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Comparison of Multiple Hop Test Kinematics Between Force-Platforms and Video Footage – A Cross Sectional Study

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ABSTRACT

Background: Multiple hop performances have been assessed using force-platforms and motion-capture cameras. However, the accessibility of these technologies might be a hindering factor for many performance coaches. Currently, tablet devices are being used as alternatives to measure jumping and hopping performances. **Objective:** This study aimed to compare multiple hop kinematics using the Kinovea application with force-platforms, the gold standard. **Methods:** Using an observational cross-sectional study design, male athletes (n=44; age 20.1 ± 1.4 years) completed triple hops (3-Hop) and quintuple hops (5-Hop) on force-platforms while being filmed using an iPad. Ground contact time, flight time and total time were analysed using Kinovea and compared with the force platform data. **Results:** Statistical analysis showed a high level of agreement across all variables of interest but significant differences (flight time; -2.14 to -5.96 %, ground contact time; 4.89 to 5.83 %, total time; -0.37 to -0.58%) were observed across all variables of interest. A systematic bias for flight and ground contact times were seen for 3-Hop and 5-Hop. **Conclusion:** The use of iPad and Kinovea application can be used as a valid alternative to measure multiple hop kinematics when performance coaches do not have access to expensive force-platforms or motion-capture cameras.

Key words: Hop Test, Validation, Plyometric, Video Analysis, Reactive Strength, Performance Testing

INTRODUCTION

Physical performance testing is essential for evaluating injury predisposition and athlete readiness. Hopping based tests such as triple (3-Hop) and quintuple hops (5-Hop) are valid and reliable tests to measure lower limb physical performance among athletic populations (Stolberg et al., 2016). Both tests have been used to assess stretch load tolerance and unilateral propulsive and braking force capability of athletic populations (Baker & Newton, 2008; Chu & Korchemny, 1989; Habibi et al., 2010; Lockie et al., 2014; Young et al., 2002). The 3-Hop and 5-Hop tests are used in clinical and athletic setups, but the total hop time and distance are the commonly measured variables. Kinematic outputs measured during multiple hop assessments such as ground contact time, flight time and resultant step frequencies have shown strong correlations with measures of athletic performance, and particularly with sprinting characteristics (Nagahara et al., 2018; Nagahara et al., 2014; Rabita et al., 2015). But measuring these intricate variables is time and resource consuming.

The kinetic and kinematic outputs of multiple hop assessments have been determined using force platforms, accelerometers, and high-velocity motion capture cameras, with the force platform assessment method widely acknowledged as the gold-standard. However, lack of affordability and access to force platforms is a limiting factor for coaches working in community level athlete development programmes. The availability of a valid, reliable, low-cost, and accessible technology would be ideal for coaches seeking to assess multiple hops in series practically on-field rather than in a laboratory setting.

A recent review in the utility of mobile phone or tablet device applications for measuring athlete vertical jumping height has shown high levels of validity and reliability (Sharp, Cronin, & Neville, 2019). Vertical jump data captured using mobile device applications have previously been compared with force platform data and shown high validity (r = 0.60-0.995) (Balsalobre-Fernandez et al., 2015; Carlos-Vivas et al., 2018; Driller et al., 2017; Gallardo-Fuentes et al., 2016; Stanton et al., 2017). However, the validity and reliability of horizontal hopping assessments in the frontal

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plane using mobile phone or tablet device applications have not been reported. Hence, the current study aimed to determine the validity of utilising a mobile device application to measure kinematic variables of horizontal multiple hops in series and compare these with force platform gold-standard technology. If the study findings prove that assessing multiple hops using mobile tablets are valid then, it could be recommended as a reliable alternative for sports coaches wanting to assess multiple hop performances.

