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RELIABILITY OF THE OPTOJUMP NEXT SYSTEM FOR MEASURING TEMPORAL VALUES IN ELITE RACEWALKING

Running head: Reliability of racewalking temporal measures

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ABSTRACT

Racewalking is an Olympic event where athletes are not permitted a visible loss of contact, with the result that competitors try to minimise flight times. The accuracy of measurements taken during testing is dependent on valid and reliable systems to determine temporal values. The aim of the study was to compare different methodologies used to measure contact and flight times in overground and treadmill racewalking. Eighteen racewalkers completed overground and instrumented treadmill trials at 5 speeds, during which flight and contact times were measured using the OptoJump Next photocell system (1000 Hz), high-speed videography (500 Hz), and force plates (1000 Hz). Results from OptoJump Next were extracted using 5 settings based on the number of light emitting diodes (LEDs) activated (GaitIn_GaitOut), and annotated as 0_0, 1_1, 2_2, 3_3 and 4_4. Regarding flight time measurements for the overground condition, the 2_2 LED setting had the best 95% confidence interval (95% CI) for Intraclass Correlation Coefficient (ICC) (0.978 – 0.988), the least bias (0.000 s), and the lowest random error (0.008 s). For the treadmill condition, the 0_0 LED setting had the best 95% CI for ICC (0.890 – 0.957), the least bias (0.004 s), and the lowest random error (0.017 s). Although high-speed videography also provided highly reliable results, the equally reliable and quicker availability of results using OptoJump Next is beneficial in laboratory-based testing. Coaches and researches are advised to alter the system’s LED settings as appropriate, and to report these settings with their findings.

Key words: biomechanics; force plate; testing; track and field; treadmill

INTRODUCTION

Racewalking is an Olympic event within the track and field program defined as a progression of steps so taken that no visible (to the human eye) loss of contact with the ground occurs, and the leg must be straightened from first contact with the ground until the “vertical upright position” (Rule 230.2) (16). Although loss of contact (or “flight time”) is judged by the naked eye during competition, measurements have been undertaken for research, athlete support, and judge education using several different methodologies. These include standard camcorders (14), high-speed videography (19-21), optoelectronic systems (7), force plates (13) and an inertial sensor (9). Previous research suggested that judges and coaches cannot reliably identify flight times lasting less than 40 ms (8,17), and this value has since been used as a guide to what constitutes legal racewalking in subsequent research (12). Given the importance of flight time measurements to racewalkers and their coaches (e.g., in comparing its duration between different phases of the training season), using a reliable system is critical in determining the actual duration of flight time.

One device that could be particularly useful in laboratory and field-based testing for measuring temporal variables is the OptoJump Next system. This system (its name is used interchangeably with “OptoGait”) is increasingly being used in gait research to measure spatiotemporal variables such as step length, step frequency and flight time (3). It works by placing transmitting and receiving bars (1 m long) apart and parallel to one another, either as a single pair (e.g., on a treadmill) or serially connected to create a longer data capture area for overground gait analysis (10). A series of light emitting diodes (LEDs) are used to detect the presence or absence of ground contact. Previous research has found strong agreement between the OptoJump Next system and force plates in jumping (11), and in some validity studies the measurements obtained using the OptoJump Next have been used as the measurement standard (6,10). However, because the OptoJump Next sensors are located 3 mm from the ground (4), it is possible that they are interrupted too early for accurate detection of heel strike, and too late for accurate detection of toe-off, leading to systematic bias (11). For this reason, it is possible to alter the number of LEDs that must be interrupted in the software before these gait events are identified. To our knowledge, alteration of this setting has not previously been reported.

Although there is no prescribed limit as to what constitutes loss of contact except as a subjective visible occurrence, the accurate measurement of racewalkers' flight times during laboratory testing is invaluable in reducing the risk of disqualification in competition. This applies to both overground and treadmill racewalking, as both are used in training and testing (12,13). The measurement of flight times during racewalking is therefore of great interest to coaches, athletes and judges, as well as researchers who are keen to improve external validity. However, it is crucial that the measurements taken are reliable so that the athlete is not misinformed about their flight time, leading to potential negative performance impacts. Establishing the reliability of the OptoJump Next system that is used in training and research will assist coaches when assessing their athletes' techniques. For strength and conditioning professionals, the ease of use (and transport) means the OptoJump Next system can be used within gymnasium-, laboratory-, field- and personal training-settings, and thus knowing the reliability of the OptoJump Next system (and what adjustments are available or might be necessary) is important for correct measurement of performance variables. Because this system (and force plates) cannot be used in competition, whereas non-invasive camcorders can, a concurrent evaluation of the reliability of measuring flight times using high-speed videography is also important. The aim of the study was to compare different methodologies used to measure contact and flight times in overground and treadmill racewalking.

