VALIDITY OF A TREADMILL-MOUNTED PHOTOELECTRIC SYSTEM FOR MEASURING SPATIOTEMPORAL PARAMETERS OVER A RANGE OF RUNNING SPEEDS

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The purpose of this study was to determine the concurrent validity of a treadmill-mounted photoelectric system (Optojump) for measuring spatiotemporal parameters of runners at a range of running speeds (12-16 km/h). Ten participants ran for 20 s at each of three different speeds (12, 14 and 16 km/h) on a HP Cosmos Pulsar treadmill while spatiotemporal parameters were measured by both the Optojump and a high-speed camera (960 fps). The Optojump was placed on the sides of the treadmill as per the manufacturer protocols. Large timing errors for contact time (13.1%) and swing time (6.8%) were recorded, while excellent validity was shown for the other parameters of stride time, stride length and stride frequency (errors less than 0.6%). Increases in gait speed resulted in significantly lower error values for both contact time and swing time, but had no effect on the other variables. Early identification of initial contact and delayed identification of toe-off in the Optojump system due to placement on the slightly elevated sides of the treadmill are hypothesised to be the cause of the notable errors in contact time and swing time. However, these systematic errors do not negatively affect the other spatiotemporal parameters of stride time, stride length and stride frequency which are all still accurately measured by the Optojump in this set-up.

KEYWORDS: spatiotemporal parameters, treadmill running, photoelectric system, validity.

INTRODUCTION: Spatiotemporal parameters of running are recognised as critical variables in understanding the biomechanical profile of an individual's running gait. Adaptations of these important parameters have been documented in response to barefoot/shod running (e.g. Bonacci et al., 2013), running speed (e.g. Mero & Komi, 1985), strength training (e.g. Gómez-Molina et al., 2018), and several other running-related factors. Direct links between running economy and spatiotemporal parameters have also been highlighted by Moore (2016). The accurate measurement of such parameters in a range of research and applied settings is therefore required in order to comprehensively evaluate an individual's running biomechanics.
A range of methods are used to measure spatiotemporal parameters of running including force platforms, optoelectronic motion analysis, body-worn sensors, high speed video and photoelectric systems such as the Optojump/Optogait (Lee et al., 2014). The Optojump is an optical measurement system consisting of a transmitting and receiving bar (each 1 m in length), with each bar housing 96 LED sensors. Gait parameters are detected based on the timing and spatial location of interruptions to these LEDs (Microgate S.r.l., 2015).
The Optojump system has been observed to show high concurrent validity in measuring stride time, cadence and step length for overground walking (Lienhard et al., 2013). However, a tendency to overestimate contact time and underestimate swing time during walking and running has also been shown for the Optojump when used both overground and on a treadmill (García-Pinillos et al., 2019; Lee et al., 2014; Lienhard et al., 2013). These errors in the stance and swing components of the gait cycle are hypothesised to relate to the elevation of the LED height above the ground (approx. 3mm in conventional overground set-up), thus causing an early identification of initial contact and a delayed identification of toe-off. While the validity of the Optojump for spatiotemporal parameters has been described previously, the influence of gait speed and elevated treadmill sides has not been described. Therefore, the aim of this study was to assess the concurrent validity of the Optojump (compared to high speed video) for spatiotemporal parameters of running at three different running speeds using a treadmill with slightly elevated sides.

METHODS: Ten healthy subjects (5 male, 5 female) aged 18-40 years old were recruited to take part in the study. For inclusion, participants were required to have a typical weekly training volume of at least 3 hours/week and be proficient and familiar with treadmill running. Following ethical approval, participants gave informed consent to take part in the study.
Each participant performed a single trial at 12, 14, and 16 km/h on the treadmill (HP Cosmos Pulsar; HP Cosmos Sports & Medical GMBH, Nussdorf Traunstein, Germany). The trials lasted for 1 minute with 1 minute of rest between trials. Participants were asked to wear a t-shirt, shorts and runners for the test session. Their height and body mass were measured before undertaking the treadmill protocol. Prior to testing, they completed a standardised warm up on the treadmill, which consisted of a 2-minute walk at 5 km/h followed by a 3-minute jog at 8 km/h. Prior to trials, the participants were instructed to have their feet on the side of the treadmill and hands on the hand rails while the treadmill was brought up to the desired speed. Once at the required speed participants were asked to lower themselves onto the moving treadmill belt. They were instructed to start running with their right foot. Once the participant's running position had stabilised between the Optojump bars (usually after 5-7 strides) the following 20-second period of running was used for comparison of spatiotemporal parameters.
Optojump Set-up: The Optojump system (Optojump-next, Microgate, Italy) was positioned securely on either sides of the treadmill in line with the manufacturers guidelines (see Figurea). The Optojump systems sensor was placed 20 cm from the front barrier of the treadmill and 67.5 cm from the back of the treadmill. The Optojump systems optical sensors are located 0.30 cm from ground level when placed on the ground. However, as shown in Figure 1b, the elevated treadmill side on the HP Cosmos Pulsar treadmill adds 1.5 cm to the sensor height. The Optojump samples at 1000 Hz and the data was exported to Microsoft Excel for analysis. The system automatically began data collection once the subject broke the beam with their initial step (right foot).