METHODS

Participants and Study Design

Using an observational cross-sectional study design, male university athletes (n= 44; and mean ± SD descriptive data, age: 20 ± 1 years; height:171.9 ± 5.1 cm; weight: 71.2 ± 8.6 kg) of various sporting success and codes participated in the study. A participant classification framework identified them at a range of Tier 0-3 (McKay et al., 2022). To be included in the study all participants had to be healthy and injury free at the time of testing with no history of major reconstructive surgery of the lower limb or significant historic injuries that could affect performance in the previous two years. The Auckland University of Technology Ethics Committee (reference: 17/133) approved the study. The participating athletes provided their written informed voluntary consent prior to testing.

Study Design

Multiple hop performance

A hopping familiarisation session was conducted for all athletes three days prior to the testing. Familiarisation included a warmup consisting of explosive bounding movements to replicate testing demands, and progressive sprinting over 30 metres. The athletes executed both the 3-Hop and 5-Hop on a series of force platforms, while being video recorded simultaneously. Each multiple hop trial started with the athlete balanced on their trial leg before propelling themselves forward for the required number of contacts and subsequent landing. The 3-Hop test protocol consisted of two hops on the same leg followed by a double foot landing, and the 5-Hop test consisted of four hops on the same leg followed by a double foot landing. Athletes were cued to "reach the furthest horizontal distance in the fastest time possible". Contact on the ground with the athlete's hands post-landing was permitted if the movement did not result in further steps forward. Upper limb motion was allowed during the hops replicating motor patterns associated with athletic movements. All athletes completed three trials for 3-Hop and two trials for 5-Hop on both their non-dominant and dominant limbs in a randomised order with two minutes rest between efforts. Only two repetitions of the quintuple hops were performed on each leg due to the very high stretch-load demands and to reduce any significant effects of fatigue on performance.

Equipment

Force platform

Athletes performed multiple hops in series on a synthetic indoor track surface covering a series of embedded inground force platforms (TF-90100, TF-3055, TF-32120, Tec Gihan, Uji, Japan) covering the entire hopping distance. The force platforms collected ground reaction forces (GRFs) at a sampling rate of a 1000 Hz by connecting to a single computer. GRF force data was processed as described in previous studies investigating temporal events (Nagahara et al., 2018) using embedded force platforms in series. The GRF signals collected during the hop trials were filtered using a 4th order Butterworth low-pass digital filter with cut off frequency of 50 Hz. Hop temporal events including ground contact, flight and total times were identified by a vertical GRF threshold set at 20 N in a purpose-built algorithm (MATLAB R2021a, The Mathworks Inc, Massachusetts, USA).

Video analysis mobile device application

To record the multiple hops in series an iPad Pro A1584 (Apple Inc, Cupertino, Ca, USA) was used. The iPad recorded the multiple hops at 1080 pixels and 120 frame per second secured on a tripod at 30 cm height above the ground and positioned at 14 and 19 metres from the start line directly in front of the athlete for triple and quintuple hop tests, respectively. The video footage and force platform data were obtained simultaneously. The video footage recorded using the iPad was processed using the Kinovea application, this application has been used to analyse kinematic parameters in several athletic jumping performance studies (Balsalobre-Fernandez et al., 2014; Garhammer & Newton, 2013; Sakadjian et al., 2014; Sanudo et al., 2016).

Video Footage Analysis

The event of 'toe off' was defined as the first frame after loss of contact with the ground, and the event of 'heel strike' defined as the first frame of clear ground contact in in line with previously documented methods using Kinovea (Balsalobre-Fernandez et al., 2014). Ground contact and flight times were determined by the interval of detection of 'toe off' and the subsequent 'heel strike' for both triple and quintuple hops. A slow motion and magnifying tool (2.5 x) built into the Kinovea application was used to simplify detection of each event. Frame numbers were logged into a spreadsheet (Microsoft Excel, Microsoft Corporation, Washington, USA) in which flight times, ground contact times and total times were automatically calculated.

