Biomechanical differences between self-paced and fixed-speed treadmill walking in persons after stroke.

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Abstract

Background: Using self-paced treadmills for gait analysis requires less space compared to overground gait labs while a more natural walking pattern could be preserved compared to fixed-speed treadmill walking. Although self-paced treadmills have been used in stroke related intervention studies, studies comparing self-paced to fixed-speed treadmill walking in this population are scarce.

Methods: Twenty-five persons after stroke (10 males/15 females; 53 ± 12.05 years; 40.72 ± 42.94 months post stroke) walked on a treadmill in a virtual environment (GRAIL, Motek) in two conditions (self-paced and fixed-speed). After familiarization, all participants completed two trials (3 min) at comfortable walking velocity in randomized order. A paired-sample t-test or Wilcoxon Signed Rank test was used to calculate differences between both conditions for spatiotemporal parameters. Statistical Parametric mapping was conducted using the t-tests (SPM(t)), to statistically compare the kinematic and kinetic curves.

Results: The self-selected walking velocity on the treadmill was higher in the self-paced condition compared to the fixed-speed condition ($p<0.001$). However, most variability and symmetry measures were similar in both conditions. Only the standard deviation of the step length at the paretic side was significant higher ($p=0.007$) and step length symmetry was significantly better ($p=0.032$) in the self-paced condition. Detected kinematic and kinetic differences were small (< 3°, < 0.1 Nm/kg) and stride to stride variability was comparable in both conditions.

Conclusion: Based on the results of the current study, self-paced walking can be used as an equivalent to fixed-speed treadmill walking in persons after stroke. Accordingly, this justifies the use of this more functional mode in clinical gait assessment and rehabilitation trials.

Key words: stroke – gait analysis – self-paced – fixed-speed – treadmill walking

1. Introduction

Over the past decades the use of instrumented treadmills in gait analysis has increased because of the advantages compared to overground analysis (van der Krogt et al., 2014). Besides the fact that a treadmill only uses up a third of the space of traditional gait labs, the safety of the patients is more easily ensured by the use of a safety harness and hand rails (Parvataneni, 2009). Additionally, treadmill walking facilitates a continuous way of walking which allows measuring more consecutive steps within a smaller area compared to overground gait analysis (Plotnik et al., 2015; van der Krogt et al., 2014). This increased amount of steps can also be captured within a shorter amount of time due to the force sensors embedded in the treadmill (Hong et al., 2017). This in contrast to traditional labs where the force plates are integrated in the floor capturing only a few steps per transition of the walkway . Notwithstanding the benefits, walking on a treadmill is not always perceived to be equivalent to walking overground and potential differences should therefore be taken into account before automatically implementing it. Especially with respect to the needs and behavior of certain populations. For example, persons after stroke seem to walk slower (Bayat et al., 2005; Hesse et al., 1999; Kautz et al., 2011) and more symmetrically (Harris-Love et al., 2001) on a fixed-speed treadmill compared to overground.

Recent developments allow the use of self-paced treadmills, where the belt speed is automatically adjusted to the real-time individual walking velocity based on the position of the person on the treadmill. This may overcome certain challenges as the use of this self-paced walking potentially enables the individual to select and control his own walking velocity which may result in a more natural gait pattern compared to predetermined fixed-speed walking (Sinitski et al., 2015; Sloot et al., 2014b). Apart from the fact that healthy adults show increased variability of walking velocity and stride length in self-paced treadmill walking (Sloot et al., 2014b), no further clinically relevant differences between self-paced and fixed-speed walking could be detected in healthy controls (Sinitski et al., 2015; Sloot et al., 2014b) and transtibial amputee patients (Sinitski et al., 2015). A study examining children with Cerebral Palsy showed that stride width was wider when walking on the self-paced treadmill compared to overground walking and that there were small kinematic differences that need to be taken into account (van der Krogt et al., 2014). Although self-paced treadmills have been used in rehabilitation trials (Fung et al., 2006; Hacmon et al., 2012; Kizony et al., 2010; Krasovsky et al., 2013) and might induce a higher cognitive engagement of persons after stroke (Oh et al., 2021), studies comparing self-paced to fixed-speed treadmill walking in this population are scarce. Donlin et al. (2021) reported a smaller step width, but no changes in step length, step time or step time symmetry between self-paced and fixed-speed treadmill walking. However, they did not report on kinematics or kinetics (Donlin et al., 2021). Ray et al. (2020) reported no differences in peak ground reaction forces, but greater trailing limb angles when walking in self-paced mode compared to fixed-speed mode at the same velocity (Ray et al., 2020). In view of using these treadmills in self-paced mode for research and clinical treatment of , it is essential to know if the use of the self-paced mode influences the gait pattern of persons with stroke.

Therefore this study aimed to compare spatiotemporal (including variability and symmetry measures), kinematic and kinetic gait parameters between self-paced and fixed-speed treadmill walking in persons after stroke. Based on previous research we hypothesized a higher walking velocity and increased variability, but similar symmetry in self-paced compared to fixed-speed condition. Results could yield the feasibility of the use of this self-paced mode and whether important biomechanical differences should be taken into account during gait analysis or training on a self-paced treadmill.

