Original Article

Targeting effect on gait parameters in healthy individuals and post-stroke hemiparetic individuals

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Abstract

Background: A targeting effect may occur in any gait analysis trial where the participant is instructed to step in a particular area or a clearly marked target is in their path. The targeting effect may affect the gait parameters and any variability being studied in regard to the participants. There are few studies examining this effect for healthy subjects and none for special populations.

Methods: This study aimed to investigate if any targeting effects occurred in healthy and stroke-survivor populations. Eight male participants were recruited, four of whom exhibited right-hand side hemiparesis resulting from stroke. Each participant performed a series of gait trials at a comfortable walking pace after being made aware of the force plate in the centre of the walkway. The participants gait was then analysed and compared before and after the target force plate.

Results: The results of the trials showed significant variations ($p < 0.005$) in the spatiotemporal gait parameters in both the healthy and stroke-survivor groups indicating a targeting effect.

Conclusions: The effects were similar in both groups with the step speed and length being slower and shorter for the targeting step compared to the step after the force plate.

Introduction

Quantitative gait analysis is a useful tool in the research and treatment of pathological gait patterns and studies in sport biomechanics. It allows the person conducting the gait analysis to assess spatiotemporal, kinematic and ground reaction force (GRF) parameters at a specific point in the subjects gait or over several steps to supplement their own observations. Most commonly this is recorded by attaching reflective markers to the anatomical landmarks and using equipment such as a motion capture systems, force plates, and EMG sensors.

Current professional level equipment such as the VICON 3D motion capture system have been proven to provide accurate and reliable results and are often used as the standard by which other motion capture equipment are tested.[1,2] The reliability such systems confer is of key importance to their use in research and clinical settings as it ensures that less trials are unusable due to poor or missing data. This reduces the overall time an experiment takes. Within research this means that a larger sample size can be used; it also benefits clinical analysis where time and expertise may be in limited supply for each patient to be analysed.[3]

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Considering this, one of the major issues present in gait analysis is the reliable acquisition of the force data. Generally, most gait analyses use one or more small force plates embedded in the walkway. To provide useful data, the participant's footfall must land solely within the boundaries of the force plate and their next step must not land even partially on the same force plate; anything other than this leads to unrepresentative and unusable kinetic data which often means that the trial must be performed multiple times. To minimise this issue, the force plate might be clearly marked in the walkway and the participants instructed to aim to step within this marked area.

This method of providing explicit instruction to the participants speeds up data acquisition, reducing the number of trials necessary during an experiment. However, treating the force plate as a target that must be hit can affect the participants gait; they may shorten or lengthen their steps to hit the force plate as centrally as possible as investigated in previous research.[4,5] This research has identified that the targeting effect involves a separate control scheme employed by the brain during gait. Regular gait, without obstacles/targets, occurs under the motor programming scheme (normative). When an obstacle/target is introduced, the control scheme employed switches to visual control (targeting) which assists the person in ensuring that their foot lands in the right place to ensure balance and safety.

This control scheme shift should be thoroughly investigated to understand its effects on gait analysis and whether it is producing any systematic or random error in experimental results. Additionally, whether the targeting effect will manifest purely from instruction or visual guidance should also be investigated. Similar concerns had been expressed nearly two decades ago by Oggero et al.[6] who suggested that targeting effects are not fully representative and that hidden force plates should be used instead to ensure normative gait is captured.

Despite this, there is limited research into this area with literature mostly offering restricted overall conclusions. Early studies focused mostly on the kinetic parameters from the force plate with only general spatiotemporal information being looked at. These found that there were no significant effects of targeting gait on the kinetic parameters by comparison to normative gait.[7,8]

Since 3D camera capture systems have become the industry standard, there has been only one recent study utilising these systems to observe this targeting effect.[9] Verniba et al. found that there was evidence of targeting during the trial, the participants exhibited decreased variability in step length leading up the force plate. However, it produced no significant differences in the spatiotemporal, kinematic or kinetic gait parameters or their variability for a young and healthy population.

Their paper made suggestions for further study to be undertaken in this field, specifically looking at the effect of targeting in populations of people who suffer from pathological gait conditions, i.e. special populations.

To add to this area of research, gait analysis records from a healthy population were compared against records from the stroke afflicted population for this study using statistical methods to observe any significant differences that could be attributed to the targeting effect. As the previous studies gave conclusions that indicated that the kinetic parameters were not affected by targeting in the healthy population particular emphasis was put on the spatiotemporal and kinematic parameters.

Stroke survivors were chosen as the special population of interest for this study as stroke has been found to be a leading cause of disability in adults,[10] leaving 72% of survivors suffering from lower limb weakness.[11] This increases survivors dependence on others to perform basic daily activities[12] and can be a contributing factor to the prevalence of long-term depression in survivors.[13] Thus, research into this condition and its associated effects, particularly hemiparesis, is of considerable importance and as such must be thoroughly understood.

