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Original research

A simple method for quantifying jump loads in volleyball athletes

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ABSTRACT

Objectives: Evaluate the validity of a commercially available wearable device, the Vert, for measuring vertical displacement and jump count in volleyball athletes. Propose a potential method of quantifying external load during training and match play within this population.
Design: Validation study.
Methods: The ability of the Vert device to measure vertical displacement in male, junior elite volleyball athletes was assessed against reference standard laboratory motion analysis. The ability of the Vert device to count jumps during training and match-play was assessed via comparison with retrospective video analysis to determine precision and recall. A method of quantifying external load, known as the load index (LdIx) algorithm was proposed using the product of the jump count and average kinetic energy.
Results: Correlation between two separate Vert devices and three-dimensional trajectory data were good to excellent for all jump types performed ($r = 0.83$–0.97), with a mean bias of between 3.57–4.28 cm. When matched against jumps identified through video analysis, the Vert demonstrated excellent precision (0.995–1.000) evidenced by a low number of false positives. The number of false negatives identified with the Vert was higher resulting in lower recall values (0.814–0.930).
Conclusions: The Vert is a commercially available tool that has potential for measuring vertical displacement and jump count in elite junior volleyball athletes without the need for time-consuming analysis and bespoke software. Subsequently, allowing the collected data to better quantify load using the proposed algorithm (LdIx).

1. Introduction

Volleyball is a sport characterised by repetitive maximal and sub-maximal jump and land efforts followed by brief recovery periods.[1] In addition to match-play, volleyball athletes experience high weekly jump counts during training, reported to be in excess of 650 impacts per week for male, school-aged participants,[2] whilst anecdotal evidence suggests that these are in the thousands for national teams. As such, there is a high demand on the repetitive and rapid application of large amounts of force especially for the lower limb extensor musculature. This may lead to cumulative microtrauma and subsequently the prevalence of chronic, overuse injuries such as patellar tendinopathy is high.[3]

Modifiable risk factors associated with the development of patellar tendinopathy include increased training volume and match play exposure. A four-year longitudinal study of elite, adult volleyball athletes demonstrated significantly increased risk of injury for every additional hour of training (odds ratio = 1.72) and set of match-play performed per week (odds ratio = 3.88),[4] however neither the count nor thresholds of jump and landing impacts associated with these increases in workload have been specifically investigated. Increased jumping ability expressed as greater vertical displacement, has also been linked with the presence of patellar tendinopathy in both volleyball and basketball athlete cohorts.[5,6] Landing from an increased height increases the mechanical demand and eccentric force of the impact, which has in turn been shown to increase ankle, knee and hip peak extensor joint moments.[7] Furthermore, it has been shown that volleyball athletes with a history of patellar tendinopathy may use a landing strategy is a risk factor for further injury.[8] Together with total exposure to training and

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match-play it is reasonable to assume vertical displacement may also be important with respect to increased injury risk, given that magnitudes of two to four times body weight may be experienced during landing.[7]

Traditionally, methods for counting jumps have been constrained to notational video analysis conducted retrospectively.[2] This method is time-consuming, labour intensive and not feasible outside of the research setting. Furthermore, this method provides only a simplistic count of jumping motions rather than an actual measurement of load. A more robust measurement of load would also need to take into account the height of the jump performed. Recently, more novel methods have emerged with the introduction of accelerometers, whereby jumps may be measured in real-time.[9,10] However, limitations exist with these methods as currently their use is constrained to a research setting, requiring bespoke software that is potentially cost-prohibitive.

A commercially available and inexpensive device may offer a more practical and real-world solution for coaches and athletes to not only quantify jump counts but also the capacity to give a more reflective assessment of load. The Vert (Mayfonk Athletic, Florida, USA) is a small inertial sensor measuring $6 \times 3 \times 0.5$ cm. Inserted into an elastic waistband, the sensor time stamps and calculates the vertical displacement of each jump. Data is subsequently streamed to a smartphone (or similar device) via Bluetooth. If found to be valid, the Vert device may provide a simple, inexpensive and efficient method of measuring jump counts. Additionally, the Vert may offer a more robust measure of external load to be calculated that discriminates between jumps of varying heights. This will subsequently give researchers greater resolution when investigating the prospective relationship between jump load and injury and may allow for safe workload prescriptions to be determined.

Therefore the aims of this study were twofold. Firstly, to evaluate the validity of Vert derived vertical displacement by comparing it to three-dimensional motion analysis and jump count against retrospective video-analysis. Secondly, to propose a more robust method of quantifying athlete jump load that progresses beyond a simple counting measure and includes the influences of both jump height and mass of the athlete by calculating kinetic energy (KE) for each jump.

