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Concurrent validity of the portable gFlight system compared to a force plate to measure jump performance variables

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Title

Concurrent validity of the portable gFlight system compared to a force plate to measure jump performance variables

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Abstract

Objective: Lower-limb strength and power is commonly assessed indirectly by measuring jump performance. A novel portable system (gFlight) that can be used in applied settings provides measures of jump performance. The aim of this study was to validate jump performance measures provided by the gFlight to those provided by a force plate.

Approach: Thirty-six participants performed three countermovement jump and drop jump trials. Jump height, contact time, and reactive strength index were simultaneously recorded by a force plate and gFlight sensors to assess concurrent validity.

Main Results: The gFlight provided significantly higher measures of jump height during the countermovement jump (Mean: +8.79 ± 4.16 cm, 95% CI: +7.68 to 9.90 cm, $P<0.001$) and drop jump (Mean: +4.68 ± 3.57 cm, 95% CI: +3.73 to 5.63 cm, $P<0.001$) compared to the force plate. The gFlight sensors displayed significantly higher measures of reactive strength index (Mean: +0.48 ± 0.39 $\text{m}\cdot\text{s}^{-1}$, 95% CI: +0.37 to 0.58 $\text{m}\cdot\text{s}^{-1}$, $P<0.001$) and lower measures of contact time (Mean: -0.036 ± 0.028 s, 95% CI: -0.044 to -0.029 s, $P<0.001$) during the drop jump compared to the force plate. The bias displayed by the gFlight for jump height, contact time and reactive strength index measures are reduced using corrective equations.

Significance: The gFlight sensors are a cost-effective, portable measurement system with high concurrent and ecological validity for the objective measurement of jump performance in applied settings. Corrective equations should be used to reduce measurement biases so comparisons can be made to force plate measurements of jump performance.

Keywords: Countermovement jump, drop jump, jump measurement, field-based, applied practitioners.

List of abbreviations:

JH, jump height; CMJ, countermovement jump; DJ, drop jump; SSC, stretch-shortening cycle; RSI, reactive strength index; SD, standard deviation; CV, coefficient of variation; SEE, standard error of estimate; CI, confidence interval.

Introduction

Lower-limb power is commonly assessed indirectly by measuring jump height (JH) performance during vertical jumping tasks such as the countermovement jump (CMJ) and drop jump (DJ) (1–3). The measurement of JH is a frequently used method to assess and monitor physical performance and adaptations by coaches and researchers (4,5), along with being one of the most prevalent activities performed in a wide range of sports (6). Assessing lower-limb performance during jumping tasks provides coaches and researchers with information relating to the utilisation of the stretch shortening cycle (SSC) and reactive strength index (RSI) during the CMJ and DJ, respectively (5,7).

Force plates are considered the 'gold standard' to measure jump performance (8,9). Force plates are mechanical systems that provide measurements of ground reaction forces and moments involved with human movement (10), however, these are often expensive (~20k£), bulky and require specialist software to collect and analyse data. The use of force plates to measure JH where access to laboratory facilities are limited are therefore impractical, however, applied practitioners still need to assess and monitor the physical performance and readiness of the athletes they support.

In order to make traditional lab-based performance tests more accessible, advances in technology have provided applied practitioners and athletes with access to field-based measures of JH that can be used in their own environments. These include contact mats (Just Jump system), velocity systems (GymAware), linear position transducers (MyoTest, Vertec), optical photoelectric cells (OptoJump), and mobile phone applications (MyJump), (6,9,11,12). These field-based alternatives, however, all use different software and calculations to provide JH measurements meaning results can vary depending on the system used. With portable and wearable technologies increasing in popularity, more research is being published to evaluate the reliability and validity of these measurement systems (13,14).

Recently in 2018, a novel portable measurement system was developed (Exsurgo gFlight v2,) that can fit into a small bag and connects to a free downloadable smartphone application (gTechAMS, Exsurgo Technologies, LLC) via Bluetooth. The system consists of two photoelectric boxes; one transmitter and one receiver that are placed at a maximum of 5.8 m apart at floor level. The gFlight measures JH via time in air, CT and RSI, with participants instructed to stand with their fifth metatarsal in line with the beam. The portability and relatively low price ($399) of the gFlight makes this system an accessible option for applied practitioners, as well as improving the ecological validity of the measurements taken. The validity of the gFlight however is unknown, with no studies currently published evaluating the validity of the measures provided by the gFlight system against those provided by the 'gold standard' force plate.

The aim of this study is to provide a novel evaluation of the concurrent validity of the gFlight compared to the 'gold standard' force plate to measure JH, CT, and RSI during a countermovement jump and drop jump. The evaluation of this novel measurement system will provide researchers and practitioners with knowledge as to the validity of the measures provided by the gFlight for the first time.

Method

Participants

With institutional ethics approved by Northumbria University research and ethics committee, 36 young healthy adults (27 male, 9 female) participated. The age, stature and mass of participants, reported as Mean ± SD, were 22.0 ± 4.4 yrs; height: 1.75. ± 0.08 m; 74.87 ± 11.88kg. The inclusion criteria for participation in this study were that participants had to be aged 18-35 years, and free from physical limitations or musculoskeletal injuries that could affect their ability to perform the testing procedures. Participants were excluded if they had an injury to the lower limb or had any condition that would affect jumping performance. Participants represented a wide range of abilities and training status from recreational to highly trained, participating in 1.5 to 14 h of moderate to strenuous physical activity per week, as defined in the American College of Sports Medicine (ACSM) Physical Activity Guidelines (15). This was to ensure the gFlight system could be validated across a wide range of jump heights. All participants were asked to refrain from strenuous exercise in the 24 h prior to testing. Testing procedures were conducted on two separate occasions separated by 1-week at the same time of day (1300-1700), with participants wearing the same pair of their own athletic shoes with cushioning for all trials.

