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Research article

Paretic propulsion changes with handrail Use in individuals post-stroke

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ABSTRACT

Background: Roughly 800,000 people experience a stroke every year in the United States, and about 30% of people require walking assistance (walker, cane, etc.) after a stroke. Gait training on a treadmill is a common rehabilitation activity for individuals post-stroke and handrails are typically used to assist with walking during this training, however individual interaction with these handrails are not usually considered and quantitatively reported. Individuals may exert force onto the handrails to aid with propulsive force, but the relationship between limb propulsive force and handrail propulsive force are not known.
Research question: How do individuals post-stroke alter paretic propulsive force when using an assistive device, such as handrails on a treadmill?
Methods: Twenty-one individuals post-stroke (eight current assistive device users and thirteen individuals who do not use an assistive device) walked on a treadmill for 3 min during three conditions: no handrail use, light handrail use (<5% BW) and self-selected handrail use. Three multilevel models were used to compare percent handrail, paretic and nonparetic propulsion between handrail conditions and assistive device groups.
Results: The handrail propulsive impulse was more during the self-selected handrail condition compared to the light handrail condition ($p = 0.002$). The assistive device use group and the handrail condition fixed effects significantly improved the model fit for paretic propulsive impulse ($p = 0.01$). The interaction between assistive device use group and handrail condition significantly improved the model fit for nonparetic propulsive impulse ($p < 0.001$).
Significance: These results suggest that handrail use may impact paretic propulsive impulse. Our initial results suggest that if the goal of rehabilitation treadmill training is to increase the paretic propulsive impulse, having the clinician encourage walking with the handrails may be optimal to promote paretic propulsion.

1. Introduction

Most individuals post-stroke experience hemiparesis, or muscle weakness contralateral to the brain lesion [1], with more than 40%

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of stroke survivors having moderate or greater functional impairments [2]. Gait training is a common rehabilitation tool after a stroke and can occur in a variety of settings. Gait training on a treadmill provides an easy way to manipulate variables such as speed, while keeping a well-controlled environment. There are many individuals post-stroke that use assistive devices, such as a cane or handrails on a treadmill, for various reasons, including balance control, body support or added somatosensory information [3,4]. As such, many individuals post-stroke utilize handrails on a treadmill despite the fact that handrail use is not understood or controlled when assessing rehabilitation protocols. In order to better inform clinical care, there is a need to understand how handrail use may be changing the walking practice that individuals post-stroke are getting during treadmill training.

Little information is available about the biomechanical changes in gait which occur as a result of handrail use. Studies found that, while utilizing handrails, individuals post-stroke had a decrease in energy cost of walking, an increase in step length, a decrease in step width, an improvement in step length symmetry [3], an improvement in paretic single leg support and an improvement in temporal symmetry [5]. Another study found that arm movements, including handrail use, influenced the muscle activity of the lower limbs [6]. However, it is unclear how lower limb forces are altered when force is applied to the handrails. A common, but unproven idea, is that handrail use could redistribute loads from the lower limbs to the upper limbs and, in turn, impact gait.

An important component of lower limb force in individuals post-stroke is propulsion. Propulsion compensates for the energy loss and slowing down that occurs during heel strike, which makes it crucial for maintaining walking speed [7]. Individuals post-stroke typically have a lower propulsion on their paretic side, and this decreased propulsion is related to a decrease in walking speed [8,9]. Due to the importance of propulsion for walking and the common use of handrails among individuals post-stroke, information regarding the relationship between propulsive force and force applied to the handrails is needed.

The purpose of this study was to determine how the paretic propulsive force was altered with handrail use on a treadmill in individuals post-stroke, including individuals that were not reliant on an assistive device during usual walking and individuals that currently used an assistive device. Specifically, this study focused on anterior handrail force, as it was assumed that anterior handrail force would have the greatest contribution to anterior propulsion. We hypothesized that there would be an interactive effect of assistive device group and handrail use on propulsion. Specifically, we hypothesized that individuals who did not use an assistive device would not alter their propulsion with handrail use but individuals that currently used an assistive device would produce less propulsive force when using the handrails compared to walking without handrails.