2. Methods

A sample of eighteen male, elite junior volleyball athletes (mean ± SD 16.94 ± 1.47 years, 85.50 ± 8.07 kg and 1.96 ± 0.07 m) volunteered to participate in this study. All procedures were approved by the Australian Institute of Sport ethics committee and written informed consent or assent where applicable was obtained for each participant or parent/guardian prior to the commencement of the study. Participants were included if they were pain and injury free at the time of testing and reported no significant lower limb injuries in the month prior. The study involved three distinct phases: 1—Validity of the Vert to measure vertical displacement against a laboratory reference motion analysis system. 2—Validity of the Vert to count jumps against retrospective video analysis. 3—The proposal of a method for quantifying external load in these athletes.

A concurrent validity design was utilised in phase one to evaluate the vertical displacement measure in reference to a 20-camera motion analysis system (Vicon, Oxford, United Kingdom) sampling at 250 Hz. A subset of ten athletes (mean ± SD 17.40 ± 1.56 years, 85.17 ± 9.53 kg and 1.96 ± 0.07 metres) attended a single testing session whereby two separate Vert devices were secured in a pouch via an elastic waistband with anti-slip material present on the skin side of the band and applied tightly around the midline of each participant. The band was positioned directly inferior to the umbilicus as recommended by the manufacturer. Utilising two Vert devices allowed the inter-device reliability to be assessed. One retro-reflective marker was firmly attached to the outer surface of the pouch that contained the two inertial sensors. All athletes were shirtless, so as to not impede data collection.

Each Vert device was connected via Bluetooth to a smartphone application, with an initial jump being performed to allow synchronisation between the two systems. Athletes performed a standardised routine that included a selection of jumping and non-jumping motions typically encountered during volleyball training and match-play, including set, spike, block and serve jump types as well as multidirectional shuffling motions, digging and diving. All these motions have been previously described in detail.[11] To provide task representation, both a volleyball net and ball were included for all relevant jumping motions within the capture area. Trajectory data was collected and processed using Vicon Nexus 1.8.5 software (Vicon, Oxford, United Kingdom). A baseline height was established as the three-dimensional height of the retro-reflective marker during passive upright standing. Vertical displacement was calculated by establishing the maximum three-dimensional trajectory height for each jump and subtracting the initially collected baseline measure. The association between the Vert devices and motion analysis trajectory data was assessed depending on its distribution using either Pearson or Spearman correlation coefficients where appropriate. Furthermore, as visual inspection of histograms and box plots indicated the data was normally distributed, Bland–Altman assessments were used to determine and visually represent the bias. A linear regression was also performed to determine the presence of a proportional bias.

Phase two evaluated the capacity of the Vert to correctly identify jumps during training and match-play. Twelve participants (mean ± SD 16.67 ± 1.31 years, 84.37 ± 6.11 kg and 1.96 ± 0.07 m) wore a Vert device (standardised position described above) during a number of volleyball sessions that included; standardised controlled training drills, uncontrolled training sessions and uncontrolled match-play. All sessions were simultaneously recorded with a Sony HXR NX90P video camera (Sony Corporation, Tokyo, Japan) with time stamp capture capability. Each session was uploaded to the software package Sportscode (Sportscode Elite, Version 10.3.11, Sportstec, Warrierwook, Australia) and coded for type and the time it was performed. A jump was defined as any occasion where both feet of the athlete were visually inspected to leave the ground at approximately the same time. To synchronise data collection, all athletes performed a single jump in view of the camera at the beginning of each session. Video data was initially analysed by two separate assessors to determine inter-rater reliability using Cohens Kappa statistics.[12] Coding was subsequently completed by the first assessor, once adequate reliability had been determined ($k = 0.953$). Additionally, intra-rater reliability was determined whereby assessor one repeated the coding process from a training and match play session three weeks later ($k = 0.874$).

All Vert jump data files were exported to a Microsoft Excel (2013) spreadsheet (The Microsoft Corporation, Redmond, Washington) for subsequent matching with jumps derived from the video based coding. Data from both sources were synchronised based on the time of the initial jump. This allowed jumps recorded by the Vert device and from the video coding method to be accurately matched based on the time they occurred. The video-detected jumps were also compared to those recorded by the Vert device using a set of performance measures to identify True Positives (TP; a jump detected by video coding and Vert), False Positives (FP; a jump detected by the Vert but not the video) and False Negatives (FN; a jump detected by video but not the Vert) based on previously described methods.[13] These metrics enabled calculation of the ability of the Vert to correctly identify jumps (low FP and high TP) and recall, the ability for the Vert to correctly detect jumps (low FN and high TP).[13]

Point estimates of all correlations were interpreted based on parameters provided by Portney and Watkins[14] and are as follows: good to excellent (>0.75), moderate to good (0.50–0.75) or fair correlations (<0.50) with P values being deemed significant at <0.05. All analyses were performed using the Statistical Package for Social Sciences (SPSS) (IBM Corporation, Chicago) version 20.0.