Study Design

All participants performed 3 maximal trials of the countermovement jump (CMJ) and the drop jump (DJ) with hands placed on the hips throughout, following a standardized 10 min warm-up. Data for each trial were simultaneously recorded using a floor integrated force plate (AMTI Biovac 1100, Watertown, MA, USA) (criterion instrument) and a pair of Exsurgo gFlight sensors (Exsurgo, Virginia, USA) (practical instrument) to assess the concurrent validity of this latter system, with the averages of the 3 CMJ and DJ trials used for further analysis. The dependent variables were jump heights of the CMJ and DJ, and the contact time and reactive strength index (RSI) of the DJ. The independent variables were the measurement tools; specifically, the force plate as the gold-standard criterion measure, and the gFlight sensors as the practical experimental measure.

Procedures

Upon arrival to the laboratory, a full explanation of the experimental protocol and procedures was provided to participants. Following this, participants completed a standardized 10 min warm-up led by the principal investigator following the raise, activate, mobilise and potentiate (RAMP) protocol (16) consisting of movements similar to those detailed in similar previous studies (6,17,18). At the end of the warm-up participants performed 3 submaximal CMJ and 3 submaximal DJ at 50, 75, and 90% perceived maximum effort, familiarizing participants with the jump protocols. Each participant subsequently performed the 3 maximal CMJ trials and the 3 maximal DJ trials on the force plate and between the gFlight sensors. All jump trials were separated by 30 s of rest, with 2 min between the types of jumps.

For the standardisation of all jumps, participants kept their hands on their hips throughout the entire movement and were instructed to jump vertically with as little horizontal displacement as possible and land in the same place as take-off. For the CMJ, participants stood in an upright position with feet approximately shoulder width apart. From this position, participants were instructed to squat to approximately 90° of knee flexion as fast as possible before then jumping as high as possible. For the DJ, participants stood in an upright position with feet shoulder width apart on a 0.30 m box before stepping forwards off of the box. Upon contact with the ground, participants jumped as high as possible, as quickly as possible, attempting to achieve the greatest jump height with the least ground contact time (19). Jump trials not meeting these procedures were deemed invalid and participants repeated the trial.

The Exsurgo gFlight sensors were placed at the extremities of the force platform without touching it, in a parallel and horizontal position to one another at a distance of 0.56 m (Figure 1). The Exsurgo gFlight sensors were connected via Bluetooth to an iPhone SE (Apple Inc., USA) to record jump trials on the Exsurgo gtech application, with all dependent variables (jump height, contact time, and RSI) automatically calculated. The force plate (AMTI Biovac 1100, Watertown, MA, USA) was integrated into the floor to measure the vertical ground reaction force (VGRF) during jumping at a sampling rate of 2000 Hz (Figure 1). The force time trace recorded for each trial was used to directly calculate all dependent variables (jump height, contact time, and RSI). Contact times and flight times were obtained using a threshold of >10 N to determine contact and <10 N to determine flight (20). Jump height from force plate data was estimated as $9.81 \times \text{flight time}^2/8$ (1). The RSI was calculated by dividing the jump height by the contact time (7,21).

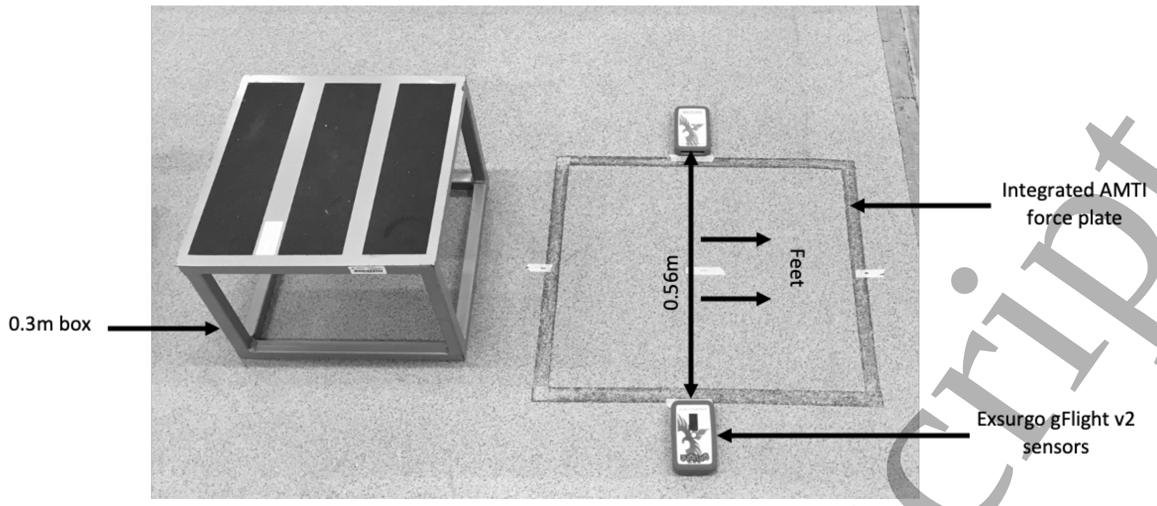

Figure 1 - Experimental setup showing the 2 measuring tools, distance between the gFlight sensors, the 0.3m box for drop jumps, and the position of the feet on the force plate recording area.