Quantitative gait analysis has had a long history with researching issues surrounding stroke such as investigating the effects of orthopaedic devices on the users gait[14] or to investigate whether audio cueing can help improve the gait patterns of stroke survivors.[15] Additionally, it has been used within clinical settings to compare and choose between different training methods[16] and as tool to help predict the likelihood that a stroke survivor would be at risk of a fall.[17] Reliable and representative data are key to the success and clinical usefulness of this type of research.

As part of our experiment, we will gather data that allow for comparison against previous studies in this area and investigation of the general effects of targeting on stroke survivors helping improve the designs of future gait analysis experiments. If the targeting effect is shown to be significant then this indicates that gait analysis experiments that make the participant target the force plate are producing data that are unrepresentative of normal gait. As such in this case, it would be recommended that experiments use a hidden force plate to be a representative study. This would generally lead to more gait trials having to be performed due to a likely increase in steps outside the force plate area.

If there are no significant effects of targeting found then it would indicate that participants could be told to specifically target the force plate without compromising the data produced. This could significantly reduce the number of invalid trials during an experiment and increase its efficiency.

The objective of this study is to assess whether the targeting effect has a significant impact on the gait of a stroke survivor. This will be compared against a healthy control group and findings from previous studies. The hypothesis being tested can be stated as:

Having a target in a gait analysis setup (i.e. a clearly marked force plate) has no statistically significant effect on the gait parameters of a participant by comparison to if there was no target present, regardless of whether the participant was healthy or had suffered a stroke.

Methods

Participants

The experiment conducted was carried out on a group of eight males, including four healthy participants (age: 28 ± 4 years, height: 168 ± 3 cm, weight: 78 ± 4 kg) and four stroke participants (age: 32 ± 3 years, height: 167 ± 2 cm, weight: 82 ± 3 kg). All participants were recruited via local advertising. The stroke survivors selected for the experiment were suffering from right side hemiparesis due to the stroke event and all healthy participants had no history of neurological disorders or brain damage. Ethical approval for the methods used in this study was sought and obtained from West Midland Rehabilitation Centre (WMRC), Birmingham.

Experimental equipment and set-up

The experiment was conducted using a VICON MX System for motion measurement and analysis. The system used 12 cameras situated around the testing area, 6 were MX3+'s and 6 were MX T40's, both of which were capturing at 100 Hz. These cameras captured positional data using reflective markers that had been placed upon the participants' lower body based on the Oxford foot model. All the cameras were calibrated by an Active Wand before starting the experiment.

Participants were asked to wear clothing that was tight to the body to ensure the markers remained close to their anatomical landmarks. The markers were positioned such that the upper leg, lower leg and foot all contained at least three markers. This allowed the markers to be used to define a distinct plane for each section of the leg. The system was able to report the kinematic positioning data of each of these sections by comparing against a set of normative trials that were done for each participant.

Two additional digital cameras were used to capture each gait trial, one focused along the walkway to record the frontal view and one records the lateral view. These cameras captured data at 50 Hz and were used to assist data processing and data syncing.

The path set up for the subject to walk down was 10 m long and a Kistler force plate (collecting data at 100 Hz) was situated at the centre of the walkway. The dimension of the target was 600 mm × 400 mm. The force was measured in X, Y and Z axes and the magnitude of the force vector was considered in this study. The width of the walkway was indicated by lines to help ensure the participant did not step off to one side of the plate, invalidating the trial. The force plate was marked so that its boundary was clearly visible to the participant as shown in Figure 1.

Procedure

All post-stroke participants had the ability to walk without assistance. Each participant performed at
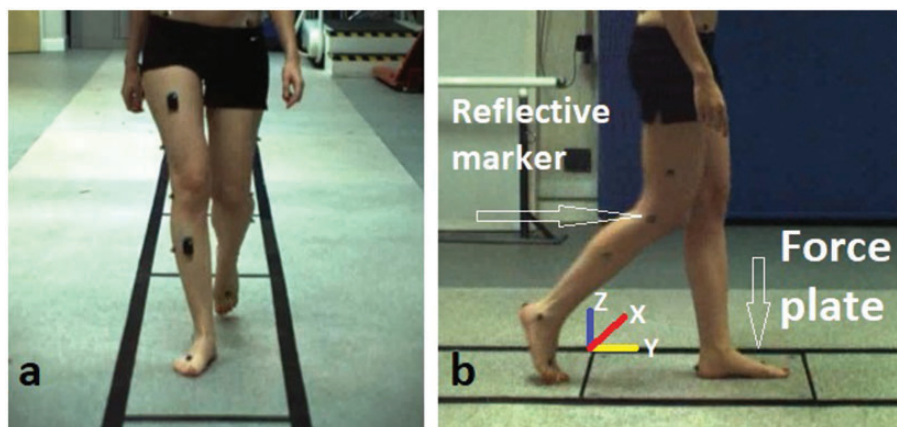

