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Title Page

Is there a role for GPS in determining functional ankle rehabilitation progression criteria?

A preliminary study.

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Abstract

Context: Contemporary developments in GPS technology present a means of quantifying mechanical loading in a clinical environment with high ecological validity. However, applications to date have typically focussed on performance rather than rehabilitation. **Objective:** To examine the efficacy of GPS micro-technology in quantifying the progression of loading during functional rehabilitation from ankle sprain injury, given the prevalence of re-injury and need for quantifiable monitoring. Furthermore, to examine the influence of unit placement on the clinical interpretation of loading during specific functional rehabilitation drills. **Design:** Repeated measures. **Setting:** University athletic facilities. **Participants:** 22 female intermittent team sports players. **Intervention:** All players completed a battery of 5 drills (anterior hop, inversion hop, eversion hop, diagonal hop, diagonal hurdle hop) designed to reflect the mechanism of ankle sprain injury, and progress functional challenge and loading. **Main Outcome Measures:** GPS-mounted accelerometers quantified uni-axial PlayerLoad for each drill, with units placed at C7 and the tibia. Main effects for drill type and GPS location were investigated. **Results:** There was a significant main effect for drill type ($P<0.001$) in the medio-lateral ($\eta^2=0.436$), anterio-posterior ($\eta^2=0.480$), and vertical planes ($\eta^2=0.516$). The diagonal hurdle hop elicited significantly greater load than all other drills, highlighting a non-linear progression of load. Only medio-lateral load showed evidence of progressive increase in loading. PlayerLoad was significantly greater at the tibia than at C7 for all drills, and in all planes ($P<0.001$, $\eta^2\geq0.662$). Furthermore, the tibia placement was more sensitive to between-drill changes in medio-lateral load than the C7 placement. **Conclusions:** The placement of the GPS unit is imperative to clinical interpretation, with both magnitude and sensitivity influenced by the unit location. GPS does provide efficacy in quantifying multi-planar loading during (p)rehabilitation, in a field or clinical setting, with potential in extending GPS analyses (beyond performance metrics) to functional injury rehabilitation and prevention.

The epidemiology of ankle sprain injury in sports has been well described, with a mechanism of injury commonly associated with ankle inversion and plantar flexion.[1] Injury risk is therefore increased in sports characterised by multi-directional demands,[2] with ankle sprains prevalent in soccer,[3] field hockey [4] and rugby.[5] Re-injury risk is also high in these sports,[6] and thus the recent growth in participation of women's intermittent team sports [7,8] has implications for injury risk and management.[9,10] Contemporary developments in the use of tri-axial accelerometry embedded within GPS technology offer potential to quantify mechanical loading during functional rehabilitative tasks. Recently, medio-lateral loading imbalances were highlighted in a case study of ankle sprain injury in elite male soccer.[11]

However, to enhance the clinical application of GPS micro-technologies, the placement of the unit requires consideration. The typical placement of a GPS unit at a position approximating C7 is intended to maximise satellite reception for GPS metrics, but offers little relevance to injury mechanism. The traditional C7 site has been compared with a second unit at the skull investigating accelerations associated with the whiplash mechanism in rugby tackling events.[12] Similarly, C7 and lumbar accelerations have been compared in fast bowling,[13] with unit location dictated by epidemiological data and a prevalence of lumbar spine injuries. In relation to ankle sprain injury, but given the logistical and mechanical implications associated with unit placement, the present study uses a location at mid-tibia. This placement provides the closest anatomical reference point where a unit can be securely located, without restricting movement.

The purpose of the current study is to compare mechanical loading derived from tri-axial accelerometry at the tibia with the traditional C7 location across a number of functional tasks. These tasks have been designed to reflect the multi-planar mechanism of injury, and a progression of drills used in late functional rehabilitation aligned to injury prevention. The field-based nature of the data collection provides high ecological validity, with potential implications in quantifying mechanical loading and determining effective progression criteria during ankle injury rehabilitation. The comparison of a traditional GPS placement with an anatomical placement specific to the pathomechanics of lateral ankle injury may help determine appropriate progression if greater sensitivity to functional demands is evident at the tibia than at C7.