Statistical Analyses

All data are presented as mean ± standard deviation (SD). Normality was assessed by visual inspection of box plots for all dependent variables before analyses. The dependent variables obtained from the 3 CMJ trials and the 3 DJ trials performed by each participant were averaged for further analyses. Paired samples t-tests (and associated 95% confidence intervals) were used to detect systematic differences (also referred to as bias) between tools (validity) for all dependent variables. Concurrent validity between measurement tools for all dependent variables were examined using bivariate linear regression, coefficient of variation (CV), and Pearson's correlation coefficient (r). The Standard Error of Estimate (SEE) was calculated to assess the accuracy of the predictive equation from the linear regression. The coefficient of determination (R^2) was calculated to demonstrate the relationship between the dependent variables measured from the two measurement tools. Effect sizes (*d*) were calculated to determine the magnitude of differences between the two measurement tools for all dependent variables. A modified scale was used for the interpretation of *d*; *d*<0.2 as trivial, 0.2-0.6 as small, 0.6-1.2 as moderate, 1.2-2.0 as large, 2.0-4.0 as very large, and >4.0 as extremely large (22). The magnitude of correlation (r) was interpreted as; <0.10 as trivial, 0.10-0.30 as small, 0.30-0.50 as moderate, 0.50-0.70 as large, 0.70-0.90 as very large, and 0.90-1.00 as almost perfect (23). All analyses were performed using the Microsoft Excel (2013) statistical package using a spreadsheet for validity (24). Statistical significance was accepted when $P<0.05$.

Results

Jump Height

The gFlight sensors demonstrated a *very large* agreement with the force plate for the measurement of jump height (JH) in both the CMJ (r = 0.83) and the DJ (r = 0.83). Despite this agreement, the gFlight displayed a significant systematic bias with higher measures of JH provided in comparison to the force plate during the CMJ (Mean: +8.79 ± 4.16 cm, 95% CI: +7.68 to 9.90 cm, *d*: 1.25, $P<0.001$) and the DJ (Mean: +4.68 ± 3.57 cm, 95% CI: +3.73 to 5.63 cm, *d*: 0.83, $P<0.001$) (Table 1). The systematic bias demonstrated between the two measurement tools increased with increasing JH, as predicted by the linear regression equations for both the CMJ (Figure 2A) and the DJ (Figure 3A); with 69% and 68% of the variance in JH explained by the respective equations. The standard error of estimate (SEE) was ±3.80 cm during the CMJ and ±2.81 cm during the DJ. The coefficient of variation (CV) describing the concurrent validity between measurement tools were 13.60% for the CMJ and 13.40% for the DJ (Table 1).

Correcting the gFlight measurement of JH using the linear regression equations for the CMJ: corrected CMJ height = 0.7595 × raw gFlight JH + 0.6306; and the DJ: corrected DJ height = 0.647 × raw gFlight JH + 4.7173; reduced the significant systematic bias displayed between the two measurement tools in both the CMJ (Mean: 0.00 ± 3.77 cm, 95% CI: -1.00 to 1.01 cm, $d<0.001$, $P=0.99$) and the DJ (Mean: 0.00 ± 2.78 cm, 95% CI: -0.74 to 0.74 cm, $d<0.001$, $P=0.99$) (Table 2). The corrected gFlight JH measures demonstrated *very large* agreement with the force plate in both the CMJ (r = 0.83) and the DJ (r = 0.83), with the linear regression equations displaying a *nearly perfect* relationship in the CMJ ($y = 1x + 6\times10^{-6}$; Figure 2B) and the DJ ($y = 1x - 0.0001$, Figure 3B).

Contact time and Reactive Strength Index

The gFlight sensors displayed a significant systematic bias for the measurement of contact time and reactive strength index (RSI), with a lower measure of contact time (Mean: -0.036 ± 0.028 s, 95% CI: -0.044 to -0.029 s, *d*: -0.75, $P<0.001$) and a higher measure of RSI (Mean: +0.48 ± 0.39 $m\cdot s^{-1}$, 95% CI: +0.37 to 0.58 $m\cdot s^{-1}$, *d*: 0.97, $P<0.001$) provided compared to the force plate (Table 1). Pearson correlation values demonstrated *very large* agreement between measurement tools for both contact time (r = 0.83) and RSI (r = 0.75). The systematic bias displayed by the gFlight sensors compared to the force plate for the measurement of contact time was consistent as predicted by the linear regression equation, with a SEE of ±0.028 s and the equation explaining 69% of the variance observed (Figure 4A). The systematic bias observed between the two measurement tools increased with increasing RSI as predicted by the linear regression equation, with a SEE of ±0.25 $m\cdot s^{-1}$ and the equation explaining 56% of the variance observed (Figure 5A). The CV values describing the concurrent validity between measurement tools for contact time and RSI were 13.70% and 26.20%, respectively (Table 1).

Correcting the gFlight measures of contact time and RSI using the linear regression equations: corrected DJ contact time = 0.9497 × raw gFlight contact time + 0.0458; and corrected DJ RSI = 0.4781 × raw gFlight RSI + 0.2994; reduced the significant systematic bias displayed between the two measurement tools for contact time (Mean: 0.00 ± 0.028 s, 95% CI: -0.008 to 0.008 s, $d<0.001$, $P=0.99$) and RSI (Mean: 0.00 ± 0.25 $m\cdot s^{-1}$, 95% CI: -0.07 to 0.07 $m\cdot s^{-1}$, $d<0.001$, $P=0.99$) (Table 2). The corrected gFlight measures of contact time (r = 0.83) and RSI (r = 0.75) demonstrated *very large* agreement with the force plate, with the linear regression equations displaying a *nearly perfect* relationship for contact time ($y = 1x + 8{\times}10^{-7}$; Figure 4B) and RSI ($y = 0.9999x + 1{\times}10^{-5}$; Figure 5B).

Table 1 – Concurrent validity between the gFlight and force plate for the measurement of all dependent variables during the Countermovement Jump (CMJ) and the Drop Jump (DJ). Data presented as Mean ± Standard Deviation.

