

The Effects of Visual and Audio Secondary Cognitive Tasks During Landing: A Statistical Parametric Mapping Analysis of Hip and Knee Biomechanics

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Abstract

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<https://doi.org/10.70252/KGHI3479> ACL injuries often occur when athletes perform cognitive tasks while performing a landing/cutting movement. This study investigated the effects of secondary cognitive tasks on hip and knee biomechanics during single limb landing. Sixteen recreational athletes (10 females and 6 males, age: 21.6 ± 2.5 years, mass: 65.2 ± 8.9 kg, height 1.66 ± 0.07 m) performed landings on their dominant limb as a single task and while simultaneously performing secondary cognitive tasks (mental arithmetic) provided through audio and visual means. Hip and knee joint angles and moments were calculated in all three planes of motion and analysed using statistical parametric mapping repeated-measures ANOVA. Hip adduction angle was significantly greater in audio and visual secondary task conditions compared to the single task condition during 88% to 100% of the landing period. Hip internal rotation was significantly greater in the visual secondary task condition compared to the single task condition during 68% to 92% of the landing period. There were no significant differences between task conditions for hip moments, knee moments or knee angles in all three planes of motion. These findings suggest secondary cognitive tasks, whether visual or audio, affect hip kinematics which may reflect reduced dynamic stability at the hip, contributing important further knowledge on the effect of secondary cognitive tasks during landing biomechanics.

Keywords: Dual-tasking, multi-tasking, kinematics, kinetics, ACL injury

Introduction

Anterior cruciate ligament (ACL) injuries are common in sports, with over 120,000 ACL injuries reported in the United States each year¹ and annual injury rates reported at approximately 5% in female soccer and basketball athletes.² ACL injuries result in extended absence from sports, with Harris et al.³ reporting only half of the 49 studies included in their systematic review to have permitted return to sport without restrictions 6 months after ACL injury. The majority (70 to 90%) of ACL injuries are reported to be sustained through non-contact mechanisms, where the knee does not experience direct external impact.⁴⁻⁷ These injuries are common during landing and cutting movements when taking place in a sporting environment involving dynamic and reactive situations. Sports such as basketball and soccer therefore have a high

incidence of non-contact ACL injury². Furthermore, landing in single limb stance is associated with higher incidence of injury compared to double-limb stance.⁸

Much of the previous research investigating the biomechanics associated with ACL injury during landing/cutting manoeuvres have assessed participants performing those movements as a single task, meaning athletes are able to focus the majority of their attention on completing the task in an effective and safe manner. During competition, athletes will usually complete these motor tasks while simultaneously performing cognitive tasks which requires them to monitor and respond to external stimuli. These stimuli may be both visual (e.g. ball or player or opponent movement) and audio (e.g. calls/sounds from teammates or opponents) in nature. Athletes must therefore divide their attention between multiple tasks, assigning an appropriate amount of their attentional capacity to each task. In order to investigate the effects of cognitive demand on landing/cutting biomechanics, dual-task testing protocols have been used where participants are required to divide their attention between two tasks at the same time.⁹ Previous research has employed secondary tasks such as performing a basketball chest pass,¹⁰ mental arithmetic (counting backwards or summing numbers),¹¹ recall of numbers,¹² tracking shapes¹³ or reacting to a light signal.¹⁴ While the number of studies to date is small, previous research investigating the effects of secondary cognitive tasks on landing/cutting biomechanics suggests that the cognitive tasks may increase ACL injury risk through reducing the knee flexion angle at initial contact,^{11,14} reducing the peak knee flexion angle,¹⁰ increasing the peak knee valgus angle,¹⁰ increasing the vertical ground reaction force (GRF)^{11,14} and increasing the posterior GRF.¹¹ These previous studies all report discrete biomechanical variables rather than examining differences between dual-task conditions during the entire time-series curve of the landing period. Focusing the analysis of biomechanical data on discrete time points during a landing may overlook potential differences at other time points during the landing period. Statistical parametric mapping (SPM) is a method of statistically analysing a given biomechanical parameter during an entire movement and has been shown to be a highly suitable method of analysis for one-dimensional biomechanical data, such as joint angles and moments.¹⁵