Figure 1. Two different views of a healthy participant during targeted walking along the walkway in the gait lab; (a) frontal view, (b) lateral view.

least six trials in total, three with their left leg leading and three with their right leg leading. Trials were repeated until there were three trials recorded for each leg in which the participant stepped completely within the force plate boundaries. Before starting the experiment, static tests, where the participant stands still on the force plate, were performed in order to calibrate the force plate and to measure the participants' body mass and height.

Participants were informed about the presence and location of the force plate before beginning the trials, but they were not told to step on the force plate necessarily, and there were normally a couple of trials per participants in which they missed the target or they did not step on the force plate completely.

This form of instruction was chosen as it presents the condition where the force plate is an obvious target for the participant to aim for but avoids using direct instruction which have already been suggested to add variability to gait analysis.[18] This keeps the focus on the targeting effect manifesting from visual cues. As mentioned previously, the instruction would also have an effect but for this experiment, a single focus was chosen.

Participants were not stopped if they missed the target or if they did not step on the target completely. However, these failed and non-usable trials were discarded from our analysis at the end. There were no psychological pressure on the participants and participants did not have to remain at constant speed in all the trials.

Data processing and analysis

The data from each gait trial were captured and processed using VICON Nexus 1.8 Gait Analysis Software. For each subject, the trials were examined and trials which had foot placement outside of the force plate were set aside. From the remaining trials, six were selected for further analysis. Half of the selected trials had the left foot stepping on the force plate and the other half had the right foot stepping on the force plate.

Using the regular cameras, the frames in which the toe-off and heel-strike gait events occurred were noted allowing the 3D positioning data to be synchronised with the visual recording. This was performed over a three step section of the participants' gait, i.e. 1.5 gait cycles. This period began with the toe-off of the foot that would connect with the force plate as shown in Figure 2.

Verniba[9] showed how a small difference in the variability of the step was present immediately after the force plate targeting step. While Verniba did not mark this as a significant difference, it would comply with the known theory of targeting that after the target has been achieved, the participant would revert to
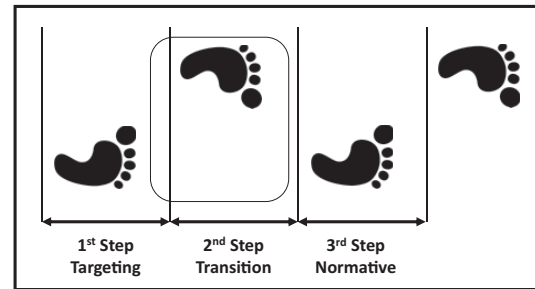

Figure 2. One step before the force plate and two steps after the force plate are the control zones that gait parameters have been studied and compared to each other. The first, second and third steps are considered as targeting step, transition step and normative step, respectively.

normative gait. Thus, for the data analysis within this paper, the comparison will be made within trials between the targeting step landing on the force plate, the first step and the third step that is assumed to be representative of normative gait.

The spatiotemporal parameters that were calculated for the first and third steps included step speed, step length and step time. The step length was calculated from the change in position of the heel marker in the Y axis between the toe-off and heel-strike gait events. The difference in time between these two events gave the step time and was used to find the step speed. The coordinate system is shown in Figure 1.b.

The kinematic parameters were found by the VICON system which calculated the angles of the planes created by the markers at the thigh and shank referenced against the participants standing posture. The parameters that were used in the statistical analysis were the sagittal plane angles between these limb segments at the moment of heel strike to give a snapshot of the position of each leg at each crucial gait event.

The positional data were then exported from the VICON software into an excel file and a code was then created in Matlab R2016A which would isolate the relevant sets of gait data over the relevant period and output the chosen parameters. The length and weight parameters were normalized to percentages of the participants' height and body weight as these parameters have a large impact on the variations of gait; normalized values are more comparable to inter and intra groups.[19]

Statistical analysis

Statistical analyses were conducted on the experimental data using the IBM SPSS Statistics 22 program. A three-factor ANOVA was performed to compare each of the spatiotemporal and kinematic parameters between groups. The three grouping variables used

were control versus stroke, left trials versus right trials and first step versus third step. This test indicated whether any significant difference is present and what effect the grouping variables or interaction effects between the grouping variables had.