It is hypothesised that loading will be greater at the tibia than at C7 given its location relative to ground contact. It is further hypothesised that the tibial location will be more sensitive to changes in drill type, and thus offer greater scope to inform clinical interpretation.

Methods

Design

This field-based experimental study included multiple familiarisation sessions which were embedded within team training sessions, providing ecological validity to the research paradigm. The functional drills used within the experimental trials represented an integral component of warm-up and/or conditioning drills for each participant. Completion of the experimental battery was observed on a minimum of three occasions for all participants prior to data collection. A single experimental testing session was conducted, with the independent variables defined as the drill type (from a battery of 5 drills) and GPS unit location (C7, tibia). The dependent variable was defined as the uni-axial PlayerLoad accrued in each of the medio-lateral, anterio-posterior, and vertical planes. All testing was completed on a third generation artificial turf, consistent with the participants' habituation and training exposure.

Participants

Given the focus of the study, inclusion criteria required that all participants be competitively involved in field-based intermittent team sports (soccer, rugby, field hockey), with a minimal weekly exposure of two training sessions and one competitive match. Additionally, all participants were required to be injury free for three months prior to data collection, and with no history of ankle sprain injury (given the risk associated with previous injury). An *a priori* power calculation from data collected during the final familiarisation session identified that a sample size of 22 participants was sufficient to evaluate the interactions for all dependent variables (for statistical power 0.8, $P \leq 0.05$). Therefore, 22 female games players completed the study, providing written informed consent in accordance with the departmental and university ethical procedures, and in accordance with the spirit of the Helsinki Declaration.

Procedures

The participants were required to wear two MinimaxX S4 GPS units (Catapult Innovations, Scoresby, Australia); one placed within a neoprene vest and located at C7, and another placed at the mid-tibia. Figure 1 highlights the placement of each unit during testing, with the unit at the tibia secured with underwrap and the unit at C7 enclosed within the customised vest. Tri-axial acceleration data was collected at 100Hz.

Each participant completed five drills designed to provide a functional challenge of relevance to the mechanism of ankle sprain injury. The battery of drills was further designed to replicate progressions in ankle joint rehabilitation, transitioning from planar to multi-planar movements, and with increased loading challenge. Data analysis was restricted to those trials performed on the dominant leg, and technique was standardised by utilising commercially available agility ladders and 15 cm hurdles. The same equipment was commonly used during participants' training exposure. Figure 2 provides a schematic description of each drill. Participants were verbally reminded that there was no time restriction or measure on performance, and that the aim was to complete each drill with precision and in accord with feedback provided during familiarisation sessions. Drills were completed as a plyometric action rather than a hop-and-hold technique, requiring a dynamic foot contact rather than an emphasis on stability.

The first three drills comprised 10 foot contacts, whereas Drill 4 comprised a total of 18 foot contacts. Given the increased challenge associated with Drill 5, this was reduced to 5 foot contacts, consistent with training exposure and familiarisation. Subsequent comparison of drills was standardised for a total of 10 foot contacts in each drill.

Uni-axial PlayerLoad (arbitrary units a.u.) was calculated in the medio-lateral, anterio-posterior, and vertical planes for each drill, and for each GPS unit location. PlayerLoad was calculated based on the rate of change of acceleration in each plane, but with uni-axial values used rather than a total value expressed as summative of each plane.[11,13]

Statistical Analyses

The assumptions associated with a repeated measures and uni-variate General Linear Model were assessed to ensure model adequacy. To assess the residual normality for each PlayerLoad variable, q-q plots were generated, and Mauchly's test of sphericity was completed for all variables with a Greenhouse Geisser correction where appropriate. Subsequently, inferential analyses were performed using a two-way (drill *x* GPS location) repeated measures GLM to examine differences in uniaxial PlayerLoad between drill, and between GPS placement. Where significant main effects for drill type were observed, post-hoc pairwise comparisons with a Bonferonni correction factor were used. As a measure of meaningfulness, partial eta-squared (η^2) values were calculated to estimate effect sizes for main effects. All data are reported as the mean ± standard deviation, with significance accepted at $P<0.05$.

