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Introduction

Kinetic and kinematic analyses of human gait have existed for many years and are widely used within the fields of rehabilitation and gait research (Whittle, 2007). Within rehabilitation, overground walking and walking on a treadmill is commonly used to train, plan and evaluate optimal treatment for patients. The use of a treadmill in this process has become increasingly utilized as some patient groups are able to walk 20 times the distance on a treadmill as compared to overground walking in parallel bars (Rupp & Gerner, 2008). Correspondingly, within gait research, treadmills are also increasingly used as an alternative to overground walking since they require a smaller amount of space, allow measurements of consecutive gait cycles and - through the use of embedded force plates - enable ground reaction forces to be measured (Sloot, van der Krogt & Harlaar, 2014). Despite this, Plotnik et al. (2015) and Sloot et al. (2014) highlights concerns regarding treadmill walking, such as differences detected between gait patterns when walking on a treadmill with a fixed velocity as opposed to walking overground. These differences in gait patterns when walking on a treadmill are evident through a decrease in stride length and preferred gait velocity (Batlkham, Oyunaa & Odongua, 2014; Marsh et al., 2006; Stolze et al., 1997). Additionally, walking on a treadmill also causes minor changes in EMG activity and a small decrease in range of motion at certain joints (Lee & Hidler, 2008; Riley, Paolini, Della Croce, Paylo & Kerrigan, 2007). This is the reason walking on a treadmill, regardless of chosen fixed gait velocity including the self-selected preferred gait velocity, does not reflect overground walking accurately (Plotnik et al., 2015). A suggested solution to this is self-paced walking on a feedback-controlled treadmill where velocity is adapted to the user, enabling the user to control and vary their gait velocity in a more natural way (Plotnik et al., 2015; Sloot et al., 2014). With these self-paced treadmills, it is the feedback of the user's walking velocity and position that controls the treadmill's velocity meaning an acceleration-line is placed near the middle of the treadmill and based on the user's position in relation to this line, the treadmill will accelerate or decelerate depending on whether the user is placed in front or behind this line respectively (Sloot et al., 2014). However, walking on a self-paced treadmill is still a fairly new field which needs more research, yet resent studies have compared self-paced and fixed velocity treadmill walking, with results showing that self-paced walking on a treadmill can be used as an alternative to fixed velocity treadmill walking (Sloot et al., 2014). Furthermore, studies have compared self-paced treadmill walking with overground walking, with results indicating that self-paced treadmill walking resembles overground walking (Plotnik et al., 2015; Sloot et al., 2014). Nevertheless, a deeper understanding of the effects of the association between velocity and position is needed to gain a better understanding of how the self-paced treadmill works and in which ways it can be used since self-paced treadmill walking intent to represent real life walking.

Background

Previous research indicates that people regularly engage in performing multiple tasks at the same time, though several studies have shown a decrease in performance when doing so (Koch, Poljac, Müller & Kiesel, 2018). Numerous theories explain this such as *The Limited Resource Hypothesis* (Wickens, 1980) and *The Multiple Resource Theory* (Wickens, 1984), which suggests that humans have a limited amount of common cognitive resources available for both cognitive and motor tasks and how performing two or more tasks at the same time, requiring some of the same resources, will result in the tasks interfering, because of the competition for the common resources needed. These theories describe, how people are not capable of performing numerous endless tasks requiring some of the same cognitive resources at the same time and how dual-tasking will result in either a slower task performance or errors in the task performed in one or both tasks. Within gait this has been established by individuals exhibiting a reduced walking velocity when performing a cognitive dual-task (Al-Yahya et al., 2011; Beauchet, Dubost, Herrmann & Kressig, 2005; Springer et al., 2006; Yogev-Seligmann et al., 2010) regardless the kind of cognitive task (Wrightson, Ross & Smeeton, 2016).

It could be anticipated, that people's individual prioritization of either the cognitive task or the gait could affect the performance of the tasks. This has been investigated in several studies, which have shown that when subjects were given a cognitive dual-task while walking, they would automatically and unconsciously choose the cognitive dual-task as the highest prioritization and therefore lower their performance in walking, expressed through a decrease in gait velocity (Patel, Lamar & Bhatt, 2014; Wrightson et al., 2016; Yogev-Seligmann et al., 2010).

It would therefore be expected that if people were to perform a color-word Stroop task while walking at a self-selected velocity on a self-paced dual-belt treadmill in a virtual reality (VR) environment, they would prioritize the cognitive task higher, resulting in a decreased gait velocity. Nevertheless, previous unpublished research described by Jeschke (2017) has shown that this is not the case. When subjects were to perform a dual-task in the form of a color-word Stroop task while walking in a 180° VR environment on a self-paced dual-belt treadmill (Gait Real-time Analysis Interactive Lab (GRAIL) system, Motek Medical BV, The Netherlands), the gait velocity significantly increased instead of decreased (Jeschke, 2017). This increase in gait velocity was thought to be caused by the subjects increasing their step length and was an unexpected finding in comparison to previous studies (Patel et al., 2014; Springer et al., 2006; Wollesen, Voelcker-Rehage, Regenbrecht & Mattes, 2016) and the author's expectations (Jeschke, 2017). Jeschke therefore proposed to investigate a number of aspects of the experimental setting and how these could have affected the subjects' gait velocity. Jeschke (2017) investigated three aspects of the experimental setting and its effects on the subjects' gait velocity on the treadmill:

- subjects could have felt aroused during the experiment
- the subjects experienced a discrepancy in the optic flow which could have affected their gait velocity
- subjects could have redirected their gaze and looked at the white plane instead of near the focus of expansion which was placed lower.

The results of this study showed that it was not the aroused feeling, the cognitive demand or the discrepancy in optic flow that was a causing factor for the subjects to increase their gait velocity. On the contrary, the findings revealed that the change in gaze direction was a reason why the subjects increased their self-selected gait velocity. It was further hypothesized that this increase in gait velocity when looking above the focus of expansion was a result of the subjects not being able to determine their position on the treadmill because of the lack of a visible reference point. The subjects would as a result of this, unconsciously place themselves further in the forward direction on the treadmill and thereby increase their gait velocity, because they were afraid of falling off the treadmill (Jeschke, 2017).

With the existing study means for this project, it is not possible to investigate, if the subjects will experience an unsafe feeling when performing a color-word Stroop task projected above the focus of expansion while walking on a self-paced dual-belt treadmill in a VR environment with the absence of a reference point. Since the treadmill's velocity is controlled mainly by the subject's position on the treadmill, one could imagine that the increase discovered in gait velocity (Jeschke, 2017) could be a consequence of the subjects positioning themselves more to the front on the treadmill when lacking a reference point to ensure not getting to close to the back edge of the treadmill. To the authors' knowledge no studies have examined this relation between velocity and position when walking on a self-paced treadmill. Furthermore, it will be examined if it is possible to substitute the lack of a reference point by providing the subjects with real-time feedback about their position on the treadmill.

Aim of study

The aim of this study is to determine if the measured increase in gait velocity when walking on a self-paced dual-belt treadmill in a VR environment while performing a color-word Stroop task (Jeschke, 2017) is caused by the relation between velocity and position making the increase in velocity a consequence of the subjects positioning themselves further in the forward direction on the treadmill. Additionally, it will be investigated if it is possible to substitute the lack of a reference point through real-time feedback.

It is hypothesized that subjects will increase their gait velocity when the acceleration-line, is moved to the back, since it is theorized that the subjects will position themselves more in the forward direction in relation to the acceleration-line thereby making the increase discovered by Jeschke (2017) a consequence of the subjects' position. Furthermore, it is hypothesized that subjects will decrease their gait velocity by placing themselves more in the back on the treadmill when they are being provided with real-time feedback on their position on the treadmill making the feedback function as a substitute for the missing reference point.

Methods

Subjects

Twelve volunteers participated in this study including 8 females and 4 males. All subjects were students or employees at University Medical Center Groningen (UMCG) and were between the ages of 20 and 30 years as in the previous study (Jeschke, 2017). The participants would be excluded, if they had any self-reported physical problems that could affect the walking pattern or were using any assistive walking devices or orthoses. Since the study was conducted in Dutch, it was required for the participants to be fluent in Dutch to receive the information given before and during the trial. Furthermore, to be eligible for this study, the subjects could not have impaired hearing or vision, due to the demands of the interventions and also needed to be unaware of the purpose of the study and the outcome measures.

Ethical considerations

All subjects participated voluntarily according to the Helsinki Declaration (World Medical Association, 2013) and were verbally informed about the study before signing the written informed consent form (Appendix 1) prior to the beginning of the study. Information about the participants was treated with confidentiality throughout the entire process including the final project and presentation. Since the study is not a medical research study, but a technological research study, it was considered not to expose the subjects to any health-related risks. The study was approved by the local Medical Ethics Committee (2017/188).

Study design

In this experimental study, all measurements were gathered during only one session with each subject. All subjects were assigned to an intervention group where they would function as their own control since no control group was formed. The subjects would be evaluated during each intervention in the trial and the study does therefore not fit perfectly in one of the standard study designs explained in the ”Study Design Classification Scale” (Hafner, 2008). This type of study is categorized as a repeated measure within subject design which resembles the “controlled before-and-after trial” (Hafner, 2008), with the difference being when the subjects are evaluated and the outcome measures assessed.

Experimental setting

The study took place at UMCG Beatrixoord in Haren, The Netherlands where all subjects were to walk on a self-paced dual-belt treadmill for a total of 18 minutes and 40 seconds, while a VR environment was projected on a 180° semi-cylindrical screen and onto the treadmill (GRAIL, Motek Forcelink BV, The Netherlands), showing a straight infinite path leading to a mill with a house next to it (Figure 3A). Before walking on the treadmill, the subjects' balance was determined, and they were tested if they suffered from any color vision deficiencies through Romberg's and Ishihara's test respectively. Furthermore, the subjects' preferred gait velocity was calculated by measuring the time it took for them to walk ten meters and they filled out the Physical Activity Readiness Questionnaire (PAR-Q) and a small questionnaire regarding their hobbies, sports, surgery and medication (Appendix 2). Afterwards, while walking on the treadmill, the subjects were to perform seven of eight different tasks called the interventions. During these interventions, subjects would perform a color-word Stroop task projected with words appearing on a white plane (40 x 140cm) with an interval of 1,5 seconds at the height of 165cm (Figure 3B) as in the previous study by Jeschke (2017). All subjects kept walking during their trial and all tasks were performed in Dutch. The eight different interventions are explained below under the section experimental conditions and interventions.

Experimental conditions and interventions

Ioriginal1 and Ioriginal2: This was an intervention similar to the original intervention described by Jeschke (2017). Here the subjects were to perform the color-word Stroop task without any feedback or other interferences. This intervention was given to all the participants as the first (Iorginal1) and last intervention (Ioriginal2) in the trial, to enable a within subject comparison to detect any effects that could be caused by tiredness, learning or a decline in concentration.

