VALIDITY OF STRIDE LENGTH ESTIMATES OBTAINED FROM OPTOJUMP

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The purpose of the present study was to ascertain the validity of stride length estimates obtained from OptoJump (Microgate, Bolzano, Italy) using displacement data derived from three-dimensional videography as criterion. One subject repeatedly ran through a 4 m section of OptoJump to obtain real-time stride length estimates. Corresponding criterion stride length estimates were also obtained from the displacement data derived from video. 95% limits of agreement were applied to the 56 pairs of measurements revealing an error interval of 4.2 ± 23.1 mm. We concluded that stride length estimates obtained from OptoJump lacked sufficient validity for use in motor control studies. However, the capability of this system to acquire other relevant data in real-time, provides sufficient scope to suggest pursuing the development of this system.

KEY WORDS: OptoJump, validity, stride length, three-dimensional videography

INTRODUCTION: OptoJump (Microgate, Bolzano, Italy) is a new optical measurement system designed to measure contact and flight times with an accuracy of 1/1000 s during the performance of a series of jumps. The system consists of a series of transmitter and receiver units (known as “springboards”) which can be placed up to 3 m apart and parallel to each another. Each 1 m transmitter unit contains 32 light emitting diodes (LEDs) which are positioned 3 mm from ground level at 31.115 mm intervals. The “walkjump” acquisition facility in the OptoJump 3.0 software displays real-time step length, speed and acceleration calculations for each individual stride during a running trial.
The uniqueness of this system to display step-by-step stride length estimates in real-time also increases its potential appeal to motor control theorists when evaluating gait regulation during the approach run phase of sports activities. To date, a variety of procedures have been used within their limitations. Montagne *et al.* (2000) simply measured the distance between each footfall imprint left on a cinder track and the take-off board in their exploration of a perception-action type coupling in long jumping. However, photogrammetric techniques are more common. Both two-dimensional stationary (e.g. Hay, 1988) and panning (e.g. Lee *et al.,* 1982) camera techniques have been employed. Chow (1987) developed a commonly used procedure for the analysis of selected kinematics of running. Although the author recommended it as a suitable determinant of stride length, this method does not have high accuracy (Challis *et al.,* 1997). Sources of errors in measurement using these photogrammetric techniques include the relatively small size of the digitised image, the variable size of the digitised image when panning cameras are used and random error contaminates from manual digitising. Furthermore, the requirement of manual digitisation in photogrammetric techniques drastically increases the amount of processing time required.
The purpose of the present study was to ascertain the validity of stride length estimates produced by OptoJump. Three-dimensional video analysis provided criterion evidence as literature reports that it has an accuracy of within 10 mm (Yeadon, 1992). Providing that the estimates obtained from OptoJump agree to within acceptable levels of the criterion measure, this device would be deemed valid, thus fulfilling it’s potential as an accurate and reliable stride length estimator during running.

METHOD:
Participant: One healthy male (age = 22 yrs; mass = 92.6 kg; stature = 1.81 m) volunteered to act as a subject in this study. A full explanation of the purpose of the study as well as the experimental procedures was provided before testing commenced. The participant’s task was to repeatedly run through a 4 m section of OptoJump in order to obtain stride length estimates.

Data Collection: Two 3-CCD Sony DSR-PD100AP digital camcorders were mounted upon stationary Manfrotto 117 rigid tripods to record each trial for digitising purposes. Both cameras were fitted with 4.3 to 51.6 mm zoom lenses and were mounted at heights of 1.10 m (measured using a plumbline) to satisfy the conditions of colinearity and coplanarity required for three-dimensional videography (Allard *et al.,* 1995). Both were operating at 50 fields per second with shutter speeds of 1/300 s. The optical axis of each camera converged over the running lane at approximately 10° and the focal length was adjusted to encompass a 5 m field of view. Both were placed 11 m from the mid-line of the running lane with distance between the cameras set at 2 m. This is a similar equipment configuration to that reported by Yeadon *et al.* (1999) in their study of the accuracy of running speed measured using photocells. The two cameras were placed together to increase the accuracy of displacement estimates in the direction of the run at the expense of the accuracy in the lateral direction (Yeadon *et al.,* 1999).
Two cameras were used to permit a three-dimensional analysis, since a planar analysis is prone to parallax or perspective error when points lie outside the calibration plane (Doolittle, 1971). To obtain data for calibrating the cameras using a direct linear transformation (DLT), a calibration pole containing three spherical markers was filmed sequentially in six locations surrounding the area of performance.

Data Processing: All video images were manually digitised using an Apex Imager 24 bit colour image capture board (Millipede Electronic Graphics, Bury St Edmunds, Suffolk, UK) in an Archimedes 410 microcomputer running Target software (Loughborough University of Technology, Loughborough, Leics, UK). An interfaced Panasonic AG-7350 sVHS video-cassette recorder was used to capture each trial in real time to the image capture board to avoid inaccuracies caused by geometric image distortion. The Apex Imager video frame store had a resolution of 768 pixels horizontally and 576 pixels vertically but the measurement resolution was increased to 12288 horizontally to 9216 vertically with the implementation of a sub-pixel cursor (Kerwin, 1995). A high-resolution Sony PVM-14M4E colour video monitor was used to view all video sequences.
Each of the 18 calibration markers was digitised in five consecutive fields for each camera view. The digitised calibration coordinates were then used to calculate the 12 camera parameters for each camera using a DLT procedure with a correction for radial lens distortion (Karara, 1980). For each running trial, the distal end of the support foot was digitised on the first field where full foot contact was observable. The two sets of comparator coordinates obtained from digitising from each view were then transformed to object-space coordinates using a DLT algorithm. The difference in horizontal location of the distal end of the running shoe for two sequential foot placements was then used to estimate stride length. Corresponding stride length estimates were also obtained from the OptoJump 3.0 software.
The reliability of criterion stride length estimates was also evaluated by repeatedly digitising two consecutive foot placements. The mean and the standard deviation of the stride length estimates was then used to calculate the coefficient of variation (%CV; equation 1).