METHODS

Experimental Approach to the Problem

In this study, values for temporal data found using the OptoJump Next system (5 different LED settings) and high-speed video were compared with measurement standard force plate conditions during overground and treadmill racewalking over a range of training and competitive speeds.

Subjects

Eighteen international racewalkers participated in the study, of whom 11 were men (age: 25.7 ± 4.1 years, height: 1.77 ± 0.06 m, mass: 64.4 ± 4.7 kg, 20 km personal record: 1:23:06 ± 2:26) and 7 were women (age: 25.9 ± 4.1 years, height: 1.68 ± 0.10 m, mass: 56.7 ± 11.0 kg, 20 km personal record: 1:30:14 ± 1:58). Fifteen of the athletes had competed at the 2016 Olympic Games and / or 2017 World Championships. The School Research Ethics Committee approved the details of the study including consent documentation and information to subjects before commencement. In accordance with the Institutional Review Board's policies for use of human subjects in research, all subjects were informed of the benefits and possible risks associated with participation before taking part and informed of their right to withdraw at any point. All subjects were over the age of 18 and gave written informed consent to indicate their voluntary participation.

Procedures

For the overground condition, the men race racewalked multiple times down a 45-m indoor track at 11, 12, 13, 14 and 15 km·h^{-1}, measured using Witty timing gates (Microgate, Bolzano, Italy) and in a randomized order, whereas the women's trials were at 10, 11, 12, 13 and 14 km·h^{-1}. Trials had to be within 3% of the target time to be included for analysis. Step, contact and flight times were measured for each trial using 3 adjacent 900 x 600 mm force plates (1000 Hz) (Kistler, Winterthur, Switzerland), 5 interconnected 1 m strips of an OptoJump Next system (1000 Hz; 96 LEDs per 1 m) (Microgate, Bolzano, Italy) and a high-speed camera (500 Hz) (Fastec Imaging, San Diego, CA, USA). The force plates were placed in a customized housing in the center of the track and covered with a synthetic athletic surface so that the force plate area was flush with the OptoJump Next strips that ran parallel to it. The camera was placed 4.00 m from the running track, with its lens at a height of 0.62 m and perpendicular to the center of the middle force plate. The shutter speed was 1/2000 s and the *f*-stop was 2.0. The resolution of the camera was 1280 x 960 px, and a 25-mm fixed lens was used. Extra illumination was provided by 26 overhead lights (4 kW each).

For the treadmill condition (conducted on a separate day), each subject racewalked on an instrumented Gaitway treadmill (h/p/Cosmos, Traunstein, Germany) at 5 speeds for 3 min each. The speeds chosen were the same as during the overground condition and were conducted in a randomized order after a 10-min warm-up and familiarization period (18). The treadmill's inclination was set at 0% during data collection (1,24) to match the overground condition, and because racewalking events are held on flat, even surfaces. The treadmill incorporated 2 in-dwelling piezoelectric force plates (Kistler, Winterthur, Switzerland) that recorded vertical ground reaction forces (GRF) (1000 Hz) from both feet. Data were collected for 30 s toward the end of each speed condition.

Two-dimensional video data were simultaneously collected at 500 Hz using the same high-speed camera as for the overground condition. The camera was placed 1.60 m from the center of the treadmill, at a height of 0.62 m and perpendicular to it; the settings were the same as for the overground testing described above. Extra illumination was provided by 4 lights (750

W each) placed to the sides of the camera. Data were also collected simultaneously using two 1-m OptoJump Next strips (1000 Hz) placed on opposite sides of the treadmill, and which were flush with the treadmill belt. All 3 systems (in both overground and treadmill conditions) were simultaneously activated using the same triggering device (National Instruments, Austin, TX, USA).

The GRF data from the force plates were analyzed using Bioware version 5.3.0.7 (Kistler, Winterthur, Switzerland) and were smoothed using a recursive second-order, low-pass Butterworth filter (zero phase-lag). The optimal cut-off frequency was calculated for each individual force trace using residual analysis (25). The results showed a mean optimal cut-off frequency of 47.8 Hz (± 2.1). For the treadmill GRF data (which were exported from the Gaitway software), the mean optimal cut-off frequency was 43.7 Hz (± 2.8). For both systems, the mean and standard deviation (SD) of the noise occurring during the final 50 ms before ground contact (visual inspection) were calculated, and initial contact was considered to begin when the vertical force magnitude was greater than the mean plus 3 SD of the noise (2). The mean and 3 SD of the noise during the first 50 ms after toe-off were used in a similar way to identify the end of contact and the beginning of flight.