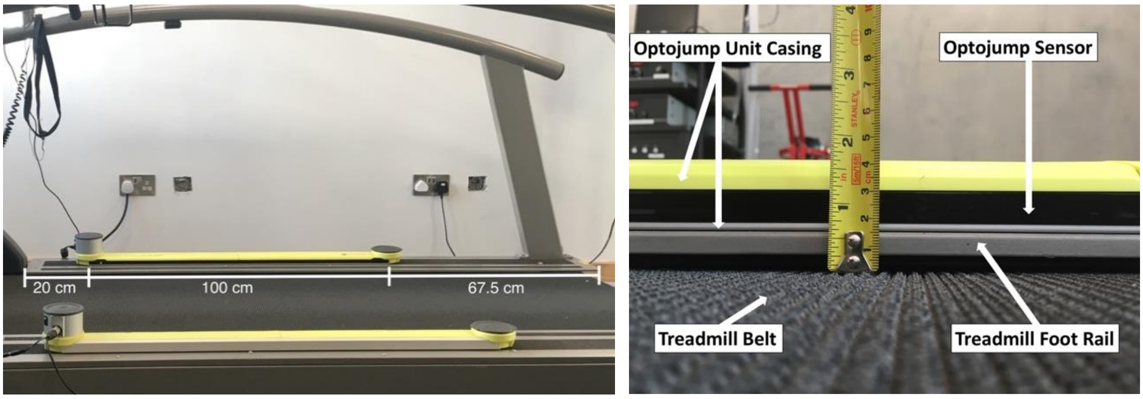

Figure 1: (a) Optojump set-up on the treadmill; (b) Distance between the treadmill belt and the Optojump system.

High-Speed Camera System: The Sony NEX-FS700R Super 35 Camcorder was used with a sampling frequency of 960 fps. The camcorder was fitted with a 24 mm lens and the focal length was set at 2.8. It was mounted at a height of 1.10 m and was positioned 5.3 m perpendicular to the treadmill, as per the protocol used by Santos-Concejero et al. (2014). Additional lighting behind and in front of the participant was used to illuminate the camera view. Kinovea video analysis software was used to analyse the data from the high-speed camera. The subject's first step was used to accurately synchronize the two data sets. Visual identification of initial contact and toe-off along with the treadmill speed were used to calculate the following variables in accordance with previous research (Padulo et al., 2013) that were then compared with the Optojump data: contact time, swing time, stride time, Stride length, and stride frequency.
Error scores between the Optojump and high-speed camera system were calculated for each stride. Positive errors indicated the Optojump value being higher. Mean absolute error values

(magnitude only) were calculated in both seconds and as percentage errors for each individual at each speed. Concurrent validity was assessed using these mean absolute errors. Data was assessed for normality using Shapiro Wilks test and based on the outcome of this a repeated measures ANOVA or Friedman's test was used to analyse the effect of running speed on measurement errors.

RESULTS: Errors in contact time and swing time (Table 1) were consistently greater than 0.025 s (averages ranging from 0.026 s to 0.035 s). These represent considerable errors of 5.9-13.7% of these critical swing durations. These errors were linked to repeated overestimation by the Optojump of contact time and repeated underestimation of the swing time by the Optojump. However, stride time, stride length and stride frequency all showed mean absolute errors of less than 1% (Table 1).

Table 1: Mean absolute errors and mean percentage errors in spatiotemporal parameters. Standard deviation value in brackets.

	Mean absolute error				Mean percentage error (%)			
	12 km/h	14 km/h	16 km/h	**All speeds**	12 km/h	14 km/h	16 km/h	**All speeds**
Contact time (s)	0.035 (0.004)	0.032 (0.006)	0.026 (0.005)	**0.031 (0.006)**	13.7% (1.4)	13.6% (2.2)	11.9% (2.4)	**13.1% (2.1)**
Swing time (s)	0.034 (0.005)	0.031 (0.006)	0.026 (0.007)	**0.030 (0.007)**	7.6% (1.3)	7.0% (1.4)	5.9% (1.6)	**6.8% (1.6)**
Stride time (s)	0.002 (0.001)	0.002 (0.001)	0.002 (0.001)	**0.002 (0.001)**	0.3% (0.2)	0.3% (0.1)	0.3% (0.2)	**0.3% (0.2)**
Stride length (cm)	1.4 (1.0)	1.4 (0.8)	1.0 (0.9)	**1.3 (0.9)**	0.6% (0.4)	0.5% (0.3)	0.4% (0.3)	**0.5% (0.4)**
Stride frequency (s/min)	0.41 (0.32)	0.37 (0.30)	0.60 (0.68)	**0.46 (0.46)**	0.2% (0.2)	0.2% (0.2)	0.3% (0.4)	**0.3% (0.3)**

Running speed had a significant effect (p<0.01) on error magnitude for both contact time and stride time. In both cases, as speed increased the magnitude of the error decreased (see Figure 2). Post hoc tests revealed that the significant effect of speed was present between each of the three speeds used. There was no significant effect of running speed on error magnitude for stride time, stride length or stride frequency (all p >0.05).

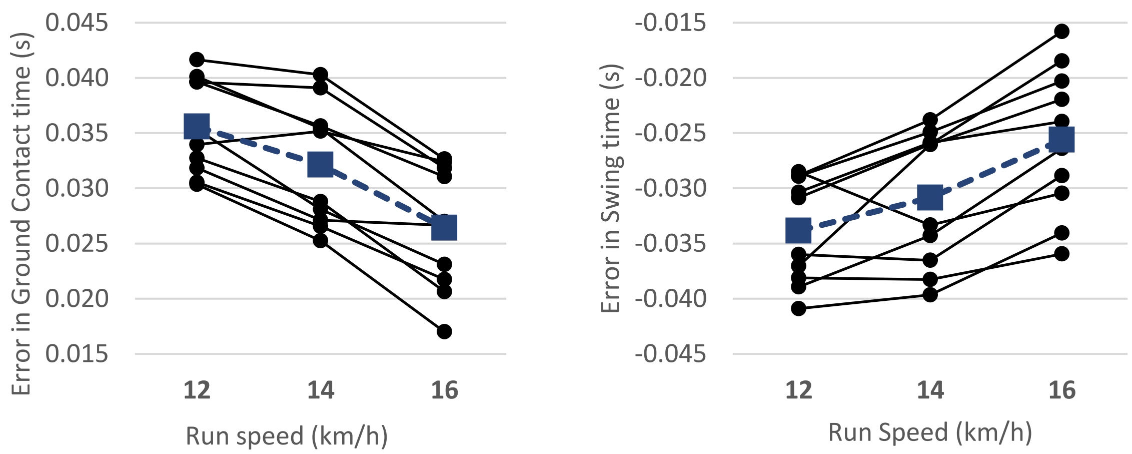

Figure 2: (a) Errors in contact time for 12, 14 and 16 km/h. (b) Errors in swing time for 12, 14 and 16 km/h. Negative values represent underestimation by the Optojump. Averages shown with dashed line.

DISCUSSION: The Optojump system displayed excellent validity for stride time, stride length and stride frequency when used on a standard treadmill with slightly elevated sides (1.5 cm) at three running speeds, with average errors of just 0.3-0.6%. However, the stride sub-phases of contact time and swing time displayed large timing errors of 5.9-13.7%. The direction of these errors match those reported by Lee et al. (2014) for treadmill walking and García-Pinillos et al. (2019) treadmill running, however the magnitude of errors in the current study are higher. Similar to these papers, the expected cause of these errors in contact time and stride time is the early identification of initial contact and delayed identification of toe-off due to the Optojump sensors being elevated above the treadmill belt (1.8 cm). The magnitudes of errors were shown to reduce as running speed increased, but were still of a clinically important magnitude at the highest speed.

In an applied context, the Optojump offers an excellent practical solution for the assessment of spatiotemporal parameters both overground and on a treadmill. However, practitioners should be aware of the possible high errors in the sub-stride phases of contact time and swing time, and that these errors appear to be amplified at slower speeds and in the case of treadmills with elevated sides. It is likely that these errors affect the accuracy of these variables much more than their test-retest reliability (Lee et al., 2014), therefore directional changes in contact time (for example) following an intervention may still be valid.

CONCLUSION: Stride time, stride length and stride frequency display excellent validity when measured using the Optojump on a treadmill with slightly elevated sides at 12, 14 and 16 km/h. Measurements of contact time and swing time are not accurate using the Optojump in this set-up. Correction factors which incorporate running speed, beam height above treadmill belt and running style should be investigated in order to reduce these errors in an applied setting.

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