IzerolineA: This intervention consisted of the subjects performing a color-word Stroop task without being informed about the fact, that the acceleration-line was moved 15 cm to the back. The acceleration-line is the line on the treadmill that determines the area for acceleration and deceleration. If the subjects move in front of this line the treadmill will accelerate, and if they move behind this line the treadmill will decelerate. The aim of this intervention was to investigate if the increase in gait velocity when performing a color-word Stroop task while walking self-paced on a dual-belt treadmill in a VR environment (Jeschke, 2017) could be caused by the subjects trying to place themselves more in the forward direction on the treadmill, thereby making the increase in gait velocity a consequence of the subjects' position. By moving the acceleration-line more to the back, it would be possible to do a within subject comparison between this intervention, IzerolineB and Ioriginal1, which has an acceleration-line at 0, to investigate how the subjects place themselves and with what self-selected gait velocity.

IzerolineB: This intervention consisted, like IzerolineA, of the subjects performing a color-word Stroop task without being informed about the fact that the acceleration-line was moved 15 cm to the front. The aim of this intervention was like with IzerolineA, to investigate if the found increase in gait velocity (Jeschke, 2017) was caused by the subjects placing themselves in a more forward direction on the treadmill making the increase in gait velocity a consequence of this more forward position. By moving the acceleration-line more to the front, it would like with IzerolineA, be possible to do a within subject comparison between this intervention, IzerolineA and Ioriginal1 to investigate the theory illustrated in figure 1.

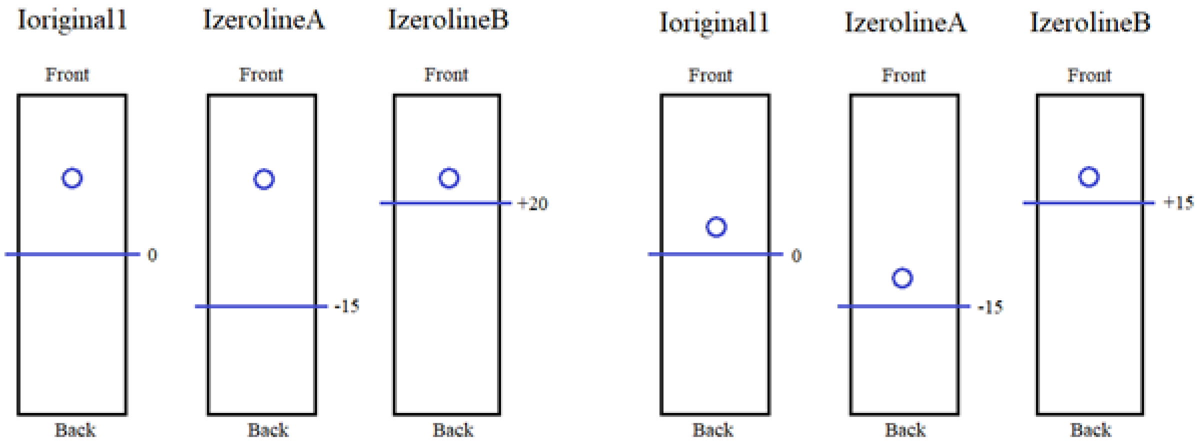

Figure 1: The placement of the acceleration-line in Ioriginal1, IzerolineA and IzerolineB. If the increase found in gait velocity is a consequence of the subjects' positioning themselves in a more forward direction on the treadmill, they will theoretically place themselves with a specific position on the treadmill as the blue dots on the treadmills to the left. If this is the case, it will be possible to detect a higher increase in gait velocity the further to the back the acceleration-line is placed. If the subjects on the contrary are focusing on their self-selected gait velocity, they will theoretically place themselves as the blue dots on the treadmills to the right.

Ineutralzone: In this intervention, the subjects performed a color-word Stroop task while walking self-paced on the treadmill, which was provided with a neutral zone ranging from 20 cm in front to 20 cm behind the original acceleration-line from Ioriginal1. The neutral zone consisted of an area in which the acceleration and deceleration was not active, resulting in the subjects having to cross the borders of the neutral zone to be able to change their gait velocity. The aim of this intervention was to investigate if the found increase in gait velocity (Jeschke, 2017) could be caused by the subjects positioning themselves in a more forward direction on the treadmill. By giving the subjects an area in which they would be able to place themselves without it affecting their gait velocity, it would be possible to do a within subject comparison between this intervention and Ioriginal1 to investigate the differences in gait velocity and position.

Ivisual: In this intervention, the subjects performed a color-word Stroop task while walking self-paced on the treadmill with the neutral zone and visual feedback active, thereby providing the subjects with real-time feedback on their whereabouts on the treadmill. The visual feedback consisted of the blue sky in the VR environment fading to red the closer the subjects got to the back edge of the treadmill, while fading to green the closer the subjects got to the front edge of the treadmill (Figure 3C and 3D). The fading of the visual color feedback began at the borders of the neutral zone at 20 cm in front and 20 cm behind the acceleration-line, as illustrated in figure 2. The purpose of this intervention was to explore, if the increase in gait velocity discovered by Jeschke (2017) could be caused by the subjects not knowing their position on the treadmill because of the lack of a reference point affecting the subjects to place themselves in a more forward direction on the treadmill thereby leading to the found increase in gait velocity. By providing the subjects with real-time visual feedback on their position on the treadmill, it would be possible to investigate how having the opportunity of knowing your position on a treadmill affects gait velocity and position though a within subject comparison between this intervention and Ineutralzone. Since both the visual feedback and the color-word Stroop task required visual attention, the feedback intervention was also done having audio feedback instead, making the subjects use another sense to perceive the feedback given on their placement on the treadmill.

Iaudio: In this intervention, the subjects performed a color-word Stroop task while walking self-paced on the treadmill with the neutral zone and audio feedback active, thereby providing the subjects with real-time audio feedback on their position. The audio feedback consisted of a sequence of beeps increasing in frequency the closer the subjects got to the front or the back edges of the treadmill thereby functioning as the park assist in a car. The first beeps would begin at the borders of the neutral zone at 20 cm in the front and 20 cm behind the acceleration-line and hereafter increase in frequency the further away from the acceleration-line the subjects got. By providing the subjects with real-time audio feedback, it would like with Ivisual be possible to investigate how having the opportunity of knowing your position on a treadmill affects position and velocity and it if was possible to substitute the lack of a reference point through a within subject comparison between Ineutralzone and this intervention.

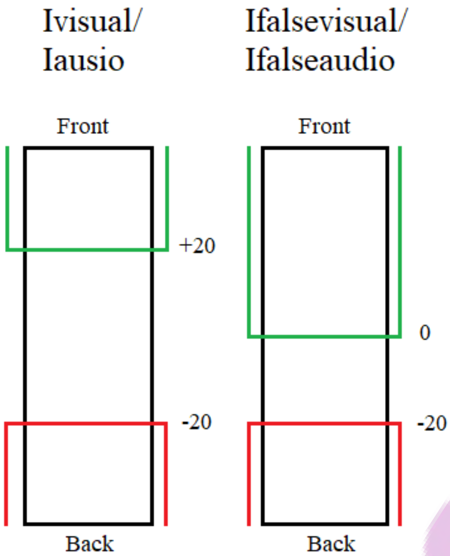

Figure 2: Placement of the feedback during Ivisual, Iaudio, Ifalsevisual and Ifalseaudio. This figure illustrates where the feedback is placed during the four feedback interventions. The neutral zone ranges from +20cm to -20cm in all interventions with a neutral zone regardless the placement of the feedback.

Ifalsevisual: In this intervention, the subjects performed a color-word Stroop task while walking self-paced on the treadmill with the neutral zone active and a false version of the visual feedback active. The false version of the visual feedback differed from the normal visual feedback intervention by changing the borders defining where the visual feedback would begin. The back border of the feedback would not be changed do to security reasons and remained therefore at the same distance from the acceleration-line at 20 cm behind this line. The front border of the false visual feedback was moved from 20 cm in front of the acceleration-line to exactly at the acceleration-line to let the feedback start sooner when the subjects would move forward thereby making the subjects believe that they were more anterior placed on the treadmill than they actually were, as illustrated in figure 2. The aim of this intervention was to investigate if the subjects would position themselves based on the information given through the feedback about their placement and if it was possible to place the subjects more in the back on the treadmill than they would otherwise do themselves because of the shorter distance to the back edge.

Ifalseaudio: In this intervention, the subjects performed a color-word Stroop task while walking self-paced on the treadmill with the neutral zone active and a false version of the audio feedback. The purpose of this intervention was, like with Ifalsevisual, to investigate if the subjects would position themselves based on the audio feedback given and if it is possible through providing them with false audio feedback on their position to make them place themselves more posterior on the treadmill than they otherwise would on their own. The false version of the audio feedback consisted of changing the borders from where the audio feedback would begin. These borders would be positioned at the same place as the borders in Ifalsevisual with the back border 20 cm behind the acceleration-line and the front border at the acceleration-line to enable the feedback to starter sooner, when the subjects would move more to the front on the treadmill. This way the false audio feedback would inform the subjects on being more anterior placed on the treadmill than their actual position, making it possible to do a within subject comparison between this intervention and Iaudio to investigate how this affects the subjects' position on the treadmill.

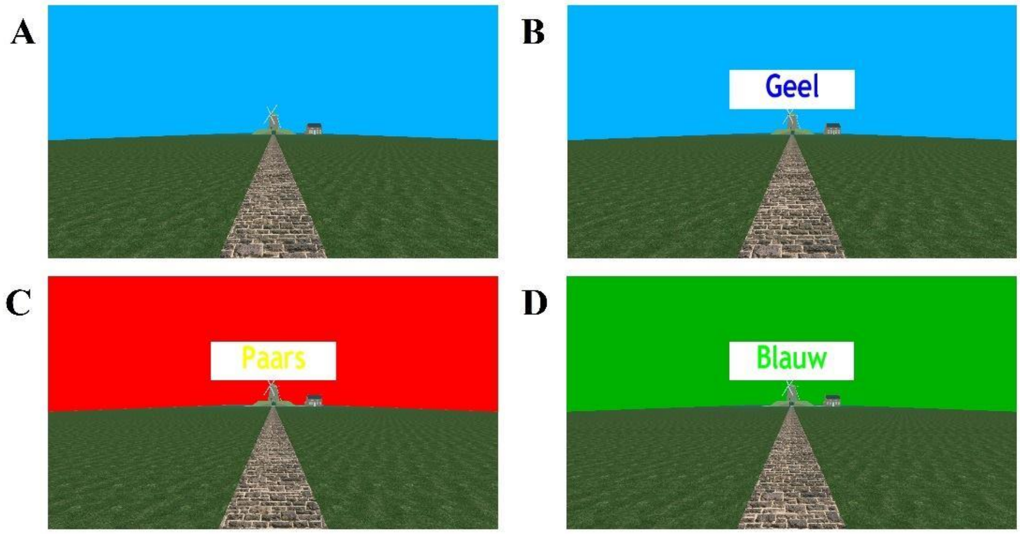

Figure 3: Screenshots of the VR environment projected onto the 180 semi-cylindrical screen. (A) The VR environment during all control conditions. (B) The VR environment with the color-word Stroop task as it would be experienced during all interventions. (C) The VR environment from Ivisual where the color-word Stroop task was projected and the real-time visual feedback was on. The sky would fade to red the closer the subjects got to the back edge of the treadmill, here the most possible red sky is illustrated. (D) The VR environment from Ivisual where the color-word Stroop task was projected and the real-time visual feedback was on. The sky would fade to green the closer the subjects got to the front edge of the treadmill, here the most possible green sky is illustrated.