At present, little is known regarding the effects of the medium (i.e. visual or audio) used to provide the information required for the secondary task to the participant. There are differences in the way in which audio and visual information are processed, since audio information is processed over time as the sounds is produced whereas visual information is often available all at once, resulting in some studies showing that the type of secondary task may have differing effects on motor performance.¹⁶ Furthermore, when secondary task instructions are provided through a visual means, participants are required to focus their vision on a specific location which may inhibit their ability to use their vision to anticipate ground contact compared to when the same secondary task instructions are provided through audio means. Interference to visual input during landing has been proposed to influence stability during landing,¹⁷ therefore visual secondary tasks may have a greater influence on landing biomechanics compared to audio secondary tasks. The aim of this study was to investigate the effects of visual and audio secondary cognitive tasks on hip and knee biomechanics during single limb landing using SPM analysis of the full landing period. It was hypothesised that landing biomechanics would be significantly altered by performing a secondary cognitive task and that a visual secondary task would cause greater changes in landing biomechanics compared to an audio secondary task.

Methods

Participants

An a priori sample size prediction was performed using G*Power software (v. 3.1, Dusseldorf, Germany). Based on an estimated medium effect size of 0.5,¹⁰ for a repeated-measures ANOVA it was predicted that a sample size of 6 participants was required when using an α of 0.05, a β of 0.20 and a within-factor correlation of 0.7. Following ethical approval from the institutional review board, 16 recreational athletes (10 females and 6 males, age: 21.6 ± 2.5 years, mass: 65.2 ± 8.9 kg, height 1.66 ± 0.07 m) were recruited to participate in the study. All participants met the inclusion criteria of participating in recreational activity at least three times per week for at least 30 minutes, being aged between 18 and 30 years, reported as being healthy and free of injury at the time of testing, and provided informed consent. Participants reported participating in a variety of sports and physical activities (including taekwondo, dance, weight training, running, judo, volleyball, basketball, soccer, badminton and softball), resulting in a relatively broad range of physical activity levels between participants. Participants with previous lower limb injury were allowed to participate as long as they reported as being injury free and therefore were actively participating in their recreational activities at the time of testing, with no exclusion criteria around the extent or time since their previous injury. This research was carried out fully in accordance with the ethical standards of the *International Journal of Exercise Science*.¹⁸

Protocol

Following a short warm-up, participants performed three maximum height countermovement vertical jumps from a Just Jump System (Probotics, Huntsville, AL, USA), which has been shown to provide a valid and reliable measure of jump height, which is derived from the flight time of the jump.¹⁹ The participants were instructed to start in a standing position on two feet and then squat down and jump up as high as they could in one continuous movement, while keeping their hands placed on their hips. The average jump height recorded across the three trials was later used to calculate each person's drop height for the subsequent landing trials, as it was felt that this provides a good measure of the typical drop height a given participant would perform a landing from. A custom marker set, developed based on recommendations from Wu et al²⁰ comprised of 37 markers adhered to the body at the following landmarks: spinous process of the 7th cervical vertebra, Jugular notch, right scapula, acromioclavicular joints, anterior superior iliac spines, posterior superior iliac spine, Iliac crests, greater trochanters, lateral thighs, anterior thighs, lateral epicondyles of the knee, medial epicondyles of the knee, tibial tuberosities, inferior shanks, lateral shanks, lateral malleoli, medial malleoli, calcaneus', big toes, fifth metatarsal heads. The three-dimensional (3D) coordinates of the markers were recorded using a 10-camera motion capture system (Vicon Motion Systems Ltd, Oxford, UK) sampling at 240 Hz and ground reaction force (GRF) was recorded by two force plates (AMTI, Watertown, MA, USA) sampling at 2400 Hz.

For landing trials, participants were initially asked to climb up a step stool and hold on to a bar suspended from the lab ceiling. In an effort to standardise drop height across individuals, the vertical position of the bar was adjusted so that when each participant was holding on to the

bar, their feet were at the same height above the lab floor as their previously recorded jump height. The average height was 0.41 ± 0.10 m, which is comparable to what has been used in previous research.²¹ Once the participant had a firm grip on the bar, such that they could support their own weight, the step stool was slowly removed so that they were suspended directly above the force plates. Participants would then let go of the bar as soon as they heard an audio signal (a short beep sound) and land on the force plate located below in single limb stance on their dominant leg (defined as the leg they would use to kick a ball for maximum distance), with arm position was not being controlled during the landing. A computer screen (0.6 m wide by 0.35 m high) was placed 3.5 m in front of the force plates with the centre of the screen at a height of 1.15 m above the lab floor. Audio speakers were placed either side of the computer screen. The screen was used to display numbers/calculations and the speakers were used to play audio required for some of the secondary cognitive tasks described below. A purely vertical landing was used in an attempt to standardize the horizontal distance between the participants and the computer screen/speakers so that participants did not have to adjust their visual focus during the task and to minimize any potential for audio delay. The testing was completed when each participant had completed three successful trials (where the entire foot of the dominant leg made contact with the force platform and the participant did not touch down with any other body part prior to reaching the lowest point of the landing) in each of the following conditions, performed in a randomized order:

- 1) Single landing task- landing on their dominant limb when performed as a single task.
- 2) Visual secondary task- landing on their dominant limb while also verbalising the answer to a series of random calculations involving either adding or subtracting two single-digit numbers (numbers between 1 and 9, 162 possible calculations), when provided through a visual means (numbers displayed on the computer monitor), with 2 seconds between each calculation.
- 3) Audio secondary task- landing on their dominant limb while also verbalising the answer to a series of random calculations, as described in the previous task, but provided through audio means (recordings played through a speaker).

During the secondary tasks, participants would hang from the suspended bar while verbalising the answers to the calculations for between 3 and 10 calculations prior to the drop signal being provided. They were not informed prior to each task when the drop signal would be given and the number of calculations completed before the drop signal was varied between trials in order to reduce any potential anticipatory effects. Trials where participants were unable to verbalise all the correct answers to the calculations within the two second time period were discarded and repeated.

The trajectory of each marker was reconstructed and labelled in Vicon Nexus software before being exported to Visual 3D (C-Motion Inc., Rockville, MD, USA) for analysis. Marker trajectories and GRF data were both smoothed using a fourth order Butterworth filter with the same cut-off frequency of 15 Hz for both signals, in accordance with recommendations made by Kristianslund et al.²² for performing inverse dynamics. The cut-off frequency of 15 Hz was

chosen as being most appropriate for removing high-frequency noise without distorting the underlying signal following visual inspection of a number of different trials from different participants filtered using various cut-off frequencies. An eight-segment model of the body was created, comprised of a trunk, pelvis, left and right thigh, left and right shank, and left and right foot. Joint angles were calculated for the hip and knee joints in all three planes of motion, where hip angles were defined as the orientation of the thigh segment relative to the pelvis and knee angles were defined as the orientation of the shank segment relative to the thigh. The Cardan sequence order of rotations was x-y-z, as is commonly used in previous research examining lower limb biomechanics during landing,^{23,24} where the x axis was mediolateral providing joint flexion/extension, the y axis was anteroposterior providing joint abduction/adduction and the z axis was vertical providing joint internal/external rotation. Net internal moments about the hip and knee joints were also calculated in all three planes of motion through inverse dynamics solution using segmental data from Hanavan.²⁵ Joint moments were normalized to the product of body weight and height (BW.Ht) for each participant. For both joint angles and moments, flexion, abduction and internal rotation were defined as positive whereas extension, adduction and external rotation were defined as negative. The landing period was defined as the time between initial contact with the ground (IC) and when the knee flexion angle reached maximum, where IC was defined as when vertical GRF exceeded 10 N. All data were subsequently time normalized between IC and maximum knee flexion.

Statistical Analysis

SPM repeated-measures ANOVA were used to examine the effects of secondary cognitive tasks (single task, secondary audio task, secondary visual task) on hip and knee angles and moments in all three planes of motion during the landing period. To conduct these statistical tests, the open-source spm1d package (v. 0.4, www.spm1d.org)²⁶ was implemented in MATLAB (v. 9.4.08, The Mathworks Inc., Natick, MA, USA). A significant effect was observed when adjacent points of the SPM curve exceeded a critical threshold (value at which only 5% of smooth random curves would be expected to cross). Where a significant effect was observed, SPM paired samples t-tests were performed to identify which conditions were significantly different from each other.

Results

There was a significant effect for task condition in hip adduction angle during the time period from 88% to 100% of the landing ($p = 0.043$) (Figure 1). Post-hoc paired t-tests showed that hip adduction angle was significantly greater in both audio and visual secondary task conditions compared to the single task condition, but there was no significant difference between audio and visual secondary task conditions. There was also a significant effect for task condition in hip internal rotation angle during the time period from 68% to 92% of the landing ($p = 0.025$) (Figure 1). Post-hoc paired t-tests showed that hip internal rotation was significantly greater in the visual secondary task condition compared to the single task condition but there were no significant differences between audio and visual secondary task conditions or between the audio and single task conditions. There were no significant differences between task conditions observed for hip moment in all three planes of motion during the landing period (Figure 2). There also were no

significant differences between task conditions for the knee joint, both in terms of angles (Figure 3) or moments (Figure 4), in all three planes of motion during the landing period.