Phase three of the study involved the proposal of a more robust measure of external load or the load index (LdIx), calculated as the product of the jump count and the average KE, as measured in kilojoules (kJ) allowing jumps of greater vertical displacement to be weighted more heavily. In order to quantify KE, final velocity (vfin) of the athlete prior to landing was calculated as the relationship between gravity (g) and vertical displacement (vd),[15] as seen below:

$$\text{vfin} = \sqrt{2g \times \text{vd}}$$

KE of the athlete was subsequently calculated as the relationship between the athletes mass (m) and vfin[15] as seen below:

$$\text{KE} = \frac{1}{2} m \times \text{vfin}^2$$

3. Results

During phase one a total of 249 jumps were performed (mean vertical displacement ± SD 46.87 ± 11.81 cm) with the correlation between both Vert devices being excellent for all jump types (r = 0.96–0.99), with a mean bias of −0.83 cm with LOAs ranging from −4.55 to 2.89 cm. Correlation between three-dimensional trajectory data and both Vert devices was good to excellent (r = 0.83–0.97), however the biases were larger when comparing between the Vert devices and motion analysis, being 3.57 and 4.28 cm for Vert 1 and Vert 2 respectively. When combined, Vert data demonstrated on average an overestimation of vertical displacement, however no relationship between vertical displacement and measurement error was detected (r = 0.109). Differences between jump types were observed with biases ranging from 0.02 and 0.96 cm for the set jump and 6.89 and 7.51 cm for the spike jump. The widths of LOA ranged between 12.15 and 12.17 cm for the set jump and 16.89 and 20.19 cm for the spike jump. While the mean bias in all jump types demonstrated an overestimation of vertical displacement from the Vert, each jump type did contain examples of underestimation with an average of 10% across all jumps. Underestimation percentages ranged from 7% for block jump to 48% for set jumps. These results are individually detailed in Supplement 1 and Fig. 1.

During phase two, a total of 1487 jumps were identified and coded for type via visual retrospective video analysis using Sportscode and are presented in Table 1. These jumps were correctly matched with 1307 recorded using the Vert, resulting in a recall of 0.879. When total jumps were split by session type, matchplay demonstrated the highest level of recall (0.930), followed by controlled drills (0.903) and complete training sessions (0.814). The performance measures of precision and recall for each jump type are also presented in Table 1. The results indicate the Vert has excellent precision for all jump types analysed (0.974–1.00). Recall was excellent for block, spike and serve jumping motions (0.957–0.991) however it was lower for setting jumping motions (0.754).

4. Discussion

This study evaluated the validity of a commercially available inertial sensor, the Vert for quantifying vertical displacement and jump count in volleyball athletes. Additionally, we have proposed an algorithm that provides a more robust measure of load known as the LdIx.