All interventions lasted for 60 seconds and all subjects were exposed to all interventions except the intervention including false feedback. Here the participants would either receive the false audio feedback or the false visual feedback depending on which normal feedback intervention order they were randomized to. Since it could be expected that the subjects would gain too much information about the study's intentions by performing the false feedback intervention, the false feedback intervention regardless which one they received, was in the end of the trial only followed by Ioriginal2.

Before each intervention the subjects were exposed to a control condition (CC) consisting of walking for 20 seconds at a fixed velocity of 1 m/s followed by walking self-paced for 60 seconds without any kind of Stroop task being displayed at any time. The fixed velocity was used to reset the subjects' gait velocity after each intervention while the self-paced velocity was used to determine the subjects' preferred gait velocity when they were not performing a color-word Stroop task and to examine, if there was an increase in velocity when performing a color-word Stroop task by comparing it with the subsequent intervention.
Furthermore, some of the control conditions included a learning period, where the subjects would walk self-paced for 60 seconds while being exposed to either the neutral zone, the audio feedback or the visual feedback after having walked 20 seconds at the fixed speed of 1 m/s. These control conditions including a learning period were called CCneutralzone, CCaudio, CCvisual, CCaudio2 and CCvisual2 and were used to let the subjects get familiar with the neutral zone and the feedback, before using them while performing the color-word Stroop task in the interventions. The difference between CCaudio/CCvisual and CCaudio2/CCvisual2 was that CCaudio and CCvisual included a pre-set voice in the beginning, informing the subjects how the feedback worked by saying either "you will now be provided with real-time visual feedback on your placement on the treadmill, the sky will fade to red the closer you get to the back edge of the treadmill, while it will fade to green the closer you get to the front edge" or "you will now be provided with real-time audio feedback on your position on the treadmill, a sequence of beeps will increase in frequency the closer you get to the front or back edge of the treadmill". This information was not given during CCaudio2 and CCvisual2 since these control conditions would always be given as the last control condition only followed by a normal CC.

Below is a flowchart explaining one of the possible combinations for the trial when the interventions were randomized. The color of the different interventions explains the possible randomization for the trial.

CC → Ioriginal1 → CC → IzerolineB → CC → IzerolineA → CCneutralzone → Ineutralzone → CCvisual → Ivisual → CCaudio → Iaudio → CCaudio2 → Ifalseaudio → CC → Ioriginal2

Figure 4: Experimental design. Within the trial, two different randomizations took place independently of one another. The order of the two red interventions was randomized and the order of the two blue interventions was randomized. The blue interventions' associated control conditions (CCaudio and CCvisual) would still be placed just before each their respective feedback intervention causing them to be dependent on the randomization order of the blue interventions. The false feedback intervention and its corresponding control condition (CCaudio2 and CCvisual2) also followed the randomization order of the blue interventions being assigned dependent on which blue intervention came last. The order of all green interventions and control conditions were therefore sorted dependent on the randomization order of the blue interventions. All black control conditions and interventions would be placed as illustrated in all trials.

Materials

In this study, a self-paced dual-belt treadmill and a 180° semi-cylindrical screen was used with a VR environment projected onto them (GRAIL, Motek Forcelink BV, The Netherlands). A self-paced velocity algorithm (Sloot et al., 2014) was used to make the optic flow synchronize with the treadmill continuously. Furthermore, the subjects wore 4 reflective markers on the pelvis to determine their position and gait velocity while walking on the treadmill though an integrated motion capture system (VICON Bonita 10, Oxford, UK). To integrate and synchronize all the components, D-Flow software (Version 3.28, Motek Forcelink BV, The Netherlands) was used. The following variables were saved for data analyzing later on: Time, Intervention number, Treadmill velocity, vCOMz and COMz.

Data analysis

Before it was possible to perform the statistical analyses, the data was processed in MATLAB (Version R2016b for Windows, The Mathworks Inc. Natick, UN) and then transferred to Microsoft Excel (2016), where the mean gait velocity, mean standard deviation of gait velocity, mean velocity overground, mean position in relation to the acceleration-line and mean standard deviation of the position in relation to the acceleration-line were created. Regarding gait velocity only the last 30 seconds were used from each control condition and intervention, since reaching a self-selected gait velocity takes a smaller amount of time (Plotnik et al., 2015). With the position it was also chosen to use only the last 30 seconds of each intervention and control condition, since the subjects showed a tendency to use the first 10-15 seconds to resolve how the treadmill setting affected them. Furthermore, it was expected that the subjects would not end up at the acceleration-line because of the self-paced mode, but instead keep positioning themselves in relation to the acceleration-line thereby making it possible to use the last 30 seconds of the interventions.
Graphs were made for the different interventions showing mean position over time and mean velocity over time. It was observed that two subjects walked with an unusual velocity pattern during Ivisual, Iaudio and Ifalseaudio as compared to the rest of the subjects. A decision was therefore made to do a second data set where subject 7 and 12 were excluded containing the same variables as the complete data set.

Statistical analysis

When performing the statistical analysis, the software Statistical Package for the Social Sciences (SPSS) (IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp.) was used. Shapiro-Wilk's test was performed first to determine whether the collected data were normally distributed or not. Since it was the same subjects who were exposed to all interventions, where position and gait velocity were measured repeatedly, the data was dependent resulting in the following tests being used.
For the parametric data a two-way analysis of variance repeated measurements (ANOVA) was used to examine if there were any significant differences between the different interventions and control conditions regarding both position and gait velocity. In cases where $p<\alpha$ ($\alpha=0{,}05$) a significant difference was present, and a paired sample t-test was further used to analyze the difference found between each intervention and control condition separately. When performing the ANOVA test, a Mauchly's test of sphericity is automatically done to determine, whether the demands of the sphericity

is met which is the case if p>α (α=0,05). If on the other hand p<α (α=0,05), the sphericity is violated and a difference exists between the different interventions and control conditions. In this case, a correction such as Greenhouse-Geisser and Huynh-Feldt is needed to describe the statistical significance between the interventions and control conditions. If one of these values is below the chosen significance level while the other one is above, the mean of these two numbers are calculated and depending on whether this mean is higher or lower than the chosen significance level, the value above or under the significance level is used respectively. If both values on the contrary are above or below the chosen significance level, the Greenhouse-Geisser is used because of its more conservative nature (Hinton, McMurray & Brownlow, 2014).
For the non-parametric data the Friedman's test was used to examine if there were any significant differences between the different interventions and control conditions for both gait velocity and position. A significant difference was again present for p<α (α=0,05) and in these cases Wilcoxon Signed Rank test was used to further analyze the difference found, by investigating the interventions and control conditions separately.
For all statistical tests executed α=0,05 (confidence interval = 95%). Below is a flowchart illustrating the different statistical steps throughout the process (Figure 5).

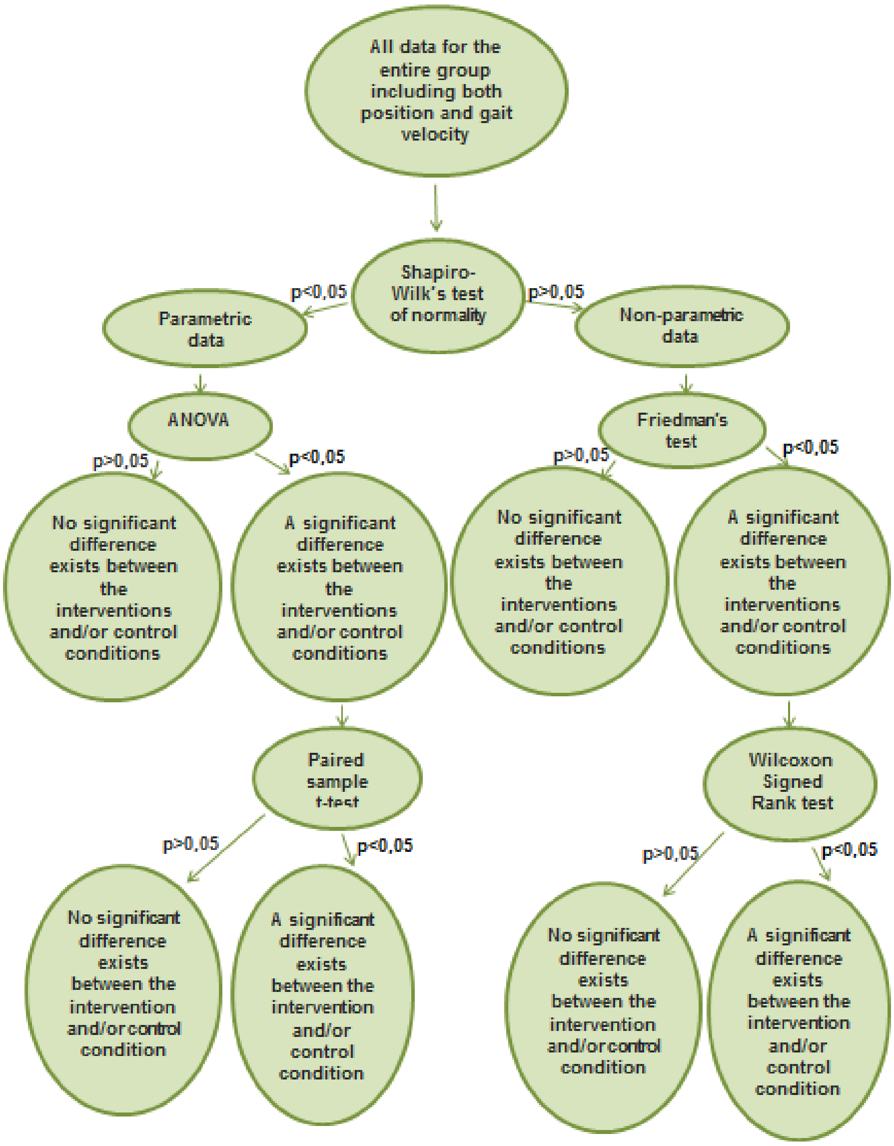

Figure 5: The entire statistical process done for all data.