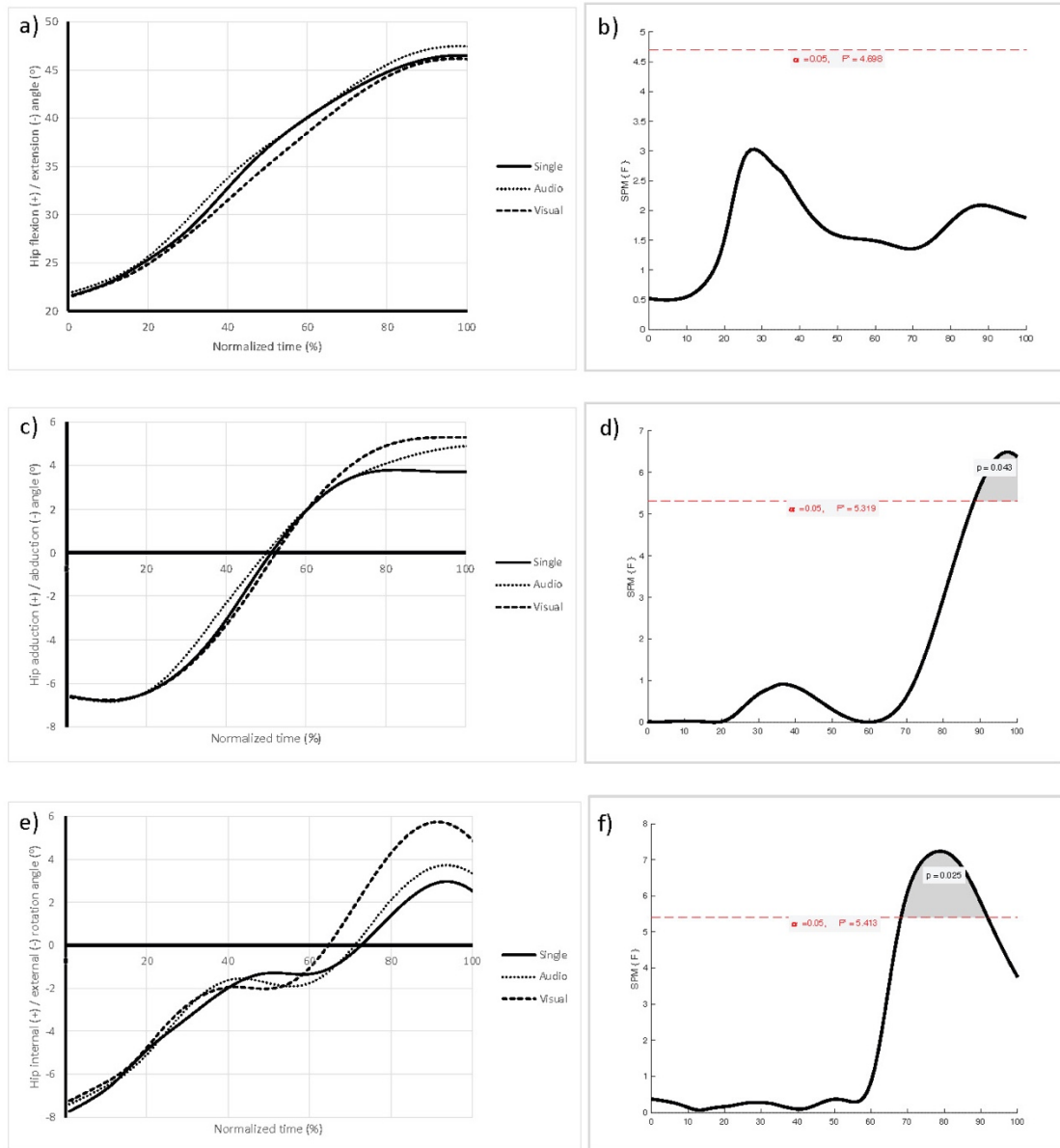


Figure 1. Ensemble average curves for hip angle in the sagittal (a), frontal (c) and transverse (e) planes for single, audio and visual dual task conditions, along with their respective SPM results (b, d and f, respectively).

