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Full length article

Effects of interventions on normalizing step width during self-paced dual-belt treadmill walking with virtual reality, a randomised controlled trial

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A R T I C L E  I N F O

Keywords:
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Step width
Spatiotemporal gait parameters
Virtual reality
Gait analysis

A B S T R A C T

Background: Step width is increased during dual-belt treadmill walking, in self-paced mode with virtual reality. Generally a familiarization period is thought to be necessary to normalize step width. Aim: The aim of this randomised study was to analyze the effects of two interventions on step width, to reduce the familiarization period.

Methods: We used the GRAIL (Gait Real-time Analysis Interactive Lab), a dual-belt treadmill with virtual reality in the self-paced mode. Thirty healthy young adults were randomly allocated to three groups and asked to walk at their preferred speed for 5 min. In the first session, the control-group received no intervention, the ‘walk-on-the-line’-group was instructed to walk on a line, projected on the between-belt gap of the treadmill and the feedback-group received feedback about their current step width and were asked to reduce it. Interventions started after 1 min and lasted 1 min. During the second session, 7–10 days later, no interventions were given.

Findings: Linear mixed modeling showed that interventions did not have an effect on step width after the intervention period in session 1. Initial step width (second 30 s) of session 1 was larger than initial step width of session 2. Step width normalized after 2 min and variation in step width stabilized after 1 min.

Interpretation: Interventions do not reduce step width after intervention period. A 2-min familiarization period is sufficient to normalize and stabilize step width, in healthy young adults, regardless of interventions. A standardized intervention to normalize step width is not necessary.

1. Introduction

Because the advantage of a small laboratory setting and the possibility to analyze multiple steps in comparison to overground walking, the use of treadmills in gait analysis is increasing \cite{1,2} and aimed to collect valid gait data \cite{3}. Dual-belt treadmills, with two separate belts and a gap in between (between-belt gap), are becoming more common to perform separate force plate measurements of each foot. A fairly new instrument with a dual-belt treadmill is the GRAIL (Gait Real-time Analysis Interactive Lab, MotekForceLink Amsterdam BV, between-belt gap of 1.5 cm). Walking on a treadmill affects gait performance as can be seen in changes in step width, step length, cadence, stance time (spatiotemporal parameters) \cite{4}. These changes might be due to limited length of the belt, imposed treadmill speed and an increased need for controlling the medial-lateral balance in walking \cite{5}. A familiarization period is necessary to normalize those spatiotemporal parameters \cite{2,6,9} (for example step width) in treadmill walking.

Dual-belt treadmill walking (fixed-speed) leads to an increase in step width in comparison to single-belt treadmill walking (fixed-speed) \cite{1} and overground walking \cite{3}. An increase in step width is also seen when using virtual reality \cite{10} and self-paced walking leads to an increased step width compared to fixed-speed \cite{11}. Different periods, between 5 and 20 min, have been applied to familiarize to treadmill walking \cite{2,6,9}, but most studies ignored measuring step width during such a period \cite{6,7,9}. In dual-belt treadmill walking, one study did not find normalization of step width after a 10-min familiarization period \cite{1}, while another study described a gradual decrease of step width, during a 5-min familiarization period in healthy young adults \cite{2}. During dual-belt treadmill walking, subjects appear to avoid stepping on the between-belt gap. After being told that stepping on the physical gap (4 mm) between the belts would not cause adverse effects, subjects decreased step width \cite{12}. This finding suggests that more detailed
instructions reduces the familiarization period. The above-mentioned results show that the extent of a familiarization period to normalize step width is not well established. As in gait analyses on a treadmill the aim is to mimic overground walking as much as possible, we assumed an intervention that shortens the familiarization period, which is necessary in gait analysis of patients, who may not be able to walk a long period, can provide us with more valid data.

In our study a combination of dual-belt, virtual reality and self-paced was used. This combination of elements is assumed to offer a more natural walking pattern on a treadmill and is therefore preferred to be used [11,13].

The aim of this study was to normalize step width and reduce the familiarization period to a minimum compared to the results of a control group. We expected that step width, during self-paced dual-belt treadmill walking with virtual reality in healthy young adults, would decrease by giving an intervention, aimed to normalize step width and that this decrease in step width would be retained after one week.