Jump	Variable	gFlight (95% CI)	Force plate (95% CI)	Systematic Bias (95% CI)	CV%	Effect size (*d*)	Inference
CMJ	**Height (cm)**	39.16 ± 7.34 (37.20 to 41.12)	30.37 ± 6.73 (28.58 to 32.16)	+8.79 ± 4.16* (7.68 to 9.90)	13.60%	1.25	Large
DJ	**Height (cm)**	26.62 ± 6.31 (24.93 to 28.30)	21.94 ± 4.94 (20.62 to 23.26)	+4.68 ± 3.57* (3.73 to 5.63)	13.40%	0.83	Moderate
	Contact Time (s)	0.194 ± 0.045 (0.182 to 0.206)	0.230 ± 0.051 (0.217 to 0.244)	-0.036 ± 0.028* (-0.044 to -0.029)	13.70%	-0.75	Moderate
	RSI ($m \cdot s^{-1}$)	1.49 ± 0.58 (1.33 to 1.64)	1.01 ± 0.37 (0.91 to 1.11)	+0.48 ± 0.39* (0.37 to 0.58)	26.20%	0.97	Moderate

CMJ; Countermovement Jump, DJ; Drop Jump, 95% CI; 95% Confidence Interval, CV; Coefficient of Variation, RSI; Reactive Strength Index

*Significant bias displayed by the gFlight measure compared to the force plate measure ($P<0.001$).

Table 2 - Concurrent validity between the force plate and the corrected gFlight measures using the respective linear regression equations for all dependent variables during the Countermovement Jump (CMJ) and the Drop Jump (DJ). Data presented as Mean ± Standard Deviation.

Jump	Variable	Corrected gFlight (95% CI)	Force plate (95% CI)	Systematic Bias (95% CI)	CV%	Effect size (*d*)	Inference
CMJ	**Height (cm)**	30.37 ± 5.57 (28.88 to 31.86)	30.37 ± 6.73 (28.58 to 32.16)	0.00 ± 3.77 (-1.00 to 1.01)	13.60%	<0.001	Trivial
DJ	**Height (cm)**	21.94 ± 4.09 (20.85 to 23.03)	21.94 ± 4.94 (20.62 to 23.26)	0.00 ± 2.78 (-0.74 to 0.74)	13.50%	<0.001	Trivial
	Contact Time (s)	0.230 ± 0.042 (0.219 to 0.242)	0.230 ± 0.051 (0.217 to 0.244)	0.00 ± 0.028 (-0.008 to 0.008)	13.50%	<0.001	Trivial
	RSI ($m \cdot s^{-1}$)	1.01 ± 0.28 (0.94 to 1.09)	1.01 ± 0.37 (0.91 to 1.11)	0.00 ± 0.25 (-0.07 to 0.07)	26.20%	<0.001	Trivial

CMJ; Countermovement Jump, DJ; Drop Jump, 95% CI; 95% Confidence Interval, CV; Coefficient of Variation, RSI; Reactive Strength Index