2. Methods

2.1. Participants

Twenty-one individuals post-stroke (>6 months) completed this study (59.43 ± 13.37 yrs, 1.67 ± 0.09 m, 87.48 ± 17.23 kg, 13F/8 M, 13L/8R, 2.00 ± 2.02 years since stroke (range = 0.53–6.54 years)) and were split into groups based on whether they currently used an assistive device (AD Yes) (N = 8) or if they did not use an assistive device currently (AD No) (N = 13). All individuals were able to walk for at least 3 min either independently or while using an assistive device. Individuals were excluded if they had more than one stroke or evidence of a cerebellar stroke on an MRI. Written consent was collected from all participants and the study was approved by the Institutional Review Board at the University of Nebraska Medical Center.

2.2. Experimental procedure

Sixty-five retroreflective markers were attached to the participants upper and lower extremities, such as bilaterally at the feet, ankles, knees, greater trochanters, pelvis, elbow, wrist, and shoulders, as well as their torso. Marker shells were placed bilaterally at the thigh and shank segments. A split-belt instrumented treadmill with two embedded six degree-of-freedom force platforms (Bertec Corp, Columbus, OH) and custom designed instrumented handrails (Bertec Corp, Columbus, OH) with kinetic data captured at 1000 Hz was used. The marker data were collected used a 16-camera motion analysis system at 100 Hz (Vicon Motion Systems, CO). All treadmill trials were at the participant's self-selected speed. To determine the participant's self-selected walking speed, the treadmill was initially set to 0.1 m/s and increased by 0.1 m/s until the participant verbally indicated they were walking at a comfortable speed. The participant was asked to walk without the handrails to determine their self-selected speed if they were able to and proceeded to walk at their comfortable speed for 30 s before stopping the treadmill. Once their self-selected speed was found, the same speed was used for every condition. Each treadmill condition was 3 min long and the three conditions were: no handrail use (NHR), light support handrail use (LHR) and self-selected handrail use (SSHR). Individuals wore a safety harness for all trials and the harness provided no body weight support. For SSHR, participants were instructed to hold onto a side handrail with their non-paretic hand. For LHR, real time feedback of the handrail forces were displayed on a screen that was in front of the participant. Participants would see either a red "X" or a green "O" in front of them on the screen. The screen displayed the green "O" while all forces (vertical, horizontal, lateral) applied to the treadmill handrail remained below 5% of the participants' body weight. If the force threshold was exceeded, the symbol turned to a red "X". The participants were instructed to lessen the amount of force they were putting on the handrails if they saw the red "X". For the NHR condition, participants were instructed not to use the handrails during the 3-min trial. Seventeen out of twenty-one total participants were able to complete this trial. The three treadmill trials were randomized, and participants were allowed 3–5 min or longer of rest between walking trials if needed.

2.3. Data analysis

Kinematic and kinetic data from the treadmill conditions were processed in Nexus (VICON, Oxford, UK). Calculations were performed in Visual 3D software (C-Motion, Inc., Germantown, MD, USA) as well as MATLAB (Mathworks, Natick, MA, USA). Kinetic data were filtered at 60 Hz and kinematic data were filtered at 6 Hz both using a 4th order low pass Butterworth filter. Anterior handrail force was calculated as the positive impulse during the stance phase of the paretic leg. Two participants could not walk using only one handrail, so they used both handrails; all other participants used only one handrail on their non-paretic side. Representative graphs of the anterior handrail force from two participants (one current assistive device user and one non-current assistive device user) are shown in Fig. 1. Paretic and nonparetic positive impulse were calculated during stance using unnormalized data and the total propulsive impulse were calculated as the sum of the paretic and nonparetic positive limb impulse as well as the handrail positive impulse [9]. The percent paretic propulsion was calculated as the paretic impulse divided by the total propulsive impulse, the nonparetic percent propulsion was the nonparetic impulse divided by the total propulsive impulse and the handrail percent propulsion was the handrail impulse divided by the total propulsive impulse. The percent propulsion was calculated for each person by averaging across each handrail condition.

2.4. Statistical analysis

Three multilevel models were used for paretic propulsive impulse, nonparetic propulsive impulse and handrail propulsive impulse. For all models, after the baseline model, the fixed effects added to the model were assistive device groups (current or not current user) as the first variable, followed by handrail condition (NHR, LHR, SSHR for propulsive impulse and LHR and SSHR for handrail force), and then the interaction between handrail condition and assistive device group. Those subsequent models were evaluated for improvement in model fit by likelihood ratio tests, assuming a Type I error rate of 0.05, which was the significance cutoff. Specifically, a model was declared to be a better fit when the p-value corresponding to a given likelihood ratio test (comparing two nested models0 was less than 0.05. All participants were retained in the analysis, including the four individuals who could not complete the no handrail condition. The multilevel model used was able to account for the missing data.