Results

Medio-Lateral loading

Figure 3 summarises the influence of drill type and GPS location on the total accumulated medio-lateral PlayerLoad. There was a significant main effect for GPS location ($P < 0.001$, $\eta^2 = 0.747$), with greater medio-lateral loading at the tibia than at C7 for each drill. There was also a significant main effect for drill type ($P < 0.001$, $\eta^2 = 0.436$). The anterior hop elicited significantly less loading than the inversion hop ($P = 0.018$) and the diagonal hop ($P = 0.031$), with all drills eliciting significantly less medio-lateral loading than the hurdle hop ($P < 0.001$).

Anterio-posterior loading

Figure 4 summarises the influence of drill type and GPS location on the total accumulated anterio-posterior PlayerLoad. There was a significant main effect for GPS location ($P < 0.001$, $\eta^2 = 0.662$), with loading greater at the tibia than at C7 for each drill. There was also a significant main effect for drill type ($P < 0.001$, $\eta^2 = 0.480$). The hurdle hop elicited significantly greater anterio-posterior load than all other drills ($P < 0.001$), which were themselves no different ($P \geq 0.713$).

Vertical loading

Figure 5 summarises the influence of drill type and GPS location on the total accumulated vertical PlayerLoad. Consistent with all uni-axial planes, there was a significant main effect for both GPS location ($P < 0.001$, $\eta^2 = 0.688$) and drill type ($P < 0.001$, $\eta^2 = 0.516$). Loading was again significantly greater at the tibia than at C7 for each drill, and the hurdle hop elicited significantly greater vertical load than all other drills ($P < 0.001$), which were themselves no different ($P \geq 0.437$).

Discussion

The aim of the current study was to compare uni-axial mechanical loading at the tibia and mid-scapulae across a battery of functional rehabilitation drills related to ankle sprain injury mechanism. The practical and clinical applications of the study relate to the efficacy of GPS-based micro-technologies as a means of quantifying functional rehabilitation progression criteria. Given the prevalence of re-injury, and the socio-economic cost associated with injury within the elite sporting and public health domains, methods to inform rehabilitation from injury and injury prevention strategies warrant investigation. The contemporary developments in GPS analysis, and the widespread use of this technology in elite sport has typically been associated with performance metrics.[14-16] However, the opportunity to collect multi-planar acceleration data at a relatively high frequency, but with far greater ecological validity than laboratory-based paradigms, offers potential to inform clinical practice when determining effective and progressive functional rehabilitation and conditioning drills.

The influence of GPS location

In the present study, the PlayerLoad exhibited mid-tibia was significantly ($P < 0.001$) greater than at C7 across all tasks. This is perhaps not surprising, given the role of the musculo-skeletal system in dampening load. The closer proximity to the ground contact is intuitively going to provide higher loading than the cervical spine, and previous literature has highlighted the limitations of using the C7 location to approximate lower limb loading.[11,13,17] These findings concur with existing research that show GPS-mounted tri-axial accelerometers placed at C7 cannot accurately identify load experienced at the lower extremities when performing functional movements,[18] and that body-worn tri-axial accelerometery can only measure the acceleration of the segment at which it is located.[19] The clinical interpretation of acceleration data collected at C7 should therefore be treated with caution, where inferences are made based on the magnitude of load.

Further analysis of the data revealed greater sensitivity in identifying differences between drills at the tibia. The main effect reported for drill-type is based on a statistical model which pools C7 and tibia data. With this data set collapsed to consider each GPS location discretely, the C7 location failed to identify any significant difference in medio-lateral loading between the anterior hop and the inversion or diagonal hops. The C7 placement was only able to detect a significant difference between the hurdle hop and all other drills. The tibia placement was able to identify significant differences in medio-lateral loading between specific drills. This greater sensitivity to detect differences between drills is fundamentally important with regards to clinical application when progressing functional rehabilitation. This finding suggests that anatomical placement of the GPS unit is fundamental to the interpretation of data, and subsequent clinical interpretation and decision making.