Statistical Analysis

Descriptive statistics (estimated mean, mean differences, and confidence intervals) were reported for all statistical comparisons. Assumption checks for homogeneity, linearity and normality of residuals were determined to be acceptable for both 3-Hop and 5-Hop data across methods. The validity of video footage measures against the force platform data was determined by several statistical tests. Firstly, a linear mixed-effect model was used to compare any differences in variables across limbs, methods, trials, and athletes. Statistical significance was set at an alpha level of $p < 0.05$. Effect sizes were reported using Cohen's *d*, and interpreted as very small (< 0.2), small (0.21-0.5), moderate (0.51-0.79) and large (> 0.8) (Cohen, 1988). Secondly, the linear mixed-effect model was used to determine any bias between the force platform and video footage. The ground contact times and flight times were specified as the dependant variable in each analysis, between force platform and video footage, hops (3 or 2 per leg), and their interaction were specified as fixed effects. A nested random intercept structure was specified for the random effect, with trials nested within the athletes' repeated measures. Thirdly, further visual representation of the level of agreement and any bias between force platform and video footage as the method of analysis was constructed using Bland-Altman plots (Bland & Altman, 1986), where the differences between methods were plotted against their averages (force platform – video footage), and the 95% limits of agreement (Bland & Altman, 1999). Finally, an intra class correlation coefficient with 95% CI was calculated for ground contact times, flight time and total time for both the 3-Hop and 5-Hop to establish the concurrent validity between the iPad footage and the data from the force platform. The RStudio (version 1.4.1103, PBC, Boston, USA) software was used for performed all the statistical analysis.

RESULTS

The differences observed were not significant ($p < 0.05$) between the non-dominant and dominant limbs during 3-Hops and 5-Hops and so all trials were pooled for analysis to compare methods. Estimated means, standard deviations (SD) and 95% confidence intervals (CI) are shown for flight and ground contact for both 3-Hop and 5-Hop in Table 1.

Visual analysis of Bland-Altman plots showed the between method differences (force plate versus video) for flights times, ground contact times and total times was consistent across the hops and that the majority of the data points are within the 95% CI. There were notable differences (Table 2) in flight time which decreased with both the 3-Hops (-0.015, -0.012, -0.008 secs) and 5-Hops (-0.016, -0.013, -0.013, -0.011, -0.009 secs) as the athlete came closer to the iPad, however, the effect size for the differences in flight time were trivial (0.08-0.017) and not statistically significant. Ground contact times from the video footage were consistently overestimated in comparison to the force plate across both 3-Hops and 5-Hops. Interestingly these differences (0.013 to 0.014 secs) showed very small changes across hops and as the participant hopped came closer to the iPad. These differences were trivial (0.21-0.29) and not statistically significant.

In summary, there is a systematic bias between the two methods of analysis, but the bias is uniform (between dominant and non-dominant legs, and across trials and hops). Bland-Altman comparisons indicated a good level of agreement between the video footage and force platform, with mean bias across all variables ranging from 0.009 to 0.016 seconds which represents approximately 1-2 video frames at 120 Hz.

DISCUSSION

This study determined the validity of utilising a mobile device with Kinovea to assess kinematic variables of hor-

Table 1. Estimated means & standard deviations (95% CI) of hop kinematics between the force platform and video footage