To understand if there was a difference between individuals who regularly use assistive devices and individuals who typically walk independently, independent sample t-tests were used between groups for grand total propulsive impulse, percent paretic propulsion, percent nonparetic propulsion, and percent handrail propulsion. Conditions (NHR, LHR and SSHR) were collapsed into one value, since the value of this analysis was between groups. Grand total propulsive impulse was the sum of propulsive impulse during paretic, nonparetic and handrail, collapsed across conditions. This was analyzed to confirm there was no difference in the denominator for propulsive impulse between groups.

Commonly reported effect size measures (e.g., Cohen's d, Hedges g) may not be appropriate for multilevel models because they do not take into consideration random effects or other covariates in a model [10]. Effect sizes concerning random effect components (random intercepts) of the model were estimated as intraclass correlation coefficients derived from the variance components in the model according to the following equation:

$$ICC = \frac{\sigma_{u}^{2}j}{\sigma_{u}^{2}j + \sigma_{\epsilon}^{2}}$$

where $\sigma_{u}^{2}j$ is the variance between subjects and σ_{ϵ}^{2} reflects within subject variance. Here, ICC essentially measures the proportion of variance accounted for due to individual differences. After determining the best fitting model, effect sizes for individual effects and pairwise comparisons were computed by first z-score normalizing the dependent variables. Then, effect sizes were determined from the

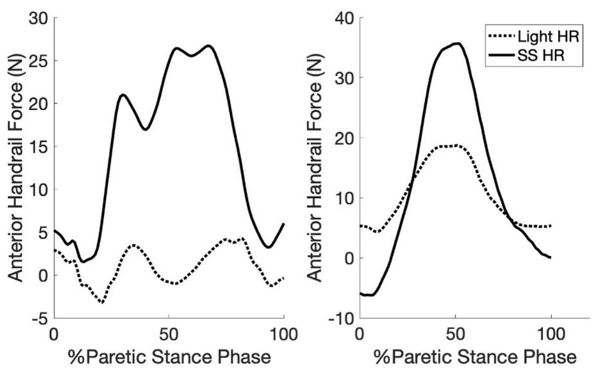

Fig. 1. Anterior Handrail Force. The time series of the anterior handrail force across the paretic stance phase (paretic heel strike to paretic toe-off). The dashed line is the light handrail condition (<5% BW) and the solid line is the self-selected handrail condition. A participant who currently does not use an assistive device is on the left (walking speed = 0.95 m/s) and a participant who currently uses an assistive device is on the right (walking speed = 0.25 m/s).

standardized regression coefficients in the case of models without interactions and by pairwise comparisons in the case of models with interactions. In both cases numerical quantities (i.e., regression coefficients and estimated mean differences) are given in standard deviation units (SDs).

3. Results

3.1. Handrail propulsive impulse

The assistive device use group and the handrail condition fixed effects significantly improved the model fit for handrail propulsive impulse (X^2 (1, N = 21) = 14.23, p < 0.001, ICC = 0.817) (Table 1) compared to the model with just the fixed effect for assistive device group. The interaction did not significantly improve the model X^2 (1, N = 21) = 0.00, p = 0.971). Based on the estimates from the model, individuals who currently used an assistive device in everyday life had 6.96% (~0.*45* SDs) greater amount of handrail propulsive impulse compared to individuals not reliant on assistive devices in everyday life (t = −1.05, p = 0.306), however it was not significant. Additionally, during the self-selected handrail condition, the handrail propulsive impulse was 6.27 N/s (~0.41 SDs) more than during the light handrail condition (t = −4.40, p = 0.002), a large effect (Fig. 2A).