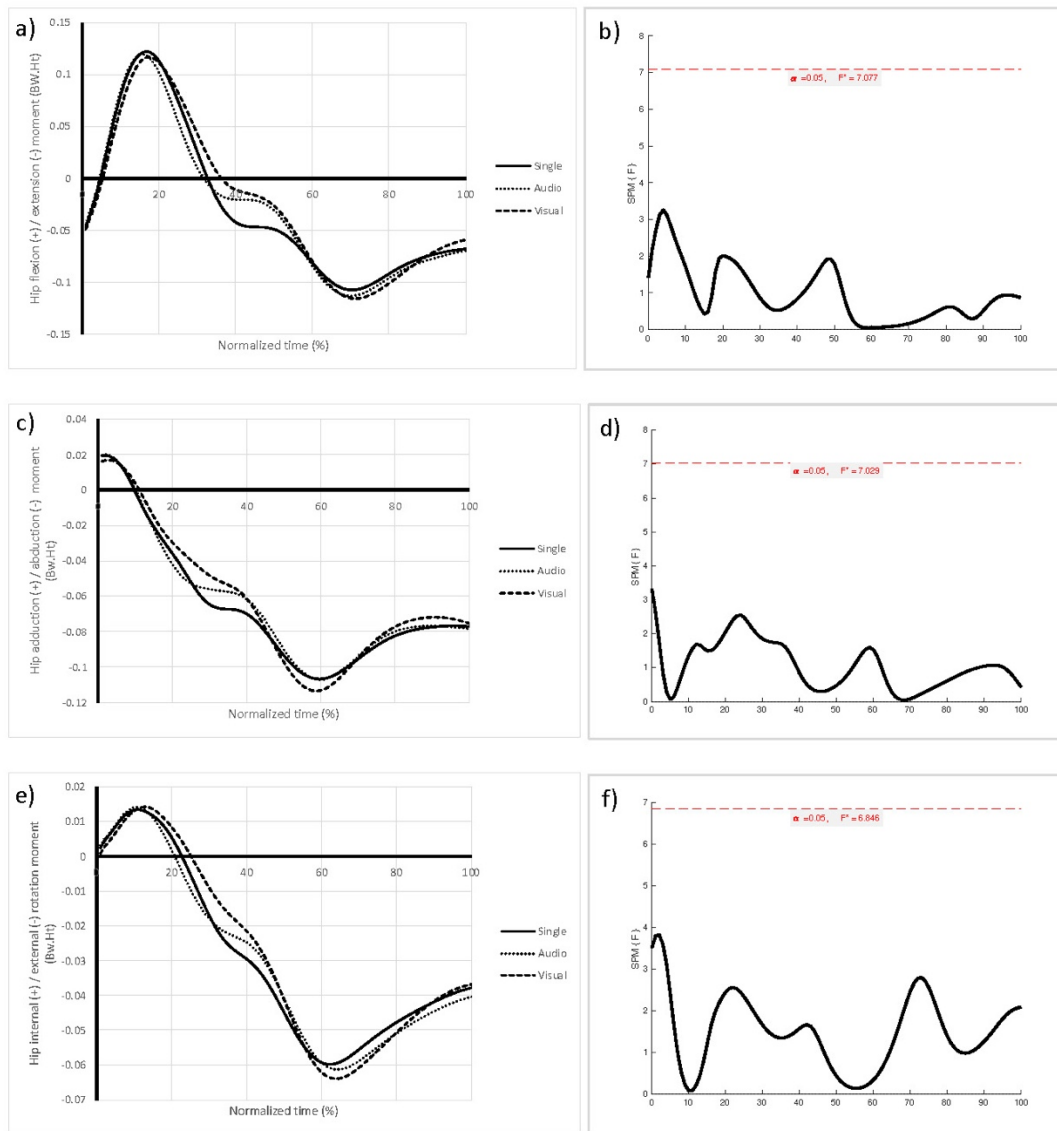


Figure 2. Ensemble average curves for hip moment in the sagittal (a), frontal (c) and transverse (e) planes for single, audio and visual dual task conditions, along with their respective SPM results (b, d and f, respectively).