Furthermore, besides performing all the above mentioned tests on the complete data set, the exact same tests were performed on the second data set where subject 7 and 12 were excluded to be able to investigate how these two subjects could have affected the final results.

Results

All twelve participants (8 females and 4 males) completed the study. The subjects had a mean age of 23,07 ± 1,79 years, a mean height of 176,16 ± 5,92 cm and a mean weight of 72,53 ± 13,32 kg. More specific demographic information for each subject is presented in table 1. Furthermore, Romberg's test, Ishihara's test and the PAR-Q questionnaire were negative for all subjects.

Table 1: The subjects' individual demographic data and mean walking velocity during overground walking.

Subject	Gender	Age	Height [cm]	Weight [kg]	Mean velocity, overground walking [m/s]
1	Female	23	169	64,8	1,53
2	Female	22	170	75,7	1,43
3	Male	21	183	78,8	1,34
4	Female	23	173	65,4	1,38
5	Female	22	178	69,7	1,37
6	Female	22	170	70,4	1,66
7	Female	25	170	108,9	1,34
8	Male	20	183	59,8	1,27
9	Female	22	176	59,3	1,43
10	Male	20	182	74	1,47
11	Male	25	185	79,5	1,54
12	Female	26	175	64,1	1,45

The ANOVA and Friedman's test showed a significant difference between the different interventions and control conditions for the parametric data for gait velocity (p=0,009), the parametric data for position (p=0,000) and the non-parametric data for velocity (p=0,026). No significant difference was found between the non-parametric data for position consisting of two interventions (p=0,564).

Velocity

Results showed a significant increase in gait velocity when the subjects were exposed to the original color-word Stroop task in both the beginning and the end of the trial with Ioriginal1 (p=0,001) and Ioriginal2 (p=0,002). Furthermore, no significant difference was found in velocity between the two Ioriginal interventions (p=0,480) meaning that no tiredness or decline in concentration was detected.

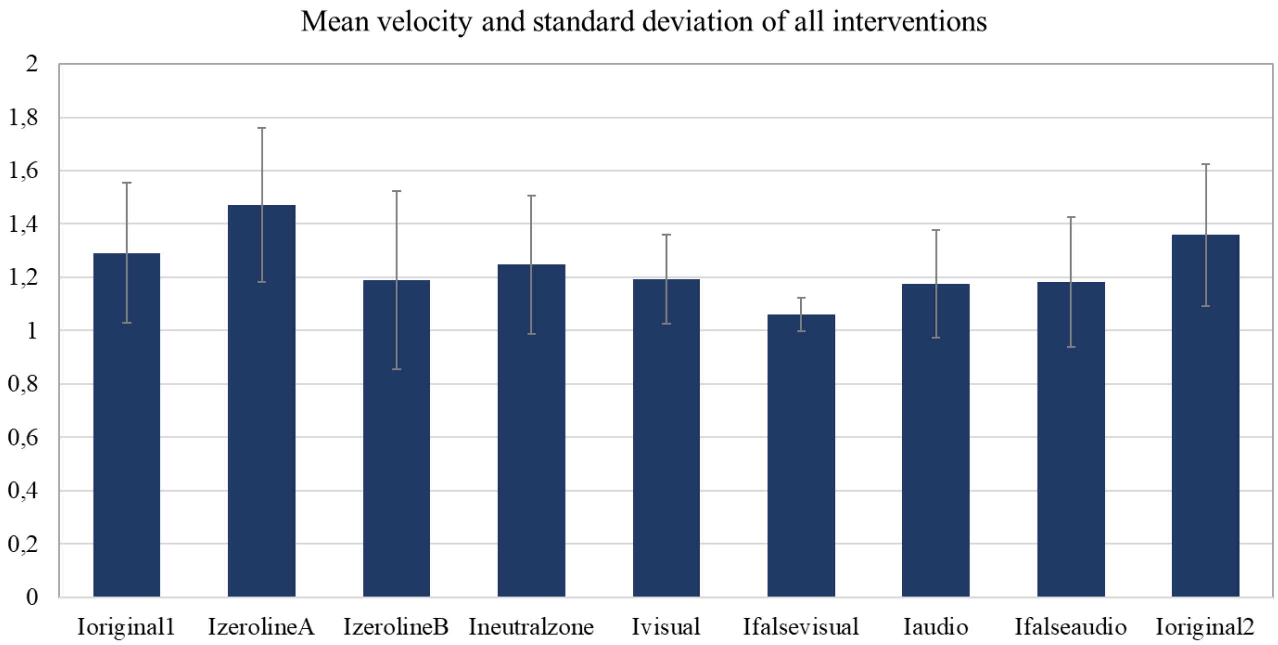

Figure 6: Mean velocity and standard deviation for all interventions based on the last 30 seconds of each interventions.

The presentation of the mean velocities for all interventions in figure 6 shows a general higher gait velocity the more to the back the acceleration-line is placed. A significant difference in gait velocity was found between IzerolineA and IzerolineB (p=0,034) with an increase of 23,5 %. An increase in gait velocity of 14 % between Ioriginal1 and IzerolineA was found not to be significant (p=0,066).

When comparing Ineutralzone to Ivisual and Iaudio no significant differences were found (p=0,814 and p=0,584 respectively). Additionally, when comparing Ivisual to Ifalsevisual and Iaudio to Ifalseaudio no significant differences were found (p=0,304 and p=0,917 respectively).

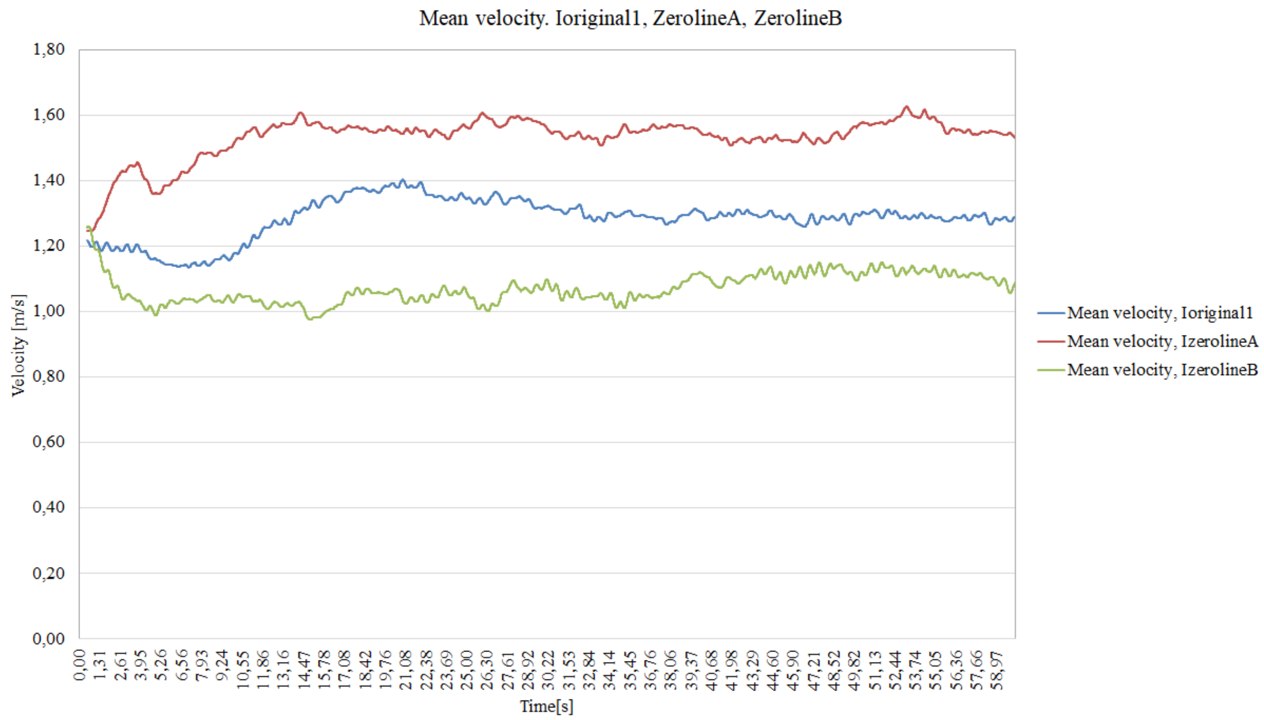

Figure 7: Mean velocity for all 60 seconds of Ioriginal1, IzerolineA and IzerolineB.

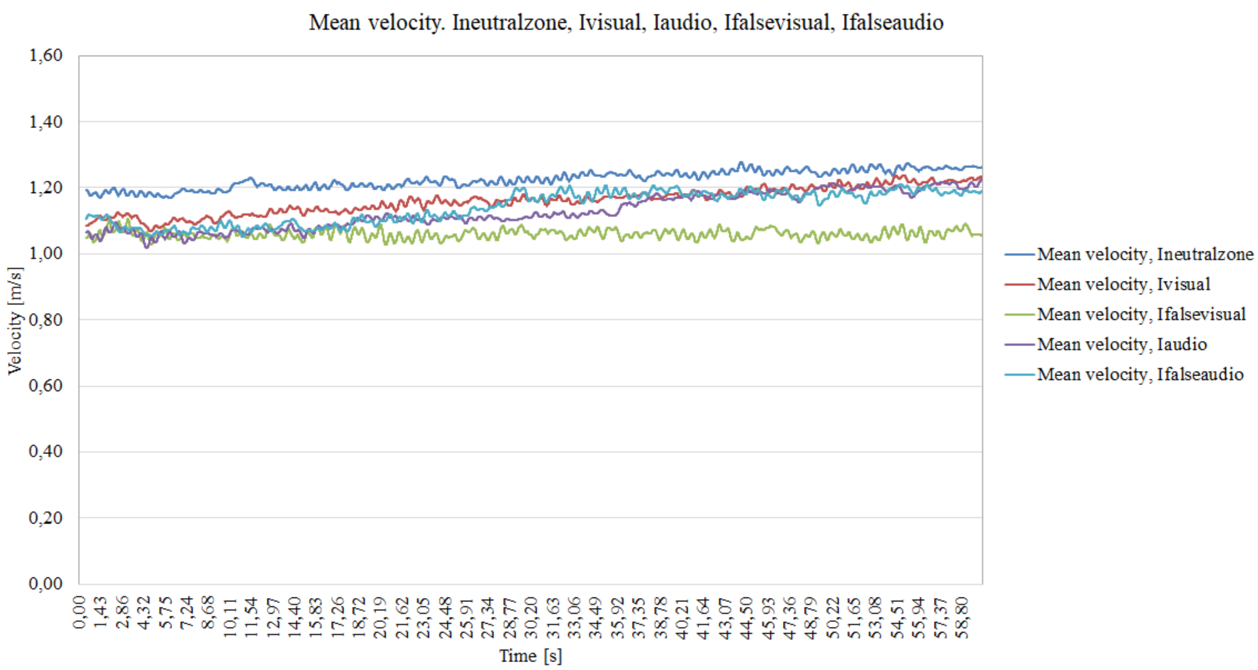

Figure 8: Mean velocity for all 60 seconds of Ineutralzone, Ivisual, Iaudio, Ifalsevisual and Ifalseaudio.