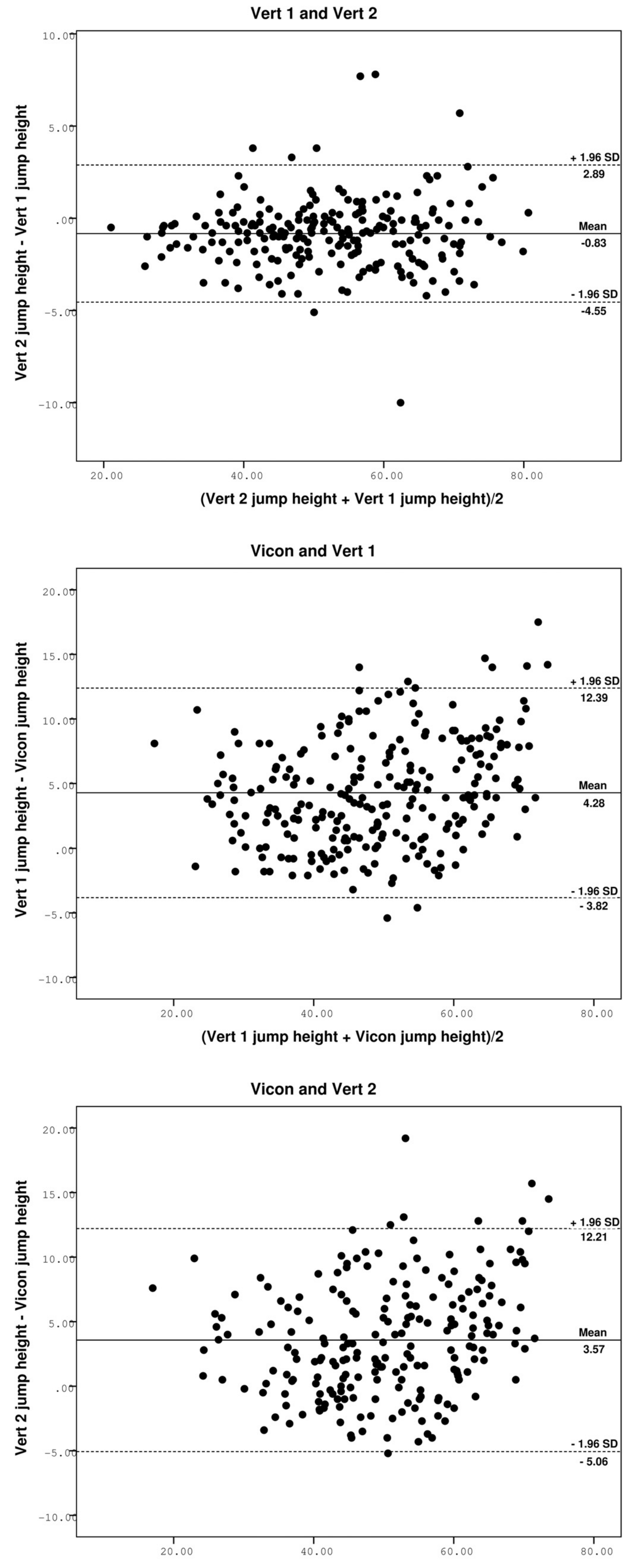

Fig. 1. Bland–Altman plots depicting the association and limits of agreement (LOA) between heights recovered by the two Vert devices, and between each Vert device one and Vert device two and three dimensional motion analysis trajectory data (Vicon), respectively.

Table 1
Comparison of number of jumps recorded via Vert devices and retrospectively with Sportscode.

	True Positives	False Positives	False Negatives	Precision	Recall
Session type					
Match-play	423	0	32	1.000	0.930
Controlled drill	445	0	48	1.000	0.903
Whole session	439	2	100	0.995	0.814
Jump type					
Block	433	1	17	0.998	0.962
Spike	428	0	19	1.000	0.957
Serve	106	0	1	1.000	0.991
Set	303	0	99	1.000	0.754
Other[a]	37	1	44	0.974	0.457
Total	1307	2	180	0.998	0.879

[a] Refers to jumping motion whereby two feet have left the ground, however does not fall into the alternative categories. For example, this may be a digging type motion.

When comparisons were made between Vert devices, correlations were shown to be excellent. Results also indicated that while the Vert device was highly correlated with a laboratory reference three-dimensional motion analysis system and reported small, non-significant biases (3.57–4.28 cm) that overestimated vertical displacements, large LOA were seen for all jump types. The Bland–Altman analysis (Supplement 1) revealed that the range in vertical displacement varied between 12.15 and 20.19 cm depending on jump type, with all jump types having trials reporting vertical displacements that were underestimated by the Vert, indicating that systematic error or a fixed bias did not exist between the two systems. Variations in under reporting were observed between jump types and ranged between 7% (block jump) and 48% (set jumps). Whilst previous research has drawn links between different vertical jumping techniques and discrepancies in vertical displacement calculations,[16] it is difficult to draw definitive comparisons given the unknown methods used by the Vert device to calculate vertical displacements. It is however suggested, that future research more thoroughly explore potential reasons for vertical displacement discrepancies between different volleyball jump types. It is acknowledged that errors in vertical displacement exist when comparing the Vert to a motion analysis system; however, we feel that this offers a 'real world' benefit in the sporting environment due to its capacity to provide near real time data with limited resources or impact on the athlete.