$$\%CV = (\sigma / \bar{x})\ 100 \qquad (1)$$

where σ = standard deviation of the repeated stride length estimates
$\bar{x}$ = mean of the repeated stride length estimates

Data Analysis: 95% limits of agreement (equation 2; Bland and Altman, 1986) were employed to assess the validity of stride lengths obtained from OptoJump.

$$\text{Boundaries of Agreement} = \delta \pm 1.96\sigma \qquad (2)$$

where δ = mean of the differences between data sets
σ = standard deviation of differences between data sets

In total, 56 pairs of stride length estimates were obtained, exceeding the minimum recommended sample size ($n > 40$) advocated by Altman (1991) in order to extrapolate the data to a given population. Normal distribution of the differences was verified by applying an Anderson-Darling Normality plot as implemented in MINITAB (Minitab Inc., 1995). A paired *t*-test was used to identify if systematic bias was statistically significant ($P = 0.05$). Heteroscedasticity was formally examined by plotting the absolute differences against individual means (Nevill and Atkinson, 1997). With objective criteria for interpreting the meaningfulness of the error interval unavailable, analytical goals were applied to identify whether the error interval was narrow enough for the measurements to be deemed valid (Atkinson and Nevill, 1998).

RESULTS & DISCUSSION: The DLT reconstruction error estimates for the calibration points were 8.4 mm in the direction of running, 13.1 mm laterally and 7.8 mm vertically, thus reflecting the intention to increase accuracy of displacement estimates in the direction of running at the expense of accuracy in the lateral direction. The %CV for the reliability of stride length estimates was approximately 0.26%. This means that one would expect the 'true value' (the average value obtained over many measurements) to lie within twice the coefficient of variation (Bland, 1995). Thus, the maximum amount of random error in criterion stride length estimates was approximately 0.52%. The differences were found to be normally distributed ($P = 0.167$). Fig. 1 graphically displays difference against mean (Bland-Altman plot) with precise 95% limits of agreement for the two sets of stride length estimates. A paired *t*-test proved that the systematic bias was statistically significant ($P < 0.05$). The existence of a non-significant ($P = 0.67$), negative correlation ($r = -0.06$) between absolute differences and individual means revealed no evidence of heteroscedasticity. The resulting error interval was thus calculated to be 4.1 ± 23.1 mm.

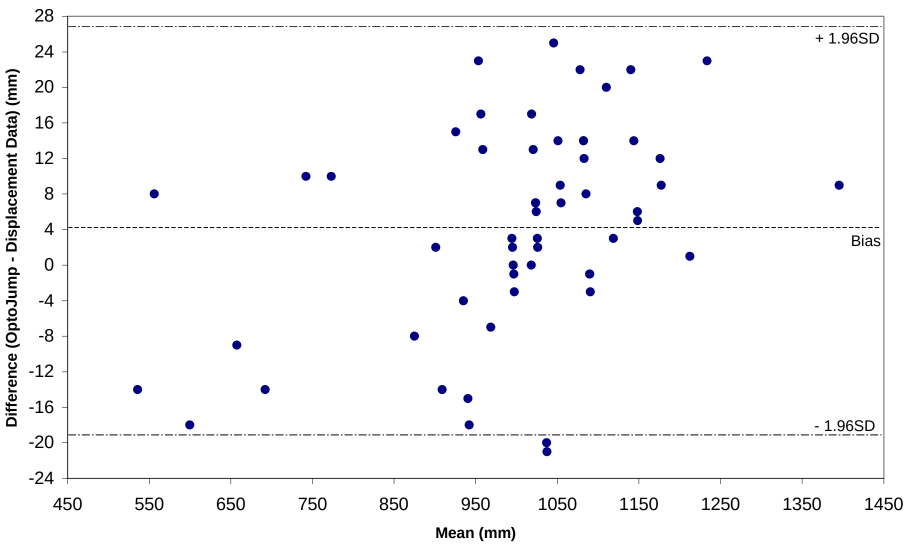

Fig. 1. A Bland-Altman plot with bias line and random error lines forming the 95% limits of agreement.

From these results, the maximum random error component could be as much as approximately 27 mm. Despite inevitable random error contaminates in the criterion measurement introduced by human intervention, we suggest that the amount of random error inherent in OptoJump displacement measurements as well as the possible accumulation over a number of strides may lead to erroneous conclusions in gait regulation studies. How this effects speed derivatives is unclear and warrants further investigation, but we suspect accurate speed measurements are largely dependent on temporal measurement resolution rather than highly accurate displacement data (the manufacturer claims temporal accuracy of ± 1.5 ms). The high temporal resolution of this system also benefits accurate calculation of contact and flight times, providing an insight into ground impulse characteristics. Moreover all of these variables are calculated in real-time, thus saving the laborious task of manual digitising and offering a provision for immediate data feedback to both coach and athlete.

CONCLUSION: To summarise, the amount of random error in stride length estimates obtained from OptoJump suggests insufficient validity in this measurement variable from a motor control perspective. However, the capability of this system to measure other variables relevant to biomechanical and motor control research in real-time, highlights the potential of this system as an effective measurement tool.

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