Position

When looking at figure 9, an increase in position (a more anterior placement on the treadmill in relation to the acceleration-line) can be seen when the acceleration-line is placed furthest to the back in IzerolineA, however no significant differences were found in position when comparing Ioriginal1 to IzerolineA (p=0,060) and Ioriginal1 to IzerolineB (p=0,485).

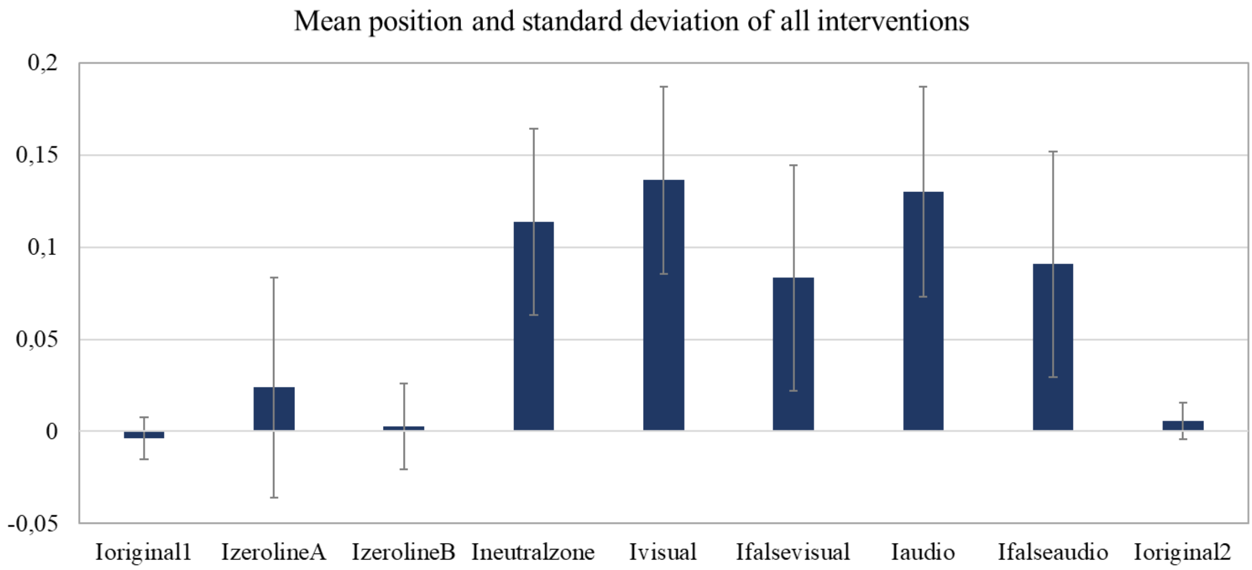

Figure 9: Mean position and standard deviation for all interventions based on the last 30 seconds of the interventions.

Between Ioriginal1 and Ineutralzone an increase in position of 11,76 cm was found to be significant. When comparing Ineutralzone to Ivisual and Iaudio, no significant differences were found (p=0,187 and p=0,372 respectively). In figure 9 which shows the mean position for all interventions, a decrease is seen between the feedback interventions and each their respective false feedback intervention. This decrease in position of 38,9 % for the visual feedback and 30,2 % for the audio feedback were not significant (p=0,187 and p=0,297 respectively).

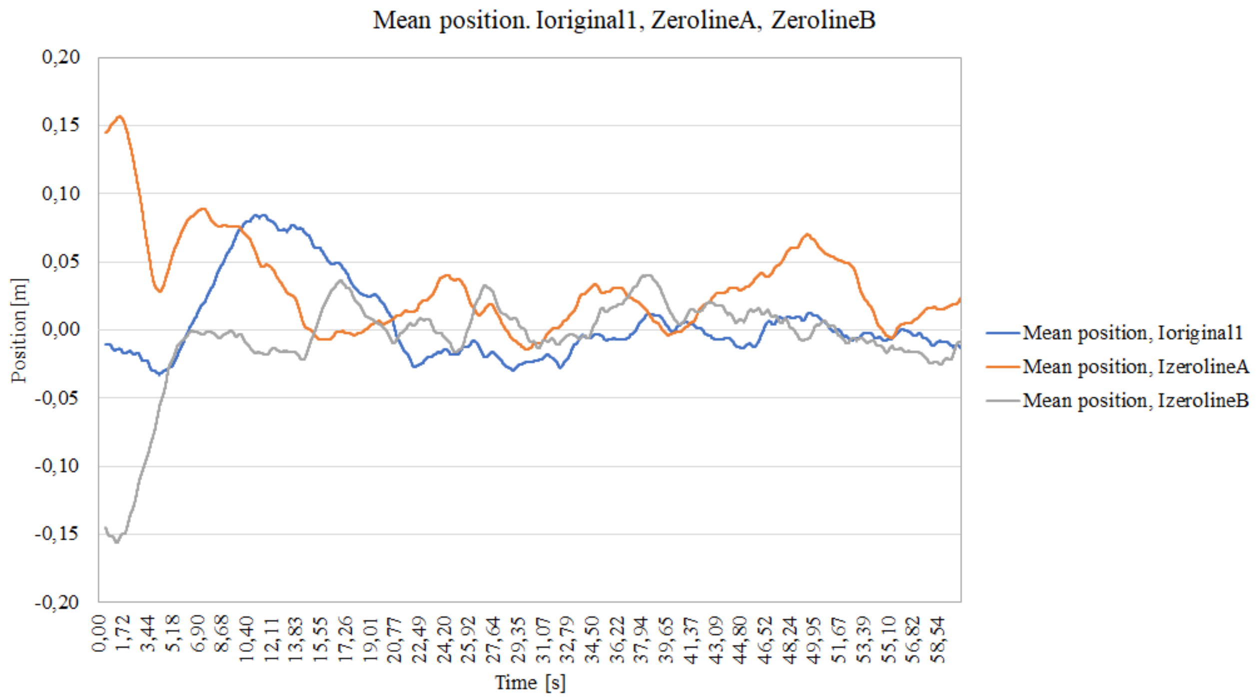

Figure 10: Mean position during Ioriginal1, IzerolineA and IzerolineB. This figure shows the mean position of the subjects during all 60 seconds of the interventions. The graph of IzerolineA and IzerolineB has been moved +0,15m and -0,15m respectively, so that all three interventions' acceleration-lines is placed at zero on the y-axis in this figure in order to simplify comparison.

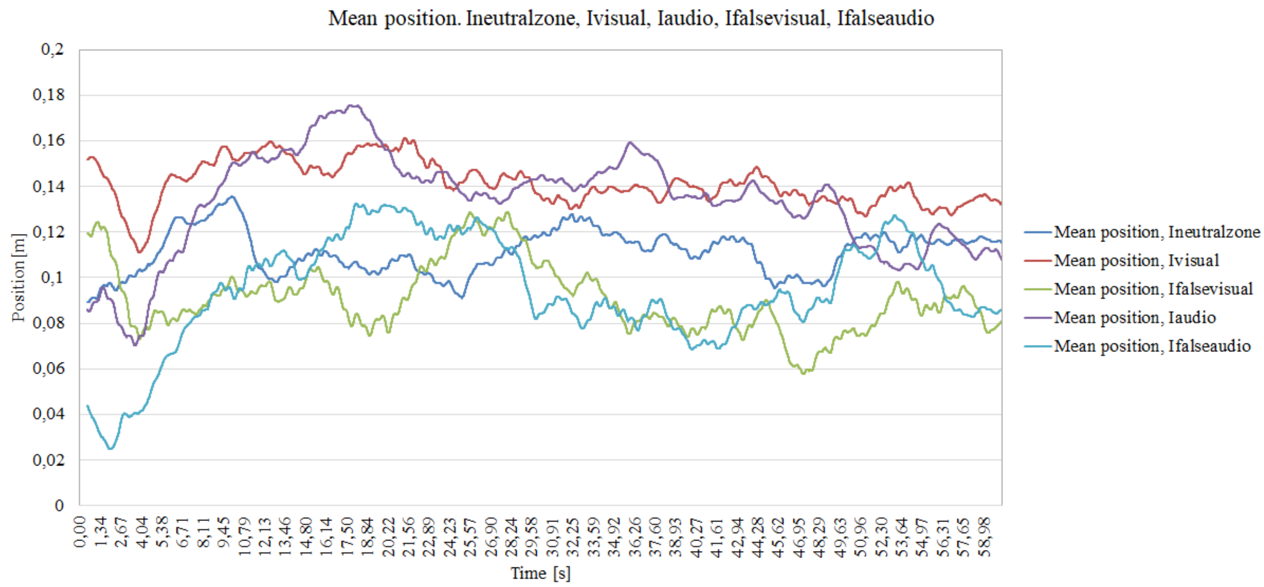

Figure 11: Mean position during all 60 seconds of Ineutralzone, Ivisual, Iaudio, Ifalsevisual and Ifalseaudio. The neutral zone in all displayed interventions ranges from -0,2m to +0,2m.

An overview of all results for all interventions and control conditions are shown in table 2.

Table 2: Mean velocity and mean position of the last 30 seconds for all interventions and control conditions including the standard deviation.

	Mean velocity [m/s]	Mean position [m]
CC	1,16 ± 0,24 *	0,0049 ± 0,0163
Ioriginal1	1,29 ± 0,26	-0,0037 ± 0,0113
CC	1,22 ± 0,18	0,0083 ± 0,0109
IzerolineA	1,47 ± 0,29	0,0238 ± 0,0597
CC	1,25 ± 0,17	0,0027 ± 0,0090
IzerolineB	1,19 ± 0,33 **	0,0026 ± 0,0234
CCneutralzone	1,18 ± 0,19	0,1081 ± 0,0437
Ineutralzone	1,25 ± 0,26	0,1139 ± 0,0505 *
CCvisual	1,09 ± 0,11	0,1148 ± 0,0683
Ivisual	1,19 ± 0,17	0,1364 ± 0,0507
CCvisual2	0,89 ± 0,42	0,1022 ± 0,0368
Ifalsevisual	1,06 ± 0,06	0,0833 ± 0,0611
CCaudio	1,06 ± 0,15	0,0847 ± 0,0745
Iaudio	1,17 ± 0,20	0,1302 ± 0,0571
CCaudio2	1,09 ± 0,17	0,1083 ± 0,0323
Ifalseaudio	1,18 ± 0,24	0,0908 ± 0,0613
CC	1,22 ± 0,18 ***	0,0046 ± 0,0086
Ioriginal2	1,36 ± 0,27	0,0056 ± 0,0098

* A significant difference is present when compared to Ioriginal1.
** A significant difference is present when compared to IzerolineA.
*** A significant difference is present when compared to Ioriginal2.

