



## Gait adjustments in response to an obstacle are faster than voluntary reactions

V. Weerdesteyn<sup>a,b,\*</sup>, B. Nienhuis<sup>a</sup>, B. Hampsink<sup>a</sup>,  
J. Duysens<sup>a,c,d</sup>

<sup>a</sup> *Sint-Maartenskliniek Research B.V., P.O. Box 9011, 6500 GM Nijmegen, The Netherlands*

<sup>b</sup> *Institute for Fundamental and Clinical Human Movement Sciences, Faculty of Human Movement Sciences, Vrije Universiteit, Van der Boechorststraat 9, 1081 BT, Amsterdam, The Netherlands*

<sup>c</sup> *Department of Biophysics, University of Nijmegen, P.O. Box 9101, 6500 HB Nijmegen, The Netherlands*

<sup>d</sup> *Department of Rehabilitation, University of Nijmegen, P.O. Box 9101, 6500 HB Nijmegen, The Netherlands*

---

### Abstract

It has been reported that obstacle avoidance reactions during gait have very short latencies. This raises the question whether the cortex can be involved, as it is in voluntary reactions. In this study, latencies of obstacle avoidance (OA) reactions were determined and related to latencies of voluntary stride modifications and simple reaction times (SRT) of hand and foot. Twenty-five healthy young adults participated in this study. While they were walking on the treadmill, an obstacle suddenly fell in front of their left leg. The first reaction to the obstacle was the moment at which the differentiated acceleration curve of the foot deviated from the control signal. Latencies of OA reactions were 122 ms (SD 14 ms) on average. Two very different avoidance reactions (lengthening and shortening of the stride) were noticed, but there was no avoidance strategy effect on OA latencies. OA latencies were significantly shorter as compared to latencies of voluntary stride modifications and simple reaction times of hand and

---

\* Corresponding author. Address: Sint-Maartenskliniek Research B.V., P.O. Box 9011, 6500 GM Nijmegen, The Netherlands. Tel.: +31 24 365 9243; fax: +31 24 365 9154.

E-mail address: [v.weerdesteyn@smk-research.nl](mailto:v.weerdesteyn@smk-research.nl) (V. Weerdesteyn).

foot. The short OA latencies could not only be explained from the dynamic nature of the task. It is suggested that subcortical pathways might be involved in obstacle avoidance.

© 2004 Elsevier B.V. All rights reserved.

*PsycINFO classification:* 2323; 2330

*Keywords:* Obstacle avoidance; Human walking; Reaction times

---

## 1. Introduction

In daily life, many obstacles are encountered and have to be avoided while walking. If the obstacle remains unnoticed, a trip and possibly a fall will be the result. In most cases, however, the obstacle will have been noticed by the visual system and in response, the locomotor pattern will be adjusted pro-actively in order to avoid the obstacle. It has been shown that these adjustments are fast, as they can be implemented in the normal walking pattern within one step cycle (Chen, Ashton-Miller, Alexander, & Schultz, 1994a, 1994b; Patla, Prentice, Rietdyk, Allard, & Martin, 1999; Weerdesteyn, Schillings, Van Galen, & Duysens, 2003). But how fast are they exactly and how does the latency of these responses compare with voluntary reaction times?