		Force platform		iPad video footage	
		Mean ± SD	**CI low-high**	**Mean ± SD**	**CI low-high**
3-Hop FT	1	0.281 ± 0.038	0.265 – 0.295	0.266 ± 0.040	0.250 – 0.280
	2	0.330 ± 0.056	0.314 – 0.344	0.318 ± 0.056	0.302 – 0.333
	3	0.441 ± 0.052	0.425 – 0.455	0.433 ± 0.055	0.417 – 0.447
5-Hop FT	1	0.277 ± 0.035	0.263 – 0.294	0.261 ± 0.037	0.247 – 0.277
	2	0.317 ± 0.053	0.303 – 0.334	0.304 ± 0.053	0.290 – 0.321
	3	0.327 ± 0.049	0.313 – 0.344	0.314 ± 0.050	0.300 – 0.331
	4	0.345 ± 0.048	0.331 – 0.362	0.334 ± 0.048	0.320 – 0.351
	5	0.447 ± 0.061	0.432 – 0.463	0.437 ± 0.064	0.423 – 0.454
3-Hop GCT	1	0.281 ± 0.036	0.270 – 0.291	0.295 ± 0.037	0.284 – 0.305
	2	0.260 ± 0.035	0.249 – 0.270	0.273 ± 0.038	0.262 – 0.282
5-Hop GCT	1	0.273 ± 0.032	0.263 – 0.282	0.287 ± 0.033	0.277 – 0.296
	2	0.244 ± 0.029	0.234 – 0.253	0.258 ± 0.030	0.249 – 0.268
	3	0.239 ± 0.030	0.229 – 0.248	0.252 ± 0.030	0.242 – 0.261
	4	0.241 ± 0.032	0.231 – 0.250	0.253 ± 0.032	0.244 – 0.263

Mean ± SD presented in seconds, CI = confidence interval; 3-Hop = triple hop; 5-Hop = quintuple hop;
FT = flight time; GCT = ground contact time

Table 2. Mean difference (95% CI) of hop kinematics between the force platform and video footage

		Difference	CI low-high	*p*	*d*	Interpretation
3-Hop FT	1	-0.015	-0.020 to -0.010	< 0.001	0.17	Trivial
	2	-0.012	-0.016 to -0.007	< 0.001	0.14	Trivial
	3	-0.008	-0.013 to -0.004	0.001	0.10	Trivial
5-Hop FT	1	-0.016	-0.023 to -0.010	< 0.001	0.13	Trivial
	2	-0.013	-0.020 to -0.007	< 0.001	0.11	Trivial
	3	-0.013	-0.020 to -0.007	< 0.001	0.11	Trivial
	4	-0.011	-0.017 to -0.004	0.002	0.09	Trivial
	5	-0.009	-0.016 to -0.003	0.005	0.08	Trivial
3-Hop GCT	1	0.014	0.011 to 0.017	< 0.001	0.29	Small
	2	0.013	0.009 to 0.016	< 0.001	0.27	Small
5-Hop GCT	1	0.014	0.011 to 0.018	< 0.001	0.24	Small
	2	0.014	0.011 to 0.018	< 0.001	0.24	Small
	3	0.013	0.009 to 0.017	< 0.001	0.22	Small
	4	0.013	0.009 to 0.016	< 0.001	0.21	Small

Difference presented in seconds, Statistical significance set at an alpha level of $P<0.05$, CI = confidence interval, 3-Hop = triple hop, 5-Hop = quintuple hop, FT = flight time, GCT = ground contact time, Cohen's d effect sizes are trivial if $d \leq 0.2$, small if $d = 0.2$-0.6.

izontal multiple hops in series and compare these with force platform gold-standard technology. To the author's knowledge, such a methodology had not been investigated previously and so difficult to compare with other studies. However, the high level of agreement between video and force platform is consistent with that seen in vertically orientated jump assessments. The current study's main findings were: 1) there were significant differences ($p < 0.05$) between hop variables captured from an iPad video compared to force plate; 2) there was a consistent underestimation in flight times seen across 3-Hops (-0.015 to -0.008 secs) and 5-Hops (-0.016 to -0.009 secs) which corresponded to the distance the subject was away from the iPad, although these differences were not significantly different across flight times; 3) iPad video over estimated (0.013 to 0.014 secs) ground contact times for both 3-Hops and 5-Hops similarly, regardless of distance away from the subject; and, 4) although there were significant differences in both flight times and ground times between methods, the differences were consistent and a systematic bias was observed between methods.