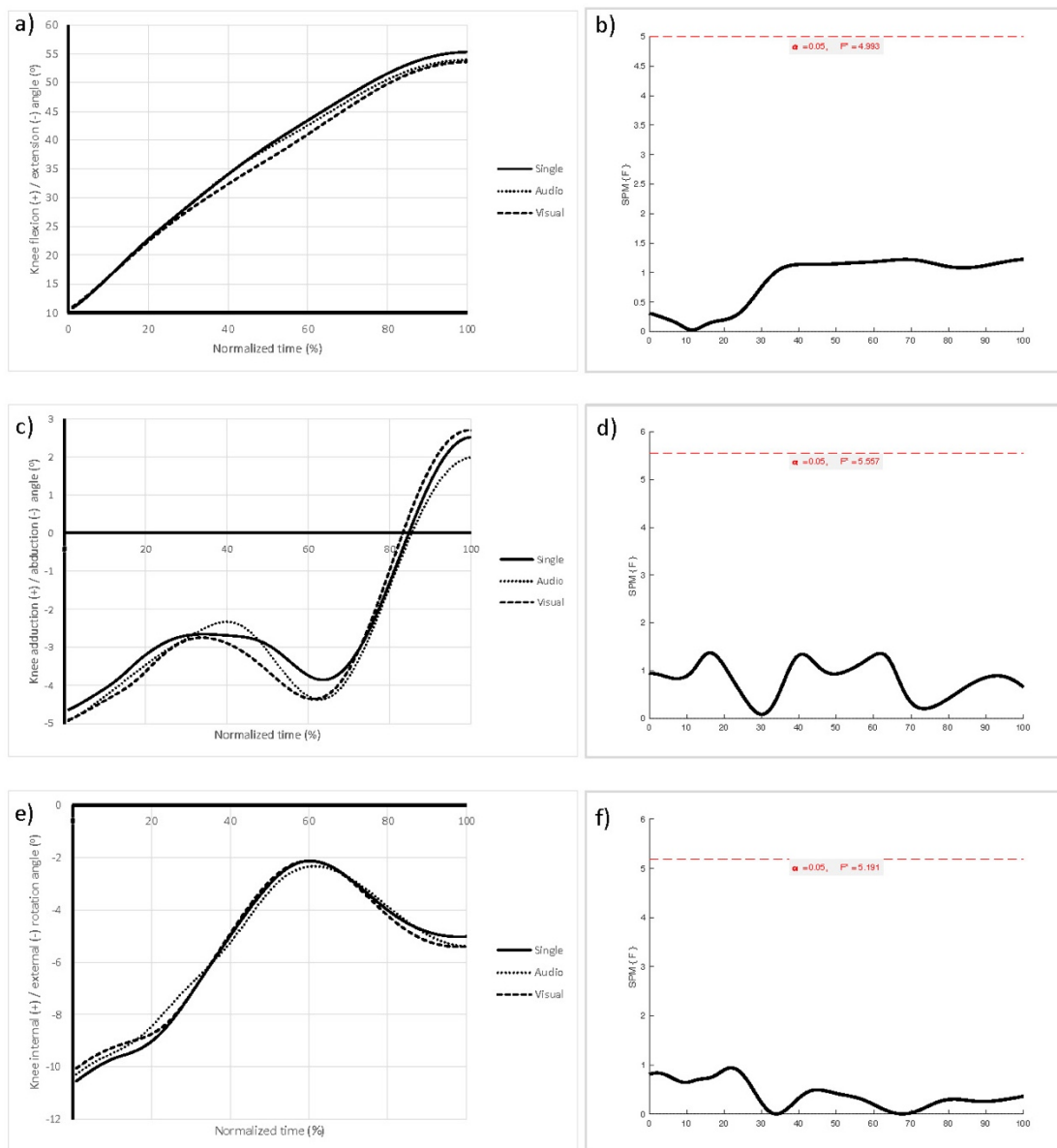


Figure 3. Ensemble average curves for knee angle in the sagittal (a), frontal (c) and transverse (e) planes for single, audio and visual dual task conditions, along with their respective SPM results (b, d and f, respectively).