This is an important issue, because the answer could provide more insight into the processes involved in this perception–action coupling. In previous studies, the choice of an avoidance strategy has been a topic of interest (Chen, Ashton-Miller, Alexander, & Schultz, 1994b; Patla et al., 1999; Weerdesteyn, Sierevelt, Nienhuis, & Duysens, 2001). The latency of these reactions could indicate whether they can be regarded as voluntary choices or as more automated behavior. Obstacle avoidance requires a response to a visual stimulus. Latencies during simple visual reaction time tasks start from approximately 200 ms and the latency increases when more than one response can be triggered during choice reaction time tasks (e.g. Carson, Chua, Goodman, Byblow, & Elliott, 1995). Typically, these responses are obtained from a stationary starting position. However, obstacle avoidance reactions are different in that they do not require initiation of a movement from a stationary starting position. The reaction to the obstacle is characterized by modulation of an ongoing movement. Alstermark, Eide, Gorska, Lundberg, and Petterson (1984) found that cats needed only 70–120 ms to adjust their reaching trajectories when the target was displaced unexpectedly. For humans, latencies of 100–140 ms have been reported for changing the direction of reaching movements (Brenner & Smeets, 2003; Carlton, 1981; Day & Brown, 2001; Day & Lyon, 2000; Paulignan, MacKenzie, Marteniuk, & Jeannerod, 1990; Paulignan, MacKenzie, Marteniuk, & Jeannerod, 1991; Prablanc & Martin, 1992; Soechting & Laquaniti, 1983; Zelaznik & Hawkins, 1983). For both cats and humans, evidence is growing that subcortical pathways are involved in these fast reactions (Day & Brown, 2001; Perfiliev, Petterson, & Varfolomeev, 2003).

With respect to the lower limb, Patla, Beuter, and Prentice (1991) studied modification of stepping trajectories. In their study, the participants stepped over an obstacle and sometimes a second obstacle occurred behind the first. They had to traverse the two within the same step by additional lengthening. The participants chan-

ged their stepping trajectories about 120 ms after presentation of the second obstacle. The initial trajectory modification was the same for a high and a low second obstacle. After another 120 ms the low and high obstacle trajectories started to deviate. The proposed explanation for these fast responses was that the first response is a general response to the presence of the obstacle, which is fine tuned later on the basis of the properties of the obstacle. This seems to be a reasonable explanation when a response in only one direction is possible, which is additional lengthening of the step. If the responses could be in two directions, lengthening or shortening, it is conceivable that latencies differ.

The aim of the present study was to determine the latencies of obstacle avoidance reactions during treadmill walking. Both lengthening and shortening of the stride could be chosen in order to avoid the obstacle. Latencies of obstacle avoidance reactions to lengthening and shortening were compared. In addition, these latencies were compared with those obtained after voluntary stride lengthening and shortening following a visual cue. Finally, in the same subjects, the classic simple reactions times of the hand and the foot were measured with the participants at rest and compared to latencies of obstacle avoidance reactions.

## 2. Method

### 2.1. Participants

Twenty five young adults (4 men, 21 women) aged between 20 and 37 participated in the study. None of the participants suffered from any neurological or motor disorder. All participants performed the obstacle avoidance task (OA), while 12 of these participants also performed 3 additional tasks: voluntary stride modifications, a simple reaction time (SRT) task of the foot (SRT foot) and a simple reaction time task of the hand (SRT hand). They all gave informed consent to participate in the study. The study was approved by the local medical ethics committee.

### 2.2. Experimental setup and protocol

The participants walked on a treadmill (ENRAF Nonius, Type EN-tred Rea) at a speed of 3 km/h. wearing flexible gymnastic shoes (Fig. 1a). The gait speed of 3 km/h was chosen because this study was part of a larger study, in which a comparison between young and older people will be made. For the older people, 3 km/h is a comfortable walking speed (Elble, Sienko-Thomas, Higgins, & Colliver, 1991; Finley, Cody, & Finizie, 1969). A bridge, to which an electromagnet was attached, was placed above the front of the treadmill (see Schillings, Van Wezel, & Duysens, 1996; Schillings, Van Wezel, Mulder, & Duysens, 1999). A wooden obstacle, containing a piece of iron, was held by the magnet and could be released by a trigger given by the computer. The size of the obstacle was 40.0 × 30.0 × 1.5 cm (length, width, and height, respectively). The height of the obstacle was only slightly larger than the minimal toe clearance during unobstructed gait (Chen, Ashton-Miller, Alexander, &