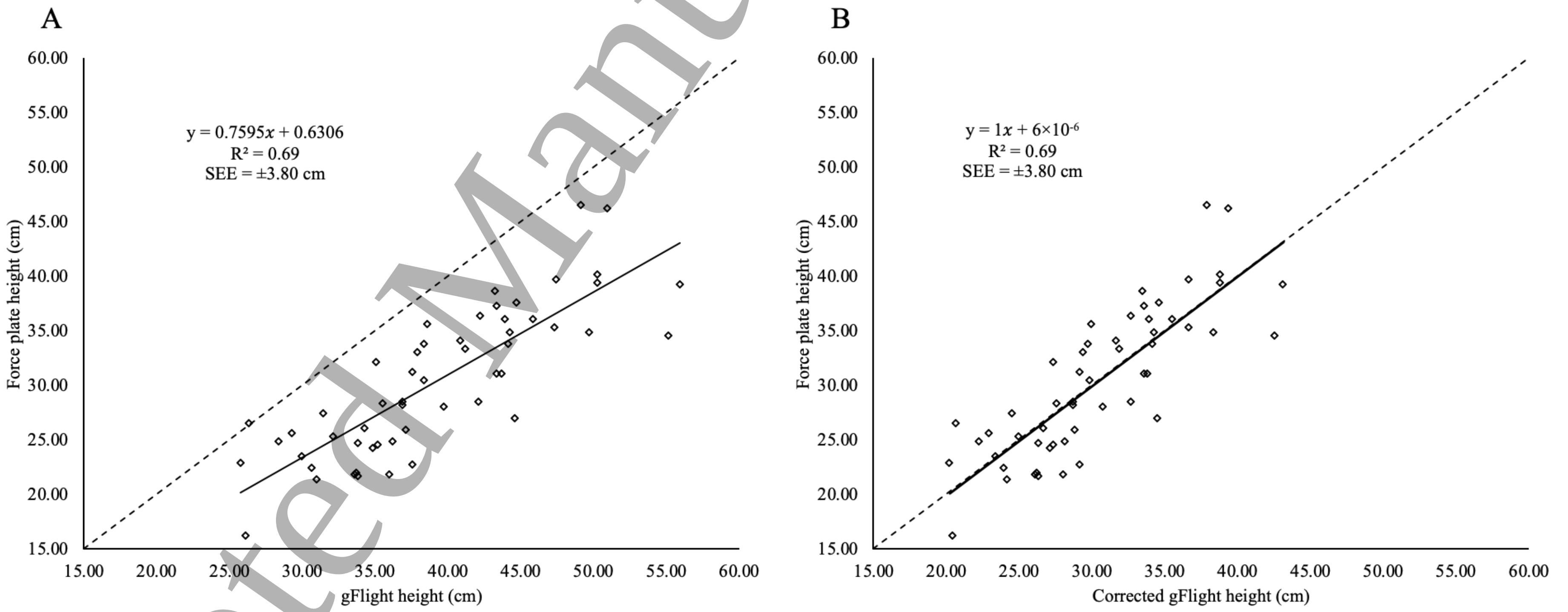

Figure 2 – Panel A: Correlation between the measurement of jump height from the force plate and gFlight sensors during the countermovement jump. The dotted line represents the line of identity (force plate height = gFlight height). The solid line shows the linear regression fit of the two measurement tools with the associated regression equation, coefficient of determination (R^2), and standard error of estimate (SEE). **Panel B:** Correlation between the measurement of jump height from the force plate and gFlight sensors after correcting trials using the regression equation (corrected countermovement jump height = 0.7595 × raw gFlight jump height + 0.6306), during the countermovement jump. The dotted line represents the line of identity (force plate height = corrected gFlight height). The solid line shows the linear regression fit of the two measurement tools with the associated regression equation, coefficient of determination (R^2), and standard error of estimate (SEE).

Data points represent the average jump height values taken from the three trials performed by each participant.

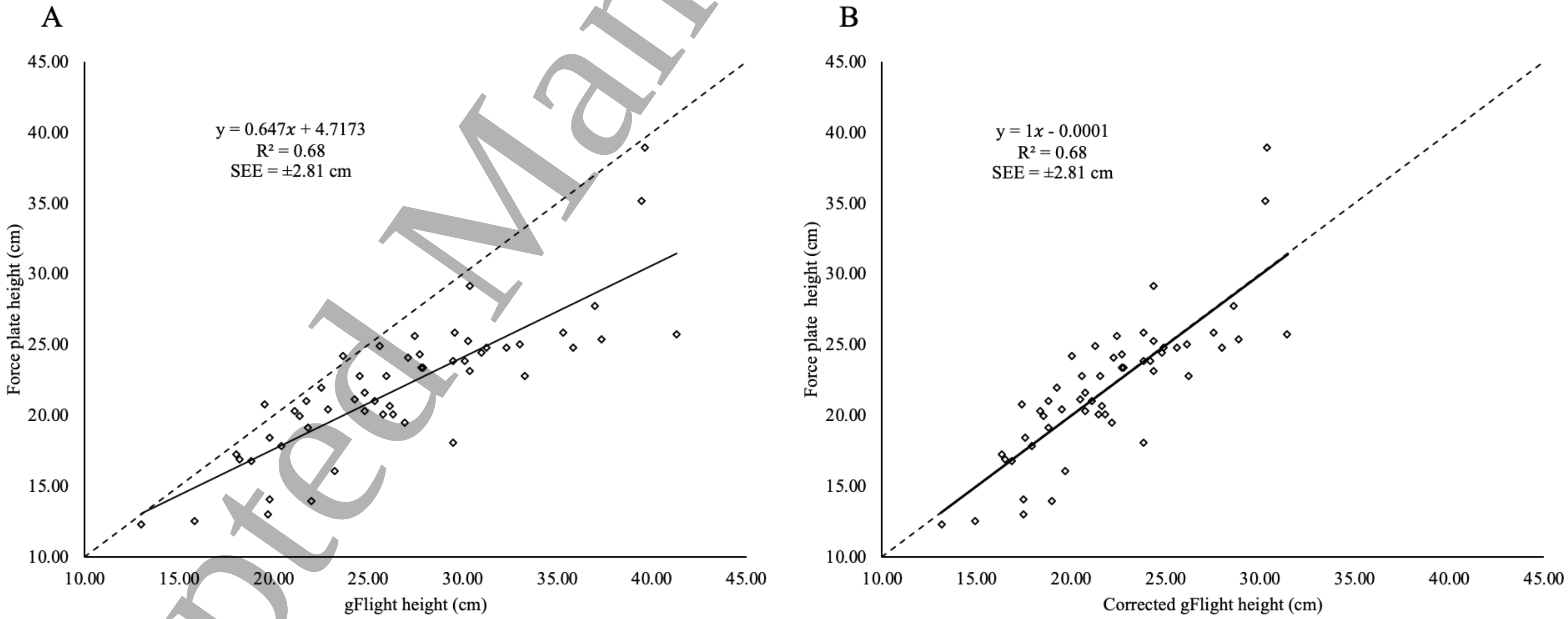

Figure 3 – Panel A: Correlation between the measurement of jump height from the force plate and gFlight sensors during the drop jump. The dotted line represents the line of identity (force plate height = gFlight height). The solid line shows the linear regression fit of the two measurement tools with the associated regression equation, coefficient of determination (R^2), and standard error of estimate (SEE). **Panel B:** Correlation between the measurement of jump height from the force plate and gFlight sensors after correcting trials using the regression equation (corrected drop jump height = 0.647 × raw gFlight jump height + 4.7173), during the drop jump. The dotted line represents the line of identity (force plate height = corrected gFlight height). The solid line shows the linear regression fit of the two measurement tools with the associated regression equation, coefficient of determination (R^2), and standard error of estimate (SEE). Data points represent the average jump height values taken from the three trials performed by each participant.