A two-way ANOVA was used to compare the peak GRFs between groups. The means and standard deviations were then compared against values obtained in a previous study conducted using foot-scan technology.[20] As the foot-scan technology is packaged in a shoe, it means there is no obstacle for the participant to target during the trial, hence removing its effect from the trial. This has been shown to be comparable to regular kinetic measurement methods[21] and as such can be used as an example of a non-targeting set of trials for comparison to this experimental data. Statistical significance level was set at $p < 0.05$.

Results

The results of the ANOVA tests are listed in Table 1 for descriptive statistics.

Spatiotemporal parameters

Step speed. As shown in Figure 3, three-factor ANOVA showed no significant interaction effects between any of the factors on step speed and no significant main effect for trial type, $F(1,88) = 0.052$, $p = 0.820$. Subject group and step number were found to have a significant effect on the parameter, $F(1,88) = 66.11$, $p < 0.001$ and $F(1,88) = 11.85$, $p = 0.001$.

It can be seen that the estimated marginal means of step speed differ consistently between the healthy group and the stroke survivors for the left and right leg trials

with the stroke survivors having a slower step speed. Additionally, for both groups and both legs, there is seen a similar gradient between the data for the first and third step speeds indicating that the step number is a significant variable which effects both groups in a similar manner and as such no interaction effect exists.

Step length. As shown in Figure 4, three-factor ANOVA showed no significant interaction effects between any of the factors on step length and no significant main effect for trial type, $F(1,88) = 0.143$, $p = 0.706$. Subject group and step number were found to have a significant effect on the parameter, $F(1,88) = 65.49$, $p < 0.001$ and $F(1,88) = 7.49$, $p = 0.008$.

Similar to step speed, the estimated marginal means of step length show clear differences between the healthy group and the stroke survivors with the stroke survivors taking shorter steps. This is consistent over both left and right leg trials showing that the group has a significant effect on this parameter but left versus right does not. In both legs, a positive
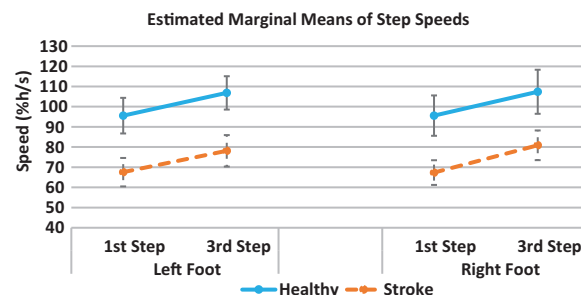

Figure 3. Interaction effects of targeting/normative on step speed.

Table 1. Descriptive statistics of recorded gait parameters.

| | Mean (SD) | | | | | | | |
	Control				Stroke			
Parameter	Left		Right		Left		Right	
Spatiotemporal	First step	Third step	First step	Third step	First step	Third step	First step	Third step
Step speed (%h/s)	95.56 (17.65)	107.39 (16.53)	95.57 (19.99)	107.39 (21.84)	67.53 (14.11)	78.12 (15.59)	67.34 (12.24)	80.86 (14.72)
Step length (%h)	40.16 (5.81)	42.73 (5.33)	39.15 (5.85)	42.74 (5.49)	30.63 (5.43)	33.63 (5.35)	30.09 (5.23)	33.41 (6.25)
Step time (s)	0.42 (0.02)	0.40 (0.02)	0.41 (0.03)	0.40 (.04)	0.46 (0.05)	0.42 (0.03)	0.45 (.05)	0.41 (0.04)
Kinematic								
Ankle angle (°)	0.3 (1.5)	1.5 (1.7)	2.9 (2.9)	3.6 (2.8)	1.1 (7.9)	0.5 (7.0)	3.4 (7.6)	4.5 (6.1)
Knee angle (°)	7.6 (2.7)	6.9 (1.6)	7.9 (3.7)	7.2 (3.0)	10.4 (12.6)	10.7 (12.2)	17.8 (14.4)	17.2 (14.8)
Hip angle (°)	33.5 (3.5)	32.8 (3.5)	32.0 (5.1)	31.7 (5.2)	29.2 (5.0)	28.9 (5.4)	34.6 (7.6)	35.2 (7.4)
Kinetic	Foot Scan	Force Plate	Foot Scan	Force Plate	Foot Scan	Force Plate	Foot Scan	Force Plate
Peak GRF (%)	118.96 (1.63)	141.08 (18.37)	118.96 (1.63)	145.45 (21.03)	100.10 (2.96)	109.56 (5.69)	97.45 (2.55)	117.19 (7.15)