2. Methods

2.1. Subjects

Thirty healthy subjects participated in this single center randomised controlled trial, 17 females and 13 males. Subjects were employees of the department, however they were all unfamiliar with self-paced, dual-belt treadmill walking with virtual reality. Inclusion criterion was an age between 20 and 50 years. Persons with self-reported restrictions in walking distance or those wearing braces/inlays or (semi)orthopedic shoes were not included. During the measurements participants wore their own shoes, high-heeled shoes were not permitted. A convenience sample of 30 healthy subjects gave informed consent and participated in the study. No significant differences between the groups were found in age, sex, weight and height (Table 1). All data were collected on a GRAIL system in a rehabilitation center in the Netherlands. An online randomisation program (www.sealedenvelope.com) was used to generate three groups with equal sample sizes (n = 10). Assignments were randomised by giving an intervention, aimed to normalize step width and that this decrease in step width would be retained after one week.

2.2. Instrumentation

The GRAIL is an instrumented dual-belt treadmill with a self-paced option and a virtual reality environment projected on a 180° semi cylindrical screen. It consists of an integrated motion-capture system (VICON Bonita 10) and two force plates embedded in the treadmill. This combination allows the calculation of kinetic, kinematic and spatiotemporal gait parameters in real-time [14]. An application for each study group was developed in D-Flow. A set of 25 markers was placed by the same investigator according to the Human body model [15]. Step width was calculated as the medial-lateral distance between the left and right heel in the frontal plane. The midpoint of the heel was defined as 1/6 of the line connecting the calcaneus marker and the midpoint between dig1 and MTP5 markers [13] (Fig. 1). Step width for every heel-strike on the right side was measured.

2.3. Procedure

A convenience sample of 30 subjects was asked to participate in two walking sessions, with an in-between period of 7–10 days. The treadmill started at fixed-speed mode (1.0 m/s), followed by the self-paced mode after 20 s. All subjects were told to walk at their preferred speed. Step width for each step was measured continuously. Based on the study of Zeni and Higginson [2], which described a familiarization period of 5 min to be sufficient, we selected 5-min-sessions with a one-minute, group-specific, intervention after the first minute. After the one-minute intervention, subjects were instructed to walk normal again.

- Control-group: no extra instruction.
- ‘Walk on the line’-group: subjects are instructed to walk on a straight line, which was projected on the middle of the between-belt gap of the treadmill. The width of the projected line was 8 cm.
- Feedback-group: in the first minute, before intervention, step width was measured. During the intervention period a number was shown on a screen in front of the subject, indicating the step width in percent. During the intervention period a decreasing percentage of initial, individual, step width resulted in positive feedback (90% during the first 15 s; 70% during 15–30 s; 60% during 30–45 s; 40% during 45–60 s). A green number indicated a step width less than or equal to the corresponding percentage (positive feedback), a red number indicated a step width larger than the corresponding percentage (negative feedback). Subjects were instructed ‘to keep, the number shown on the screen, green instead of red, by narrowing their step width’.

All subjects were asked for a second five-minute walking session (without intervention), after 7–10 days.

![Fig. 1. Step width. Three circles indicating the three footmarkers at dig 1 (tip of 1st toe), MTS (caput of the 5th meta tarsal bone, on joint line midfoot/toes) and the heel (center of the heel at the same height as the toe). The crosses are virtual markers used to measure step width.](Image 372x545 to 492x737)

### Table 1

<table>
<thead>
<tr>
<th>Group</th>
<th>Control (n = 10)</th>
<th>Walk-on-the-line (n = 10)</th>
<th>Feedback (n = 10)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex Female (%)</td>
<td>60</td>
<td>40</td>
<td>70</td>
<td>0.387#</td>
</tr>
<tr>
<td>Mean ± sd</td>
<td>Weight (kg)</td>
<td>67 ± 10.3</td>
<td>70 ± 9.0</td>
<td>77 ± 13.5</td>
</tr>
<tr>
<td></td>
<td>Height (cm)</td>
<td>175 ± 11.1</td>
<td>176 ± 5.5</td>
<td>177 ± 9.6</td>
</tr>
<tr>
<td></td>
<td>Age (yrs)</td>
<td>27 ± 4.0</td>
<td>26 ± 3.3</td>
<td>27 ± 7.2</td>
</tr>
<tr>
<td></td>
<td>Initial step width (cm)</td>
<td>12.9 ± 3.6</td>
<td>13.0 ± 3.0</td>
<td>14.5 ± 3.5</td>
</tr>
</tbody>
</table>