2. Methods

2.1. Participants

Twenty-five participants were included in this study (10 females/15 males; 53 ± 12.05 years of age; 40.72 ± 42.94 months post stroke). Demographic and clinical characteristics of the study population are reported in table 1. Overground gait velocity was on average 1.1 ± 0.3 m/s as determined by calculating the average after walking 6x10m on the GAITRite (CIR Systems, Inc.) at self-selected walking velocity (Van Bladel et al., 2022). Based on the Fugl-Meyer scores participants showed a mild impairment of the lower limb and a moderate to mild impairment of the upper limb (Duncan et al., 1983). All subjects could walk independently as indicated by the FAC score ≥ 3 (Mehrholz et al., 2007) and felt moderate concerns about falling assessed by the seven items International Falls Efficacy Scale (Short FES-I) (Delbaere et al., 2010; Kempen et al., 2008). Six participants used an ankle-foot-orthosis (AFO) during their daily activities and therefore performed all trials with the use of their AFO.

Participants were recruited at the rehabilitation center of the XXX University Hospital and through advertising on social media. Persons after stroke could participate if they were able to walk independently during at least six minutes. Participants were excluded if they suffered from other neurologic, musculoskeletal, respiratory or severe cardiovascular disorders that affected gait performance. Other exclusion criteria were bilateral stroke, cerebellar stroke, lower limb orthopedic surgery in the past and cognitive or language impairments that hamper the patients from understanding simple orders.

This study was approved by the Medical Ethics Committee of the XXX University Hospital (xxx) and registered in a public repository (NCT xxx). All recruited participants agreed and signed an informed consent prior to the study.

Table 1. Demographic and clinical characteristics of the study population.

	MEAN (SD)	RANGE	N
Age (y)	53.00 (12.1)	26 - 68	
Sex (F/M)			10/15
Time since stroke (m)	40.72 (43.0)	2 - 168	
Overground velocity (m/s)	1.10 (0.3)	0.5 – 1.5	
FM LL (/34)	28.12 (5.0)	12 - 34	
FM UL (/66)	47.48 (17.4)	15 - 66	
Short FES-I (/28)	10.32 (3.6)	7 - 18	
Stroke type (I/H)			15/10
Paretic side (L/R)			12/13
FAC (3/4/5)			1/9/15
AFO			6

SD = standard deviation; N = number; Y = years; F = female; M = male; m = months; FM = Fugl-Meyer Assessment; LL = lower limb; UL = upper limb; FES-I = International Falls Efficacy Scale; I = ischemic; H = hemorrhagic; L = left; R = right; FAC = Functional Ambulation Categories; AFO = ankle foot orthosis

2.2. Study protocol

This cross-sectional study was part of a larger protocol (clinical trials registration NCT xxx). Walking trials were performed on an instrumented treadmill (R-Mill Forcelink, The Netherlands) in a Virtual Reality environment (GRAIL, Motek Medical BV, The Netherlands). After six minutes to familiarize to walking on the treadmill in self-paced mode, all participants completed two trials at comfortable walking velocity: 1) self-paced and 2) fixed-speed condition. Walking velocity in the fixed-speed condition was determined by starting at the average walking velocity of the familiarization trial in the self-paced mode and increasing the velocity with steps of 0.1 m/s. In the meanwhile participants were asked to indicate the preferred comfortable walking speed during the first minute of the fixed-speed trial before data recording started. The chosen velocity did not change during the recorded time period. During each condition participants had to walk for three minutes. The two last minutes were recorded and used for data-analysis. Conditions were offered in randomized order based on a computer-generated sequence and were performed on the same day. Participants were wearing a safety harness (JSP, PN 21) during the assessment and completed the trials without holding the handrails. They were allowed to rest in between the trials if necessary. However, none of the participants expressed the need to rest.

2.3. Data processing

Eight spatiotemporal parameters were obtained (velocity, cadence, step width, step length, stance phase duration, swing phase duration, double limb support duration and single limb support duration). For step width and step length, the coefficient of variation (CoV) was calculated by dividing the standard deviation by the mean and multiplying by 100 (%). To assess gait symmetry, ratios were calculated between the paretic and the non-paretic leg for the step length (spatial symmetry) and for the stance and swing phase (temporal asymmetry). Three-dimensional motion data was captured at 100 Hz by a ten camera Vicon system (Oxford Metrics, Oxford, UK) using the Full Body Plug-In Gait model (Davis et al., 1991). Ground reaction forces and moments were recorded by six force sensors underneath each belt (0.5 m x 200 m) at 1000 Hz. Analogue data and target data was low-pass filtered (bidirectional 4th-order Butterworth filter). Marker labelling, foot step detection and biomechanical calculations were performed in Nexus software (version 2.9.3). Initial contact and toe-off were detected based on vertical ground reaction forces (20 N threshold). Afterwards, c3d files were imported in Visual 3D (v6.01.36, C-motion Inc., USA) to eliminate strides with incorrect foot placement and to export time normalized data (101 data frames). Matlab R2020b software (9.9.0.1467703) was used to perform Statistical Parametric Analysis. Processed kinematic variables were movements of the shoulder, trunk, pelvis and hip in the three planes and movements of the head, elbow, knee and ankle in the sagittal plane. Processed kinetic variables were the hip and knee moments around the x and y-axis, ankle moments around the x-axis and hip, knee and ankle power.