Results from the OptoJump Next system were extracted using 5 different settings based on the number of LEDs that formed the baseline (GaitIn_GaitOut), and were thus annotated as 0_0, 1_1, 2_2, 3_3 and 4_4. For example, the setting of 0_0 meant that contact time was considered to begin once more than 0 LEDs were activated (i.e., when at least 1 LED was activated), and finished once the number of LEDs activated returned to 0. The minimum threshold for flight time was set at 0.001 s when exporting the data; we set this value upon noticing that the default threshold (10 ms) prevented the detection of very short flight times at slower racewalking speeds. The high-speed videos were analyzed for temporal values using SIMI Motion 9.2.2 (SIMI Motion, Munich, Germany). For all systems, contact time was defined as the time duration from initial contact to toe-off, whereas flight time was the time duration from toe-off of one foot to the initial contact of the opposite foot (22); step time was calculated as the sum of contact and flight time.

Statistical Analyses

All statistical analyses were conducted using SPSS Statistics 24 (IBM SPSS, Inc., Chicago, IL, USA). The force plate measurements were considered the measurement standard for their respective conditions (overground and treadmill) (6) and reliability was assessed using intraclass correlation coefficient (ICC) (including 95% confidence intervals), and 95% limits of agreement (LOA) (bias and random error). The data for each tested variable were assessed for heteroscedasticity (5). The root mean square difference (RMSD) was also found between the force plate measurements and those obtained from the other conditions.

RESULTS

The values for step time, contact time and flight time using the force plate, high-speed camera and OptoJump Next (all 5 settings) are shown in Table 1.

*** Table 1 about here ***

Table 2 shows the reliability results found when comparing the measurement standard force plate data with the video and OptoJump Next data for the overground testing condition, whereas Table 3 shows the reliability results for the treadmill condition. There was no heteroscedasticity found for either testing condition.

*** Table 2 about here ***

*** Table 3 about here ***

DISCUSSION

The aim of the study was to compare different methodologies used to measure contact and flight times in racewalking. The total step time measured by each system did not differ between measurement systems or OptoJump Next LED settings for both overground and treadmill conditions (Table 1); instead, what did differ was the proportion contributed by contact time and flight time. In general, the duration of contact time reported by OptoJump Next decreased with more LEDs activated, with a concurrent increase in flight time. The consistent values found for step time suggest that calculations of other key spatiotemporal variables, such as step frequency, are accurate regardless of LED settings.

For the overground condition, the 2_2 setting on OptoJump Next had the smallest RMSD and bias, as well as the highest ICC values. The 2_2 LED setting was also slightly better than high-speed video, although random error was the same. Using the default LED setting of 0_0 resulted in a bias of –0.011 s for contact time and a corresponding bias of 0.010 s for flight time, and a much larger confidence interval. Although such systematic errors in gait analysis might not be detrimental for running research, they represent a considerable offset in racewalking where accurately measuring flight time at competitive speeds in training or sport science support is important in evaluating the likelihood of visibly losing contact. Altering the number of LEDs activated thus allows the researcher to obtain accurate results and precludes the need for corrective equations (11). The results for the high-speed video were also excellent overall, with very little bias; however, the frame rate used (500 Hz) was higher than that available for many consumer camcorders and racewalk coaches should be wary of relying too much on devices with lower sampling rates (< 200 Hz) and lower precision as a result. In competition settings, such videography systems are the only viable option; however, outside of such situations, the OptoJump Next system provides a quick and accurate method of measuring temporal variables.

With regard to the treadmill protocol, the default setting of 0_0 on OptoJump Next provided the smallest RMSD, bias and RE values for both contact and flight time. The high-speed video condition also gave very reliable results, with values very close to OptoJump Next. However, as with the overground condition, using video to extract contact and flight times was a laborious process, and more prone to subjective errors by the operator (repeated analysis of the same file by the same operator resulted in identification of the same initial contact and toe-off frames to within 0.002 s, i.e., 1 frame). The slightly larger differences between the force plate and other systems for the treadmill condition compared with overground could reflect the differences previously found in overground vs. treadmill comparisons (23), and might have contributed to the different optimal LED setting.

One useful feature of OptoJump Next when training on a treadmill is its “Biofeedback” functionality (15); this is where the software displays real-time measures of spatiotemporal variables, such as flight time in racewalking. Using the default LED setting of 0_0 is therefore crucial for obtaining accurate feedback; what is also essential is to consider other settings, in particular the minimum flight time setting. The default during running tests is 10 ms, which might be too long in cases where racewalkers have shorter flight times (there is no specific “racewalking test” included as part of the OptoJump Next software), or during very slow running tests. As with other devices used in biomechanics, OptoJump Next users should therefore become fully familiar with the system’s settings to ensure they achieve the accurate and reliable results of which it is capable.