GRF: ground reaction force.
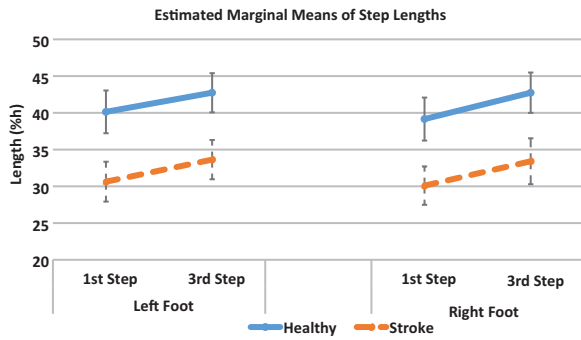
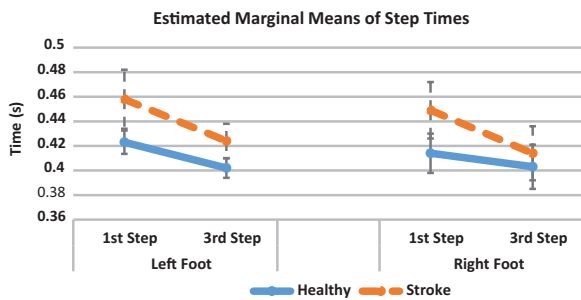**Figure 4.** Interaction effects of targeting/normative on step length.

Figure 5. Interaction effects of targeting/normative on step time.

Figure 6. Average velocity profiles of the participants' foot during the trials.

gradient was seen between the first and third steps demonstrating that the step number had a significant effect. As the gradient is similar between both groups and for each leg, this shows that there was no significant interaction effect.

Step time. As shown in Figure 5, the three-factor ANOVA showed no significant interaction effects between any of the factors on step time and no significant main effect for trial type, $F(1,88) = 0.822$, $p = 0.367$. Subject group and step number were found to have a significant effect on the parameter, $F(1,88) = 13.36$, $p < 0.001$ and $F(1,88) = 12.52$, $p = 0.001$.

The estimated marginal means of step time show significant differences between the healthy group and the stroke survivors with the stroke survivors showing slower step times for both right and left legs. In both groups, there was a negative gradient between the first step and the third step which was seen in both legs. While the gradient differs between the two groups in the right foot this is over a very small scale and overall is not considered significant. Similarly, while there were minor differences between the left and right legs, these were determined to not be significant leaving only group and step number as the significant grouping variables.
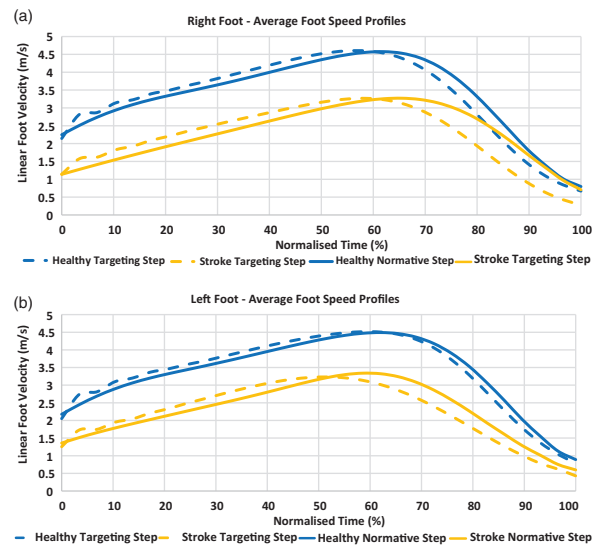
Averaged foot velocity profiles. To compare the foot velocity profiles in the direction of motion (Y-Axis) between groups, step side and the targeting and normative steps, the positions of the marker on the back of the participants' ankle were exported from the VICON data. The changes in position between each frame were then compared to find the speed of the foot during each step.

This speed profile was then normalized over the three steps of the trial for each foot such that they could be compared against each other. The profiles were then averaged within the healthy and stroke groups and the targeting and normative steps were plotted against each other. These averaged profiles are shown Figure 6(a) and (b).

Kinematic parameters

Ankle angles. As shown in Figure 7, the three-factor ANOVA showed no significant interaction effects between any of the factors on ankle angles and no significant main effect for group and step number, $F(1,88) = 0.001$, $p = 0.978$ and $F(1,88) = 0.108$, $p = 0.744$. Trial side was found to have a significant effect on the parameter, $F(1,88) = 7.528$, $p = 0.007$.

The estimated marginal means of the ankle angles show a slightly more complex relationship but over a fairly small set of angles. There is a clear difference between the left and right legs; however, while in the left leg trials the healthy subjects went from a low angle to a higher angle between the first and third steps, they showed the opposite behaviour in the right leg trials albeit with overall higher angles. This was nearly exactly opposite to the relationships shown by the
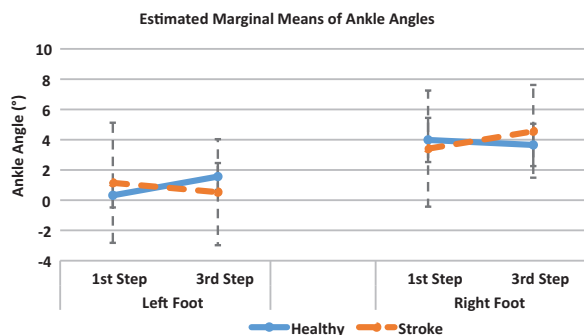
Estimated Marginal Means of Ankle Angles

Figure 7. Interaction effects of targeting/normative on ankle angles at heel strike.