The second data set
The results of the second data set where subject 7 and 12 were excluded presented a mean velocity of 1,1422m/s, 1,0932m/s and 1,0272m/s for Ivisual, Iaudio and Ifalseaudio respectively and a mean position of 0,1266m, 0,1187m and 0,0675m in relation to the acceleration-line for Ivisual, Iaudio and Ifalseaudio respectively. None of the statistical test performed had a different conclusion on whether there was a significant difference present or not, as compared to the complete data set where all the subjects were included.

Discussion

The aim of this study was to determine, if the discovered increase in gait velocity when walking on a self-paced dual-belt treadmill in a VR environment while performing a color-word Stroop task, is a consequence of the subjects positioning themselves further in the forward direction on the treadmill. Furthermore, it was investigated whether it was possible to substitute the lack of a reference point by providing the subjects with real-time feedback about their position on the treadmill. Twelve subjects completed the trial including eight control conditions and eight different interventions containing interventions with real-time feedback and others with different placements of the acceleration-line. The outcome showed a statistical significant difference in velocity between IzerolineA and IzerolineB and between Ioriginal1 and Ineutralzone. No statistical significant differences were found when comparing any of the feedback interventions.

Discussion of results

Ioriginal1, IzerolineA, IzerolineB

When looking at the results of the statistical analysis, a significant increase was found in the self-selected gait velocity between both Ioriginals and their corresponding CCs. This confirms the results discovered by Jeschke (2017), stating that subjects increase their gait velocity when performing a color-word Stroop task displayed above the focus of expansion in a VR environment while walking on a self-paced dual-belt treadmill. Furthermore, a difference between the measured gait velocity during the 10-meter overground walking test (Table 1) and the subjects' self-selected gait velocity in all control conditions (Table 2) was present. All subjects walked faster overground than on the self-paced treadmill supporting the existing literature stating that subjects in general walks slower on a treadmill as compared to overground even though they are able to walk at a self-selected comfortable gait velocity (Marsh et al., 2006). This means that even though walking on a self-paced treadmill resembles overground walking (Plotnik et al., 2015; Sloot et al., 2014), they are not identical and differences are present.

When comparing Ioriginal1 to IzerolineA and Ioriginal1 to IzerolineB, no significant differences were found on the self-selected gait velocity. Nevertheless, when looking at the mean velocity in figure 6 and 7 for Ioriginal1, IzerolineA and IzerolineB, there is a clear tendency showing an increased gait velocity the further to the back the acceleration-line is positioned. This is in consistency with what was expected, since it was hypothesized that the subjects would increase their gait velocity when performing IzerolineA and decrease their gait velocity when performing IzerolineB as compared to each other and Ioriginal1. In accordance with this, a statistical significant difference was found in gait velocity between IzerolineA and IzerolineB. Furthermore, since the velocity is controlled by the subjects' position on the treadmill, it was expected that the subjects' position would also increase in distance to the acceleration-line the further to the back edge of the treadmill the acceleration-line was placed. However, this was not the case. When looking at the results for the position in Ioriginal1, IzerolineA and IzerolineB no significant differences were found even though it is possible to detect a small increase in position for IzerolineA as compared to Ioriginal1 and IzerolineB as illustrated in figure 10.

When looking at the data for position it should be kept in mind, that the self-paced algorithm which controls the velocity in relation to the position would always automatically make the subjects keep returning to the acceleration-line, since they would otherwise keep increasing their gait velocity. It was therefore not possible to measure if the subjects would keep a specific distance to the accelerations-line in these three interventions or if they would keep increasing their position in relation to the acceleration-line the further this line was placed to the back, as it is illustrated in figure 1. However, a significant increase was found in self-selected gait velocity between IzerolineB and IzerolineA, where the difference in placement of the acceleration-line between the two interventions was 30 cm. To increase the gait velocity, a forward position in relation to the accelerations-line is needed making these results clearly indicate that the subjects positioned themselves further in front of the acceleration-line the further this line was placed to the back. This suggests that the discovered increase in self-selected gait velocity when performing a color-word Stroop task projected above the focus of expansion is a consequence of the subjects positioning themselves further in the forward direction on the treadmill.

When looking at the mean velocity for all interventions and control conditions in table 2, it is possible to identify an increase in gait velocity, however non-significant, between each control condition and their subsequent intervention with the only exception being between IzerolineB and its associated control condition. In this case where the acceleration-line in IzerolineB is moved 15 cm to the front, a decrease in velocity is found which would be the expected finding when walking self-paced on a dual-belt treadmill while performing a dual-task (Al-Yahya et al., 2011; Beauchet et al., 2005; Springer et al., 2006; Yogev-Seligmann et al., 2010). This finding suggests that if Jeschke (2017) had moved the acceleration-line further to the front on the treadmill, she would not have found an increase in gait velocity which strongly emphasizes that the discovered increase in gait velocity was a consequence of the subjects positioning themselves further in the forward direction on the treadmill.

In accordance with this, it was observed that two subjects positioned themselves so much in front of the acceleration-line during IzerolineA, that they after approximately 20 seconds reached the maximum gait velocity limit of 2 m/s. This limit was set for security reasons and because it was intended to investigate gait parameters and not the effects on running. However, this does affect the data since they were not able to reach their own maximum velocity and they reached a more anterior position in relation to the acceleration-line as the velocity was not too high to maintain. It could though also have been very interesting to see how fast they would move to keep the distance to the accelerations-line if there was no maximum velocity limit. On the other hand, if this was the case, one could argue for excluding the two subjects in the final data, since these would affect the mean velocity too much when the intention was to look at the relation between velocity and position when walking.

To the authors' knowledge, no previous studies have been investigating the association between velocity and position on a self-paced treadmill where the position of the subject controls the velocity of the treadmill. This lack of scientific literature makes this study contribute with new knowledge on the effects caused by this relation and gives a possible explanation for the detected increase in self-selected gait velocity when walking on a self-paced treadmill in a VR environment while performing a color-word Stroop task.

Ineutralzone, Ivisual, Iaudio, Ifalsevisual, Ifalseaudio

When comparing Ioriginal1 to Ineutralzone, the intention was to investigate whether the subjects would move in front of the borders of the neutral zone or position themselves within the neutral zone where their velocity would not be affected by their position. It was theorized that if the subjects stayed within the neutral zone, it would indicate that it is in fact the subjects' position which causes the increase discovered by Jeschke (2017). If the subjects on the contrary moved outside the borders of the neutral zone it would not be possible to conclude whether it was to increase their gait velocity or to place themselves in a more forward direction on the treadmill. When looking at the results, no significant difference was found in the self-selected gait velocity between Ioriginal1 and Ineutralzone, while if looking at position on the contrary, a significant difference was present. The fact that the subjects would reach almost the same velocity in both interventions but being positioned completely different, shows that the subjects would start the interventions containing a neutral zone by crossing the front border of the neutral zone to increase their gait velocity and then move more to the back to stay within the neutral zone for the rest of the intervention with an average position of 12 cm in front of the middle of the neutral zone called the zero-line equivalent to the acceleration-line in Ioriginal1. This difference in placement is also illustrated in figure 11 where it is clearly seen, that the subjects mostly stay within the front part of the neutral zone and thereby avoid the area in the back, which additionally indicates that the subjects position themselves further in the front on the treadmill in relation to the acceleration-line when performing a color-word Stroop task. As earlier mentioned, this more anterior placement of the subjects is most likely the explanation for the detected increase in gait velocity in Ioriginal1.
A disadvantage with the neutral zone is the fact that the subjects could have problems accelerating and decelerating the treadmill because of the longer distance between the two borders defining the acceleration and deceleration. Since the subjects were observed to walk more in the front in the neutral zone, this explained disadvantage could be expressed through the subjects easily being able to increase their gait velocity and then not being able to decelerate it again, because of the long distance to the back border of the neutral zone. This could result in the subjects walking faster than they would prefer if it was easier for them to decelerate their gait velocity. This confounder is suspected to have affected the gait velocity in the interventions containing a neutral zone and might have contributed to the non-significant result in velocity between Ioriginal1 and Ineutralzone.

When looking at the results of the interventions with feedback, the statistical analyses showed no statistical difference in either position or velocity when comparing Ineutralzone to Ivisual and Iaudio and when comparing the two feedback interventions with each other. Jeschke (2017) suggested that the lack of a visible reference point could be a contributing factor to the discovered increase in gait velocity. The feedback interventions were created with the intention of substituting the lack of a reference point and thereby enable the subjects to know their position on the treadmill and the distance to the edges. It was theorized that if the subjects walked outside the borders in Ineutralzone, they would also do it in these interventions and experience a decrease in gait velocity because they would be made aware of their position and the fact that they were not too close to the back edge of the treadmill. If the subjects on the contrary did not move outside the borders in Ineutralzone it was theorized that they would not do it here either and therefore not activate the feedback causing them not to experience it and therefore not be able to position themselves based on it. The lack of significant results within these interventions is therefore a result of the subjects positioning themselves within the neutral zone causing them not to experience the feedback making them walk with the same position and gait velocity as in Ineutralzone.
When comparing the two feedback interventions, Ivisual and Iaudio, the authors were surprised not to find any statistical differences in either velocity or position. It was anticipated that the audio feedback would make a stronger impression and therefore not be overlooked as easily as the visual feedback might have been, based on the authors own experience during the programming of the trial. This result could again be explained by the results in Ineutralzone, where the subjects placed themselves within the neutral zone which describes why the subjects did not experience the feedback as much as it was intended.
As with the feedback interventions, no statistical differences were found in position and gait velocity when comparing Ivisual to Ifalsevisual and Iaudio to Ifalseaudio. The intention with these false feedback interventions was to determine whether the subjects would position themselves based on the feedback or ignore it. The lack of statistical difference between the interventions could as previously described be an effect of the results in Ineutralzone. However, when looking at the mean position in table 2, it is possible to detect a pattern where the subjects positioned themselves 4 cm further to the back in Ifalsevisual and Ifalseaudio as compared to each their associated feedback interventions. This suggests that the subjects to a certain point used the false feedback given, informing them on being more anterior placed than their actual placement, to position themselves on the treadmill.

Since the results from Ineutralzone interfered with the results of the feedback interventions, it could have been very interesting to investigate how the feedback would have affected the subjects' position and velocity if the neutral zone had been non-existing or half the size causing the subjects to cross the front border of the neutral zone and thereby activating the feedback more.