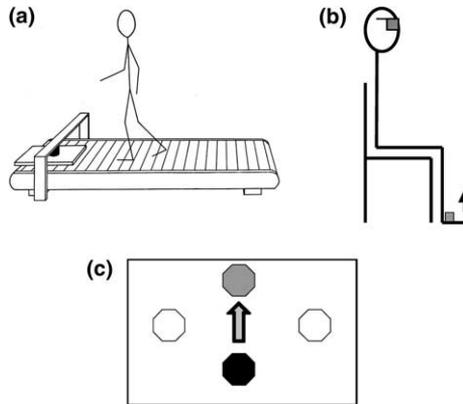


Fig. 1. (a) Schematic diagram of the experimental setup. The electromagnet (colored black) is attached to a bridge over the front of the treadmill. After the electromagnet has been switched off by a trigger from the computer, the obstacle falls onto the treadmill in front of the participant's left (ipsilateral) foot. (b) Schematic diagram of the simple reaction time task of the foot. In response to the cue of the Plato Spectacles, dorsiflexion of the foot was required. Foot accelerations were measured. (c) Schematic diagram of the simple reaction time task of the hand. When a light was turned on in the target button (grey) the home button (black) should be released as soon as possible. Fig. 1a is reprinted from *J. Neurosci. Meth.*, 67, A.M. Schillings, B.M.H. Van Wezel, J. Duysens, Mechanically induced stumbling during human treadmill walking, 11–17, Copyright (1996), with permission from Elsevier Science.

Schultz, 1991; Chou & Draganich, 1997), so adaptations of the stride length were required rather than vertical adaptations.

After release, the obstacle always fell in front of the left foot. Two markers (diameter 3 cm) were attached to the left (ipsilateral) heel and hallux. A third marker (diameter 3 cm) was placed on top of the obstacle. Marker positions were recorded by a 6-camera 3-D motion analysis system (Primas<sup>®</sup>) at a sample rate of 100 Hz. These positions were processed in real time and an algorithm was used to determine heel strike. Stride times (heel strike to heel strike) were calculated. Next, heel strike moment and position were estimated from the marker positions of the previous strides and the correct moment of obstacle release was calculated. The obstacle was released after at least five unperturbed strides were taken from the start of the trial and when the difference between two consecutive strides was less than 50 ms. The reason for this criterion was that stride regularity was a prerequisite for precise timing of obstacle release, which was necessary in the present experimental procedure. Hence, obstacle release did not occur after a fixed number of strides, but depended on the regularity of the walking pattern. In addition, an accelerometer was placed on top of the foot, proximal to the metatarsal joints. Foot accelerations in three directions were measured at a sample rate of 2400 Hz.

Each participant performed 30 obstacle avoidance trials, divided over three series of 10 trials. Participants were instructed to keep walking at a position, at which the most anterior position of the toes had a distance of approximately 10 cm to the obstacle prior to its release. The obstacle was dropped at six different phases during

the step cycle, which varied from mid stance to mid swing. These moments were randomly divided over the three series. Two of the moments of obstacle release (10 trials) were just before and right after toe off of the ipsilateral leg. In many young adults obstacle release at the transition from stance to swing corresponds to the moment at which they switch from long stride strategy (LSS) towards short stride strategy (SSS; Weerdesteyn, Nienhuis, Mulder, & Duysens, *in press*). These moments (10 trials) were used to determine the latency of the avoidance reaction. The other phases (20 trials) were introduced to prevent that the participants could predict the moment of obstacle release with respect to the step cycle. These trials were not further analyzed. A control experiment was performed to rule out the role of auditory information on OA latencies. The sound of the obstacle falling onto the treadmill could provide auditory information. Five subjects performed the normal experimental procedure and the same procedure when hearing was blocked. Hence, 10 trials per condition per participant were analyzed. Differences between mean latencies of both conditions were tested by means of paired *t* test and there was no significant difference between both conditions (mean latency 111.2 ms vs 111.4 ms with and without auditory information, respectively, SD of the difference 6.1 ms,  $p = 0.95$ ). Hence, the participants showed no benefit from the presence of auditory information.