The Vert was able to correctly identify jumps with an average recall of 0.879 when compared to video analysis. In terms of session type, increased accuracy was evident for match-play compared with training sessions. This may be due to the low recall recorded for set and "other" jump types. Jumps coded as 'other' were smaller in height, are most often performed in a warm-up and may explain why they are sometimes not detected by the Vert. The lowest vertical displacement recorded was 17 cm and as expected, it would appear that the Vert algorithm contains a minimum threshold for the detection of a jump. While this successfully prevents other non-jumping movements such as running being falsely detected as jumps, as evidenced by the high precision scores, it may result in a lower recall for smaller jumps. In the training environment players typically perform a range of smaller jumping movements during warm-up that are not used in game play, such as submaximal hopping and lateral jumping translations which explains the higher recall values noted during game play. Whilst it could be argued that retrospective video coding is potentially more accurate, it is constrained by temporal inefficiency. In the sporting setting is not a viable option, even within a well-resourced high performance environment.

Recent studies have also assessed the use of accelerometers to assess jump and landing impacts in volleyball athletes. Jarning et al.[10] investigated a custom tri-axial accelerometer to measure jump count using variables of peak vertical acceleration and resultant acceleration in volleyball athletes. However, the variables investigated did not allow adequate differentiation between some jump types and the device had difficulty distinguishing between jumping and non-jumping motions. Additionally, wide intra and inter-subject variability was reported. Gaegler et al.[9] evaluated the validity of a custom-built inertial sensor to detect both jump count and time of flight, in volleyball athletes, allowing for the possible differentiation of jump type based on flight times. This inertial sensor correctly identified 95% of all jumps when compared with retrospective video analysis. Whilst promising, these devices and methods are somewhat limited to a research setting requiring software that is not freely available and more time-consuming analysis.

In addition to validating a device that has the capacity to be utilised in the training and testing environments, that operates through a "coach friendly application", this study has also proposed an algorithm that gives a more robust measure of load (LdIx). The load algorithm takes into account the vertical displacement of each jump as well as the mass of the athlete. The acknowledgement of the interaction of these two variables is critical in moving towards a measure of load that is more reflective of what the jumping athlete is experiencing rather than that of the simple jump count method. Previous literature has linked the need for greater power production from the lower leg musculature in order to increase vertical jump heights.[17] From a physics perspective, increasing the height of a jump increases the linear velocity it experiences at landing due to the influences of gravity. This subsequently increases the energy related to the mass, in this case the athlete, or what is known as KE (calculated also using the mass of the athlete) at landing.[15] Increases in KE can therefore be linked not only to increased muscular power production but also to greater ground reaction forces (GRF). It must be noted that GRFs are influenced by the landing mechanics and remain difficult to calculate without more sophisticated kinematic analysis.[7] The ability to accurately and more effectively monitor loads allows coaching and support staff the opportunity to avoid training spikes, which have been shown to increase risk of injury.[4,18,19] This type of load monitoring would also allow the prospective exploration of the association between load and subsequent injuries that are common in volleyball athletes.[3]

It should be noted, that there were technical difficulties with some of the collected Vert trials. There appeared to be a shift in the chronological time, where the Vert appeared to drop or lose time. Whilst jump data could still be matched, it was not possible to accurately evaluate the rate of jumping activity or "jumps per minute". Additionally, it is acknowledged that the Vert uses algorithms and signal processing procedures that are not available for public inspection, thus it remains unclear as to how a jump was defined within the software or what the thresholds (minimum and maximum) for a jumping motion were, remaining a limitation to the study.

It is recommended that future research explore the prospective relationship between LdIx, the incidence of injury and the landing mechanics of volleyball athletes. Given that appropriately prescribed training loads have been shown to protect against injury,[19] the ability to accurately capture these loads would potentially inform training and match-play guidelines, similar to those seen in cricket for example whereby upper and lower bowling thresholds are recommended for injury prevention purposes.[20,21]

5. Conclusion

The Vert device demonstrated acceptable validity for measuring vertical displacement and jump count in volleyball athletes, both in the training and match-play environments, that is certainly an improvement on current practices. A more reflective measure of external load (LdIx) may be calculated beyond that of a simplistic jump count, giving greater potential to prospectively monitor loads and their association with injury. It is acknowledged that errors in vertical displacement will influence KE calculations; however, the proposed method still represents an improvement in the management of athlete load, compared with current practices. The Vert device also offers the advantages of being relatively inexpensive, commercially available and with the ability to provide instantaneous information. This makes the device a preferential tool, especially for sub-elite populations of athletes.

Practical applications

- The Vert is a commercially available inertial sensor that is valid for measuring vertical displacement and jump count in junior male elite volleyball athletes.
- The Vert is a more efficient alternative to time-consuming retrospective video analysis.
- Data collected from the Vert device offers the potential to manage and monitor a more reflective measure of external load in volleyball athletes using the LdIx algorithm.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jsams.2016.07.007.

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