3.2. Paretic propulsive impulse

The assistive device use group and the handrail condition fixed effects significantly improved the model fit for paretic propulsive impulse (X^2 (1, N = 21) = 9.18, p = 0.010, ICC = 0.83) (Table 2), compared to the model with just the fixed effect for assistive device group. The interaction of handrail condition and assistive device group did not improve the model fit (X^2 (1, N = 21) = 2.95 p = 0.229). Based on the estimates from the model, individuals who currently used an assistive device in everyday life had 6.52% (~0.71 SDs) less paretic propulsive impulse (t = −1.57, p = 0.129), although it was not significant. Within the handrail conditions, there was a significant decrease in model means for the NHR compared to the SSHR (2.41 N/s (~0.26 SDs), t = −3.08, p = 0.010). There was a slight increase from the LHR to the SSHR (1.39 N/s (~0.15 SDs), t = −1.93, p = 0.143) and a slight decrease from LHR to NHR (1.01 N/s (~0.11 SDs), t = 1.30, p = 0.406), but it was not significant (Fig. 2B).

3.3. Nonparetic propulsive impulse

The interaction between assistive device use group and handrail condition significantly improved the model fit for nonparetic propulsive impulse (X^2 (1, N = 21) = 17.19, p < 0.001, ICC = 0.85) (Table 3), compared to the model that included only the fixed effects for assistive device group and handrail condition. When looking at pairwise comparisons within each assistive device group, individuals who were reliant on assistive devices varied their nonparetic propulsive impulse based on the handrail condition. These individuals had a 0.95 N/s (~0.07 SDs) greater nonparetic propulsive impulse in the LHR compared to NHR (t = 0.56, p = 0.845), although it was not statistically significant. They had an 8.53 N/s (~0.65 SDs) greater nonparetic propulsive impulse in the SSHR compared to the LHR condition (t = −6.56, p < 0.001) and a 9.48 N/s (~0.72 SDs) greater nonparetic propulsive impulse in the SSHR compared to the NHR condition (t = −5.52, p < 0.001). The individuals who were not reliant on assistive devices varied their nonparetic propulsive impulse as well and it was dependent on handrail condition. Specifically, individuals produced a 4.10 N/s (~0.31 SDs) greater nonparetic propulsive impulse in the SSHR compared to the NHR condition (t = −4.02, p < 0.001), as well as 2.65 N/s (~0.20 SDs) greater nonparetic propulsive impulse in the LHR compared to the NHR condition (t = 2.60, p = 0.033). While there was a slightly greater (1.44 N/s (~0.11 SDs)) nonparetic propulsive impulse in the SSHR compared to the LHR, it was not statistically significant (t = −1.42, p = 0.340) (Fig. 2C). All propulsive impulse data are found in Supplementary Table 4.

3.4. Percent propulsion and grand total propulsive impulse

Total propulsive impulse was not significantly greater between groups (Current AD User: 139.16 ± 88.11 N/s, No AD User: 126.131

Table 1
Model Building Steps for Handrail Propulsive Impulse, Handrail Condition & Assistive Device Group. The first row is the baseline model or the intercept only model. The second row is the first input of assistive device use group, which was the individual either currently used an assistive device during most daily activities (cane, walker, etc.) (Yes AD) or the individual did not currently use an assistive device (No AD). The third row is the model that also includes an input of handrail condition, which is whether the walking trial was with no handrails (No), light handrail use (Light) or self-selected handrail use (SS). The fourth row is the model that includes the previous steps as well as the interaction between assistive device use group and handrail condition.

Model Step	AIC	BIC	logLik	Deviance	X^2	df	p
Intercept	329.42	334.63	−161.71	323.42			
Handrail Propulsive Impulse ~ Assistive Device Use Group	330.24	337.19	−161.12	322.24	1.18	1	0.278
Handrail Propulsive Impulse ~ Assistive Device Use Group + Handrail Condition	318.01	326.7	−154.01	308.01	14.23	1	<0.001
Handrail Propulsive Impulse ~ Assistive Device Use Group + Handrail Condition + Assistive Device Use Group * Handrail Condition	320.01	330.44	−154.01	308.01	0.00	1	0.971

Note: AIC = Akaike information criteria, BIC: Bayesian information criteria, logLik: Log likelihood.

