Wilmut, K

Locomotor adjustments when navigating through apertures

Wilmut, K and Barnett, A L (2010) Locomotor adjustments when navigating through apertures. Human movement science, 29 (2). pp. 289-298.

Doi: 10.1016/j.humov.2010.01.001

Locomotor adjustments when navigating through apertures

Kate Wilmut and Anna L. Barnett

Department of Psychology, Oxford Brookes University, Gipsy Lane, Oxford, OX3 OBP

Corresponding author:

Kate Wilmut

Department of Psychology,

Oxford Brookes University,

Gipsy Lane,

Oxford, OX3 0BP

E-mail: k.wilmut@brookes.ac.uk

Tel: +44 (0) 1865 483 781

Fax: +44 (0) 1865 483 887

Key words:

Obstacle avoidance; Navigation; Apertures; Locomotion

Acknowledgements:

We would like to thank Roy Barnett for constructing the partitions, Fleur Corbett for data collection, the Movement Science Group at Oxford Brookes University for providing the motion capture system and the School of Social Sciences and Law at Oxford Brookes University for funding this project.

1. Abstract

During everyday locomotion we encounter a range of obstacles which require specific motor responses. One example of such an obstacle is a narrow passage or aperture which forces us to rotate the shoulders to pass through. Research has demonstrated that the decision to rotate the shoulders is body scaled (Warren & Whang, 1987) and that the visuo-motor system generates a shoulder rotation proportional to the size of the aperture (Higuchi, Cinelli, Greig, & Patla, 2006). The current study considered how much of a movement is tailored to aperture size by measuring the shoulder angle and movement speed. Aperture sizes were classified into shoulder/aperture ratios (SA ratio) and included two SA ratios for which participants had to rotate (0.9 and 1.1) and two SA ratios for which participants could pass freely (1.5 and 1.7). Movement towards and through these apertures were measured in nine young adults. During the initial approach phase (first three seconds of movement), shoulder rotation and movement speed were invariant across SA ratio. Later in the movement, angle of shoulder rotation and the magnitude and timing of the reduction in speed were all proportional to SA ratio, even when no shoulder rotation was present. The timing of the reduction in speed was progressively earlier in the movement as SA ratio decreased. In fact, the timing of the reduction in speed was different for the two SA ratio conditions where no shoulder rotation was needed. This suggests that early adjustments of a movement, such as the timing of the reduction in speed are tightly tuned to the ratio between aperture size and shoulder width, even when no later body adjustments are needed.

2. Introduction

In order to successfully interact with the environment we need to understand what actions are possible in a given situation. Gibson (1979) defined the opportunities for a given organism in a given environment as the *affordances* of that environment. Affordances are tied to the interaction between the physical properties and capabilities of the actor and the physical properties of the environment (Gibson, 1979). A standard chair might afford an adult to sit but would afford an infant to steady themselves while standing. A rich, ever moving environment, in a task such as navigating a busy street, requires constant monitoring in order to use visual information to accurately perceive the behavioural possibilities or the affordances of the environment and then plan for necessary adjustments (Turvey, 1992).

Warren & Whang (1987) considered how people decided whether or not an aperture affords passage. Participants passed through a variety of aperture sizes, ranging from 35cm to 70cm in 5cm increments; a number of these aperture sizes were smaller than shoulder width, thus forcing participants to rotate their shoulders. Warren and Whang (1987) found that the decision to rotate the shoulders was based on body scaled information (Warren & Whang, 1987). In fact, participants consistently left a margin of 1.3 times shoulder width, rotating for any aperture smaller than this. These results suggest that participants are able to accurately perceive the affordance of an aperture in order to guide locomotion (Warren & Whang, 1987). Previous work has similarly indicated that judgements of stepping height are also based upon body dimensions (Warren, 1984). Since this seminal work by Warren and Whang, the flexibility of scaling to body size has been demonstrated by accurate judgements even after changes in body size, such as during pregnancy (Franchak & Adolph, 2007) or when able bodied participants are asked to pass through an aperture in a wheelchair (Higuchi et al., 2006)

In a recent study Higuchi et al. (2006) extended the work of Warren and Whang by considering how shoulder rotation while passing through an aperture is tailored to aperture size. They used aperture sizes scaled to shoulder width below the critical aperture ratio of 1.3, thus forcing participants to rotate the shoulders for all aperture ratios. Higuchi et al. (2006) found that as aperture size decreased, angle of shoulder rotation at the door increased. In fact they found that shoulder rotation at point of door crossing was proportional to the size of the aperture. This tuning of shoulder rotation to aperture size suggests that the visuo-motor system accurately judges the amount of shoulder rotation needed to pass a specific aperture rather than generating a maximum shoulder rotation every time. In addition to investigating shoulder rotation at the aperture Higuchi et al. (2006) also considered the walking speed throughout the movement. They observed a reduction in speed just prior to crossing the aperture, they suggested that this change in movement speed allows the visuo-motor system more time to process visual information and plan an appropriate behavioural response. This is in line with more recent studies which have also found a reduction in speed prior to the initiation of a shoulder rotation when approaching oscillating doors (Cinelli & Patla, 2008). However, Patla, Prentice, Robinson, & Neufeld (1991) report that in order to maintain control of the body during a direction change a reduction in speed is needed, thus the decrease in speed could be an artefact of the shoulder rotation itself and may not occur if no shoulder rotation is needed. Alternatively, the reduction in speed could simply be a protective mechanism to minimise injury if a collision occurs, and may be apparent when crossing any threshold regardless of whether a body turn was needed. It is unclear from the Higuchi et al. (2006) study which, if any, of these factors could explain the reduction in speed.