For the voluntary stride modifications the same experimental setup was used. The participants wore Plato Spectacles (Portable Liquid Apparatus for Tachistoscropy via visual Occlusion) that could be switched from transparent to translucent by a signal given by the computer. The output signal to the spectacles was recorded by the computer. First the LSS and SSS were practiced as a reaction to the obstacle. Each strategy was practiced at least 10 times. The participants were instructed to keep these movements in their minds and were told that they had to make the same movements (both LSS and SSS) during the task without the obstacle.

The experimental procedure consisted of one series of 15 lengthened strides and one series of 15 shortened strides. The trigger for the reaction was given by the Plato Spectacles. The subjects were instructed to start the required reaction as soon as the spectacles were switched from transparent to translucent. The spectacles remained translucent for 500 ms. The spectacles became translucent at three moments during the step cycle: just before toe off, right after toe off, and during mid swing. Analogous to the obstacle avoidance task, the former two moments (10 trials) were analyzed to determine the latency of the reactions.

The simple reaction time task of the foot was performed while the participants sat on a chair, with both hips, knees, and ankles at 90° angles. The trigger was given by the Plato Spectacles at random time intervals and the required reaction was dorsiflexion of the left foot (Fig. 1b). The accelerometer was placed on the foot at the same place as during the obstacle avoidance task. Fifteen trials were performed by each participant.

The simple reaction time task of the hand was a push button task. The participants started pushing the home button. After random time intervals a light was turned on in the target button. In reaction, the participants were required to push the target button as soon as possible (Fig. 1c). The reaction time was defined as the time span between turning on the light and letting go of the home button. Each

series contained 15 trials and after two practice series the reaction times were measured during the third series.

### 2.3. *Data sampling and analysis*

First, for each trial of OA and of the voluntary stride modifications it was checked whether obstacle release or the visual cue had indeed occurred during late stance or early swing. The criterion was that the moment of obstacle release had to occur between 150 samples before and 150 samples after toe off. The stride before the obstacle was dropped was the control stride. The control strides were determined for all 30 trials. In order to determine the latency of the obstacle avoidance reaction, the marker position and accelerometer recordings of the avoidance stride were compared to the recordings of the control strides. The moment when the obstacle started to fall was determined from the marker position recordings. The mean height ( $z$ -position) and standard deviation of the obstacle marker during the control stride was calculated. The moment at which the obstacle started to fall was defined as the moment when the  $z$ -position of the obstacle marker during the avoidance stride was 1 mm below the mean  $z$ -position minus one standard deviation. Next, the accelerometer signal was filtered (second order Butterworth, cut off frequency 75 Hz.). The acceleration in the  $z$ -direction (perpendicular to the foot in the sagittal plane) was differentiated for all the control swing phases. The mean and standard deviation of the differentiated signals were calculated. The first observable reaction to the approaching obstacle was defined as the moment at which the differentiated acceleration curve of the avoidance swing phase exceeded the mean  $\pm 2$  standard deviations of the control swing phases. The latency was the time span between this moment and the moment when the obstacle started to fall (Fig. 2). For each participant, the median latency was used for analysis, because outlying high values occurred more frequently than outlying low values.

To quantify lengthening and shortening latencies in response to the Plato spectacles, the moment at which the trigger was given was determined from the recorded output signal to the spectacles. The accelerometer signals were analyzed in the same way as described for the obstacle avoidance task. The median values for both lengthening and shortening were used for analysis.

For the simple reaction time task of the foot, the recorded output signal to the Plato Spectacles was taken as the moment at which the spectacles became translucent. The first kinematic response was defined as acceleration in  $z$ -direction larger than baseline value plus  $2 \times \text{sd}$ , which is analogous to the determination of the kinematic response in the OA task.

