INTER TREADMILL VARIATION IN BELT VELOCITY REGULATION

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The purpose of the present study was to develop a novel method to quantify instantaneous belt velocity and to investigate differences in belt velocity regulation between different types of treadmills. We used circular cut-outs of reflective tape attached to the lateral aspects of the treadmill to determine its instantaneous belt velocity. By testing three treadmills with seven participants we were able to identify clearly different instantaneous belt velocity patterns between treadmills. Peak deviation amplitudes correlated positively with the body mass of runners, even though the slope of this relationship was different between treadmills for positive deviations from target speed. These results highlight the importance of considering belt velocity regulation differences in human locomotion studies and treadmill training.

KEYWORDS: Locomotion, running mechanics, reproducibility, belt speed.

INTRODUCTION: Treadmills play an important role in the analysis of human motion. They are manufactured at different scales, with different geometries and different motors. Treadmill belt velocity regulation is the result of a complex interplay of the friction between the belt and its supporting surface, motor power and algorithms controlling power output of the motor to keep the average belt velocity set by the operator (Savelberg, Vorstenbosch, Kamman, van de Weijer & Schambardt, 1998). Certain calculations in locomotor biomechanics and applied physiology require a precise knowledge of average and instantaneous belt velocity. This includes for example the calculation of running economy, as well as center of mass and whole-body power calculations. Knowledge of the instantaneous belt velocity pattern is also essential when considering the transfer of knowledge gained from treadmill to over ground locomotion. Despite the common use of treadmills in locomotion research and the variability of treadmill designs, it is remarkable that the quantification of instantaneous belt velocity is not a standard task for researchers in this field.

Therefore, the purpose of the present study was to develop a novel method to quantify instantaneous belt velocity and to investigate differences in belt velocity regulation between different types of treadmills. We hypothesized that due to different motor power and due to different regulation algorithms, different belt velocity patterns would emerge between treadmills. We further hypothesized that fluctuations of belt velocity would be more pronounced in heavier runners due to higher frictional forces acting between treadmill belts and their supporting surfaces.

METHODS: We analyzed seven recreational runners (6 male; 1 female; body mass: 60.7-108.2 kg; body height: 1.63-1.98 m) running at a target speed of 3 m/s on three different treadmills. Participants gave written consent prior to testing after having received verbal explanations of the experimental procedure.
In order to quantify the instantaneous treadmill belt velocity, we developed a novel method using motion capture technology (Willwacher, Fohrmann, Mai, Mählich, Kurz, Koopmann & Kantarev, 2019). The method is relying on optical 3D motion capture systems of different manufacturers. We made the underlying algorithms freely available as a Matlab (The Mathworks, Natick, MA, USA) function through Matlab's file exchange server

("getBeltVelocity.m"). For this method, we attached flat, circular (diameter = 16 mm) markers of retro-reflective adhesive tape (3M, St. Paul, MN, USA) to the lateral parts of the treadmill belt (Fig. 1A). The interval between markers was chosen so that at least five markers were visible on the top of the treadmill at each instant in time (Fig. 1A).

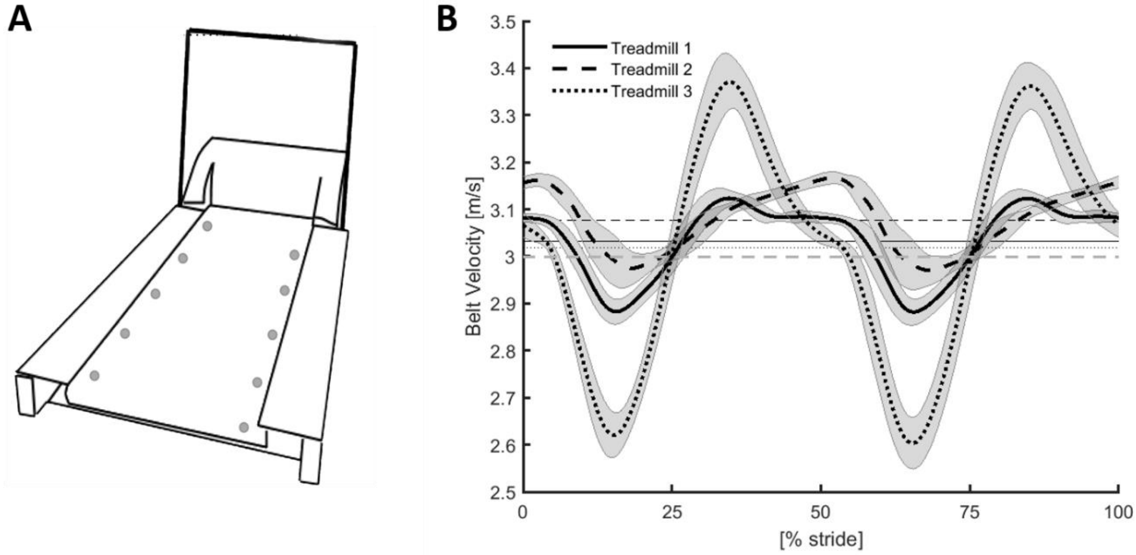

Figure 1: A: Marker placement on the treadmill belt. B: Stride cycle (right touchdown to right touchdown) averaged (n=7) instantaneous treadmill belt velocities for three different treadmills. Grey areas indicate ranges of ± 1 standard deviation around the mean curve.

During running, the 3D trajectories of these markers were tracked using optical 3D motion capture systems (250Hz, Treadmill 1: Vicon Bonita, Vicon Motion Systems, Oxford, UK; Treadmills 2 and 3: Qualisys Miqus, Qualisys AB, Gothenburg, Sweden). For the novel method, motion capture trials need to be saved as ".c3d" files. No further labeling is necessary, because the method works with unlabeled "ghost markers".
We developed an algorithm to distinguish between unlabeled markers which are attached to the treadmill belt and other unlabeled markers in the trial using specific boundary conditions depending on the treadmill dimensions and lab coordinate system conventions. The algorithm determines the velocities of the belt markers in the running direction and averages marker velocities of all visible markers. For this step, the algorithm consideres only markers from the mid-part of the treadmill being visible for more than 20 consecutive gap-free frames. Subsequently, a 4th order recursive Butterworth filter (20Hz cut-off frequency) is applied to the averaged raw velocity data. This way, we determined the instantaneous belt velocity in all time-frames of each trial. We captured data for 17 seconds and determined right leg initial ground contact by means of kinematic methods and additional markers placed on the lower extremities of the participants (Fellin, Rose, Royer & Davis, 2010). For each stride cycle, we determined the mean belt velocity as well as the peak negative and positive deviations from the nominal belt velocity (i.e. 3 m/s). Subsequently, we took the mean value for each participant in each condition, by averaging all values from all stride cycles within the 17 s trials. Why performed a one factor (treadmill type) repeated measures analysis of covariance with body mass as covariate (α = 0.05).

RESULTS: We obtained clear differences in belt velocity patterns between treadmills (Fig. 1B). On average, peak negative deviations from target speed were highest for treadmill 3 (-13.7 ± 1.8%) compared to treadmill 1 (-4.3 ± 1.0%) and treadmill 2 (-1.9 ± 2.0%). On average, peak positive deviations from target speed were highest for treadmill 3 (13.1 ± 2.1%) compared to treadmill 2 (5.8 ± 0.4%) and treadmill 1 (4.8 ± 0.6%). Higher body mass was related to greater peak deviations from the target speed (Fig. 2A,C). However, for peak positive target speed deviation, the effect was more pronounced on treadmill 3 compared to the other two treadmills (Fig. 2C), indicated by the steeper slope of the linear regression line (Fig. 2A,C) and a significant treadmill by body mass interaction effect (p = 0.005). Mean belt velocity was only minimally affected by body mass (Fig. 2B), but we identified a significant treadmill main effect (p = 0.007). Highest mean belt velocity deviation from target speed was obtained for treadmill 2 (2.6 ± 0.3%), followed by treadmill 1 (1.1 ± 0.3%) and treadmill 3 (0.6 ± 0.03%)

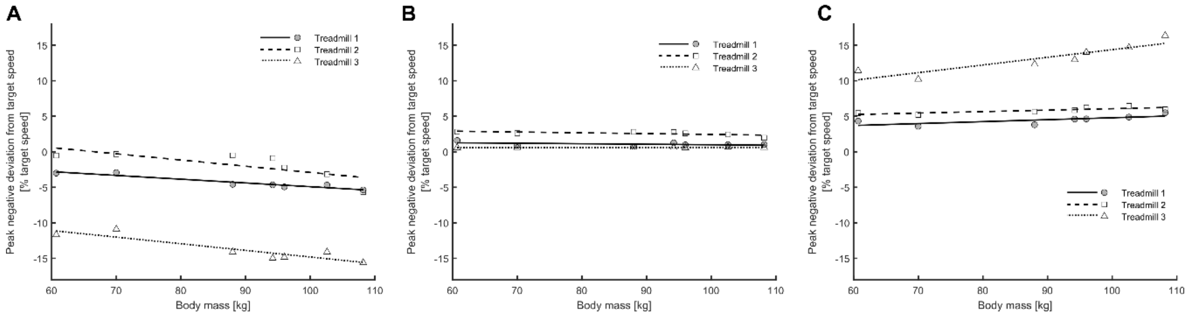

Figure 2: A: Peak negative deviation plotted over body mass. B: Mean belt velocity plotted over body mass. C: Peak positive deviation plotted over body mass. Each data point indicates the mean of stride cycles in a 17 s interval of an individual runner on one of the three treadmills under analysis.

DISCUSSION: The purpose of the present study was to develop a novel method to quantify instantaneous belt velocity and to investigate differences in belt velocity regulation between different types of treadmills.

We successfully applied the novel method to all our seven participants while running on different treadmill types. We captured the motion of the treadmill markers with a minimum of nine motion capture cameras (treadmill 1) and a maximum of twelve motion capture cameras (treadmills 2 and 3) without the need for further post processing (e.g. labeling or gap filling) of belt marker trajectories. Consequently, the novel method can serve as a time efficient method to quantify instantaneous belt velocities in future studies. We further believe that this should become a standard task in locomotion studies performed on treadmills, because providing this information will improve comparability between studies using different treadmill types. Further, with this information it will be much easier to quantify whether the center of mass deceleration / acceleration behavior is comparable to over ground situations.

The results of the present study provide a clear indication for the importance of reporting instantaneous treadmill belt velocity patterns, since pronounced differences in all analyzed parameters and also their interaction with the body mass of runners were obtained. Future studies need to explore whether these differences between treadmill types persist at walking or higher and lower running speeds.

CONCLUSION: In summary, our results highlight the importance of considering the instantaneous belt velocity regulation of treadmills. This task has important implications for the improvement of the comparability between studies, the extrapolation of results from treadmill studies to over ground locomotion and for the improvement of calculation methods requiring precise horizontal center of mass velocity quantification (e.g. center of mass power calculations). Furthermore, athletes and coaches who are using treadmills in their training protocols should consider possible differences in treadmill belt velocity regulation between manufacturers and potential interaction effects with the body mass of their athletes.

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