Higuchi et al. (2006) indicated that the visuo-motor system can accurately tailor movements to aperture size. In their study, timing of the reduction in speed was not measured and so adjustments tuning the movement to the specific aperture size could have been made at any point during the approach phase. Patla, Niechwiej, Racco, & Goodale (2002) suggested that full visual information is vital early in the approach phase and degrading visual information during this stage, but not later in movement, is detrimental to stepping over an obstacle. In agreement with this, Montagne, Buekers, de Rugy, Camachon, & Laurent (2002) have shown that visual information is not translated to changes in movement until a step or two before they are needed. Therefore, it seems that full visual information is vital in the acquisition of information about the environment early on, but that this information does not lead to adjustments in the movement until the end of the approach phase. Whether this is the case while approaching an aperture is unclear.

In the current experiment we considered the pattern of movement while approaching an aperture from the start point, across the initial approach phase, up until the point of crossing. We used an aperture range of 35cm to 70cm (as used by Warren & Whang, 1987), this provided us with apertures through which participants could pass freely (without a shoulder rotation) and apertures that forced participants to rotate their shoulders. This study had two main aims: 1. to consider how a movement towards an aperture is tailored during the initial approach phase of a movement (first three seconds) by measuring shoulder angle (with respect to the frontal plane) and movement speed throughout the approach phase. Previous studies have shown that movement is not adapted until a step or two before the adjustment is needed (Montagne et al., 2002); however , this has only been shown for a stepping task and whether a similar pattern will be seen while passing through an aperture remains to be seen; 2. to consider how a movement to an aperture is tailored after the initial phase during the adaptive phase. Again, adjustment of movement was considered in terms of shoulder angle and movement speed. Previous studies have indicated that shoulder rotation at the point of crossing is proportional to aperture size (Higuchi et al., 2006; Warren & Whang, 1987). However, it was not known whether a reduction in movement speed, would also be proportional to aperture size. Both of these aims were addressed by comparing within and between apertures which force a rotation versus those which allow passage without rotation.

3. Methods

3.1. Participants

A group of nine male participants were included in this study; this was an opportunistic sample of postgraduate students and research staff at Oxford Brookes University. The group had a mean shoulder width of 41.5 (range: 40.0cm-42.5cm) and a mean age of 27 years (age range: 21years-30years). All participants had normal or corrected vision and were naïve to the purpose of the experiment.

3.2. Apparatus

Participants stood 5m away from the centre of an aperture (or doorway) formed by two sliding partitions (2m x 1m). The partitions consisted of a single piece of wood attached to a triangular base which was supported by castors. When viewed from the front neither the base nor the castors were visible. The back wall of the room lay 2m behind the partitions. See Figure 1 for an illustration of the setup. A Pro-reflex 3D motion capture system (Qualysis) running at 120Hz was used to track the movement of three reflective markers (15mm in diameter) placed on the left and right acromion process (LAP and RAP respectively) and on the seventh cervical vertebrae (C7). To determine the point at which a participant passed through a doorway two additional markers were also placed on the edge of the partitions.

INSERT FIGURE 1 HERE

3.3. Procedure

This project was approved by the School of Social Sciences and Law (Oxford Brookes University) ethics committee. On a given trial participants were asked to stand behind the start point (5m from the apertures) and focus on a cross marked on the floor 0.3m in front of their feet. On initiation of a trial, participants were instructed to look up and walk, at a self-selected pace, through the aperture to the stop point (1.5m past the partitions). On returning to the start point (by passing around the back and to the right of the partitions) participants were told once again to focus on the cross and not look up until instructed to do so. No specific instructions were given on how participants should act when an aperture was too small for them to simply walk through. While the participant returned to the start point the experimenter changed the aperture size by sliding the doors closer together or further apart in accordance with a measure placed on the floor. Aperture sizes ranged from 35cm to 70cm in 5cm increments (8 apertures) and each aperture was presented four times (total of 32 trials per participant). Apertures were presented in a pseudo-randomised order, whereby the same aperture was not used on two or more consecutive trials and aperture size did not predictably increase or decrease; two orders were used and participants completed one of these two sequences. Participants were prevented from viewing the aperture size prior to the start of each trial.

3.4. Data analysis

All participants successfully passed through each aperture size without colliding with either partition. Pro-reflex movement data was filtered using an optimised low pass Woltring filter with a 12Hz cut-off point and was then analysed using tailored MatLab routines. Shoulder width and aperture width was calculated using x and y position of the LAP and RAP and the door markers respectively. Actual aperture width (as determined by the door markers) was found not to deviate more than ±0.5cm from desired aperture widths; this error was considered small enough to be negligible. Separate kinematic measures were taken for the initial approach phase (defined as the first 3 seconds of movement) this covered approximately the whole movement time up to a step or two before the aperture (a similar method was adopted by Patla et al., 2002) and for movement after this initial phase, the adaptive phase. An illustration and a description of these variables can be seen in Figure 2.