The average median latency of the OA reaction was determined for all 25 participants. In order to determine whether choosing between two strategies adds to the time needed to react to the obstacle, the population was divided in three groups. One group used only the LSS ( $n = 3$ ) in response to the obstacle and the second group used only the SSS ( $n = 8$ ). The third group consisted of participants who used both strategies ( $n = 14$ ). Median latencies of each participant in these three groups were compared by one-way ANOVA. To determine whether LSS reactions were

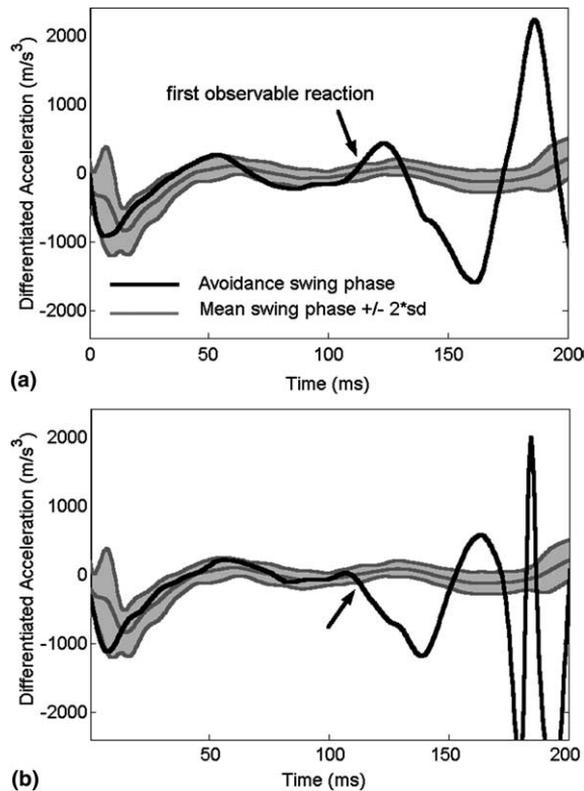


Fig. 2. Determination of obstacle avoidance latencies. The grey area represents the mean differentiated acceleration curve  $\pm 2$  standard deviations of the control swing phases. The black line corresponds to the avoidance swing phase. The arrow indicates the first observable reaction to the obstacle. The obstacle starts to fall at time = 0 ms. Fig. 2(a) shows a long stride strategy (LSS) and Fig. 2(b) shows a short stride strategy (SSS) for the same participant.

equally as fast as SSS reactions, median latencies of both LSS and SSS reactions were determined for the participants in the group that used both strategies ( $n = 14$ ). Paired  $t$  test was conducted to compare between these strategies. It was also tested whether there was a difference in latencies between late stance and early swing obstacle release trials. For all participants ( $n = 25$ ), median latencies of the late stance and the early swing obstacle release condition were compared by paired  $t$  test. For those 12 participants who also performed the voluntary stride modifications, median latencies of lengthening and shortening reactions were also compared by means of paired  $t$  test, as well as latencies of late stance and early swing cue conditions.

In order to analyze whether latencies of reactions during the four tasks were different, a repeated measures ANOVA was conducted. For this analysis, the twelve participants who performed all four tasks were included and the median latency

of each task of each participant was used. Post hoc paired *t* tests were performed to determine which tasks were significantly different. In order to determine whether there was a relation between latencies of the OA task and latencies of the other tasks, correlation coefficients were determined. An alpha level of 0.05 was used for all statistical analyses.