Abbreviations: sd: standard deviation, #: results of chi-square test, *: results of one way ANOVA.
2.4. Statistical analyses

All outcome variables were calculated using custom made code in MATLAB r2014a (The Mathworks Inc., Natick, MA, USA). Mean step width per 30-s record time and standard deviation within these 30 s were calculated and used for further analysis in SPSS Statistics 22.0 (IBM corporation). Baseline differences between the groups were tested with ANOVA for normally distributed variables (mean ± sd), and chi-square for categorical variables. Initial step width was defined as the mean step width in the second 30 s of registration (time period 0.5–1.0 min). We assume 10 s of self-paced walking is necessary to technically progress from fixed-speed (first 20 s) to self-paced walking. Step width was analyzed among groups (with the control group as reference) in a linear mixed model analysis (autoregressive first order covariance structure). The −2-log likelihood criterion was used to evaluate change in model fit. Different models to analyze effects of time on step width were explored.

Time was modeled as linear effect, a squared effect (time*time), a logarithmic (ln time) effect and an inverse effect (1/time). We found that the inverse effect had the best model fit to the data for the control group in session 1 and for all groups in session 2.

In session 1, a model fit was made directly after completion of the control intervention. Effects of initial step width, group effects and of 1/time were analyzed. Interaction effects between groups, time and initial step width were explored. Variables were removed from the model if the model fit did not increase significantly. A p-value equal to or less than 0.05 was considered statistically significant. For the data of session 2 similar analyses were performed. In order to statistically predict changes of step width over time, we performed a regression analysis based on linear mixed model analyses of session 2. Additionally to explore whether the first session had an effect on initial step width of the second session (retention effect) a paired sample t-test was performed between initial step width of the first and of the second session. To explore change of variation in step width within session 2, standard deviations per 30-s record time were analyzed in a repeated measures ANOVA with a between group comparison. Assumptions of sphericity were tested using Mauchly’s W. In case of sphericity violations, a Greenhouse-Geisser correction was performed.

3. Results

No significant differences between the groups were found in initial step width (Table 1). During interventions in session 1, time period 1.0–2.0, step width decreased to a step width of 2.4 ± 0.8 cm in the ‘walk-on-the-line’-group and 6.3 ± 2.4 cm in the feedback-group (Fig. 2A). After the intervention period, time period 2.0–2.5, we found no significant difference between groups (p = 0.58), step width of 12.2 ± 3.8 cm in the control-group; 11.4 ± 3.7 cm in the ‘walk-on-the-line’-group; 12.3 ± 2.8 cm in the feedback-group. Step width after intervention period was influenced by initial step width, p < 0.01. No significant interaction effect of time and groups was found in session 1. The main decrease was found during the first 2 min (between 1.5–2.3 cm). During the second session, a gradual reduction of step width occurred in all groups (Fig. 2B). Step width varied between 11.5 ± 2.5 to 12.6 ± 2.7 cm in the control-group; 11.2 ± 2.9 to 11.9 ± 3.3 cm in the ‘walk-on-the-line’-group; 11.5 ± 2.1 to 12.3 ± 2.8 cm in the feedback-group. Both, initial step width and 1/time influenced step width later in session 2, p < 0.01. Initial mean step width in session 1 (13.5 ± 3.4 cm) was significantly larger (p = 0.008) than in session 2 (12.3 ± 3.0 cm), difference in means was 1.2 ± 2.3 cm (95% CI: 0.3 to 2.0). There was no intervention effect (p = 0.186).

Results of the linear mixed model analysis of session 2 (Table 2) [Step width (cm) = c (0.02) + b1 (1.49 * 1/time) + b2 (0.94 * initial step width)], were used to construct Fig. 2C. Change of step width over time as statistically predicted, starting with different initial step widths (10,12 and 15 cm). It shows a mean reduction of 0.35 cm over time between initial step width and the estimated step width. Fig. 2D shows
that the variation in standard deviation decreased in the first minute (including 20 s fixed speed walking) from 2.6 to 2.0 cm. In the repeated measures ANOVA, starting at initial 30 s (time period 0.5–1.0), it was shown that standard deviations did not significantly reduce over time (p = 0.851), also the time x group interaction was not significant (p = 0.754). After initial 30 s no large differences were seen in variation (in mean standard deviations), with a maximum of 0.3 cm difference over time.