INSERT FIGURE 2 HERE

In order to address the aims of this study, to measure shoulder angle and movement speed, a number of dependent variables were considered; these are described below and are illustrated in Figure 2. **Measurements of shoulder angle**: shoulder angle was calculated with respect to the initial frontal plane (at start point) from the x and y coordinates of LAP and RAP. *Baseline rotation (^{o})* is the mean angle rotation of the shoulders across the approach phase. *Shoulder angle at door (^{o})* is the angle between the shoulders, with respect to the initial frontal plane, as C7 passed the apertures. *Time after shoulder rotation (ms)* refers to the amount of movement time remaining after the initiation of a shoulder rotation, initiation of a rotation was defined as the time of the inflection point prior to the rotation (Hollands, Ziavra, & Bronstein, 2004). *Distance from door (m)* was the distance left between C7 and door after a shoulder rotation started. These final two variables, *time after shoulder rotation* and *distance from door*, were only calculated on trials where a shoulder rotation occurred. A shoulder rotation occurred on 100% of trials for the 0.9 and 1.1 SA ratios and on 0% of trials for the 1.5 and 1.7 SA ratios. Where reported these variables are based on all available trials.

Measurements of speed: For movement speed, the least-squares approximation method was used to determine a trend line of a speed-time profile for the movement of C7 during each trial. All subsequent measurements of movement speed were taken from this trend line. A reduction in speed occurred if speed after 3 seconds dropped more than 3 standard deviations below the approach speed (all in line with Higuchi et al., 2006). *Approach speed (ms^{-1})* describes the average movement speed from second 1 to second 3 of the movement. *Reduction in speed (ms^{-1})* was defined as the change in speed, if speed from 3 seconds onwards dropped more than 3 standard deviations below the approach speed. If no reduction in speed was seen then the reduction is set as 0ms^{-1}. *Time after initiation of reduction in speed (ms)* refers to the amount of movement time remaining after the initiation of the reduction in speed. Initiation of reduction in speed was determined as the time of the inflection point prior to speed dropping 3SD below the approach speed (method used in line with the definition of shoulder rotation onset). This variable was only calculated for trials where a reduction in speed occurred, this accounts for 100% of trials for the 0.9 SA ratio, 91% of trials for the 1.1 SA ratio, 80% of trials for the 1.5 SA ratio and 78% of trials for the 1.7 SA ratio. *Speed at door (ms^{-1})* refers to the speed the participant was travelling when C7 passed through the apertures.

3.5. Classification of shoulder to aperture ratios

In order to examine locomotor behaviour across participants it was necessary to compare aperture widths which were equivalent in terms of body size. To do this we first calculated shoulder to aperture ratio (SA ratio) across all aperture widths and for each participant. The ratio at which participants turned on 50% of the trials (critical aperture ratio) was calculated as 1.33 (in line with the Warren & Whang, 1987), study). Based on this we were able to group trials into two SA ratios below the critical aperture ratio (0.9 and 1.1) and two SA ratios above the critical aperture ratio (1.5 and 1.7). As participants had varying shoulder widths the SA ratios were not exact, but the average margin of error was no more than ±1.3cm. For example, for a SA ratio of 1.5, a participant with a shoulder width of 42.5cm would need to pass through an aperture width of 63.8cm; however, the closest aperture width to this was 65cm, resulting in an error of 1.2cm. All participants rotated their shoulders on 100% of trials in the 0.9 and 1.1 SA ratios (thus termed rotation SA ratios) and rotated their shoulders on 0% of trials in the 1.5 and 1.7 SA ratios (thus termed no rotation SA ratios).

3.6. Statistical analysis

For each SA ratio data was averaged across participants. Unless otherwise specified repeated measures one-way ANOVA was used to compared each dependent variable across the four levels of the independent variable (SA ratio; 0.9, 1.1, 1.5, 1.7). Post hoc procedures were carried out for all significant main effects, these involved running all possible pairwsie comparisons and using Sidak correction to correct for the elevated risk of a type I error. Partial-eta squared (η^2) which is equivalent to r^2 (Field, 2006) is reported as a measure of effect size. Cohen (1992) reported a small effect size is indicated by r=0.10 (r^2=0.01), a medium effect size by r=0.30 (r^2=0.09) and a large effect size by r=0.50 (r^2=0.25).

4. Results

4.1. Movement during the initial approach phase: comparison of all SA ratios

Measurements of speed and shoulder angle for the four SA ratios (0.9, 1.1, 1.5 and 1.7) were compared for the initial approach phase (first three seconds of movement). These data can be found in table 1. One-way ANOVAs (SA ratio) showed no significant effect of SA ratio for baseline rotation or average approach speed [$F<1$, $p>0.05$].