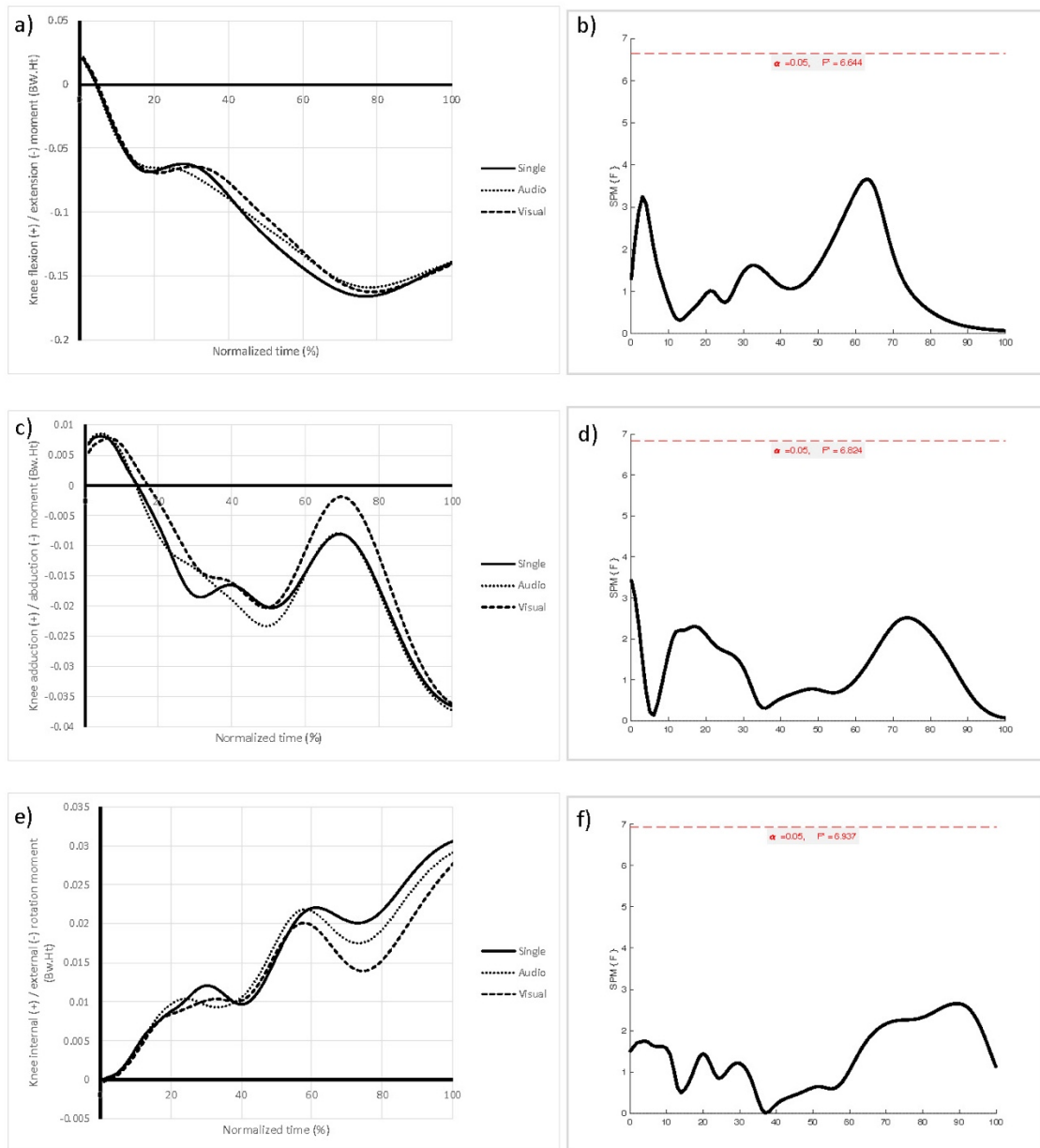


Figure 4. Ensemble average curves for knee moment in the sagittal (a), frontal (c) and transverse (e) planes for single, audio and visual dual task conditions, along with their respective SPM results (b, d and f, respectively).

Discussion

The aim of this study was to investigate the effects of visual and audio secondary cognitive tasks on hip and knee biomechanics during single limb landing. The first hypothesis, that landing biomechanics would be significantly altered by performing a secondary cognitive task, is partially accepted since hip adduction angle was significantly greater in both audio and visual secondary tasks compared to the single task condition during the time period from 88% to 100%

of landing and hip internal rotation was significantly greater in the visual secondary task condition compared to the single task condition during the time period from 68% to 92% of landing. These differences in hip kinematics in the frontal and transverse planes indicate a general inward movement pattern of the thigh, often termed dynamic limb valgus.^{27,28} Dynamic limb valgus is characterised by hip adduction and internal rotation and has been proposed to contribute to an increased risk of ACL injury.^{29,30} However, these differences in hip kinematics were observed towards the end of the landing period where the knee would be approaching its maximum flexion angle, whereas ACL injury is reported to occur close to ground contact (within 50 milliseconds).^{4,31} These differences therefore may not suggest an increase the risk of ACL injury but simply reflect a lack of dynamic stability and postural control at the hip, as was also reported by Lin et al,¹⁴ which at least may be detrimental to performance were the athlete required to perform a subsequent manoeuvre after completing the landing task.