### 3. Results

For the analysis of OA latencies, a total of 238 trials could be selected in which obstacle release occurred during late stance or early swing. The average median latency of the obstacle avoidance reaction for all subjects was 122ms (SD 14ms). In order to investigate whether choosing between two strategies adds to the time needed to react, the groups that used only one strategy (LSS,  $n = 3$ ; SSS,  $n = 8$ ) were compared to the group that used both strategies ( $n = 14$ ). The mean latency was 117ms (SD = 10ms) in the LSS group, while it was 121 (SD = 16ms) in the SSS group and 124ms (SD = 14ms) in the two-strategy group (Fig. 3). There was no significant difference between these groups ( $F(2, 22) = 0.39$ ,  $p = 0.68$ ). In Fig. 2 an example is shown of a participant who used both strategies. The accelerometer signal of an LSS is shown in Fig. 2a, while the signal of an SSS is shown in Fig. 2b. The accelerometer signals of LSS and SSS were clearly different from the onset of the deviation, but the latencies were very similar. In this analysis the group that only used the LSS did not differ from the group that only used the SSS, but power was limited as there were only three participants in the LSS group. However, the comparison between median latencies of LSS (mean 123ms, SD 16ms) and SSS (mean 125ms, SD 15ms) reactions in the group that used both strategies yielded no significant difference either ( $p = 0.70$ ). There was no significant difference in latencies of late stance

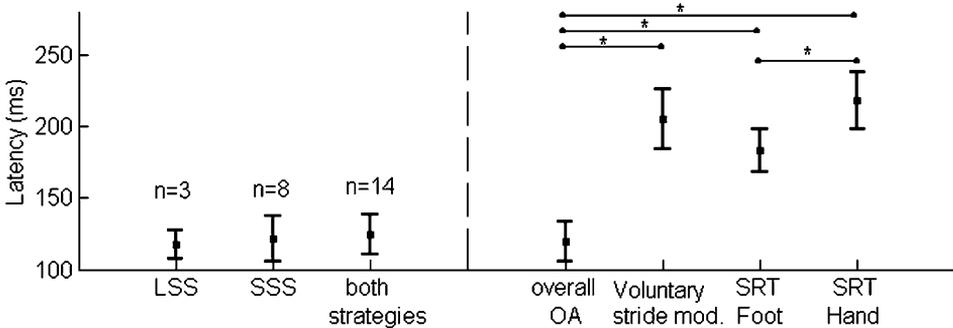


Fig. 3. Means and standard deviations of the various experimental conditions. The left part of the figure shows the mean obstacle avoidance latencies for the groups showing only LSS, only SSS, and LSS and SSS. The right part of the figure shows the latencies of the obstacle avoidance task (overall latency with all data grouped), the voluntary stride modifications (VSM), the simple reaction time task of the foot, and the simple reaction time task of the hand. The asterisks indicate significant differences ( $p < 0.001$ ).

Table 1

Correlations of OA latencies to latencies of voluntary stride length modifications, SRT foot, and SRT hand

	Task		
	Voluntary stride modifications	SRT foot	SRT hand
Obstacle avoidance	$r = 0.12$ $p = 0.70$	$r = -0.40$ $p = 0.19$	$r = 0.09$ $p = 0.78$

(mean 123 ms, SD 11 ms) and early swing (mean 122 ms, SD 17 ms) obstacle release trials ( $p = 0.98$ ).

A total of 121 trials could be selected for the analysis of voluntary stride lengthening and shortening. Trials were excluded if the visual cue did not occur during late stance or early swing, if the participant did not follow the instruction correctly (e.g. shortening of the stride when lengthening was required), or if no clear reaction could be observed. For two participants, no correct voluntary stride shortening trials could be selected for analysis. Hence, in order to determine whether latencies of lengthening reactions were different from those of shortening reactions, analysis was conducted for the remaining 10 participants. The median latency of both lengthening and shortening was 204 ms (SD 31 ms and 15 ms, respectively). There was no significant difference between the latencies of both reactions ( $p = 0.95$ ). Therefore, for each participant the median over both tasks (lengthening and shortening in response of the Plato Spectacles) was used in the subsequent analyses. The median latency in the late stance cue condition was 205 ms (SD 27 ms) and 195 ms (SD 18 ms) in the early swing cue condition. There was no significant difference between latencies of reactions in both phases of cueing ( $p = 0.25$ ).