INSERT TABLE 1 HERE

4.2. Movement during the adaptive phase: comparison of all SA ratios

Next the dependent variables relating to movement during the adaptive phase (after the initial approach phase), were considered across all four SA ratios (0.9, 1.1, 1.5, and 1.7). A significant effect of SA ratio was found for the reduction in speed [$F(3,24)=15.162$ $p<0.001$ $\eta^2=0.655$][1], see Figure 3a. Post hoc tests indicated a significant difference between 0.9/1.1 and 1.5/1.7, whereby the reduction in speed was significantly larger for the 0.9 and 1.1 SA ratio compared to the 1.5 and 1.7 SA ratio [$p<0.05$ using Sidak correction], no differences were seen within the shoulder turn SA ratios (0.9 and 1.1) or the no shoulder turn SA ratios (1.5 and 1.7). An effect of SA ratio was also found for angle at door [$F(3,24)=62.292$ $p<0.001$ $\eta^2=0.886$], see Figure 3b. Post hoc tests showed that the angle at door was significantly larger for 0.9 compared to 1.1, larger for 1.1 compared to 1.5 but not different between 1.5 and 1.7 [0.9>1.1>1.5=1.7; $p<0.05$ using Sidak correction]. No differences were seen for speed at door, this data can be seen in Figure 3c. Finally the timing of movement adjustments was considered using the timing of the reduction in speed and the timing of the shoulder rotation, see Figure 3d. An effect of SA ratio was seen for time left after initiation of the reduction in speed [lower bound correction used due to violation of sphericity: $F(1,8)=24.668$ $p<0.001$ $\eta^2=0.711$], post hoc tests indicated this difference was between all four SA ratios, with 0.9 showing the greatest amount of time left after initiation of reduction in speed, followed by 1.1, then 1.5 and then 1.7 showing the least amount of time left after initiation of reduction in speed [0.9>1.1>1.5>1.7; $p<0.05$ using Sidak correction]. This analysis indicated a linear trend suggesting a strong relationship between SA ratio and the

[1] Variables relating to the reduction in speed were only calculated for trials where a reduction in speed occurred. No significant difference was seen across SA ratio in terms of percentage of trials on which a reduction in speed occurred. In addition, approach speed was invariant across trials regardless of whether a reduction in speed occurred [F<1].

timing of the reduction in speed. This relationship was further examined by conducting Spearman correlations between exact SA ratios (ratio of aperture size and participant shoulder width) with the time left after reduction in speed. Significant negative correlations were found for all but one participant [r=-0.703 p<0.001, r=-0.811 p<0.001, r=-0.297 p=0.169, r=-0.582 p=0.006, r=-0.753 p<0.001, r=-0.762 p<0.001, r=-0.613 p=0.009, r=-0.734 p=0.004, r=-0.834 p<0.001]. A paired samples t-test was used to compare time left after initiation of shoulder rotation for SA ratios of 0.9 and 1.1, see Figure 3d (this variable could only be calculated for shoulder rotation trials). No differences were seen between the 0.9 and 1.1 SA ratio for time left after shoulder rotation started [p>0.05].

INSERT FIGURE THREE HERE

4.3. Relationship between shoulder rotation and movement speed

The reduction in speed has three possible functions: to allow more time for motor planning; to allow a shoulder rotation; or minimise risk of collision when passing through an aperture. The temporal ordering of the reduction in speed and the shoulder rotation allowed a close comparison of these functions[2]. T-tests were used to compare the time left after initiation of the shoulder rotation with time left after initiation of the reduction in speed. For both 0.9 and 1.1 SA ratios the initiation of the reduction in speed occurred significantly earlier in the movement compared to the initiation of the shoulder rotation [0.9, t(8)=5.562 p=0.001 and 1.1, t(8)=4.607 p=0.002]. In order to examine the relationship between the magnitude of the reduction in speed and the magnitude of the shoulder rotation we carried out a correlation between the reduction in speed and shoulder angle at the door. As before, only those trials where a reduction in speed was seen were used for this comparison. Individual correlations

[2] Time left after a reduction in speed could only be calculated on trials where a reduction in speed occurred. A reduction in speed was not seen on all trials; therefore, only trials where both a reduction in speed and a shoulder rotation occurred were used in this analysis.

for these two variables were carried out for each participant. Fisher's z transformation was then used to normalise the r values and an average z value was calculated. A significant positive correlation between time left after initiation of a reduction in speed and angle at door was found ($z'=1.83$ $p=0.034$).

5. Discussion

This study considered measurements of movement speed and measurements of shoulder angle while participants passed through apertures of varying sizes. In terms of the initial approach phase (first three seconds of movement) towards an aperture we have demonstrated that baseline rotation and approach speed do not differ across aperture size. This finding suggests that participants initiate a generalised walking pattern which is later updated and adapted to aperture size. Other studies have shown that visual information during the initial approach phase is vital for an accurate movement later on (Patla et al., 2002) and that adjustments are made to locomotor movements during the last few steps (Montagne et al., 2002) or in the last 2 seconds (Cinelli, Patla, & Allard, 2008) of a movement, even when visual information about the adjustments needed is available well ahead of this time. Therefore, it seems that this visual information is collected during the initial approach phase but is not translated to movement adaptations until the final stage of movement.