2.4. Statistical analysis

Spatiotemporal parameters were analyzed using SPSS statistics for Windows Version 27. Normality of the data was verified using the Shapiro-Wilk test. Based on the results of normality tests a paired-sample t-test or Wilcoxon Signed Rank test was used to calculate differences between both conditions. A Spearman correlation coefficient was calculated to detect potential correlations between the difference (between self-paced and fixed-speed mode) in walking velocity and clinical characteristics (age, time since stroke, Fugl-Meyer score, Short Fes-I). Cohen's d effect sizes are calculated by dividing the difference of two population means by the standard deviation from the data. Effect sizes are considered to be small when $d = 0.2$, medium when $d = 0.5$ and large when $d = 0.8$ (Cohen, 1988). To statistically compare the kinematic and kinetic curves, Statistical Parametric mapping (SPM) was conducted using the open-source spm1d code (www.spm1d.org). A SPM script to run a paired t-test (SPM(t)) was used to compare the kinematics and kinetics between the two conditions by calculating the conventional univariate t-statistic at each point of the gait cycle. To estimate the magnitude of significant differences between the two conditions, mean difference curves were calculated. Finally, standard deviations of hip, knee and ankle flexion/extension were calculated for each of the 101 data frames based on 25 gait cycles (Schwartz et al., 2004). The difference in kinematic variability was evaluated using a paired t-test (SPM(t)) to compare the standard deviations between the two conditions. Statistical significance was determined at $p < 0.05$ for all statistical tests.

3. Results

3.1. Spatiotemporal differences

The comparison of all spatiotemporal parameters are presented in table 2. The self-selected walking velocity on the treadmill was higher in the self-paced condition compared to the fixed-speed condition ($p<0.001$) with a mean difference of 0.09 (± 0.08) m/s. No correlations could be detected between the difference in walking velocity and patient characteristics: age ($r = -0.269$; $p = 0.194$), time since stroke ($r = 0.212$; $p = 0.309$), Fugl-Meyer lower limb score ($r = 0.095$; $p = 0.652$), Fugl-Meyer upper limb score ($r = -0.138$; $p = 0.510$), fear of falling (Short Fes-I; $r = 0.080$; $p= 0.705$). Although all spatiotemporal parameters, except step width, show significant differences between both conditions, the mean differences do not exceed the values of earlier reported minimal detectable changes (Fulk et al., 2011; Geiger et al., 2019; Kesar et al., 2011; Lewek & Randall, 2011). When looking at the variability and symmetry measures, most parameters are similar in both conditions. Only the standard deviation of the step length at the paretic side is significantly higher ($p = 0.007$; MD 0.003 m) in the self-paced condition. Additionally the step length symmetry is significantly better ($p = 0.032$; MD 0.013) in the self-paced condition. However, both differences are too small to be clinical relevant. The reported effect sizes range between 0 and (-)0.5 and are considered small to medium.

3.2. Kinematic and kinetic differences

Significant differences between both conditions could be detected at certain periods of the gait cycle for the hip flexion/extension, hip abduction/adduction, knee flexion/extension, ankle flexion/extension and shoulder abduction/adduction angles at the paretic side and for the knee flexion/extension, shoulder flexion/extension and elbow flexion/extension angles at the non-paretic side. The SPM results of the significant parameters are presented in figure 1 for the paretic side and in figure 2 for the non-paretic side. Although several kinematic parameters showed significant differences between both conditions, the mean difference curves (appendix A and B) indicate that these differences were very small (< 3°). No differences could be detected between the two conditions for other upper or lower limb kinematics nor for trunk and pelvis kinematics.

Regarding the kinetics significant differences could only be detected for the ankle extension moment (both sides) and the knee extension moment at the paretic side (figure 3). Again, differences (<0.1 Nm/kg) were not clinically relevant.