Monitoring Rehabilitation

In terms of the battery of drills used to model progression through ankle joint conditioning or rehabilitation, the anterio-posterior and vertical loading suggested a lack of linear progression. The hurdle hop drill which elicits greater mass centre displacement was associated with significantly greater loading in these planes than all other drills. This highlights a lack of progression in the transition from anterior to inversion hopping, and subsequently to multi-directional hopping. Thus in terms of anterio-posterior and vertical loading, these four drills are essentially equivalent, with implications for clinical application.

There is then a substantive increase in loading associated with the hurdle hop, which might represent too great a progression in terms of functional loading. Consideration should therefore be given to the grouping of drills associated with functional progression, and also means of developing drills which do facilitate a more linear transition between drills (or groups of drills).

Medio-lateral loading was sensitive to drill design, with implications in relation to the common mechanism of injury. The anterior hop did elicit significantly less medio-lateral loading than the inversion or diagonal hop, suggesting merit in this progression during rehabilitation. The eversion hop produced a medio-lateral loading greater than the anterior hop, but less than the inversion hop, and without statistical significance. This is perhaps due to functional anatomy with greater range of motion in inversion, but might also be indicative of greater functional relevance of inversion and greater exposure to this movement during the associated sports of soccer, field hockey and rugby.[1,3,10] The directional change in such sports will typically stress inversion mechanics, perhaps explaining the greater load tolerated in inversion. The introduction of the hurdle again produced a substantive increase in medio-lateral loading, greater than the progression seen between the ladder drills. This has clinical implications for the more linear development of progressive functional loading during rehabilitation or conditioning. The progression associated with increased vertical displacement is common in plyometric type activities, to provide continued adaptation. Whilst an increase in loading might increase the susceptibility to injury, care should be taken to avoid an 'inciting event' described in the dynamic injury aetiology model.[20] Therefore, momentum in the medio-lateral and anterio-posterior plane might better reflect the mechanism of injury, and as such 'speed' rather than 'height' might provide a more gradual functional progression of load. This might be achieved using a footwork drill, as opposed to a hopping drill for example, but this warrants further investigation. A combination of movements in the medio-lateral and anterio-posterior planes as seen with the diagonal drills can increase the shear stress on the syndesmosis,[21,22] with potentially greater severity than lateral ankle sprain.[6,23,24]

Factors influencing interpretation

In the present study the female games players were injury free, and caution should be taken when generalising the findings beyond the characteristics of the participants used. Future research might extend this study to include male participants, with a focus on specific sports, injury history, and rehabilitative programs. Furthermore, the focus of the current study on ankle sprain injury was approached using a GPS location at the tibia. In some cases the placement of the GPS unit would be more difficult, and the potential inclusion of the embedded gyroscope data in quantifying segmental accelerations warrants consideration.

Conclusions

The present study does highlight the efficacy of using tri-axial accelerometry (embedded within GPS technology) to quantify multi-planar loading during functional rehabilitation or conditioning drills. However, the placement of the unit is fundamental to the interpretation of data and subsequent clinical interpretation and decision making. The current study advocates a placement closer to the anatomical site of interest. Furthermore, the lack of reliance on the GPS element is such that the tri-axial accelerometry technology can be applied in an indoor, clinical setting. Given the mixed success of intervention strategies to date,[25,26] the use of GPS technology in monitoring functional rehabilitation warrants further consideration.

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Figure 1. GPS unit placement at C7 and mid-tibia.