Estimated Marginal Means of Knee Angles
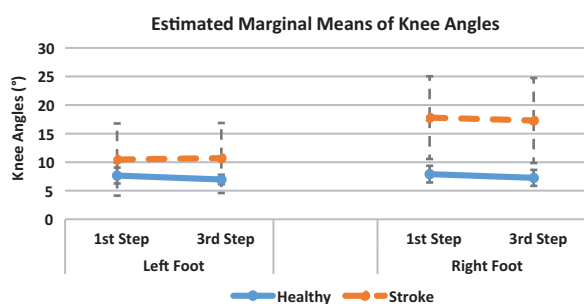
Figure 8. Interaction effects of targeting/normative on knee angles at heel strike.

Estimated Marginal Means of Hip Angles

Figure 9. Interaction effects of targeting/normative on hip angles at heel strike.

Estimated Marginal Means of Peak GRF's
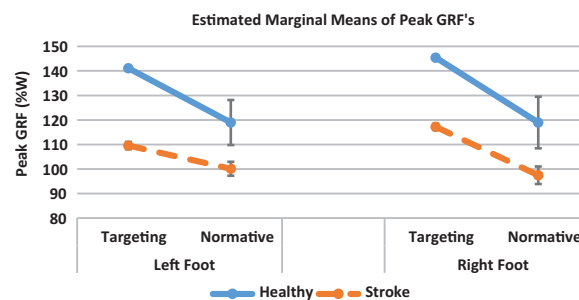
Figure 10. Interaction effects of targeting/normative on peak GRF's. GRF: ground reaction force.

stroke survivor group. From this, no major conclusions were taken aside from the obvious effect of trial side.

Knee angles. As shown in Figure 8, the three-factor ANOVA showed no significant interaction effects between any of the factors. However, the interaction effect between group and trial was much closer to significance, $F(1,88) = 2.77$, $p = 0.099$. Trial side and step number were found not to have a significant effect on the parameter though trial was also close to significance, $F(1,88) = 3.223$, $p = 0.076$ and $F(1,88) = 0.039$, $p = 0.844$. Group was found to have a significant effect on the parameter, $F(1,88) = 10.87$, $p = 0.001$. Figure 8 demonstrates this graphically.

The estimated marginal means of the knee angles show clear differences between the control group and the stroke survivors with the stroke survivors showing a higher angle across both legs. The differences between the left and right legs for the stroke group were pronounced by comparison to the minor differences in the control group which led to a near significant interaction effect between the group and trial and the significant impact of group. The change in knee angle between the first step and the third step was minor for both groups.

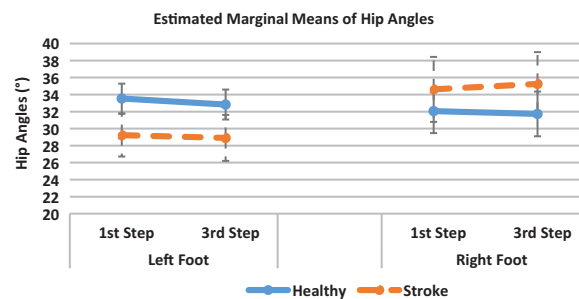*Hip angles.* As shown in Figure 9, the three-factor ANOVA showed a significant interaction effect between the group and trial side on hip angles, $F(1,88) = 9.93$, $p = 0.002$. There were no other significant interaction effects between any of the factors. Step number and group were found to have no significant main effect on the parameter, $F(1,88) = 0.024$, $p = 0.876$ and $F(1,88) = 0.222$, $p = 0.639$. Figure 9 demonstrates this graphically.

The estimated marginal means of the hip angles show that there is a side-specific difference between the healthy group and the stroke survivors with the healthy group having larger hip angles during left leg trials and lower hip angles during right leg trials. This shows the significant interaction effect between the group and trial side. There are minor observable differences between the first and third step, but these were not significant.

Kinetic parameter

As shown in Figure 10, the two-factor ANOVA showed no interaction effect between group and trial on peak GRF and there was no significant main effect from trial side, $F(1,88) = 0.501$, $p = 0.483$. Group was found to have a significant effect on the parameter, $F(1,88) = 12.43$, $p = 0.001$. This is in-line with the differences that would be expected between a stroke population and a healthy population.