A repeated measures ANOVA was conducted to analyse whether there were differences between the latencies of the four different experimental conditions, which were obstacle avoidance, voluntary stride modifications, SRT hand, and SRT foot. There was a main effect of condition ( $F(3, 9) = 120.15$ ,  $p < 0.001$ ). Post-hoc analysis revealed that the OA latency ( $119 \pm 14$  ms) was significantly shorter than the latencies of voluntary stride modifications ( $205 \pm 21$  ms,  $p < 0.001$ ), SRT foot ( $179 \pm 14$  ms,  $p < 0.001$ ), and SRT hand ( $218 \pm 20$  ms,  $p < 0.001$ , Fig. 3). There was also a significant difference between the latencies of SRT foot and SRT hand ( $p < 0.001$ ). No significant correlations were present between the latencies of the OA reactions and those of the other tasks (Table 1).

#### 4. Discussion

The aim of the present study was to compare the latencies of obstacle avoidance reactions with different types of voluntary reactions. The results showed that the swing trajectory in response to the sudden occurrence of an obstacle could be modified very quickly and that this reaction was not dependent on the phase of obstacle release. The mean latency of OA reactions was 122 ms. Obstacle avoidance reactions

were nearly 100 ms faster than voluntary stride modifications. OA latencies were also shorter than simple reaction times of the hand and the foot. Simple reaction times of hand and foot were significantly different, but the visual cues and the response criterion were not the same in both tasks. Hence, it can not be excluded that the differences in latencies between SRT hand and SRT foot may partly be explained by the differences in methodology. This was the first study to compare latencies of these various reaction tasks in the same participants.

The results of Patla et al. (1991), who examined the lower limb trajectory during stepping movements, showed many similarities to the present study, while the methods used differed. The participants started from a standing position and stepped over an obstacle. In some cases, a second obstacle was presented behind the first, in such a way that the stepping trajectory had to be modified. The first kinematic responses to the second obstacle were observed 120 ms after obstacle presentation. This observation is very similar to the results of the present study, despite the differences in task constraints. In the study of Patla et al. (1991) the participant knew where the second obstacle would occur and that they had to lengthen their step in response to this obstacle. In contrast, in the present study the participants did not know in which phase of the step cycle the obstacle would be released and whether lengthening or shortening of the stride would be the most favourable response.

The average OA latency of 122 ms also compared very well to the latencies that were found for changing trajectories of upper extremity movements. Brenner and Smeets (2003) found latencies of just over 100 ms for deviations of reaching movements towards high contrast targets when the target was displaced during movement. Latencies were shown to increase with decreasing contrast. Day and Brown (2001) found average latencies of 137 ms in response to a target jump during reaching. Paulignan et al. (1991) found that the first adjustments in wrist trajectories during prehension movements occurred within 100 ms when the target was displaced. It was hypothesized that these reactions were fast, because they started from a dynamic situation. In contrast, in response to a target jump from a stationary starting position, the movement was supposed to be newly programmed. In case of a target jump during movement, the discrepancy between target position and limb position required automatic reorganization of motor commands. This could explain the short latencies in dynamic situations during goal directed movements. The results of the present study confirm that the starting position might be an important determinant for latencies of OA reactions, as OA latencies were significantly faster as compared to those of SRT foot and hand. The SRT tasks required a response from a stationary starting position, while in the OA task the response was initiated from a dynamic situation. On the other hand, the OA latency was significantly shorter than the latency of voluntary stride modifications, while the starting position was the same in both tasks. Hence, the dynamic starting position can not explain the short OA latencies. Instead, the nature of the cue and the context in which the cue was given presumably were important determinants for the short latencies of OA reactions.