While differences existed between task conditions in hip kinematics towards the end of the landing phase, hip moments, knee angles and knee moments were not significantly affected by secondary cognitive tasks. This conflicts somewhat with other studies that have examined the effects of secondary tasks on landing/cutting biomechanics and found reduced knee flexion angle at initial contact,^{11,14} reduced peak knee flexion angle¹⁰ and greater peak knee valgus angle¹⁰ when participants were required to complete secondary cognitive tasks when landing/cutting. The reasons for the differences in findings may have been due to the type of cognitive and landing tasks used. For example, Dai et al¹¹ found that during a double-leg forward jump-landing task, knee flexion at IC was significantly greater when not counting compared to when counting backwards by 1's. While, subjectively, counting backwards by 1's may provide a similar or lesser challenge to the mental arithmetic task used in this study, the horizontal component to the jump-landing task may have made it more challenging than the vertical drop landing used in this study. The capacity model of attention³² states that an individual has a limited capacity for cognitive processing and different tasks use up different amounts of this capacity. When task demands exceed someone's attentional capacity, there may be an impairment of the central nervous system to control motor actions resulting in reduced performance. The combination of landing and secondary cognitive tasks used in this study may not have been challenging enough to overload the attentional capacity of the participants and they were therefore able to effectively complete both tasks while assigning adequate attentional resources to each.

The second hypothesis that a visual secondary task would cause greater changes in landing biomechanics compared to an audio secondary task is rejected because there were no significant differences between visual and audio secondary task conditions for hip and knee joint angles and moments in all three planes of motion during the entire landing period. It was postulated that visual secondary cognitive tasks might prove more challenging due to a potential inhibition of visual input used to anticipate ground contact compared to when the same secondary task instructions are provided through audio means,¹⁷ however this was not observed in our data. No previous study has investigated differences between visual and audio secondary cognitive tasks during landing so direct comparison to previous research is not possible. However, our findings may support the notion that continuous visual monitoring may not be required when preparing for landing, whereby initial visual perception taken before falling may be used to plan

a motor control strategy to be implemented on landing in circumstances where continuous visual information is not available during the fall.^{33,34} Since participants in this study could see how far they were from the floor in the suspended position, this would allow them to predict their falling time in advance. In addition, since all trials for each participant were taken from the same drop height, proprioceptive and vestibular information gained from the initial practice landing trials may have been used to compensate for the any impairment of vision during the visual secondary cognitive task conditions.³⁵ As well as this, the visual task did not completely inhibit a person's ability to use their vision to anticipate ground contact during the fall, since they may have been able to use their peripheral vision while still maintaining their focus on the screen where the calculations were displayed. The absence of differences between visual and auditory conditions may be attributable to the secondary task (mental arithmetic) and participants' preference for visualizing calculations on a screen rather than processing them auditorily.

The main limitations to this study are that the landing and the secondary cognitive tasks used may not have been demanding enough to bring about more significant differences in landing biomechanics that are more strongly related to risk of ACL injury. Specifically, since the landing task took place in only a vertical direction without any horizontal component and did not require a subsequent movement on completion of the landing, participants may have been able to complete this task largely automatically without being required to allocate considerable cognitive capacity to complete this task. This would have left enough attentional resources to simultaneously complete the mental arithmetic task. Another limitation was that no instruction was given to the participants on the location of their foveal vision during the tasks. Uncontrolled point-of-gaze location may have resulted in confounding effects meaning it's difficult to separate the effects of the secondary tasks from the effects of different location of foveal vision during the landing tasks. Future research should therefore examine the effects of more demanding secondary cognitive tasks on landing/cutting movements that include both a horizontal component and a subsequent movement following the landing. Furthermore, the cognitive secondary tasks used in this study were largely not representative of the types of cognitive tasks athletes are required to complete during sports. Therefore, future studies should attempt to devise more sports-specific secondary cognitive tasks to improve the ecological validity of studies examining the effects of secondary cognitive tasks during landing/cutting.

In conclusion, the results of this study showed significant differences in hip kinematics in the frontal and transverse planes between single and dual task conditions towards the end of the landing period which may reflect a reduction in dynamic stability at the hip. However, there were no significant differences between task conditions observed for hip moments, knee moments or knee angles in all three planes of motion during the landing period. These differences in hip kinematics towards the end of landing do not represent a significant increased risk of injury, since ACL injuries typically occur shortly after initial ground contact.^{8,36} The lack of difference in hip and knee biomechanics between visual and audio secondary cognitive task conditions support the notion that continuous visual monitoring may not be required in landing tasks provided prior knowledge of the drop height is available.

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