The mean values of the peak GRF were then compared against the values found in a study conducted by HyunDong et al.[20] for a superficial comparison that may be used to inform and direct further studies. The results for the targeting step showed significantly higher values of peak ground force within the control group. Additionally, within the stroke group, there was higher peak GRFs found in our study for both legs, while the other study found that there was a higher peak GRF in the unaffected limb and it was found that the opposite was true in this study.

Discussion

During the experiment, some trials were rendered invalid due to the participants not stepping wholly within the area of the force plate. Additional trials then had to be performed until there were enough usable trials for later analysis. The stroke group had a higher failure rate than the healthy group, 37% as opposed to 24% necessitating that more trials had to be performed. This is in line with what is expected for the stroke population.

In order to improve the validity of gait studies, the importance of the targeting effect for human gait must be quantified. To this end, the data from our gait analysis experiment were analysed statistically using ANOVA tests and by comparing averaged profiles of the foot velocity. These tests showed two major trends. Firstly, in the test conducted, there was an observable effect of targeting behaviour in both groups. Secondly, the differences were observed in the spatiotemporal parameters but not within the kinematic parameters. The differences in the peak GRF require further study.

Contrary to what was expected from Verniba et al.'s[9] recent study, the analysis showed significant statistical differences attributable to a targeting effect within the control group. The targeting step, the first step, of the control group was on average slower and shorter than that of their non-targeting step, the third step. These effects were found in similar proportions in both sides of the healthy participants' gait. This is closer to the effects presented in the prior study by Wearing et al.[8]

As found in the Wearing et al.'s study, there was an effect on the total variability of each step in the control group. An overall reduction in standard deviation in step speed and a slight decrease in standard deviation of step length was observed. This indicates that the healthy participants had a slightly more consistent step speed when aiming for the force plate but an increase in variability for their step length.

These findings are consistent with the theory of targeting control leading a person to make subtle adjustments to their step length during the targeting step to ensure they were within the marked area. During this process, they seem to slow down and take longer to complete their step, also reducing the variability of this speed.

The stroke-survivor group took smaller steps and had longer step times than the control group as was expected due to their impairment. This was confirmed as significant by the statistical tests. The ANOVA results also indicated that there were significant differences between their targeting and normative steps spatiotemporal parameters similar to that exhibited by the control group.

The stroke-survivors group had, on average, slower and shorter targeting steps by comparison to the normative step. These effects were similar across both sides of the stroke-survivor participants' gait. The ANOVA found no significant effect on the spatiotemporal parameters due to any interaction effects between the three factors. This shows that while there are minor differences between the left and right legs of the stroke participants between each step, this is not dissimilar to the overall effect exhibited in the control group. Thus, we can say that the targeting effect acted in a consistent way between each leg regardless of whether the participant had suffered a stroke or not.

However, the similarities between the groups did not extend to standard deviations. The right step length deviation increased on the normative step for the stroke survivors and the left step length deviation barely changing at all. This could be related to the nature of hemiparetic gait. As all of the stroke-survivor participants were impaired on their right-hand side, it is suggested that they had to focus on controlling their right leg motion more during the targeting step to compensate for their impairment. Their left leg also had a reduced standard deviation between the two steps, but this was very minor.

Comparing the two groups' spatiotemporal parameters, there were obvious differences due to the impairments of the stroke-survivors as was expected. However, both groups exhibited similar differences between the targeting step and normative step which was similarly significant for both groups by the statistical analysis. There was an overall decrease in step speed, shorter step lengths and longer step times for the targeting step in both groups. The only notable difference that was observed was the stroke survivors' right leg targeting step length standard deviation being lower than that of the normative step as opposed to the control group where the reverse was observed. This would suggest a small change in the ways that the impaired subjects compensated for targeting the force plate. This is in contrast to Verniba et al.'s[9] findings which showed little difference between normative and targeting spatiotemporal parameters.

In addition to the statistical analysis, a further investigation was made of the speed profiles of the participants' foot during the trials. The graphs produced, Figures 6(a) and (b), showcased the major difference between the two groups that was expected. The stroke survivors had significantly lower peak step speeds during the experiment and there also had a greater variation in profiles between their left and right legs. It was also found that once normalised for the time period, the profiles between the groups took on a similar shape indicating a degree of similarity between how the two groups shifted their weight forwards. This is inferred by the velocity variation corresponding to progression in the swing phase and therefore the movement of the centre of mass of the participant. This could be subject to further study in and of itself however.

It was also observed that there the targeting step consistently peaked in step speed earlier than the normative step for both groups and between both legs. This supplements the findings of the ANOVA analysis and indicates that the targeting effect changes the swing phase of the gait cycle, making the participant slow down earlier before making contact with the force plate. This could be linked with the theory that the participant is taking additional time during this targeting step to correct the foot's placement. This effect seems to be present regardless of whether the participant had had a stroke.