Secondly, in the present study, no difference was observed between latencies of LSS reactions and SSS reactions, neither during obstacle avoidance, nor during voluntary stride modifications. This indicated that both strategies had the same level of

complexity. Previous studies have been conducted on the characteristics of stride length modifications (Bonnard & Pailhous, 1993; Varraine, Bonnard, & Pailhous, 2000), but the participants knew where and when they had to modify the walking pattern. In contrast, in the present study, unexpectedly required decrease or increase of stride lengths were used. From the study of Patla et al. (1991) it was also unknown whether lengthening and shortening were equally fast, as only step lengthening was required. The observation that both LSS and SSS required the same amount of time to be implemented in the normal walking pattern is important with regards to obstacle avoidance behavior of elderly and patients. Obstacle avoidance strategies of elderly have been shown to be different from those of young adults (Chen et al., 1994a; Weerdesteyn et al., 2001). Chen et al. (1994a, 1994b) found that at the same Available Response Time (ART) elderly used the SSS somewhat more as compared to young adults. In contrast, Weerdesteyn et al. (2001) showed that elderly had a strong preference for the LSS in order to avoid an unexpected obstacle. The latter results were in line with Den Otter, Geurts, and Duysens (2003), who studied obstacle avoidance strategies of stroke patients during treadmill walking. Stroke patients also had a strong preference for the LSS, whereas age matched controls showed similar behavior to the present group of young adults exhibiting both LSS and the SSS. It may be argued that the SSS possibly took more time to be executed and therefore was used less frequently. The results of the present study provide no indication that the SSS takes more time, as there was no significant difference in latencies between LSS and SSS reactions. However, the results of present study were obtained in young and healthy participants and may not be the same for elderly and stroke patients.

In addition to the result that there was no difference between latencies of LSS and SSS reactions, participants who used both LSS and SSS were equally as fast as those who used either only LSS or SSS in order to avoid the obstacle. When both strategies were used by a participant, LSS and SSS were different from the start of the reaction (see Fig. 2). This indicated that the OA reaction is not a primary stereotypical response that is later fine tuned into either LSS or SSS. Indirect evidence for this observation has previously been reported in the study of Patla et al. (1999) on selection of alternate foot placement with respect to a virtual obstacle. It was shown that for each configuration of the foot relative to the virtual obstacle there was a single dominant avoidance strategy. When time pressure increased for the same foot-obstacle configuration (shorter Available Response Time), this dominant strategy became even more dominant. This observation and the results of the present study show that the decision about the strategy to be chosen does not add to the time to make the visuo-motor transformation in obstacle avoidance.

The difference between the latencies of the four tasks and the finding that there was no significant correlation between OA latencies and the latencies of any of the other tasks are an indication that different pathways were involved in the different tasks. The question which pathway could be involved in obstacle avoidance is of particular interest, because the reactions were very fast. To our knowledge, no previous studies were reported in which possible pathways for this kind of lower limb reactions were investigated. For fast reactions during upper limb movements, a number of possible pathways have been described. For example, fast responses were shown

to involve the parietal visual pathway (Pisella et al., 2000). Interestingly, Day and Brown (2001) provided evidence for the involvement of subcortical pathways in reaching adjustments. They studied a patient with complete agenesis of the corpus callosum, and a vestigial or absent anterior commissure. As expected, during a simple reaction time task, there was a significant difference between reaction times when the stimuli were given contralateral as compared to ipsilateral stimuli. In contrast, during reaching, trajectory adjustments in response to target jumps to left and right produced similar and very short (120ms) latencies. This was a clear indication that subcortical pathways are involved in fast reaching adjustments. So far, there is no direct evidence that subcortical pathways play a role in obstacle avoidance reactions in humans, but their possible involvement could be an interesting subject for further research.

### Acknowledgments

This study was supported by the Dutch Science Foundation (NWO) and by a EU grant to J. Duysens (Eurokinesis). The authors want to thank Daan Koppens for conducting the pilot experiments on this subject.

### References

- Alstermark, B., Eide, E., