COMPARISON OF TEMPORO-SPATIAL AND KINETIC PARAMETERS DURING DOWNHILL WALKING ON A TREADMILL AND A RAMP CONSTRUCTION

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Inclined treadmills or static ramp constructions can be used to investigate downhill gait in a standardised laboratory condition. However, it is not clear how the different systems affect the gait pattern during downhill walking. Therefore temporo-spatial (Qualisys) and kinetic data (loadsol®) of 13 healthy participants walking with a given speed (1.1 m/s) downhill with a -6° decline on a treadmill and a ramp system were analysed. On the treadmill participants walked with 8% shorter steps and shorter contact times, while they increased step frequency by 6%. Peak resultant forces remained similar compared to walking on a ramp construction. These alterations might be due to mechanical and psychological effects and have to be considered when conducting and analysing research that focuses on downhill gait.

KEYWORDS: gait on slopes, treadmill, ramp

INTRODUCTION: The use of treadmills is common in both research and clinical settings. Compared to over-ground walking in the field, the compactness of a treadmill has the advantage of requiring less space, the simple observation of repeated steps and the controllability of walking speed (Lee & Hidler, 2008), however, only recently the instrumentation with integrated force plates are devolping. Alternatively a ramp construction can be used in the laboratory including force plates to analyse gait at different inclinations. While several studies have investigated differences in level walking between walking on a treadmill and over-ground no research has been found by the authors that investigates the effect of the system (treadmill versus ramp). In level walking no clear picture with respect to the effect of the used system occurs: No differences in temporo-spatial parameters such as stride frequency, stride length and stride time between treadmill walking and level over-ground walking were observed by Riley, Paolini, Della Croce, Paylo, and Kerrigan (2007) and Hollman, Watkins, Imhoff, Braun, Akervik, and Ness (2016). While Riley et al. (2007) therefore concluded that walking on a treadmill did not result in a noticeable difference in gait parameters, Hollman et al. (2016) suggested despite the similar temporo-spatial parameters a change in invariant gait patterns, posing difficulty in translating locomotor skills gained on a treadmill to over-ground walking conditions. In contrast, other studies report that individuals walk on a level treadmill with shorter steps (Watt, Franz, Jackson, Dicharry, Riley, & Kerrigan, 2010; Yang & King, 2016), higher cadences (Watt et al., 2010), shorter swing phases (Alton, Baldey, Caplan, & Morrissey, 1998; Lee & Hidler, 2008) and slower speed (Chiu, Chang, & Chou, 2015; Yang & King, 2016) compared to level over-ground walking, resulting in a more "cautious" gait pattern on the treadmill (Yang & King, 2016). With respect to kinetic differences a reduction in ground reaction force peaks has been observed when walking on a level treadmill (Parvataneni, Ploeg, Olney, & Brouwer, 2009; Riley et al., 2007; Watt et al., 2010), which was linked to a reduced need for push-off on the treadmill (Parvataneni et al., 2009). Since walking on inclined surfaces is important in training scheme for gait restoration, but also in hiking and mountaineering, it is important that the subtleties associated with this type of walking are known (Kimel-Naor, Gottlieb, & Plotnik, 2017). Therefore, the aim of this study was to analyse temporo-spatial and kinetic parameters when walking downwards on a treadmill and on a ramp construction at a given speed.

METHODS: Six female and seven male participants (age: 25.2 ± 2.2 years, height: 1.77 ± 0.08 m, mass: 72.1 ± 11.1 kg) without injuries or surgical interventions on the lower limb were asked to walk downhill on a -6° declined treadmill and ramp construction (6 m x 1.4 m) with a predefined speed of 1.1 m/s (± 2.5% on the ramp). Reflective markers were attached on the participants in order to collect kinematic data during treadmill (nine-camera motion capture system (Miqus, Qualisys, Gothenburg, Sweden, 200 Hz) and ramp (eleven-camera motion capture system) (Oqus, Qualisys, Gothenburg, Sweden, 200 Hz) walking. To collect kinetic data on both systems (treadmill and ramp) all participants were equipped with pressure insoles (loadsol®, Novel, Munich, Germany, 100 Hz) and the same size fitted shoe type (Adidas Duramo). After a 5-minute warm-up on the treadmill (walking with 1.1 m/s), data for treadmill and ramp walking (in randomized order) were collected during the same measurement session. Three consecutive steps after walking for 90 seconds were collected on the treadmill while on the ramp construction three separate gait trails were collected. The 3rd step of each trial was taken for further analysis. Kinematic and kinetic data were merged using Visual3D software (C-motion, Rockville, MD, USA) and stance phase was detected using the insole data. Temporo-spatial parameters (step length, cadence and contact time) as well as first and second peak force of the pressure insole system were calculated. Statistical differences were analysed using a t-test with a significance level of p=0.05.