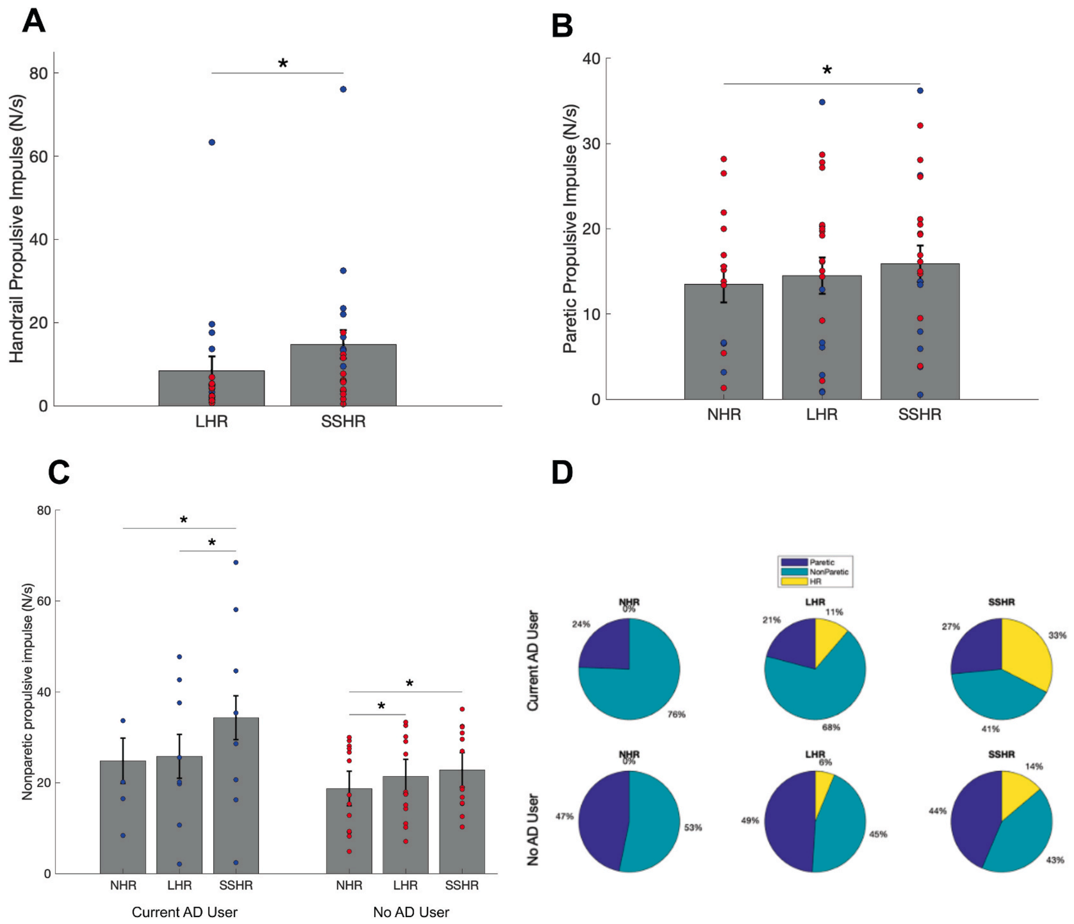

Fig. 2. Percent Propulsion. (A) The model generated means for handrail propulsive impulse, (B) paretic propulsive impulse, and (C) nonparetic propulsive impulse for each handrail condition, no handrail (NHR), light handrail condition (LHR) and self-selected handrail condition (SSHR). Error bars are standard error and points are individual participants' data points, with blue dots representing the current assistive device users and red dots representing the individuals who currently do not use assistive devices. For handrail impulse and paretic impulse, the current assistive device and individuals who currently do not use an assistive device are combined due to non-significant effects between groups. *p < 0.05 (D) Pie graphs for a representative participant from both the current AD user group and no assistive device group. The values are percent of paretic, nonparetic or handrail to total propulsion, with the no handrail (NHR) condition being on the left, light handrail force (LHR) condition being in the middle and the self-selected handrail force (SSHR) on the right.

Table 2

Model Building Steps for Paretic Propulsive Impulse, Handrail Condition & Assistive Device Group. The first row is the baseline model or the intercept only model. The second row is the first input of assistive device use group, which was the individual either currently used an assistive device during most daily activities (cane, walker, etc.) (Yes AD) or the individual did not currently use an assistive device (No AD). The third row is the model that also includes an input of handrail condition, which is whether the walking trial was with no handrails (No), light handrail use (Light) or self-selected handrail use (SS). The fourth row is the model that includes the previous steps as well as the interaction between assistive device use group and handrail condition.

Model Step	AIC	BIC	logLik	Deviance	X^2	df	p
Intercept	360.07	366.3	−177.04	354.07			
Paretic Propulsive Impulse ~ Assistive Device Use Group	359.71	368.02	−175.86	351.71	2.36	1	0.124
Paretic Propulsive Impulse ~ Assistive Device Use Group + Handrail Condition	354.54	367	−171.27	342.54	9.18	2	0.010
Paretic Propulsive Impulse ~ Assistive Device Use Group + Handrail Condition + Assistive Device Use Group * Handrail	355.59	372.21	−169.79	339.59	2.95	2	0.229

Note: AIC = Akaike information criteria, BIC: Bayesian information criteria, logLik: Log likelihood.

Table 3
Model Building Steps for NonParetic Propulsive Impulse, Handrail Condition & Assistive Device Group The first row is the baseline model or the intercept only model. The second row is the first input of assistive device use group, which was the individual either currently used an assistive device during most daily activities (cane, walker, etc.) (Yes AD) or the individual did not currently use an assistive device (No AD). The third row is the model that also includes an input of handrail condition, which is whether the walking trial was with no handrails (No), light handrail use (Light) or self-selected handrail use (SS). The fourth row is the model that includes the previous steps as well as the interaction between assistive device use group and handrail condition.

Model Step	AIC	BIC	logLik	Deviance	X^2	df	p
Intercept	415.29	421.52	−204.64	409.29			
NonParetic Propulsive Impulse ~ Assistive Device Use Group	415.4	423.71	−203.7	407.4	1.89	1	0.169
NonParetic Propulsive Impulse ~ Assistive Device Use Group + Handrail Condition	393.68	406.15	−190.84	381.68	25.72	2	<0.001
NonParetic Propulsive Impulse ~ Assistive Device Use Group + Handrail Condition + Assistive Device Use Group * Handrail	380.49	397.11	−182.25	364.49	17.19	2	<0.001

Note: AIC = Akaike information criteria, BIC: Bayesian information criteria, logLik: Log likelihood.

± 43.02 N/s, t = 0.45, p = 0.655). Percent paretic propulsion was significantly greater in individuals without assistive device use (42.26 ± 12.41 %) compared to individuals currently using an assistive device (21.04 ± 14.69 %) (t = −3.55, p = 0.002). Percent nonparetic propulsion was not significantly different in individuals without assistive device use (49.81 ± 11.57%) compared to individuals currently using an assistive device (54.45 ± 23.42 %) (t = 0.61, p = 0.550). Currently assistive device users had a greater percentage of total propulsion contributed by the handrails (28.38 ± 12.29 %) compared to the individuals that did not currently use an assistive device (11.90 ± 9.57 %) (t = 3.44, p = 0.003) (Fig. 2D).

4. Discussion

The purpose of this study was to determine how the paretic propulsive impulse was altered when using an assistive device for individuals post-stroke; specifically, when using handrails on a treadmill. We found that individuals post-stroke did alter their paretic propulsive impulse; specifically they produced a greater propulsive impulse with their paretic leg during the self-selected handrail hold, compared to the no handrail condition. These results suggested that handrail use may impact the propulsive impulse individuals post-stroke generate with their lower limbs, and individuals are able to produce the greatest propulsive impulse on their paretic side when using handrails. The handrails may enable individuals to increase their step length, which could be contributing to the greater propulsive impulse, as seen in a previous study [3]. In addition, individuals who were dependent on an assistive device produced less percent propulsive impulse on their paretic side than individuals that typically walked without an assistive device.