The current study's findings reveal that whilst the iPad video provided a valid alternative to force plate technology the results were not comparable, without some formal of statistical correction. It is likely that the differences observed in terms of the systematic bias are due to the methods used to quantify each flight and contact times. Video determined variables can only be defined by either 'contact' or 'no contact' in the selection of heel strike and toe off and limited to a sampling rate of 120 fps, whilst force plate data can be collected at 1000 Hz but can only be measured while there is contact. This contact must also be higher than the unloaded noise of the force plate, and thus a 20 N threshold is used in an aim to reduce that noise. These methodological/technological differences no doubt explain some of the observed bias.

The small but insignificant under-estimations seen in flight times can be attributed to the increased difficulty to detect heel strike and toe off due to potential perspective error at distances further away from the iPad. Of interest and difficult to explain, was the observation that greater differences were not observed during 5-Hop analysis when the camera was at an increased distance of 19 m from the athlete. We hypothesised that these differences are most likely accounted for by the period of flight time as opposed to the distance from the camera, which would also account for the consistency in the ground contact times seen across both 3-Hop and 5-Hop. Therefore, coaches can use video footage recorded using an iPad pro with the Kinovea application to accurately measure their athletes kinematic multiple horizontal hop data.

Limitations

Anecdotally the researchers noted that whilst while all reasonable measures were taken to ensure clarity of detection by way of artificial LED lighting sources, 'clean' video footage, and the video identification of heel strike and toe-off requiring visual light to be seen under the foot meant that some trials were more difficult to determine than others due to changes in environmental lighting conditions and colour of participant footwear. Interestingly this difficulty was not proven to be statistically significant.

Practical Implications

Multiple hops are movements that stress the neuromuscular system more so than most jumps due to the cyclic unilateral higher stretch loads of the consecutive hopping movements. As a movement screening diagnostic tool, it can be thought of as a progressive assessment in relation to many in place acyclic jumps, providing advanced insights into injury risk, movement competency and performance capability.

Until this study total distance was one of the only metrics used to interpret multi-hopping ability. We found a simple and cost-effective solution to capturing advanced diagnostics to provide a more granular approach to understanding high load stretch-shortening cycle performance. Inter-step and interlimb comparisons in terms of flight, contact and total time in conjunction with total distance can provide detailed insight into movement strengths and weaknesses. Furthermore, the inter-jump comparisons have been suggested to provide insight into accurate assessments of cyclical expressions of strength that are closely linked to the accelerative and maximal speed capacity of an athlete. Whilst this study does not provide a kinetic understanding of the hopping movements, the procedures could be utilised to determine a deeper understanding of injury risk and asymmetry during return-to-play protocols post injury, and high-end neuromuscular performance in the non-injured.

As an aside, a couple of observations were made in terms of inter-hop and inter-jump comparisons. Most of the ground contacts could be classified as fast stretch-shortening movements (average = 0.259 s), hence the hops being classified as high stretch load exercises given magnitude and rate of unilateral loading. As high as 6100 N in the fourth hop of a 5-Hop were seen in this study for a 70 kg athlete which equates to approximately 8.9 x bodyweights loaded unilaterally over 0.192 seconds. As such, 3-Hops and 5-Hops are thought useful assessments of cyclical expressions of strength that are closely linked to the accelerative and maximal speed capacity of an athlete. And finally, it seems as though both 3-Hops and 5-Hops have similar spatiotemporal demands, however further insight into the kinetics of multiple hops and associated neuromuscular demands is needed to fully understand the mechanics, utility, and adaptive potential of these exercises.

CONCLUSIONS

Assessing an athlete's horizontal multiple hops in series performance is important for physical performance coaches. The current study determined that 3-Hop and 5-Hop performances of athletes can be reliably, accurately, and cost-effectively measured using an iPad tablet with the Kinovea application. This study's findings may help community-level coaches who want to measure their athlete's horizontal multiple hop performance in an affordable and valid way.

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