4. Discussion

As we aimed to reduce familiarization period to a minimum when walking on a GRAIL, we analyzed the effects of two interventions to speed up the normalization of step width. No significant difference between groups in step width after the intervention period was found. Mean step width stabilized after the first 2 min and standard deviations were stable after the first minute (Fig. 2D). The first session had an effect on the initial step width of the second session (retention effect, mean difference 1.2 ± 2.3 cm). We hypothesized that a 1-min intervention would speed up the normalization of step width. Our study however, showed a 2-min familiarization period to be sufficient to normalize step width and variation in step width, irrespective of presence or type of intervention. The findings of session 1 indicate that an intervention to normalize step width in dual-belt treadmill walking is not necessary in healthy young adults. Furthermore in session 2 a retention effect was found (without intervention effect) and stable standard deviations were found after the first minute, indicating a 1-min familiarization period is sufficient in repeated sessions. Only during intervention period there was a clear effect on step width, which indicates that interventions had only an immediate effect on step width. The most important predictor for step width in session 1 was initial step width (Table 2). In session 2, both initial step width and time were predictors for step width. After the first minute in session 2 a marginal decrease in step width was found of 0.35 cm (Fig. 2C) and the variation in step width decreased, with a variation in standard deviations ≤0.3 cm.

Different periods have been applied for familiarization to treadmill walking [2,6–9], but most studies did not measure step width [6,7,9], therefore it is not clear how long that period should be to normalize step width. Secondly, different definitions of step width have been applied, such as mediolateral distance between the heel markers during a right and left consecutive midstance [1] and distance between left and right external malleoli [3]. Differences in definitions make it difficult to compare absolute values of step width. Change of step width over time, however, is not influenced by the definition of step width. Finally, different methods have been used in instructing subjects. For example in one study [1] subjects were instructed to walk as they normally would, while keeping each foot on a separate belt. In our study, we did not give the instruction to keep each foot on a separate belt. That instruction might have resulted in a larger step width.

Definition of step width in our study is based on a previous study [13], in children. This step width is not comparable to our study, because of a difference in subjects (adults vs. children) and because that study uses a 6- to 10-min familiarization period before measurements.

Only one study [2] specifically measured step width over time. A normalization of step width was found after 5 min, with a difference in mean step width of 1.3 cm, with a variation ≤0.2 cm. We found a similar decrease in mean step width in session 1 after 2 min (between 1.5–2.3 cm). In that study only dual-belt treadmill walking was used, where our study analyzed dual-belt treadmill walking, in self-paced mode with virtual reality. Maybe that difference could explain our faster normalization of step width (2-min familiarization period). Furthermore our study used a 20 s fixed speed walking period at the beginning, as a ‘rolling start’. This could result in a faster adaptation to self-paced walking, as it is assumed to make it less difficult to keep the belt moving.

Our study was performed amongst healthy young adults. Our results may differ from those to be acquired in patient groups or elderly. For example, patients suffering a stroke or patients who have had a trans-tibial amputation walk with a larger step width [16,17], to regulate stability. Older people tend to walk with a larger step width compared to young adults [18] and with a larger variation [5] in step width. We assume that, in those patient groups or elderly, an additional increase in step width and variation while walking on the GRAIL will be found. Based on our study, in healthy young adults, we cannot predict step width nor familiarization period in (older) patients.

A limitation of our study is that our results cannot be generalized to other subject categories. Familiarization period in an older and/or disabled subject category may require additional time.

4.1. Conclusion

Interventions did not normalize step width faster. Step width normalized after 2 min and variation in step width was stable after 1 min. In order to normalize and stabilize step width, prior to gait analysis in healthy young adults, a 2-min familiarization period without intervention is sufficient. The effects of the first session retained in session 2 (mean difference 1.2 ± 2.3 cm, without intervention effect) and stable standard deviations were found after the first minute, indicating a 1-min familiarization period is sufficient in repeated sessions.

Conflict of interest statement

None.

Acknowledgement

There are no acknowledgements to report.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.gaitpost.2017.07.040.

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