When comparing the complete data set and the second data set, in which subject 7 and 12 were excluded, all statistical tests performed had the same conclusions meaning that the two subjects did not affect the final results. However, when looking at the mean velocities in Ivisual, Iaudio and Ifalseaudio for both data sets, a decrease is found when subject 7 and 12 were excluded. The two subjects were observed to suddenly increase their gait velocity which is thought to be caused by them discovering that activating the feedback were without consequences, causing them to cross the borders of the neutral zone. This difference between the mean gait velocity values shows that the mean gait velocity is relatively easily affected which occurs when a variation between the subjects is present. Nevertheless, these differences did not affect the final results of the statistical tests meaning that the variance caused by these two subjects were within reason.

Discussion of methods

Subjects and generalizability

When recruiting the subjects for this study, attention was given to obtain a slightly greater amount of women in the group to be able to compare the findings with previous research (Jeschke, 2017) even though this affects the generalizability somewhat negatively. However, both genders are well represented and all subjects passed the inclusion and exclusion criteria making the subjects considered healthy and without any physiological problems which could have affected the outcome measurements through different gait deviations. The fact that all subjects were young and healthy adults with a mean age of 23,07 years ± 1,79 does not represent the general users within rehabilitation well. A reduced gait velocity has been identified in many patient groups such as stroke patients, cerebral palsy patients, amputees and many others (Donoghue, Dooley & Kenny, 2016; Goh, Tan, Yang & Ng, 2017; Mohamed, Craig, Worden & Ayyappa, 2013). Furthermore, it has been proven that gait velocity declines with age especially after turning 60 years (Whittle, 2007) making the subjects used in this study walk faster than the general rehabilitation population since a large part of the people within rehabilitation programs are older patients. Nevertheless, this study intended to investigate the association between gait velocity and position to gain a better understanding of how the GRAIL system works and in which ways it can be used. The findings will therefore be applicable to all ages and diagnoses using the GRAIL system during both rehabilitation and gait research, making this study have a high external validity. Based on these considerations, the authors find the group and number of subjects used, to be a satisfying sample for this pilot study.

Overground walking

The measured gait velocity overground was used to investigate to what extent walking on a self-paced treadmill resembles overground walking when it comes to gait velocity. When looking at the measured gait velocities during overground walking (Table 1), none of the subjects walked slower than the normal walking speed for healthy adults being 1,2 m/s to 1,4 m/s (Donoghue et al., 2016; Mohamed et al., 2013). When looking at the gait velocity measured on the self-paced treadmill during all control conditions (Table 2) where the subjects could walk at their preferred speed, all subjects walked either slower or in the very low end of the interval for normal gait velocity for healthy adults emphasizing the difference in velocity between overground walking and walking on a self-paced treadmill. These results are contradictory to the results found by Plotnik et al. (2015) stating that preferred gait velocity on a self-paced treadmill is comparable to preferred gait velocity overground with the fact in mind that they are not identical. This difference in results can be caused by the subjects in this study not being given a training period on the self-paced treadmill before conducting the trial as in the study by Plotnik et al. (2015). The subjects were only shortly told that the velocity of the treadmill was controlled by them to ensure not letting them know too much about the study and to let the subjects walk with the same baseline of knowledge. This lack of a training period could have caused the subjects to walk slower during the control conditions because they had not learned how to fully operate and use the self-paced treadmill optimally thereby resulting in the bigger difference detected in gait velocity when compared to overground walking.
Additionally, the measured gait velocity overground was also used to determine the individual subject's preferred gait velocity since this reflects the most efficient velocity to walk with for each individual subject (Mohamed et al., 2013). If the subjects walked faster or slower than this velocity, they would need to use more energy (Mohamed et al., 2013). Since a big difference was detected between the

subjects' preferred velocity during overground walking and their preferred velocity on the self-paced treadmill it can safely be said that the subjects used more energy when walking on the treadmill as compared to when walking overground. This should be kept in mind when using the GRAIL system in the future even though these results are not directly applicable for all people and patient groups.

The neutral zone

The neutral zone created in this study was used to make sure, that the subjects would not be positioned at the zero-line because of the self-paced algorithm thereby making it possible to measure their self-selected position. Additionally, it was also used to make sure, that the subjects would be able to have an area during the feedback interventions where no feedback was active. If this feedback had been given during Ioriginal1 with the borders controlling the activation of the feedback being the acceleration-line, the feedback would have been constantly active. If the feedback on the other hand was chosen to be activated a couple of centimeters in front of and behind the acceleration line, the feedback would probably never get activated due to the fact that the treadmill makes the subjects stay at or close by the acceleration-line. The borders of the neutral zone were chosen in agreement by the researchers through discussing what would be reasonable to make sure the zone would not be too big or small and by trying it out multiple times. It was important that the neutral zone was big enough for the subjects to be able to position themselves where they wanted without it affecting their velocity to be able to actually use their measured position. If they would have kept crossing the borders, the self-paced algorithm would have kept returning them to the acceleration-line making it impossible to determine anything based on their measured position. Furthermore, it was important that the neutral zone was not too big since the subjects should have the possibility of accelerating and decelerating their gait velocity by crossing the borders of the neutral zone without getting to close to the edges of the treadmill.

An interesting observation found during the interventions including the neutral zone was that many of the subjects would keep walking with the gait velocity set from the fixed speed in the control conditions or only increase it a little. The fixed speed in the control conditions was used to reset the subjects' gait velocity but since some of the subjects never crossed the borders of the neutral zone, they would keep walking with the fixed velocity of 1 m/s from the control conditions. This velocity is lower than the normal gait velocity for healthy adults (Donoghue et al., 2016; Mohamed et al., 2013) resulting in the subjects needing to use more energy to walk (Mohamed et al., 2013). The authors theorized that the gait velocity of 1 m/s was not differing enough from the subjects' otherwise preferred gait velocity for them to make the effort to cross the borders of the neutral zone. It could therefore have been very interesting to see how the subjects would have positioned themselves and with what gait velocity they would have walked, if the fixed velocity in the control conditions had been much higher or lower making the difference more extreme and noticeable.

Validity and reliability

To the authors' knowledge, no previous studies have ever used something similar to the neutral zone to measure people's position on a treadmill making it difficult to determine the validity and reliability of the method. However, the results from the neutral zone intervention are in agreement with the results from IzerolineA and IzerolineB showing that the subjects positioned themselves further in front on the treadmill than the acceleration-line in Ioriginal1 making this method achieve some validity. Nevertheless, further studies are needed to determine the reliability of the method with possible alterations of the neutral zone. As previously mentioned, the neutral zone had a flaw since it made decelerating the gait velocity extremely difficult for the subjects because the deceleration-line was positioned too much in the back of the treadmill. The gait velocity data, but not the position data, could therefore be affected by this which therefore should be adjusted in future studies.

When measuring the subjects' preferred gait velocity during overground walking, the 10-meter walking test was used. This method has an excellent reliability and validity and is very commonly used to assess peoples preferred gait velocity (Bahrami, Noorizadeh Dehkordi & Dadgoo, 2017; Hendershot, Shojaei, Acasio, Dearth & Bazrgari, 2018; Lang, Kassan, Devaney, Coloc-Semenza & Joseph, 2016; Morgan, Hafner & Kelly, 2016; Peters, Fritz & Krotish, 2013). In this study, when measuring the time taken to walk the 10 meters, with 5 meters to accelerate and decelerate before and after, a normal stopwatch on the phone was used by only one of the researchers to ensure intra-rater reliability. The researcher was standing in the end of the hallway making it challenging to determine exactly when the line furthest away was crossed affecting the validity somewhat negatively. In the study by Bahrami et al. (2017) the researchers collecting the time were standing in the middle of the hallways length making it easier to see both lines. However, the subjects were aware of the purpose of the study and knew that their gait velocity was the main outcome measure unlike in this study where the subjects were asked to normally walk up and down the hallway without being aware of their gait velocity being measured. This contributes to reaching a satisfactory level of reliability for the method used to obtain these measurements.

The markers used to track the subjects' position on the treadmill were placed by the same researcher to avoid a high variability which can occur in marker placement between professionals (Gorton, Hebert & Gannotti, 2009) and to gain certain intra-rater reliability. Of the four markers used, two were placed on spina iliaca anterior superior (SIAS) and two on its respective posterior side to be able to calculate the mean position of these four markers thereby defining the subjects' position. When defining a bony landmark with retroreflective markers, there is a change that the markers will move in relation to the underlying bone structures because of soft tissue movements (Cappozzo, Catani, Leardini, Benedetti & Croce, 1996; Holden et al., 1997; Reinschmidt et al., 1997). These movements affect the validity of the markers negatively especially within gait analysis where the tracking of each segment in relation to one another is essential (Reinschmidt et al., 1997). However, in this study the intention was not to track individual segments in relation to each other but instead measure the anterior and posterior position of the entire body thereby seeing it as one segment in total. If the markers did move in relation to the underlying bone during this study, the subjects' position would not be seriously affected since the four markers were viewed and measured in the transverse plane where the possible movement of the markers are thought to be limited thereby causing no threat to the validity of the marker method used in this study.

Subjects-expectancy effect

When during an experimental study with subjects, one could fear that the subjects taking part in the study would react or behave in relation to what they would think the expected behavior should be. This is called the subjects-expectancy effect and is described by Gomm (2008) as being subjects having an expectation of a specific result leading them to unconsciously behave in a certain way to achieve this result. However, in this study none of the subjects were observed to explicit such behavior and when the subjects were asked after each their trial about their theories on the outcome measures, none of the subjects mentioned position or gait velocity.

The interventions in this study were randomized in order to avoid the subjects-expectancy effect by ensuring that the subjects did not gather to much information during the trial to walk differently in the last interventions as compared to the first. A small increase in gait velocity is seen when comparing the first CC to the last CC and Ioriginal1 to Ioriginal2. This small increase is thought to be a small learning effect since the subjects would learn how to control the self-paced treadmill a little better during the trial. Nevertheless, this small learning effect was not significant, and it can therefore be concluded that the subjects did not gather information about the study and its outcome measures during the trial in other to walk differently during the different interventions.

Limitations

As mentioned previously, this study was limited by not being able to measure if the subjects would experience an unsafe feeling when walking on the treadmill as it was theorized in the study by Jeschke (2017). If this had been possible to measure, the study would instead of investigating if people position themselves further in the forward direction have investigated why they do it and if it is related to the fear of being too close to the back edge of the treadmill making it a completely other study.

Another limitation was the sample size. This could also as previously mentioned have been bigger, which would have made the results more representative for the population. Nevertheless, this was a pilot study which intended to identify and investigate a potential relation between position and gait velocity making it unnecessary to use more participants. More subjects should however be used in further studies.