When considering the adaptive phase (movement after the initial three seconds) our study has demonstrated that the angle of shoulder rotation at the door is proportional to the ratio between the size of the door and shoulder width, as this ratio decreases the shoulder angle at the door increases, as indicated by Higuchi et al. (2006). However, it is the measurements of speed that yielded the most interesting results. Initially, these findings confirmed those of

Higuchi et al. (2006) by demonstrating that when approaching an aperture a reduction in speed is seen. What is novel in this study is that a reduction in speed is seen regardless of whether a shoulder rotation is needed. We have previously suggested that the function of the reduction in speed could be three-fold: 1. allowing the visuo-motor system more time to process information and plan a response (supported by Cinelli, Patla, & Allard, 2008); 2. is directly linked to the shoulder rotation, (Patla et al., 1991) reported that a change in direction is linked to a reduction in speed and the same may be true for a shoulder rotation; 3. a protective mechanism to minimise injury if a collision occurs. This third option seems a likely explanation given that a reduction in speed was seen on 78-80%. Therefore, the reduction in speed must have a function which is separate from the need to rotate the shoulders. On shoulder rotation trials the reduction in speed is greater, suggesting an additional factor is involved. Our results suggest that it is unlikely that the larger reduction in speed seen on shoulder rotation trials was caused by the actual rotation itself as these events did not occur simultaneously. However, this elevated reduction in speed on shoulder rotation trials could allow additional time to process visual information and produce a suitable response as suggested by Cinelli & Patla (2008) and Higuchi et al. (2006). This conclusion would support previous findings that movement speed is slower on trials that are obstructed compared to unobstructed trials (Lowrey, Reed, & Vallis, 2007; Vallis & McFadyen, 2003).

Measurements of speed in the adaptive phase also extend previous findings and indicate that the timing of the reduction in speed was very tightly related to the ratio between aperture size and shoulder rotation. The reduction of speed occurred progressively later in the movement as aperture size increased; reduction in speed was earliest for apertures 0.9 times shoulder width (~1800ms), followed by apertures 1.1 times shoulder width (~1500ms), followed by apertures 1.5 times shoulder width (~940ms) and finally, latest for apertures 1.7 times shoulder width (~700ms). In fact, a strong negative relationship was seen between the aperture to shoulder width ratio and the timing of the reduction in speed, in all but one participant. This strongly suggests that the timing of the reduction in speed is finely tuned to the exact aperture size rather than being of a generic magnitude. Movement characteristics (such as approach speed) of the one participant who did not show a significant relationship were examined; no obvious differences between this and other participants could be identified to explain. Therefore, the reason this participant did not tailor the timing of the reduction in speed to aperture size is unclear.

To our knowledge this is the first study to show that the temporal aspects of the reduction in speed are linked to the relative size of the aperture even when no major adjustments to body position are needed. In order to consider why the timing of the reduction in speed may be so tuned to the aperture size, we must first consider this in terms of shoulder rotation vs. no shoulder rotation trials. Shoulder rotation trials: Montagne, Cornus, Clize, Quaine, & Laurent (2000) showed that the timing of the reduction in speed is linked to the size of the subsequent adjustment, thus we would expect that large shoulder rotations would need an earlier reduction in speed compared to smaller shoulder rotations. Furthermore, Higuchi et al. (2006) and Cinelli & Patla (2008) suggest that a reduction in speed prior to crossing the threshold of an aperture allows more time to process visual information and produce a suitable response, this could be extended to say that both the magnitude of a reduction and the timing of a reduction in speed maybe linked to the size of an adjustment thus allowing more processing time. No shoulder rotation trials: Higuchi et al. (2006) suggested that a reduction in speed may occur when crossing a threshold regardless of risk of collision, however, this does not explain why the timing of the reduction in speed would be linked to aperture size when no shoulder rotation was needed. Shoulder angle at the door was invariant for the two no shoulder rotation aperture ratios, indicating no differences in the final adjustment of movement. Maybe, the adaption to movement speed is timed proportionally to the aperture to shoulder width size before the decision of whether a rotation is needed is made. Thus a reduction in speed is always made, which is temporally linked to obstacle size, regardless of whether any overt adaption is needed.

This study has provided evidence that movements towards an aperture are finely tuned to the ratio between aperture size and shoulder rotation. Shoulder width across participants in this study any varied by only 2.5cm, making a comparison between ‘large’ and ‘small’ participants impossible. The results from this study, therefore, cannot be used to determine whether participants tailor movements to extrinsic variables or to body size. However, previous studies, which specifically aimed to answer this question, suggest that when passing through an aperture the degree of shoulder rotation is tuned to body size rather than aperture size (Higuchi et al., 2006; Warren & Whang, 1987).

The findings of this study provide strong evidence that the timing of the reduction in speed and the size of the shoulder rotation at the door is closely linked to shoulder to aperture ratio and participants do not simply generate a standard shoulder rotation movement or a standard no shoulder rotation movement. Tailoring early aspects of movement like the timing of the reduction in speed is functional if subsequent adjustments are also tailored, such as shoulder rotation at the door. However, it seems the timing of the reduction in speed may be tailored even when no subsequent adjustment or no shoulder rotation is needed. These findings suggest that, initially a generalised movement towards an aperture is programmed which is later updated and these adjustments are tightly related to the ratio between aperture size and body size. This happens even when no overt adjustments to direction are needed or forced by an obstacle. We conclude that humans are constantly altering the kinematics of movement in anticipation of an adjustment even when no obstacle is in our pathway. Further research is needed to strengthen this conclusion and to determine whether it extends to other types of obstacle avoidance.