3.3. Differences in variability between self-paced and fixed-speed treadmill walking

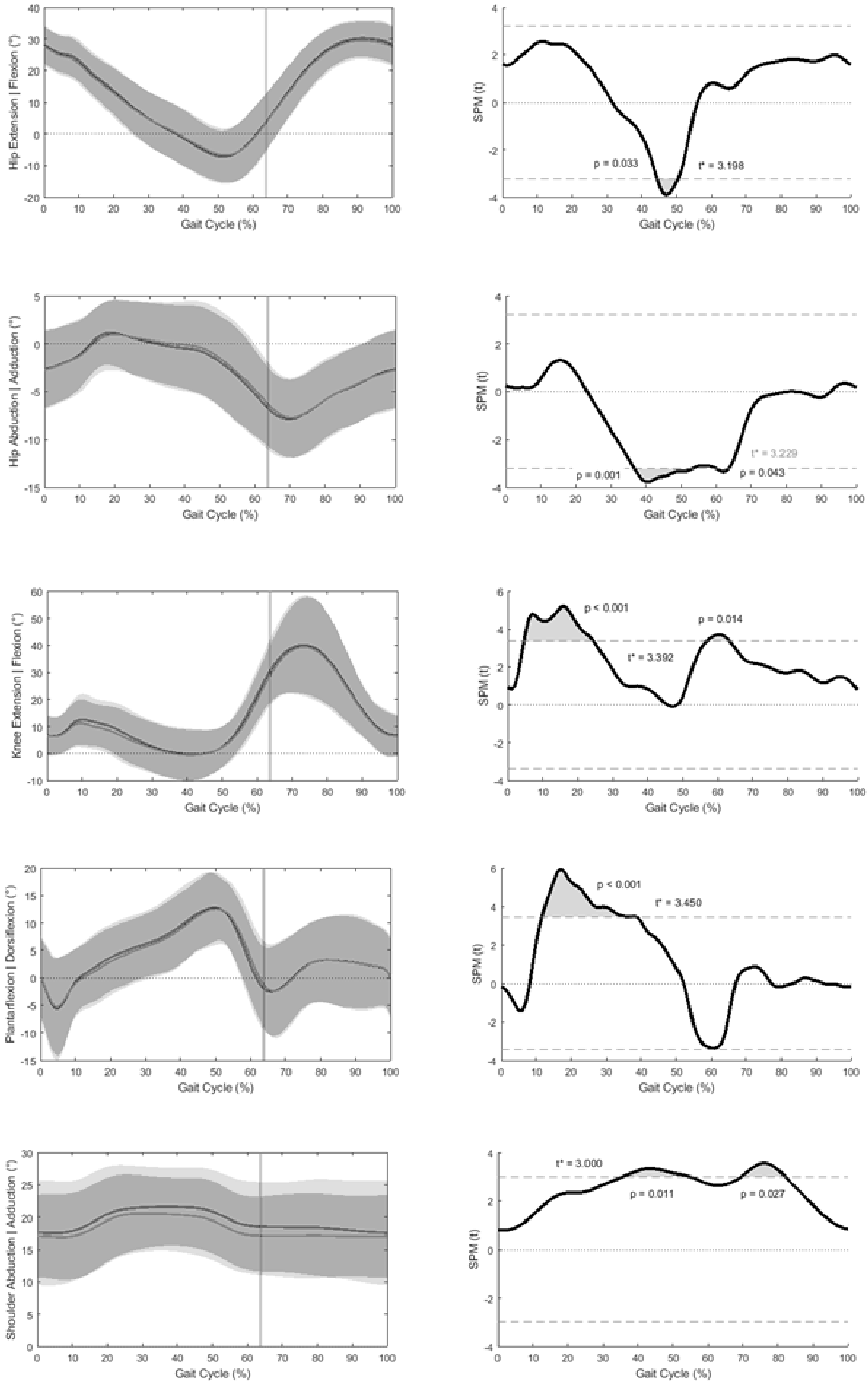
As a measure for the variability of the joint angles during walking, standard deviations of hip, knee and ankle movement in the sagittal plane were calculated for each of the 101 data frames. Based on the paired t-tests (SPM(t)) no differences in joint angle variability could be detected between both conditions.

Table 2. Comparing the spatiotemporal parameters between the self-paced and the fixed-speed treadmill condition.

	SELF-PACED		FIXED-SPEED					
	MEAN	SD	MEAN	SD	MD	95% CI	d	P
SPATIOTEMPORAL PARAMETERS								
Velocity (m/s)	0.92	0.266	0.83	0.216	0.093	0.060;0.130	0.4	**<0.001¥**
Cadence (steps/min)	103.04	15.62	98.92	13.53	4.121	2.421;5.821	0.3	**<0.001¥**
Step width (m)	0.208	0.039	0.206	0.041	0.002	-0.001;0.006	0.1	0.202¥
Step length P (m)	0.548	0.114	0.519	0.106	0.028	0.015;0.041	0.3	**<0.001¥**
Step length NP (m)	0.520	0.104	0.486	0.094	0.034	0.022;0.045	0.3	**<0.001¥**
Stance phase P (%)	63.40	2.355	63.93	2.188	-0.537	-0.872;-0.203	-0.2	**0.003¥**
Stance phase NP (%)	69.38	3.053	69.89	3.011	-0.563	-0.841;-0.285	-0.2	**<0.001¥**
Swing phase P (%)	36.60	2.355	36.07	2.188	0.537	0.203;0.872	0.2	**0.003¥**
Swing phase NP (%)	30.67	3.053	30.11	3.011	0.563	0.285;0.842	0.2	**<0.001¥**
Double limb support (%)	32.76	3.473	34.60	3.780	-1.833	-2.718;-0.947	-0.5	**<0.001¥**
Single limb support P (%)	30.68	3.037	30.11	2.990	0.578	0.300;0.856	0.2	**<0.001¥**
Single limb support NP (%)	36.59	2.340	36.07	2.170	0.520	0.180;0.859	0.2	**0.004¥**
VARIABILITY AND SYMMETRY MEASURES								
SD Step width (m)	0.021	0.005	0.020	0.004	0.001	0.000;0.002	0.2	0.060¥
SD Step length P (m)	0.025	0.007	0.022	0.006	0.003	0.001;0.005	0.5	**0.007¥**
SD Step length NP (m)	0.025	0.007	0.023	0.007	0.002	-0.001;0.005	0.3	0.111¥
CoV Step width (%)	10.27	2.49	9.95	2.50	0.322	-0.198;0.841	0.1	0.412§
CoV Step length P (%)	4.71	1.85	4.46	2.00	0.255	-0.217;0.726	0.1	0.264§
CoV Step length NP (%)	5.13	2.20	5.10	2.58	0.035	-0.568;0.638	0.0	0.904§
Step length symmetry	1.067	0.192	1.080	0.178	-0.013	-0.028;0.004	-0.1	**0.032§**
Stance phase symmetry	0.92	0.056	0.92	0.053	-0.000	-0.006;0.006	0.0	0.948¥
Swing phase symmetry	1.207	0.169	1.211	0.160	-0.004	-0.019;0.011	0.0	0.300§

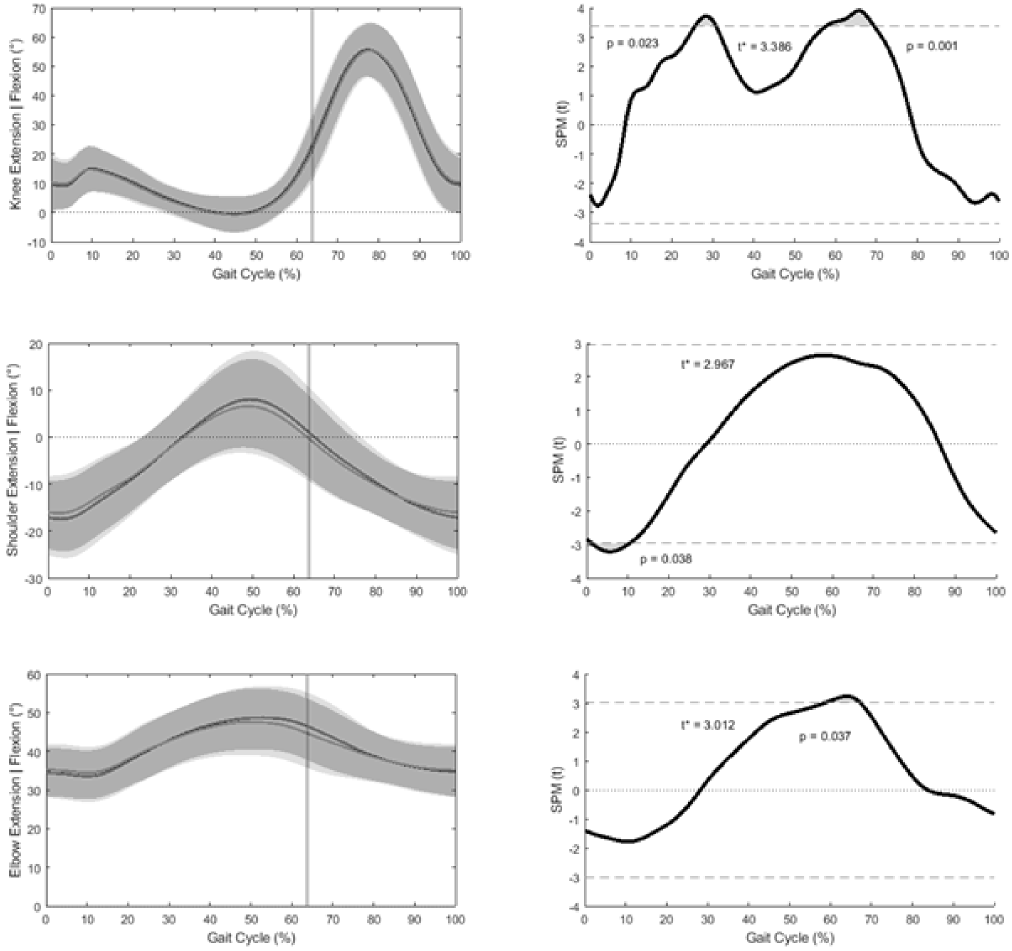
SD = standard deviation; MD = mean difference; d = Cohen's d; 95%CI = 95% confidence interval; m = meter; s = seconds; % = percentage of one gait cycle; P = paretic; NP = non paretic; CoV = Coefficient of variation; § = Wilcoxon Signed Ranks test; ¥ = Paired T-test; **$p < 0.05$**