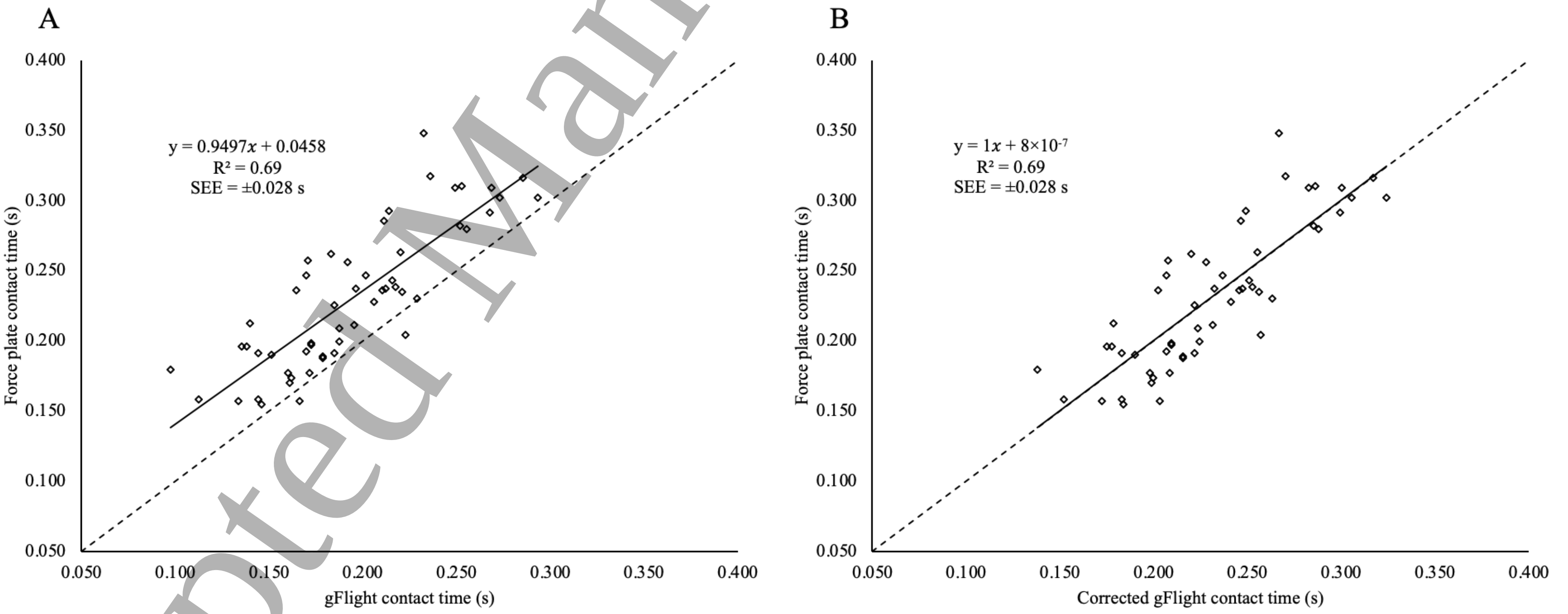

Figure 4 – Panel A: Correlation between the measurement of contact time from the force plate and gFlight sensors during the drop jump. The dotted line represents the line of identity (force plate contact time = gFlight contact time). The solid line shows the linear regression fit of the two measurement tools with the associated regression equation, coefficient of determination (R^2), and standard error of estimate (SEE). **Panel B:** Correlation between the measurement of contact time from the force plate and gFlight sensors after correcting trials using the regression equation (corrected drop jump contact time = 0.9497 × raw gFlight contact time + 0.0458), during the drop jump. The dotted line represents the line of identity (force plate contact time = corrected gFlight contact time). The solid line shows the linear regression fit of the two measurement tools with the associated regression equation, coefficient of determination (R^2), and standard error of estimate (SEE).

Data points represent the average contact time values taken from the three trials performed by each participant.