PRACTICAL APPLICATIONS

The OptoJump Next system provided highly reliable values for contact and flight times in elite racewalkers in overground and treadmill testing. High-speed videography also provided highly reliable results (a benefit in competition), although its more time-consuming nature suggests OptoJump Next is more suitable for quick analysis and instant feedback. This study showed that the default LED setting of 0_0 was suitable for treadmill testing, but a 2_2 setting was more reliable for overground testing. We also found that lowering the threshold for flight time detection from 10 ms to a lower value was important to avoid invalid recordings. We recommend that users of the OptoJump Next system (or the OptoGait system, which operates in the same way) consider setting the LED and temporal threshold appropriate for their research and report the settings used if contact and flight time measures are of particular importance. These users include strength and conditioning professionals who do not necessarily work with racewalkers, but for whom the OptoJump Next system allows them to measure performance variables such as jump height or step length. These users should also note the high reliability of this system, but also that adjustments might need to be made for more reliable results (particularly when the bars are placed on the ground). One benefit of the OptoJump Next software is that these settings can be changed after testing (e.g., the default settings can be used at the time and altered afterwards if invalid trials are discovered, as we did for the flight time threshold), but pre-planned alterations may be necessary when using the software’s biofeedback functionality.

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Table 1 Temporal values measured during the overground and treadmill conditions (mean ± SD). The mean step times do not always equate to the sum of the means of contact time and flight time as there were more contact than flight phases measured.

	Force plate	Video	0_0	1_1	2_2	3_3	4_4
			Overground				
Contact time (s)	.293 ± .034	.288 ± .034	.304 ± .034	.300 ± .034	.292 ± .034	.281 ± .033	.268 ± .032
Flight time (s)	.027 ± .016	.030 ± .016	.016 ± .014	.020 ± .015	.027 ± .015	.038 ± .015	.050 ± .015
Step time (s)	.321 ± .026	.320 ± .024	.321 ± .025	.321 ± .025	.320 ± .024	.320 ± .023	.320 ± .023
			Treadmill				
Contact time (s)	.272 ± .031	.275 ± .030	.276 ± .028	.264 ± .028	.251 ± .027	.240 ± .027	.230 ± .027
Flight time (s)	.044 ± .021	.041 ± .017	.040 ± .017	.052 ± .016	.065 ± .015	.075 ± .015	.086 ± .014
Step time (s)	.316 ± .020	.316 ± .018	.316 ± .018	.316 ± .018	.316 ± .018	.316 ± .018	.316 ± .018

Table 2 Measures of reliability for each overground condition; all values are in comparison with the force plate criterion values. All ICC results were *P* < 0.001.

	Video	0_0	1_1	2_2	3_3	4_4
Contact						
RMSD (s)	.007	.012	.009	.005	.014	.026
ICC	.990	.969	.984	.995	.958	.867
95% CI	.930 - .996	.105 - .993	.650 - .996	.993 - .996	.330 - .988	–.069 - .968
LOA bias (s)	.005	–.011	–.007	.000	.011	.024
LOA RE (s)	.010	.010	.010	.010	.015	.015
Flight						
RMSD (s)	.005	.011	.009	.004	.013	.025
ICC	.970	.856	.918	.984	.838	.552
95% CI	.783 - .990	–.122 - .959	.285 - .974	.978 - .988	–.123 - .952	–.117 - .848
LOA bias (s)	–.004	.010	.007	.000	–.011	–.024
LOA RE (s)	.008	.012	.011	.008	.014	.017

RMSD = root mean square difference; ICC = intraclass correlation coefficient; 95% CI = 95% confidence interval; LOA = limits of agreement; RE = random error.

Table 3 Measures of reliability for each treadmill condition; all values are in comparison with the force plate criterion values. All ICC results were $P < 0.001$.

	Video	0_0	1_1	2_2	3_3	4_4
Contact						
RMSD (s)	.012	.011	.013	.023	.034	.044
ICC	.962	.968	.953	.851	.726	.599
95% CI	.949 - .972	.946 - .979	.833 - .979	–.135- .958	–.139- .920	–.103 - .872
LOA bias (s)	–.003	–.004	.008	.020	.031	.042
LOA RE (s)	.022	.019	.020	.022	.026	.028
Flight						
RMSD (s)	.011	.009	.012	.023	.034	.044
ICC	.913	.934	.884	.659	.456	.311
95% CI	.886 - .933	.890 - .957	.552 - .950	–.187 - .887	–.135 - .786	–.094 - .672
LOA bias (s)	.002	.004	–.008	–.021	–.032	–.042
LOA RE (s)	.021	.017	.019	.021	.025	.027

RMSD = root mean square difference; ICC = intraclass correlation coefficient; 95% CI = 95% confidence interval; LOA = limits of agreement; RE = random error.