When comparing between groups, we found that individuals who do not currently use an assistive device were able to produce a greater percentage of total propulsion on their paretic limb than someone who currently uses an assistive device, and the difference was greater than the minimal detectable change for percent propulsion (>12.06%) [11]. The paretic propulsive impulse was not significantly different between groups, but individuals who did not use assistive devices produced slightly different paretic propulsive impulse. The total propulsive impulse was not statistically different between groups, although individuals A model was declared to be a better fit when the p-value corresponding to a given likelihood ratio test (comparing two nested models) was less than 0.05urrently use an assistive device had a slightly greater total propulsive impulse. These two relationships may have led to the significant change in percent paretic propulsion between groups. For individuals that currently use an assistive device, they are most likely using the handrail to make up for the decrease in percent propulsion from the paretic limb. The individuals who currently did not use an assistive device had a greater self-selected walking speed (0.79 ± 0.35 m/s) compared to individuals who currently used an assistive device (0.25 ± 0.11 m/s). Additionally, both groups walked slower on a treadmill compared to their overground walking speed, which was calculated as the first minute of a 6-min walk test (0.57 ± 0.29 m/s for current assistive device users and 1.09 ± 0. 25 m/s for not current assistive device users), aligning with previous studies [12]. The greater self-selected walking speed may suggest that these individuals had a higher function of the paretic limb, indicated by the higher contribution to total propulsion. The smaller percentage of total propulsion by the paretic limb of the current assistive device users might be hindering to their walking speed, since they are mainly relying on the nonparetic limb (or handrail) to drive propulsion. Previous studies have found a relationship between self-selected walking speed and propulsion, specifically increasing propulsion increased walking speed [9,13]. In addition, individuals with more severe stroke have been shown to have a decreased percent paretic propulsion than individuals with a mild stroke [9]. This is in line with our research since individuals that are reliant on an assistive device are more likely to have a more severe stroke. Therefore, focusing on ways to enable these current assistive device users to walk faster with more propulsion may be more beneficial for their recovery and overall functional status.

Interestingly, the effect of handrail condition on nonparetic propulsive impulse varied with assistive device use group. Individuals that currently used an assistive device altered their nonparetic propulsive impulse depending on handrail condition; specifically, the nonparetic propulsive impulse was significantly higher during the SSHR condition compared to both the NHR and LHR conditions. Individuals that currently did not use an assistive device also differed between handrail conditions, but their nonparetic propulsion when not using a handrail was significantly different than both handrail conditions. This suggests that handrail use is different among assistive device versus non assistive device users. For the current assistive device user group, it seems that they were able to produce the most nonparetic propulsive impulse when they had a self-selected hold on the handrail.

For the handrail propulsion, individuals who currently used an assistive device produced a greater percent propulsion on the handrails than individuals who were not reliant on an assistive device. This is in line with previous research that found that individuals post-stroke with severe motor impairments applied more force to treadmill handrails and applied the force for a longer period of time [14]. Importantly, this handrail utilization is not limited to vertical force and postural support, but includes a significant component of anterior force, which provides an additional source of force generation to advance the body forward.

There are some limitations to the study. The difference in walking speed between the current assistive device group and not current assistive device users may be contributing to some of the difference seen between the two groups. Using percent propulsion instead of peak propulsion should alleviate some of the contribution, since this measure normalizes the data to the total propulsion.

The results of this study have some potential clinical implications. Paretic propulsion is related to walking speed post-stroke and therefore, often one goal of treadmill training after stroke is to increase paretic propulsion. Our results suggest that handrail use interacts with paretic propulsive impulse and if increasing paretic propulsive impulse through treadmill training was a goal, the clinician may allow handrail use during this training. This effect was reduced with a light handrail touch. In addition, there are many other factors that are important during rehabilitation training, such as balance and joint kinematics. Determining what the goal of rehabilitation and what role handrail use has on that goal is important in determining whether or not handrail use is beneficial. Future studies could look at the role of handrail use in long-term treadmill training studies and how use of the handrail may be beneficial or not as an individual progresses through training. In addition, while our results focus on propulsion, further research is needed to determine if using handrails results in differences in other variables that are important for stroke gait, such as spatiotemporal measures.

5. Conclusions

This study found that individuals post-stroke altered their propulsive impulse when walking on a treadmill with and without handrails, regardless of dependence on an assistive device for ambulation. However, individuals who did not use an assistive device in everyday life were able to produce a greater percentage of total propulsion with their paretic limb than individuals who used an assistive device. These results suggest that handrail use may impact both paretic and nonparetic propulsive impulse. Our initial results suggest that if the goal of rehabilitation treadmill training is to improve paretic propulsion, encourage walking with the handrails may be optimal to promote paretic side propulsion.

Data availability statement

The data that support the findings of this study may be available, upon reasonable request.

Declarations

This study was approved by the University of Nebraska Medical Center Institutional Review Board (IRB#385-18-EP).

CRediT authorship contribution statement

Erica H. Hinton: Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Samuel Bierner:** Conceptualization, Data curation, Formal analysis, Methodology, Resources, Writing – review & editing. **Darcy S. Reisman:** Conceptualization, Methodology, Writing – review & editing. **Aaron Likens:** Formal analysis, Methodology, Writing – review & editing. **Brian A. Knarr:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Project administration, Resources, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e26924.

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