6. References

Cinelli, M. E., & Patla, A. E. (2008). Task-specific modulations of locomotor action parameters based on on-line visual information during collision avoidance with moving obstacles. *Human Movement Science, 27*, 513-531.

Cinelli, M. E., Patla, A. E., & Allard, F. (2008). Strategies used to walk through a moving aperture. *Gait and Posture, 27*, 595-602.

Cohen, J. (1992). A power primer. *Psychological Bulletin, 112*(1), 155-159.

Field, A. (2006). *Discovering statistics using SPSS* (Second ed.). London: Sage.

Franchak, J. M., & Adolph, K. (2007). *Perceiving changing affordances for action: pregnant women walking through doorways.* Paper presented at the Paper presented at the Vision Science Society Conference (VSS), Florida, USA.

Gibson, J. J. (1979). *The ecological approach to visual perception.* Boston: Houghton Mifflin Company.

Higuchi, T., Cinelli, M. E., Greig, M. A., & Patla, A. E. (2006). Locomotion through apertures when wider space for locomotion is necessary: Adaption to artificially altered body states. *Experimental Brain Research, 175*(1), 50-59.

Hollands, M. A., Ziavra, N. V., & Bronstein, A. M. (2004). A new paradigm to investigate the roles of head and eye movement in the coordination of whole-body movements. *Experimental Brain Research, 154*, 261-266.

Lowrey, C. R., Reed, R. J., & Vallis, L. A. (2007). Control strategies used by older adults during multiple obstacle avoidance. *Gait and Posture, 25*, 502-508.

Montagne, G., Buekers, M., de Rugy, A., Camachon, C., & Laurent, M. (2002). Control of human locomotion under various task constraints. *Experimental Brain Research, 143*, 133-136.

Montagne, G., Cornus, S., Clize, D., Quaine, F., & Laurent, M. (2000). A perception-action coupling type of control in long jumping. *Journal of Motor Behavior, 22*, 37-43.

Patla, A. E., Niechwiej, E., Racco, V., & Goodale, M. (2002). Understanding the contribution of binocular vision to the control of adaptive locomotion. *Experimental Brain Research, 142*(4), 551-561.

Patla, A. E., Prentice, S. D., Robinson, C., & Neufeld, J. (1991). Visual control of locomotion: strategies for changing direction and going over obstacles. *Journal of Experimental Psychology: Human Perception and Performance, 17*(3), 604-634.

Turvey, M. T. (1992). “Affordances and prospective control: An outline of the ontology”. *Ecological Psychology, 4*, 173-187.

Vallis, L. A., & McFadyen, B. J. (2003). Locomotor adjustments for circumvention of an obstacle in the travel path. *Experimental Brain Research, 152*, 409-414.

Warren, W. H. (1984). Perceiving affordances: Visual guidance of stair climbing. *Journal of Experimental Psychology: Human Perception and Performance, 10*, 683-703.

Warren, W. H., & Whang, S. (1987). Visual guidance of walking through apertures: Body-scaled information for affordances. *Journal of Experimental Psychology: Human Perception and Performance, 13*(3), 371-383.