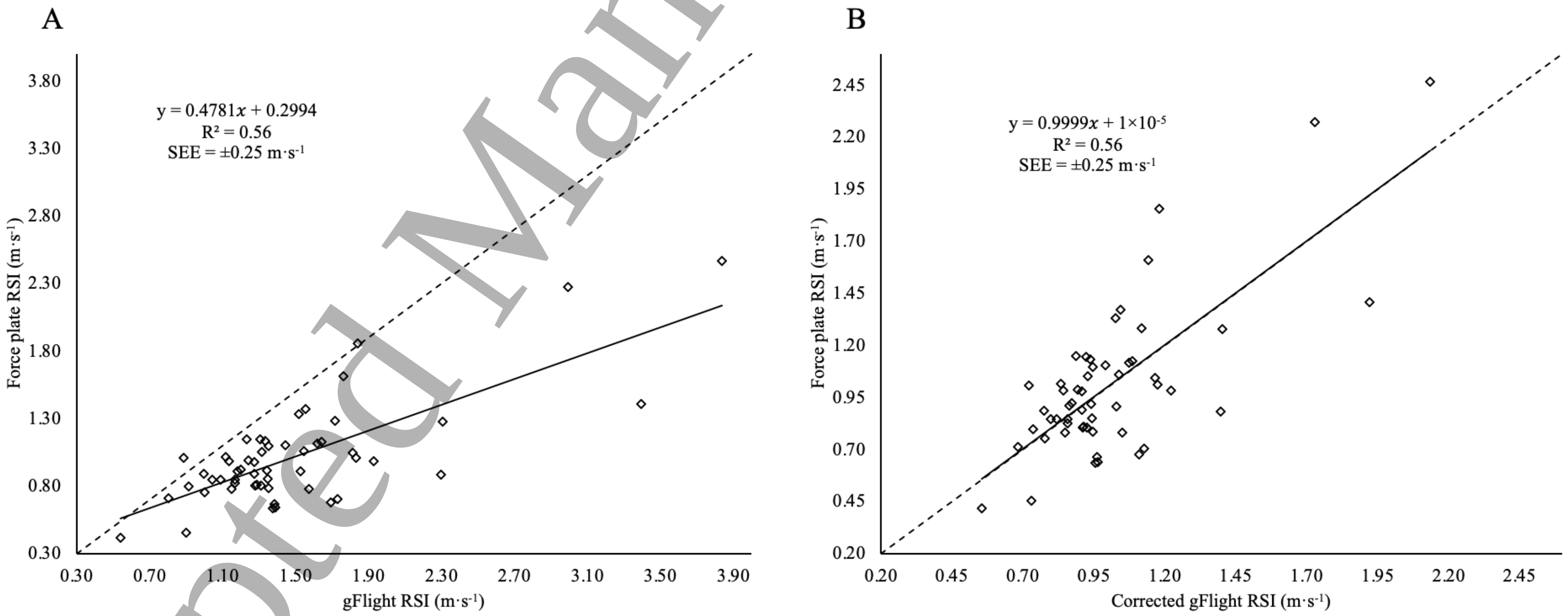

Figure 5 – Panel A: Correlation between the measurement of reactive strength index (RSI) from the force plate and gFlight sensors during the drop jump. The dotted line represents the line of identity (force plate RSI = gFlight RSI). The solid line shows the linear regression fit of the two measurement tools with the associated regression equation, coefficient of determination (R^2), and standard error of estimate (SEE). **Panel B:** Correlation between the measurement of RSI from the force plate and gFlight sensors after correcting trials using the regression equation (corrected drop jump RSI = 0.4781 × raw gFlight RSI + 0.2994), during the drop jump. The dotted line represents the line of identity (force plate RSI = corrected gFlight RSI). The solid line shows the linear regression fit of the two measurement tools with the associated regression equation, coefficient of determination (R^2), and standard error of estimate (SEE).
Data points represent the average RSI values taken from the three trials performed by each participant.

Discussion

The aim of this study was to evaluate the concurrent validity of the gFlight sensors in comparison to a force plate to measure JH, CT and RSI during a countermovement jump and drop jump. This is the first study to evaluate the novel gFlight system to a 'gold standard' criterion force plate, providing practical information pertaining to the validity of the gFlight sensors for use in applied settings. The major findings from this study were that the gFlight system demonstrated strong concurrent validity compared to the force plate for all measures during the CMJ and DJ. Despite this, a significant systematic bias was displayed between the two measurement tools, as the gFlight provided higher measures of JH and RSI during the countermovement jump and drop jump, respectively, with the observed bias increasing with increasing JH and RSI. Similarly, measurements of CT provided by the gFlight were systematically lower than those provided by the force plate, however the bias observed was consistent irrespective of the contact time measurement. Nevertheless, the gFlight demonstrated *very large* agreement for all measures (r values ranging between 0.75 to 0.83) between the gFlight and force plate. The use of corrective equations derived from the linear regression equations reduced the systematic bias observed between measurement tools for all measures, thereby making this a potentially valid measurement tool to use within applied settings.

The higher systematic bias observed between the gFlight and force plate for the measurement of jump height contrasts previous research evaluating the validity of similar systems using photoelectric cells (Optojump) to estimate JH, from the measurement of flight time. Differences between measures of jump height using the Optojump are consistently reported to be systematically lower than force plate measures of JH, typically attributed to the photoelectric cells being raised off of the ground leading to lower measures of flight time and in turn JH (6,18,25). The measurement of flight time from photoelectric cell devices is dependent upon the detection of take-off and landing (6,25). The detection area of the gFlight system is relatively small in comparison to the Optojump, therefore any horizontal displacement exhibited during the flight phase of a jump might affect the measurement of flight time due to the landing location being different to the take-off location (18). The smaller detection area of the gFlight might therefore overestimate flight time due to differences in the detection of take-off and landing, and in turn the JH measure. In comparison, the Optojump system has a larger detection area, therefore any horizontal displacement exhibited during the flight phase of a jump will not affect the JH measure provided. This difference in the size of the detection area perhaps explains the contrasting biases observed compared to the force plate for the measurement of JH. Another field-based alternative to measure JH via flight time is a smartphone application, that reportedly provides a measure of JH similar to that provided by a force plate (mean bias = 0.9 ± 0.2 cm) (17). Although the reported bias is lower than that shown here for the gFlight, the smartphone application relies on the user filming the jump trial at a suitable frame rate along with correctly identifying the take-off and landing frames for the calculation of flight time and hence JH (17). The additional input required when using the smartphone application in comparison to the gFlight might reduce the systematic bias observed, however the gFlight offers a method to measure JH instantly without additional input, along with the presented corrective equations reducing the bias. Similarly, another alternative to force plates is the use of an accelerometer to measure JH via flight time, with the reported mean bias (3.6 ± 0.1 cm) also less than the gFlight (25). The use of the accelerometer however requires specific and consistent placement on the participant for reliable JH measurements, along with specialist software to analyse the data. Furthermore, despite the accelerometer being a more cost-effective option than force plates, the price is still relatively higher than the gFlight system (26). When compared to other field-based alternatives for the measurement of JH, the gFlight demonstrates a higher systematic bias for the measurement of JH during both CMJ and DJ modalities (8,17,25,26). Nevertheless, the portability, low cost and accessibility might appeal to applied practitioners and researchers despite the greater systematic bias demonstrated compared to other field-based alternatives. With this in mind, the use of corrective equations presented herein can improve the validity of the gFlight system. The present findings show the corrective equations for CMJ JH (corrected CMJ height = 0.7595 × raw gFlight JH + 0.6306) and DJ JH (corrected DJ height = 0.647 × raw gFlight JH + 4.7173) lead to the *large* (CMJ JH: +8.79 ± 4.16 cm, $d = 1.25$) and *moderate* (DJ JH: +4.68 ± 3.57 cm, $d = 0.83$) systematic biases to be reduced to *trivial* (CMJ JH: 0.00 ± 3.77, $d = <0.001$; DJ JH: 0.00 ± 2.78 cm, $d = <0.001$) biases, effectively reducing the difference demonstrated between the force plate and gFlight. The gFlight sensors can therefore be considered valid measures of JH in both the CMJ and DJ with the use of the proposed corrective equations, which have been derived from a population of varied athletic ability.