RESULTS: All temporo-spatial parameters showed significant differences between treadmill and ramp condition when walking at the same speed. During treadmill walking step length and ground contact time were significantly reduced by 8 ± 6% ($p < 0.001$) and 8 ± 6% ($p=0.001$), respectively, while step frequency was increased by 6 ± 9% ($p = 0.009$) (Figure 1) compared to walking on the ramp construction. Force peaks did not show a significant difference (peak1: $p = 0.057$, peak 2: $p = 0.738$).

Table 1: Mean values of space-time parameters while walking in the plane as well as in different inclinations between treadmill and ramp construction.

	step length [m]	step frequency [steps/min]	contact time [s]	force peak 1 [N]	force peak 2 [N]
treadmill	0.61±0.04	109 ±6	0.67±0.04	918±116	692±79
ramp	0.66±0.05*	104±8*	0.73±0.06*	883±125	695±73

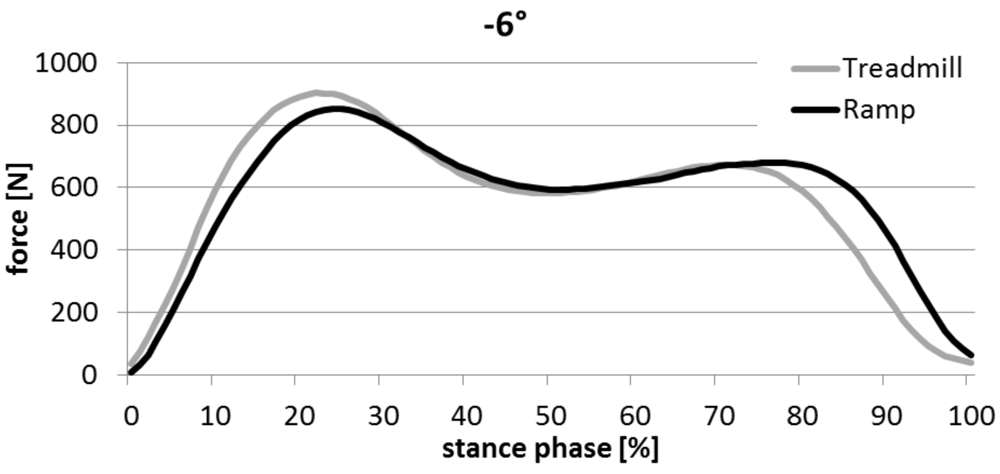

Figure 1: Loadsol forces during stance phase in 6° downhill walking on a treadmill and ramp construction during stance phase.

DISCUSSION: While walking downhill generally requires some gait alterations (shorter steps, eccentric muscle activation to counteract against gravity and enable a controlled lowering of the CoM to place the foot at a steeper level as the prior step), the differences of the system used for the analysis of downhill gait might also play an important role. Similar as in level gait (Watt et al., 2010; Yang & King, 2016) participants of this study walked downwards on the treadmill with shorter steps, and shorter contact times, but increased

stride frequency compared to downwards walking on the ramp. This might be due to mechanical constraints given by the treadmill and psychological aspects: When walking on the treadmill the belt is driven by the defined speed and participants need to react toward the given velocity. Possibly this leads to a more cautious gait pattern by reducing step length. Additionally, the relative remaining length of the treadmill belt or the ramp differs between systems, which might additionally influence the gait pattern. The intention to walk to the end of the ramp construction (3 m remaining from the step under investigation) versus approx. 1 m at the treadmill could cause longer steps on the ramp construction. A further aspect might be related to the friction experienced on the ramp and on the treadmill. Sun et al. (1996) suggested that the need for friction is reduced with smaller steps when walking downhill, hence this might be an underlying strategy of the participants for safe downhill walking on the treadmill, where the surface consisted of a rubber band versus an anti-slippery coated surface on the ramp.
Despite shorter steps the resultant force of the insole system showed no significances in peak forces, but a trend towards an increased first peak on the treadmill. In level walking a reduction in 2nd peak ground reaction forces has been suggested as result for need for a reduced push-off due to the movement of the belt (Parvataneni et al., 2009). This seems different in the declined condition, where a tendency towards an increased first peak and similar 2nd peak value during treadmill gait were observed. Further, it doesn’t seem that cushioning effects of the rubber belt of the treadmill occurred in comparison to the wooden panels of the ramp construction. It has to be noted that the resultant force of the insole pressure system has been used as kinetic parameter. It has been observed during declined gait that this force overestimates the actual force due to the mechanical deformation of the shoe, however, it reliably can be used to analyse relative differences between conditions.

CONCLUSION: This study showed that walking downhill (-6°) on a treadmill differs in temporo-spatial parameters compared to ramp walking. To maintain the same walking speed the participants walked on the treadmill with shorter, but more frequent steps. No significant differences were observed for the first and second peak of resultant force. These differences have to be considered in designing and interpreting research with respect to downhill gait.

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