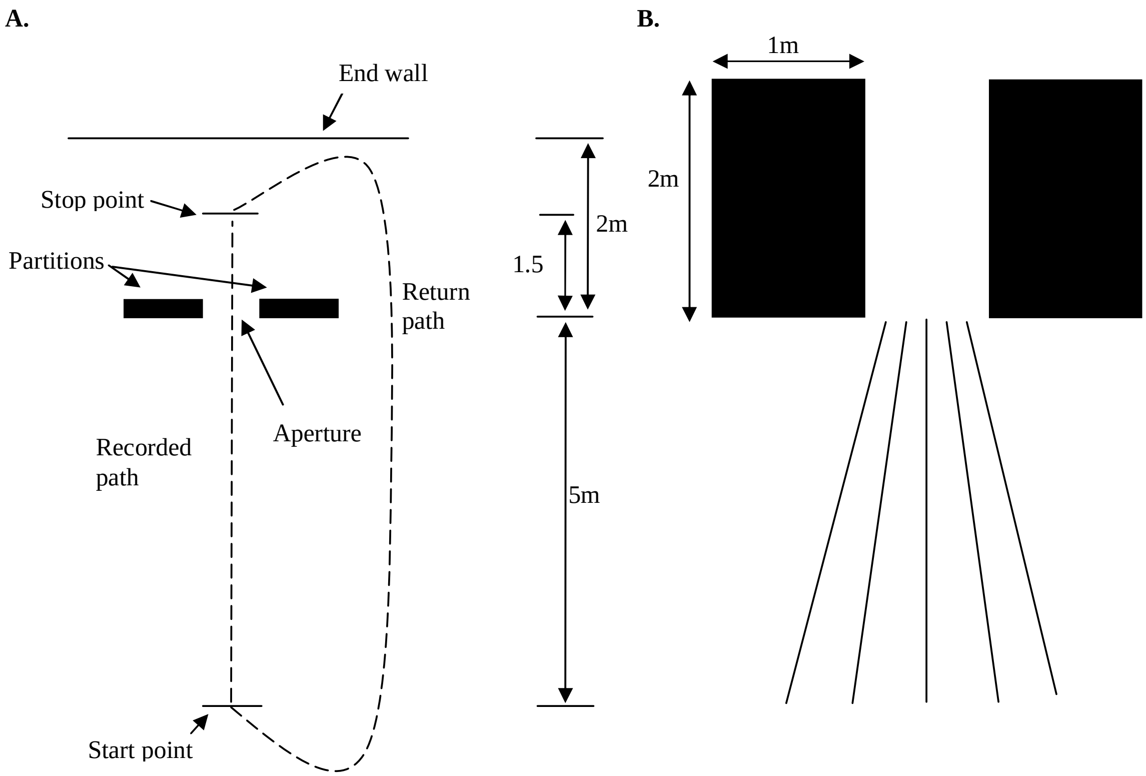

Figure 1. A. Birds eye view of the experimental setup. Participants started at the start point 5m away from the partitions. Movement was recorded as they walked through the aperture to the stop point (located 1.5 m from the apertures). Participants then returned to the start point along the return path. B. A frontal view of the experimental set up

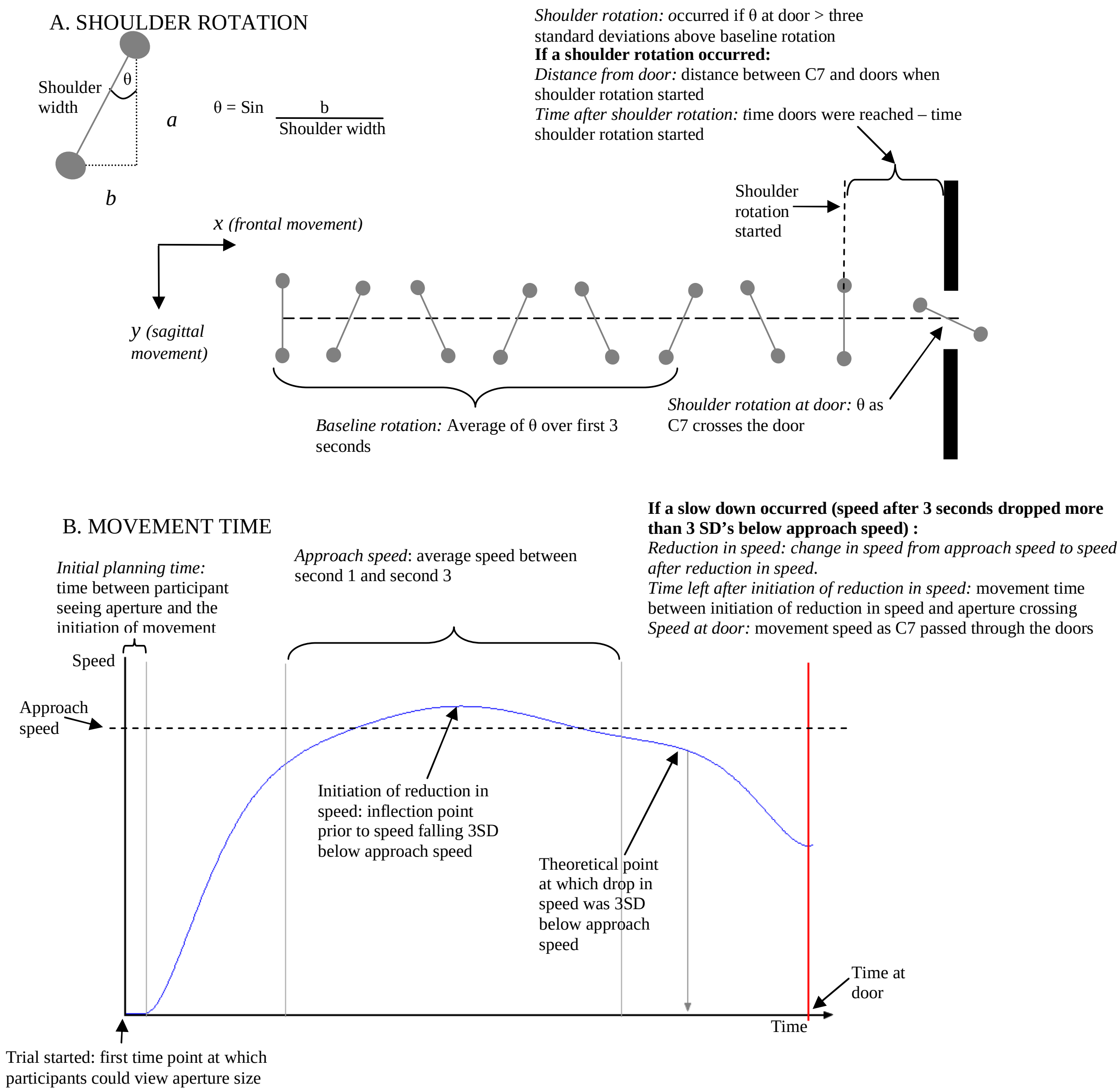

Figure 2. **A. Illustration of shoulder rotation.** Variables: *baseline rotation (°)*, average of θ during normal walking over the first 3 seconds; *shoulder angle at door (°)*, θ as C7 passed through the door and; *shoulder rotation (yes or no)*, defined as when shoulder rotation at door exceed three standard deviations above baseline rotation. If a shoulder rotation did occur two additional variables were calculated: *distance from door (m)*, distance between C7 and the door at the point of turn initiation and; *time after shoulder rotation (s)*, the time left after the initiation of a shoulder rotation. **B. Illustration of movement time.** Variables: *initial planning time (ms)*, time between participant first seeing aperture and start of movement; *approach speed (ms^{-1})*, average speed from the 1st-2nd second. If a reduction in speed did occur (if speed dropped more than three standard