The current study sought to evaluate measures of contact time and reactive strength index (RSI) provided by the gFlight during a DJ, as this information is relevant to practitioners attempting to assess the reactive stretch shortening cycle abilities (SSC) of the athletes they support (1,5,7). The RSI provides a measure of an athletes' ability to develop maximal force in minimal time through the utilisation of the fast SSC, derived from the measurement of jump height divided by the ground contact time (7). The SSC consists of an eccentric muscle contraction immediately followed by a concentric muscle contraction, with a shorter time between these phases facilitating a greater ability to generate force due the ability to utilise the SSC (1,7). The gFlight sensors provided systematically lower and higher measures of CT and RSI, respectively compared to the force plate. As RSI is calculated from jump height and contact time (7,20), the higher JH and lower CT measures provided by the gFlight result in the higher reactive strength index demonstrated in comparison to the force plate. The validity of CT and RSI measures from field-based measurement tools during a DJ is limited, as previous research has focussed primarily on vertical jumping tasks such as the CMJ or squat jump (3,6,11,13,17). The few studies that have evaluated measures of CT and RSI provided by field-based devices have reported varied findings; with lower measures of CT provided by the *MyJump 2* application (27) and the MyoTest accelerometer (28), and higher measures of CT provided by the Optojump (20,29) in comparison to force plate measures. Similarly, measures of RSI have been reported to be lower for the Optojump (20), similar for the MyoTest accelerometer (28), and higher for the *MyJump 2* application in comparison to force plate measures. The different measures of contact time and RSI provided by these various measurement tools are most likely attributed to the different methods of detection along with the study design. Such differences include the use of photoelectric systems, video recordings, linear position transducers, and accelerometers all of which use various methods to determine CT and RSI. Furthermore, measures of CT and RSI have been from hopping tasks rather than a drop jump (28), and various drop heights implemented for the DJ task (20,27,29). The differences in contact time and RSI measures provided by the gFlight system in comparison to the force plate are not dissimilar from the differences demonstrated by the aforementioned field-based alternatives. When compared to the reported differences in CT and RSI demonstrated by the Optojump (due to this system also utilising photoelectric cells), the gFlight does provide higher RSI measures and lower CT measures. This is most likely due to the size of the detection area, as previously explained. Nevertheless, in comparison to other field-based alternatives, the gFlight sensors offer a portable, time efficient and cost-effective option for applied practitioners and researchers alike to obtain objective measures of DJ performance. To allow comparisons of contact time and RSI measures to be made between the gFlight and force plate, the corrective equations presented in this study (corrected DJ contact time = 0.9497 × raw gFlight contact time + 0.0458; corrected DJ RSI = 0.4781 × raw gFlight RSI + 0.2994) can be used to reduce the systematic bias observed between the measurement tools. These equations can therefore be used to provide valid measures of CT and RSI in applied settings that have been derived from the gFlight sensors.

Limitations

The measurements of jump height, contact time, and reactive strength index provided by the gFlight in this study can be considered acceptable and valid when compared to the differences demonstrated by other validated field-based alternatives. The evaluation of the gFlight sensors, however, does not come without its limitations. The high coefficient of variation (CV) values reported (13.50 – 26.20%) are considered to be unacceptable according to previous studies reporting CV values <10% to be acceptable for biomechanical variables (30,31). The high variability observed in this study is most likely attributed to the mixed athletic ability of the participants, as demonstrated by the large range of scores for jump height (CMJ: 25.76 to 55.94 cm; DJ: 12.96 to 41.27 cm), contact time (0.097 to 0.293), and reactive strength index (0.54 to 3.84 $m \cdot s^{-1}$) measured by the gFlight sensors. It is also acknowledged that horizontal displacement can vary between participants when performing jumps, which combined with the small detection area of the gFlight sensors could potentially contribute further to the observed measurement variability, however this was not measured. Furthermore, this variability might have been present during participants perceived maximum effort warm-up trials, however, these jumps were not measured which is a possible limitation. Whilst we acknowledge the CV values can be considered unacceptable, the mixed athletic ability of the sample population allows the concurrent validity of the gFlight sensors to be tested across a wide range of jump heights. A further limitation lies in the familiarity of the participants to perform the jump protocols. Despite familiarisation and instruction, there might still be inherent learning effects, especially for the performance of the DJ protocol for participants that do not perform such activities regularly, therefore contributing to the large variation observed. In addition, it is worth mentioning the number of trials where incomplete data was provided by the gFlight when participants performed their jumps. Of the 324 trials performed, the gFlight provided incomplete data on 6 occasions (1.85%), however, this low rate had no significant impact upon the ability to complete the tests and the subsequent data analyses. It is suggested future research examining the validity of the gFlight sensors should focus on populations in which jumping activities are performed regularly, such as basketball, volleyball and netball. Such research would therefore be able to evaluate if the systematic bias and variation observed in a mixed population is evident in trained athletic populations, along with if the corrective equations presented herein are applicable to these populations.

Conclusion

This study evaluated the concurrent validity of the novel gFlight sensors to provide measures of jump height, contact time, and reactive strength index during a CMJ and DJ in comparison to those provided by a 'gold standard' force plate. The gFlight sensors provided valid measures of the dependent variables in both jump modalities, however systematic biases were demonstrated. The use of corrective equations should be used to reduce these biases and allow valid comparisons to be made to force plate measures of JH, CT and RSI during countermovement jump and drop jump tasks. The gFlight sensors can therefore be considered a cost-effective, portable measurement system with high concurrent and ecological validity for the objective measurement of jump performance in applied settings.

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