Figure 1: SPM curves to illustrate the kinematic differences at the paretic side



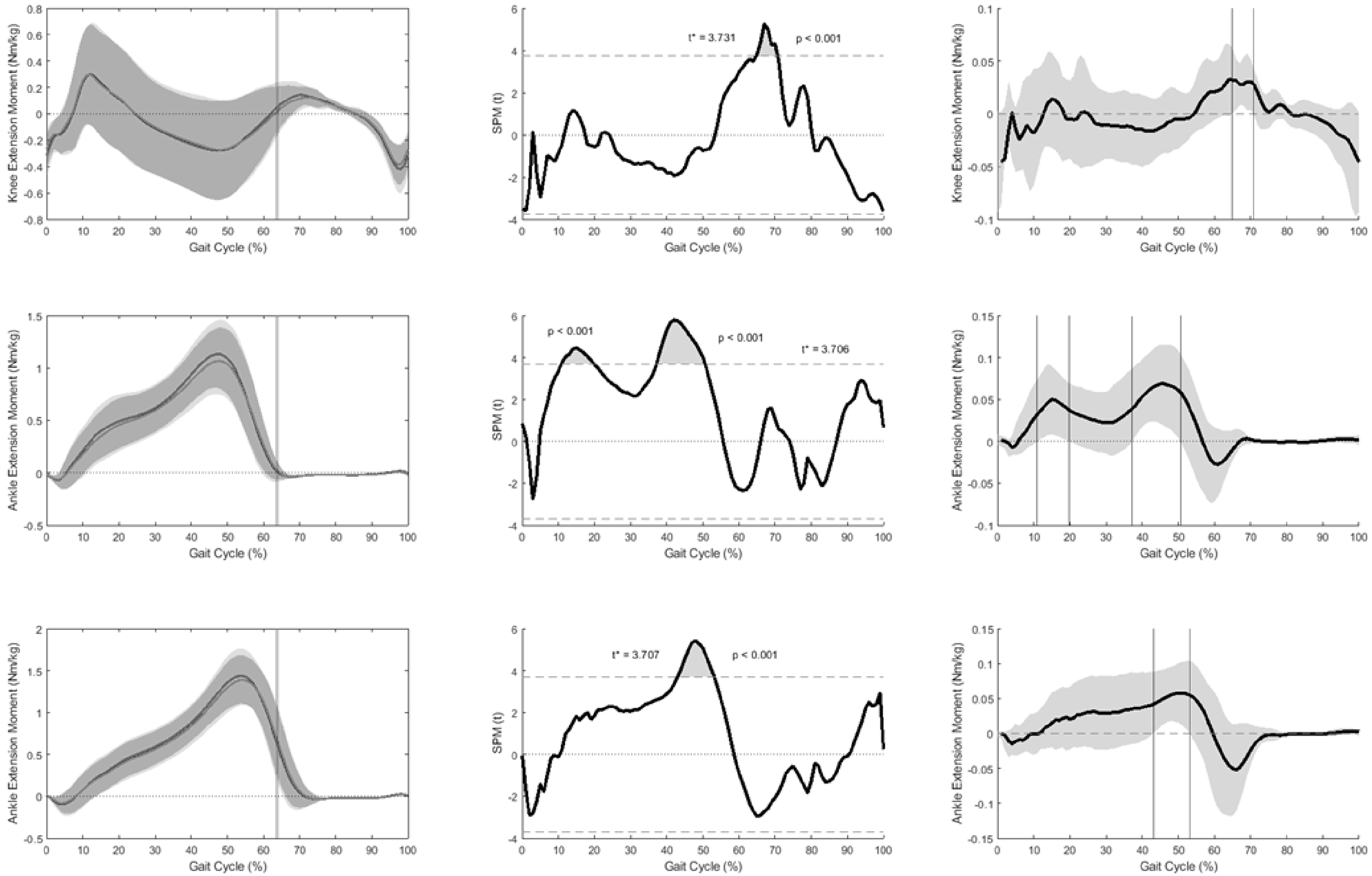
Left column shows the mean kinematic curves and standard deviations for the self-paced (gray) and fixed-speed condition (black). The right column displays the SPM (t) curves and indicates where the critical threshold was exceeded (t). Kinematic graphs display (from top to bottom) the hip flexion/extension, hip abduction/adduction,* *knee flexion/extension, ankle flexion/extension and shoulder abduction/adduction at the paretic side. The vertical line represents the push-off indicating the transition between stance and swing phase averaged over all participants.*

Figure 2: SPM curves to illustrate the kinematic differences at the non-paretic side



Left column shows the mean kinematic curves and standard deviations for the self-paced (gray) and fixed-speed condition (black). The right column displays the SPM (t) curves and indicates where the critical threshold was exceeded (t). Kinematic graphs display (from top to bottom) the knee flexion/extension, shoulder flexion/extension and elbow flexion/extension at the non-paretic side. The vertical line represents the push-off indicating the transition between stance and swing phase averaged over all participants.*

Figure 3: SPM curves to illustrate the kinetic differences at the paretic and non-paretic side



Left column shows the mean kinetic curves and standard deviations for the self-paced (gray) and fixed-speed condition (black). The vertical line represents the push-off indicating the transition between stance and swing phase averaged over all participants. The middle column displays the SPM (t) curves and indicates where the critical *threshold was exceeded (t*). The right column demonstrates the mean difference curves to indicate the mean difference at significant different time periods during the gait cycle. Time period of significant difference is illustrated by gray vertical lines. Kinetic graphs display (from top to bottom) the non-paretic knee extension moment the paretic and non-paretic ankle extension moment.*

4. Discussion

This study aimed to investigate eventual differences in spatiotemporal, kinematic and kinetic parameters between self-paced and fixed-speed walking on a treadmill in persons with stroke. Based on the mean difference between the two conditions it seems that persons after stroke selected a slower walking velocity in the fixed-speed condition compared to the self-paced condition. Accordingly, they showed a lower cadence, shorter step lengths, a longer double support phase and a shorter single support phase during the fixed-speed walking condition. Most variability and symmetry outcome variables were not different in both conditions, except for the standard deviation of the paretic step length and the step length symmetry. However, both differences are too small to be clinical relevant (Geiger et al., 2019; Kesar et al., 2011). Additionally, no clinical relevant differences could be detected for the other biomechanical parameters (kinematics, kinetics, joint angle variability). Similar to healthy adults and transtibial amputees (Sinitski et al., 2015) persons after stroke in our study preferred to walk slower in a fixed-speed compared to a self-paced condition. Although the mean difference in walking velocity (0.09 m/s) does not exceed the minimal clinical important difference (Fulk et al., 2011; Geiger et al., 2019; Lewek & Randall, 2011) and the effect size is small (0.4), it does need to be taken into account because of the potential effect of changes in walking velocity on other spatiotemporal parameters. Potential explanations for the slower walking velocity in the fixed-speed condition might be the feeling of control or feedback induced by the treadmill or the safety harness. Previous research has mentioned the challenged postural control and altered proprioceptive input when walking on a treadmill as a reason for slower walking velocities on the treadmill compared to overground (Derave et al., 2002; Stolze et al., 1997). Qian et al. (2019) also reported that self-paced walking was more unstable compared to fixed-speed walking induced by the variations in velocity during self-paced walking (Qian et al., 2019). Although none of the participants indicated to feel insecure while walking on the treadmill, some might have been careful not to increase the velocity too much in order to be sure that they could follow the treadmill velocity during the time of the trial. This in contrast to the self-paced condition, where participants were able to control their walking velocity.

Stout et al. reported no difference in spatiotemporal parameters between the non-weight bearing harness condition and no-harness condition when healthy controls walked on a fixed-speed treadmill (Stout et al., 2016). However, in contrast to the study of Stout at al. (2016) where the velocity was similar in the different conditions, self-paced walking in the current study did induce variations in walking velocity. These variations could provide sensory feedback to the participants received from the treadmill that slows down or from the stretch that they feel at the safety harness. However, these factors were not questioned during the trials.

It is known that walking velocity also influences the other spatiotemporal parameters (Fukuchi et al., 2019). Therefore, the significant differences that were reported in the current study are not unexpected and probably the direct result of the difference in walking velocity. Nevertheless, similar to the walking velocity itself, the mean differences or effect sizes were too small to be of any clinical relevance (Cohen, 1988; Geiger et al., 2019; Høyer et al., 2014; Kesar et al., 2011). Recently, Donlin et al. (2021) also compared spatiotemporal parameters of persons after stroke when walking in a fixed-speed and self-paced-driven condition. In contrast to the current results, they reported a smaller step width in the self-paced condition and no differences for step length, step time and step length asymmetry (Donlin et al., 2021). However, they only included high-functioning persons after stroke in the chronic phase after stroke and no information was provided about the walking velocity to compare to our study population.

Furthermore, we investigated if there were any kinematic or kinetic differences between the self-paced and fixed-speed condition or differences in stride-to stride variability. Similar to earlier reported results in healthy controls or children with Cerebral Palsy (Sloot et al., 2015; Sloot et al., 2014b) the mean differences at significant different time periods of the gait cycle reported in the current study were very small ($< 3°$ and < 0.1 Nm/kg) (Geiger et al., 2019; Kesar et al., 2011) and might sometimes have been influenced by differences in timing induced by the differences in walking velocity (Honert & Pataky, 2021).

The increased stride-to-stride variability reported in healthy adults when walking in a self-paced condition (Sloot et al., 2014b) could not be confirmed by our results. The only significant difference detected in the variability measures (spatiotemporal and kinematic parameters) was an increased standard deviation in the paretic step length. However, the mean difference of 2.5 cm does not exceed the minimal detectable change reported in earlier research (Geiger et al., 2019; Kesar et al., 2011).
This is the first study that described 3D biomechanics when walking on a self-paced treadmill compared to a fixed-speed mode in persons with stroke. Previously self-paced treadmills have been used in stroke rehabilitation research (Hacmon et al., 2012; Kizony et al., 2010; Krasovsky et al., 2013) because of their potential to simulate functional situations. Notwithstanding these studies identify differences between persons with stroke and healthy controls, they do not account for the potential effect of using a self-paced treadmill on post-stroke gait. Hacmon et al. e.g. reported differences in trunk kinematics only between persons with stroke and healthy controls while walking on a self-paced treadmill and did not investigate the effect of the self-paced treadmill on the trunk kinematics of the stroke population (Hacmon et al., 2012). Similarly, Kizony and colleagues, described a slower walking velocity in persons with stroke and healthy controls when walking on a self-paced treadmill during a dual task condition compared to overground without accounting for the impact of the self-paced treadmill itself (Kizony et al., 2010). Therefore, it remains unclear to what extent the use of the self-paced treadmill will influence these results.