deviations below approach speed) three additional variables were calculated: *reduction in speed* (ms^{-1}), change in speed from approach speed to speed after reduction in speed; *time after initiation of reduction in speed (s)*, amount of movement time between reduction in speed and the point of aperture crossing; and *speed at door* (ms^{-1}), movement speed at the point at which C7 passed through the threshold of the apertures.

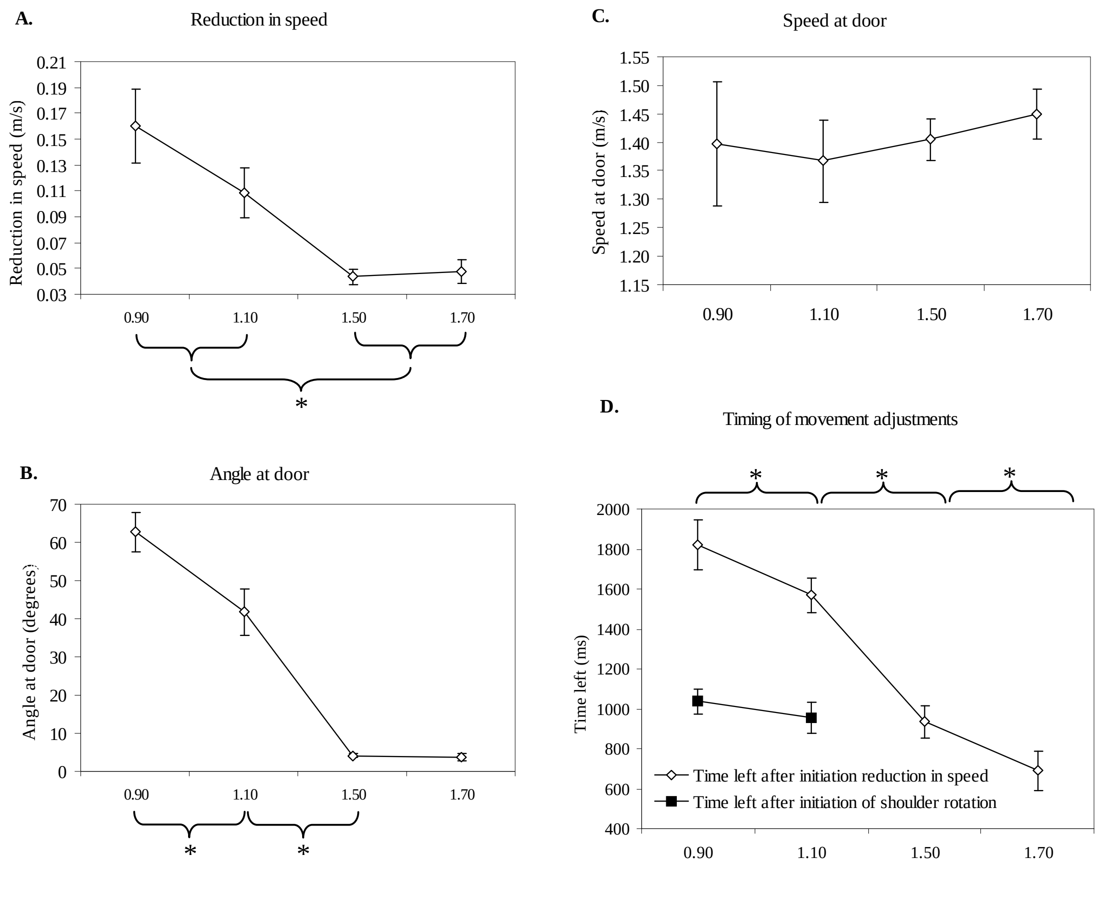

Figure 3. Data from the crossing phase of the movement. A. Reduction in speed across the four SA ratio's. B. Angle of the shoulders at the point of crossing the aperture. C. Data showing the speed when C7 passed through the apertures. D. Data showing the timing of movement adjustments. Time left after the initiation of a reduction in speed is illustrated by the hollow diamonds and the time left after initiation of a shoulder rotation is illustrated by filled squares. Significant post-hoc comparisons are indicated above and below the axis, * indicates p<0.05. Error bars illustrate standard error.

Table 1: Means for kinematic data describing the initial approach for all dependent variables across all SA ratios. Standard deviation given in parenthesis.

Aperture ratio	Approach speed (ms^{-1})	Baseline rotation (^{o})
0.9	1.48 (0.10)	3.51 (1.00)
1.1	1.47 (0.08)	3.50 (0.99)
1.5	1.47 (0.10)	3.94 (0.99)
1.7	1.50 (0.11)	3.56 (0.32)