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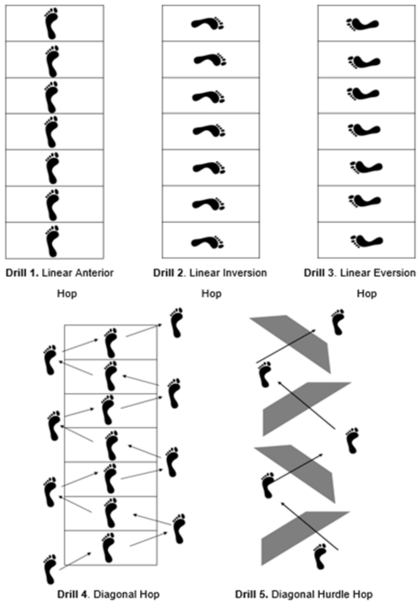

Figure 2. Schematic representation of the functional drills used.

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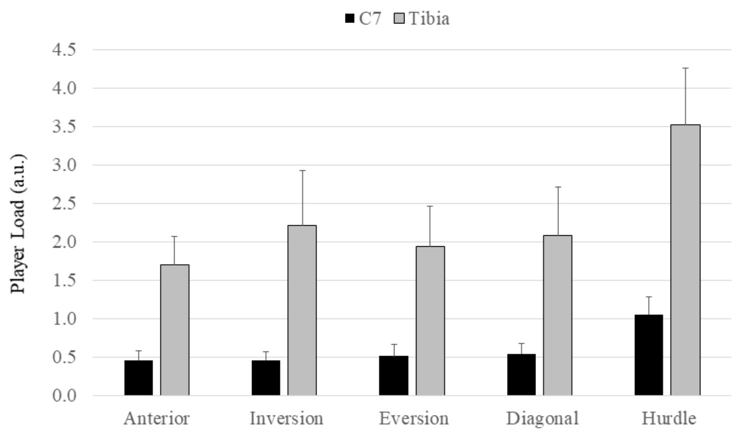

Figure 3. The influence of drill type and GPS location on medio-lateral PlayerLoad (a.u).

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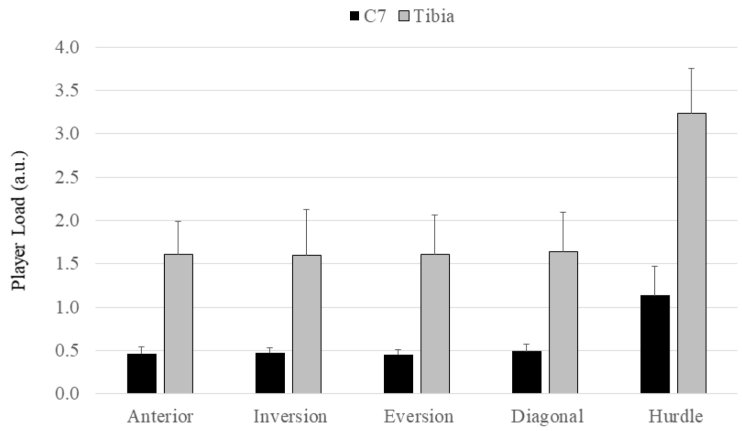

Figure 4. The influence of drill type and GPS location on anterio-posterior PlayerLoad (a.u).

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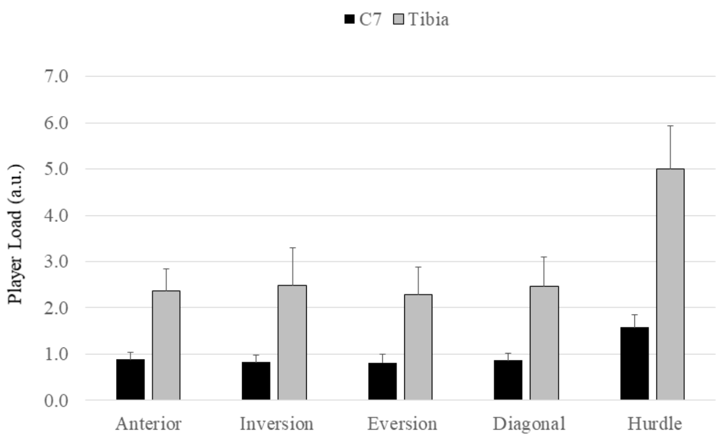

Figure 5. The influence of drill type and GPS location on vertical PlayerLoad (a.u).