However, since self-paced walking seems to induce higher levels of cortical activity in persons after stroke, probably due to the active engagement provoked by adaptations to varying treadmill velocities, (Oh et al., 2021) and no important biomechanical differences could be detected in the current study, self-paced walking can be used as an equivalent to fixed-speed treadmill walking in persons after stroke taking into account potential differences in walking velocity (Hacmon et al., 2012). Similar to previous research, the current study population walked slower on the treadmill (self-paced 0.92 m/s, fixed-speed 0.83 m/s) compared to overground (1.1 m/s). A potential solution when performing gait analysis on a self-paced treadmill, could be to determine the overground comfortable walking velocity.

In this way patients can be facilitated to walk at about the same velocity. Further research should investigate if this would allow to collect data that are more closely related to their usual walking pattern.

Limitations

Some limitations need to be taken into account. First of all, due to the limited sample size and the heterogeneity of the sample, current results cannot be generalized to the entire stroke population. However, the researchers defined the in- and exclusion criteria in an attempt to reflect the phenotype of persons with stroke that are eligible for performing a gait assessment on a treadmill. For persons with stroke that rely on walking aids to perform independent walking, gait analysis performed on a treadmill might be too challenging taking into account the difficulty to maintain their postural control elicited by the moving surface. Also, cognition might be a parameter affecting the potential of being able to use a self-paced treadmill. Although none of the participants experienced problems getting familiar with the self-paced mode in the current study, future research could provide insight on which subpopulation of persons with stroke would experience more problems with adapting to self-paced treadmill walking. Secondly, experience with treadmill walking has not been taken into account. However, a familiarization period of six minutes was provided to all participants to avoid any potential influence of experience in treadmill walking. Third, the use of a safety harness should be discussed related to trunk movements. Earlier research suggested smaller trunk movements when participants were wearing a safety harness (Aaslund & Moe-Nilssen, 2008). Although participants have worn the same safety harness in both conditions, it should be investigated if more trunk movements (and potential variations) could be detected when not wearing a safety harness. Finally, it would be interesting in the future to perform a comparison of 3D biomechanical data during fixed-speed, self-paced and overground walking on the same day to decide which treadmill mode is most closely related to overground walking in persons after stroke. Also, attention should be payed on how to determine the walking velocity in different conditions. Current study used different methods to determine the comfortable walking velocity in the self-paced and fixed-speed condition. Further research should explore the influence of this methodological aspect on the preferred walking velocity in persons with stroke.

5. Conclusion

Since no important biomechanical differences could be detected in current study, self-paced walking can be used as an equivalent to fixed-speed treadmill walking in persons after stroke. Accordingly, this justifies the use of this more functional mode in clinical gait assessment and rehabilitation trials as previous research suggested it might offer potentially added values by inducing more cortical activity and allowing persons after stroke to vary their walking pattern more similar to an overground condition compared to predetermined fixed-speed walking.

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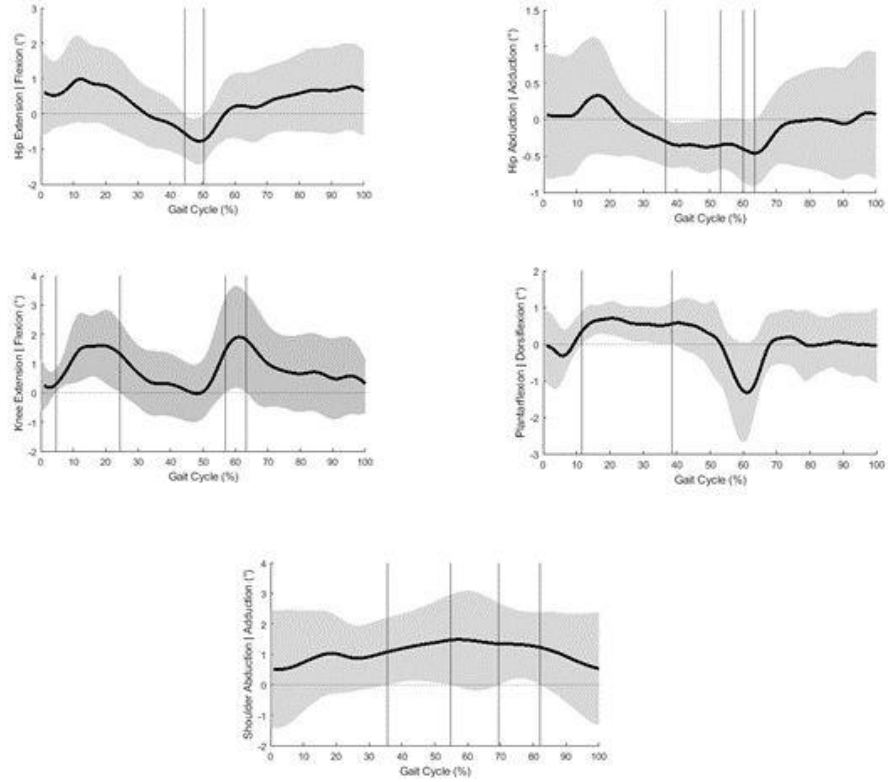
7. Appendices

7.1. Appendix A: MD curves of the paretic side kinematics



7.2. Appendix B: MD curves non-paretic side