One of the biggest limitations experienced during this study was the lack of previous studies within the research area. To the authors knowledge no previous studies have investigated e.g. preferred position on a treadmill or feedback systems informing the subjects on their real-time position, which made it necessary for the authors to invent new methods in order to measure the needed outcome parameters. Additional knowledge on the area would have meant that previously validated or investigated methods could have been used, instead of developing new ones to which the strengths, weaknesses, validity and reliability are yet to be determined. Nevertheless, this made this study contribute with new knowledge and methods which can be used and applied in the future when working with the GRAIL. The authors' knowledge about the GRAIL system and all its different possibilities and functions when determining the aim, the method and the interventions was limited. This meant that the authors lacked a deeper knowledge on the GRAIL systems' functions when inventing the new methods used to measure the desired outcome parameters. It is possible that if the authors had possessed the complete knowledge about the GRAIL, the methods and the different interventions would have looked completely different because it had been possible to design other possible ways of gathering the desired outcome measurements.

Furthermore, another limitation which could have played a smaller role, was that the participants were native in Dutch and mostly spoke so. This resulted in a language barrier between the authors and the participants where information and details had the chance of getting lost. If the authors had been fluent in Dutch no misunderstandings or loss of information could have happened.

Clinical relevance and future research

The intention of the self-paced treadmills is to resemble overground walking which is why this study intended to provide a deeper understanding of the effects of the association between gait velocity and position to thereby gain a better understanding on how the self-paced treadmills works and in what ways they can be used.

The findings in this study contribute as previously mentioned with new knowledge on the effects caused by the relation between position and gait velocity when walking on a self-paced treadmill in a VR environment while performing a color-word Stroop task displayed above the focus of expansion. Furthermore, the findings explain what contributed to the detected increase in gait velocity in the study by Jeschke (2017) and describes how real-time visual and audio feedback of the subjects' position on the treadmill can affect people's gait velocity and position. The findings in this study should therefore be reflected upon in the future to be able to either apply or avoid these effects.

One could imagine when working with the GRAIL, a need for people in certain situations to voluntarily walk faster than they otherwise would on the treadmill without removing their control over the velocity. Here, the acceleration-line could be placed in the middle of the treadmill and a cognitive task could be placed above the focus of expansion to make the subjects walk faster than they otherwise would. The acceleration-line can always be placed differently dependent on the purpose of the individual training session or research aim. Furthermore, based on the results from the interventions with the false feedback, it was possible to see that the subjects' position can be controlled through such feedback. This could again be used in the future, if it is needed to control the subjects' position in for instance training sessions.

The findings can therefore be used to exploit the effects found with the feedback and between velocity and position. Nevertheless, it is also important to keep the effects in mind to be able to avoid them. This could for instance be if the subjects' gait velocity should not be affected by performing a cognitive dual-task projected onto the 180° semi cylindrical screen. Here the task should be displayed at or below the focus of expansion in order to avoid this or the acceleration-line should be placed further in front on the treadmill. However, since this study mostly investigated if there were any effects to be found between position and velocity and when exposing the subjects to real-time feedback, further research is needed to determine the exact effect at its size. Moreover, it could be very interesting to investigate the effects found, if the sample group is changed to for instance stroke patients or amputees and how subjects would behave to other kind of real-time feedback on their position on the treadmill since the types of feedback used in this study could seem artificial and a bit aggressive. Another very interesting topic for future studies is to investigate how people walk when performing a color-word Stroop task while walking overground. This should be compared to the measured parameters in Ioriginal1 to determine if this increase in gait velocity when performing a color-word Stroop task projected above the focus of expansion also occur when the subjects walk overground or if it is related to the treadmill.

Conclusion

The placement of the acceleration-line evidently influences the self-selected gait velocity when walking on a self-paced dual-belt treadmill in a VR environment while performing a color-word Stroop task causing the increase in walking speed to be a consequence of the subjects positioning themselves further in the forward direction on the treadmill. Furthermore, the subjects positioned themselves within the neutral zone, making it impossible to conclude if it is possible to substitute the lack of a reference point with real-time feedback about their placement on the treadmill. Nevertheless, a clear tendency to be able to influence subjects' position based on false feedback about their placement was present.

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Appendix

Appendix 1

The English version of the written informed consent form the subjects signed. Below is the Dutch version which was translated from this by a co-researcher who were fluent in Dutch.

Written informed consent form

Dear participant

We kindly ask you to participate in this technological research study. It is completely voluntarily to participate and you can leave at any point without explanation and with no consequences for you, your health or the research. Before you decide whether to participate or not please read the following information letter quietly.
If you have any questions after reading the information letter please feel free to ask or contact the researchers though the contact details below.

Information about the research:
It is voluntarily to participate in this study and you they can leave at any point without explanation and with no consequences for them, their health and the research.
Information about the participation will be treated with confidentiality, all personal information will be kept in a secure manner and only handled by the group.
You will be anonymous during the entire process including the final project, and the information gathered in the study will be used for research purposes only and deleted at latest 6 months following the completion of the study.
For this research you will be asked to walk on a treadmill for around 19 minutes at UMCG Beatrixord. While walking on the treadmill you will receive some clear and simple instructions. Besides that, you will be asked to fill out a simple general questionnaire about your hobbies, sports, surgery and medication. Furthermore, you will be asked to perform a couple of simple tests before walking on the treadmill to evaluate your physical form.
The are no medical risks, pain, threads against your personal integrity or other discomforts associated with the participation in this study.
If you would like to, you can receive the research findings per email, after the completion of the study. If you're interested, please let the researches know.

Kind regards

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After having read the above written information, being verbally information and have had the opportunity to ask questions and have these answered I voluntarily agree to participate in the above explained study.

Name:

Signature: Date:

The dutch version of the informed written constent form the subjects signed. This was the form the subjects were actually given.

Schriftelijk informed consent-formulier

Geachte deelnemer,

Wij vragen u vriendelijk om mee te doen aan een medisch-wetenschappelijk onderzoek. U beslist zelf of u wilt meedoen. Voordat u de beslissing neemt, is het belangrijk om meer te weten over het onderzoek. Lees deze informatiebrief rustig door.
Hebt u na het lezen van de informatie nog vragen? Dan kunt u terecht bij de onderzoeker. Onderaan de bladzijde vindt u de contactgegevens.

Informatie over het onderzoek:
U neemt geheel vrijwillig deel aan dit onderzoek. U mag dan ook op elk moment stoppen zonder daarvoor een verklaring te geven. Dit zal geen consequenties hebben voor u, uw gezondheid of het onderzoek.
Er zal vertrouwelijk omgegaan worden met de informatie over het deelnemen aan het onderzoek en de informatie die uit het onderzoek komt. Alle persoonlijke informatie zal binnen het onderzoek blijven en niet gedeeld worden.
U van het onderzoek zullen anoniem blijven gedurende het hele onderzoek. De informatie zal allee gebuikt worden voor onderzoeksdoelen en zal minstens 6 maanden na het onderzoek verwijderd worden.
Voor dit onderzoek mag u straks gedurende 19 minuten op een loopband lopen. Tijdens het lopen op de loopband zal u duidelijke en simpele instructies krijgen. Daarnaast zijn er nog een paar korte vragen die u dient in te beantwoorden en een paar korte testen die afgenomen moeten worden voor deelname aan het onderzoek. Deze zullen door de onderzoeker ingevuld worden.
Er zijn geen medische risico's, pijn, problemen met de persoonlijke integriteit van het onderwerp of andere ongemakken die samenhangen met de deelname aan dit onderzoek.
Als u hier behoefte aan heeft dan kunt u de uitkomsten van het onderzoek ontvangen per mail, zodra het onderzoek afgerond is. Als u hier interesse in heeft, geef dit dan aan bij de onderzoeker.

Vriendelijke groeten

Line Harboe Lorentzen	Lisbeth Dauerhøj Fleckner	Fleur van Ruller
Line@5xlorentzen.dk	Lisbeth.fleckner@gmail.com	f.van.ruller@st.rug.nl
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Na het lezen van de bovenstaande schriftelijke informatie, zijnde mondelinge informatie en de gelegenheid heb gehad om vragen te stellen en deze te laten beantwoorden, stem ik vrijwillig ermee in deel te nemen aan de hierboven toegelichte studie.

Naam:

Handtekening: Datum:

Appendix 2

Needed information from the subjects

Subjectnumber:

Gender:
Age:
Weight:
Height:
Balance (Rombergs test): positive/negative

- Eyes open: positive/negative
- Eyes closed: positive/negative

Prefered walking speed (time measured over 10 meters walking):

- Speed in m/s:

Colorblindtest (Ishihara test): positive/negative
PAR-Q:

	Questions	Yes	No
1	Has your doctor ever said that you have a heart condition and that you should only perform physical activity recommended by a doctor?		
2	Do you feel pain in your chest when you perform physical activity?		
3	In the past month, have you had chest pain when you were not performing any physical activity?		
4	Do you lose your balance because of dizziness or do you ever lose consciousness?		
5	Do you have a bone or joint problem that could be made worse by a change in your physical activity?		
6	Is your doctor currently prescribing any medication for your blood pressure or for a heart condition?		
7	Do you know of <u>any</u> other reason why you should not engage in physical activity?		

What is your occupation (student/employee)?

- If working, what kind of work do you do?
- If student, what are you studing?

Do you have any hobbies? Is yes, what?
Do you participate in any kind of sports/activities? Is yes, what?
Do you take any kind of medication?
Have you ever had surgery done?

Benodigde informatie van de proefpersonen

Proefpersoonnummer:

Geslacht: man/vrouw
Leeftijd:
Gewicht:
Lengte:
Evenwicht (test van Romberg): positief/negatief

- Ogen open: positief/negatief
- Ogen gesloten: positief/negatief

Comfortabele loopsnelheid (tijd gemeten over 10 meter lopen):

- Snelheid in m/s:

Kleurenblindtest (Ishihara test): positief/negatief
PAR-Q:

	JA	NEE
1. Heeft een arts ooit gezegd dat u een hartprobleem heeft en dat u alleen fysieke inspanning op advies van een arts zou mogen uitvoeren?	☐	☐
2. Heeft u pijn op de borst bij fysieke inspanning?	☐	☐
3. Heeft u in de afgelopen maand pijn op de borst gehad terwijl u geen fysieke inspanning uitvoerde?	☐	☐
4. Verliest u wel eens uw evenwicht als gevolg van duizeligheid of verliest u wel eens het bewustzijn?	☐	☐
5. Heeft u een skelet- of gewrichtsprobleem (bijvoorbeeld aan rug, knie of heup) dat kan verergeren door een verandering in u fysieke activiteiten patroon?	☐	☐
6. Schrijft uw arts op dit moment medicijnen voor (bijvoorbeeld plas pillen) in verband met bloeddruk of hartprobleem?	☐	☐
7. Bent u op de hoogte van andere redenen waarom u geen fysieke inspanning zou mogen uitvoeren?	☐	☐

Bent u: werkende/student

- Indien werkende, wat voor werk doet u?
- Indien student, welke opleiding doet u?

Heeft u hobby's? Zoja, welke?
Doet u aan sport of andere activiteiten? Zoja, welke?
Heeft u bepaalde medicatie?
Bent u ooit een operatie ondergaan?