The analysis of the kinematic angles of both groups focused on the moment of hitting the force plate. Within the control group, the statistical analysis found no significant influence from step number on any of the parameters. The major differences present in the group were between left and right steps with the left leg showing slightly smaller ankle angles. Additionally, there was little change in any of the standard deviations of the parameters between the targeting and non-targeting step. Thus, it is suggested that this study found no effect on the kinematic properties of the healthy control group due to targeting effects confirming Verniba et al.'s findings.[9]

By comparison, the stroke group showed similar ankle angles but significantly different knee angles for both legs and leg-dependent differences in hip angles. These values correspond with expected characteristics of hemiparetic gait.[22] However, there were no significant differences attributed to the targeting step versus the normative step. Additionally, standard deviation was found to be similar across steps. The statistical analysis showed that there was no significant effect on kinematic angles at heel strike due to targeting present in either group for both legs.

During the initial stages of the experiment planning, it was found that using multiple force plates while still ensuring we could compare across normative and targeting steps was beyond our available resources. Instead, it was decided that the available kinetic data would be compared to previous studies of similar nature. This allowed broad conclusions to be drawn though their use is limited to being a stepping point for further studies.

Comparing the peak GRF value found during the targeting step in this study with data from previous gait analysis experiments shows that higher average peak GRF values were exhibited in both the healthy and stroke-survivor populations within this study.[9,20] The control group showed no statistical difference between the left and right legs which was as expected for the population. By comparison, the stroke group showed asymmetrical peak GRF values but rather than showing a larger GRF for the unaffected limb as was shown in HyunDong et al.'s study, we found that there was a larger GRF for the affected limb.

It is suggested that there may have been a side-dependent effect on the peak GRF due to targeting within the control group because of the stark contrast shown between these two studies. To confirm this, further studies would have to be conducted within the test population. This should be done with a much longer experiment involving a series of normative trials where the presence and location of the force plate are unknown followed by a series of trials, where the force plate is clearly marked and the participants are instructed to step within its boundaries.

Alternatively, as the findings of this experiment have shown, the rate at which a participant changes their spatiotemporal gait parameters after the targeting step onto the force plate back to what is suggested to be a normal non-targeting gait may be taken advantage of in further experiments. It would be possible to have a visible targeting force plate followed by a hidden force plate. The advantage of this set-up would be that the position of the participants' footfall should be fairly easy to approximate following on from the visible force plate and as such this should increase the reliability of getting valid kinetic data from a trial.

Lastly, kinetic data could also be collected in a normative manner by use of insole pressure sensors as used in HyunDong et al.'s[20] study. However, currently the sensitivity and usefulness of these devices are limited when compared with existing force plates. If the technology were to be developed further, the ability to record GRF without the use of a force plate would limit the number of trials necessary while removing the targeting effect as there would be no visual cues influencing the participant.

Until these wearable sensors see wider adoption, the most common method of gait analysis will likely still use force plates. To improve the methods that researchers and clinicians use with these set ups, it is suggested that

gait analysis experiments report the total number of trials that were failures to help determine more reliable procedures. During our experiment, we found the failure rates for stroke survivors to be significantly higher than for healthy participants. This value was not in our opinion excessive, but more work could be done to establish reliable standards for analysing gait.

The outcome of this research gives more information for researchers and gait clinicians to consider the effect of targeting on their analysis and diagnosis. Additionally, these findings can be used for developing the cognitive control strategy of various assistive-robotic systems such as Locomat, ReoAmbulator, exoskeletons and the lower-limb rehabilitation system under development at the University of Birmingham.[23,24]

Conclusions

This study has found clear evidence of the effect of targeting motor control on spatiotemporal parameters of gait in both the healthy and stroke-survivors populations. There was also a potential effect on peak GRF values in the stroke-survivor population when compared against existing studies though this would require a further study to investigate. There was no effect found on the kinematic angles upon heel strike for either population attributable to the targeting effect.

Further study is needed into the effects on targeting not only in special populations but also healthy populations as current studies have contradictory findings. With an understanding of how the targeting motor control affects the healthy and special populations, gait analysis experiments may be designed to work around this effect and provide data more relevant to natural gait. This will aid in both the research of conditions effecting gait and the interpretation and use of data collected in clinical settings.

Declaration of conflicting interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: The authors declare that there are no financial and personal relationships with other people or organisations that could inappropriately influence (bias) their work. The authors declare that submitted article was not yet published in whole or in part in any other journal or is not under consideration for publication elsewhere.

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Ethical approval

We further confirm that any aspect of the work covered in this manuscript that has involved humans has been conducted with the ethical approval of all relevant bodies and that such approvals are acknowledged within the manuscript.

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