (5 activity domains asked independently) and short (4 generic items) versions for use by either telephone or self-administered methods are available. The purpose of the questionnaires is to provide common instruments that can be used to obtain internationally comparable data on health–related physical activity.

Background on IPAQ

The development of an international measure for physical activity commenced in Geneva in 1998 and was followed by extensive reliability and validity testing undertaken across 12 countries (14 sites) during 2000. The final results suggest that these measures have acceptable measurement properties for use in many settings and in different languages, and are suitable for national population-based prevalence studies of participation in physical activity.

Using IPAQ

Use of the IPAQ instruments for monitoring and research purposes is encouraged. It is recommended that no changes be made to the order or wording of the questions as this will affect the psychometric properties of the instruments.

Translation from English and Cultural Adaptation

Translation from English is supported to facilitate worldwide use of IPAQ. Information on the availability of IPAQ in different languages can be obtained at www.ipaq.ki.se. If a new translation is undertaken we highly recommend using the prescribed back translation methods available on the IPAQ website. If possible please consider making your translated version of IPAQ available to others by contributing it to the IPAQ website. Further details on translation and cultural adaptation can be downloaded from the website.

Further Developments of IPAQ

International collaboration on IPAQ is on-going and an ***International Physical Activity Prevalence Study*** is in progress. For further information see the IPAQ website.

More Information

More detailed information on the IPAQ process and the research methods used in the development of IPAQ instruments is available at www.ipaq.ki.se and Booth, M.L. (2000). *Assessment of Physical Activity: An International Perspective*. Research Quarterly for

Exercise and Sport, 71 (2): s114-20. Other scientific publications and presentations on the use of IPAQ are summarized on the website.

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think *only* about those physical activities that you did for at least 10 minutes at a time.

1. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling?

   _____ days per week

   No vigorous physical activities → ***Skip to question 3***

   ☐

2. How much time did you usually spend doing **vigorous** physical activities on one of those days?

   _____ hours per day _____ minutes per day

   ☐ Don't know/Not sure

Think about all the **moderate** activities that you did in the **last 7 days**. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

3. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

   _____ days per week

No moderate physical activities → ***Skip to question 5***

☐

4. How much time did you usually spend doing **moderate** physical activities on one of those days?

_____ hours per day _____ minutes per day

☐ Don't know/Not sure

Think about the time you spent **walking** in the **last 7 days**. This includes at work and at home, walking to travel from place to place, and any other walking that you have done solely for recreation, sport, exercise, or leisure.

5. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time?

_____ days per week

No walking → ***Skip to question 7***

☐

6. How much time did you usually spend **walking** on one of those days?

_____ hours per day _____ minutes per day

☐ Don't know/Not sure

The last question is about the time you spent **sitting** on weekdays during the **last 7 days**. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

7. During the **last 7 days**, how much time did you spend **sitting** on a **week day**?

_____ hours per day _____ minutes per day

☐ Don't know/Not sure

This is the end of the questionnaire, thank you for participating.

Appendix C

8.3 Participant Recruitment Poster

This appendix was submitted for examination but cannot be published as it incorporates sensitive personal data and third-party copyright material.

Appendix D

8.4 QASLS scoring sheet

Qualitative analysis of single leg loading

Date: Patient:

Condition: Left Right Bilateral

QASLS	Task: Single leg squat Single leg step down Single leg hop for dist	Left	Right
Arm strategy	Excessive arm movement to balance		
Trunk alignment	Leaning in any direction		
Pelvic plane	Loss of horizontal plane		
	Excessive tilt or rotation		
Thigh motion	WB thigh moves into hip adduction		
	NWB thigh not held in neutral		
Knee position	Patella pointing towards 2nd toe (noticeable valgus)		
	Patella pointing past inside of foot (significant valgus)		
Steady stance	Touches down with NWB foot		
	Stance leg wobbles noticeably		
	Total		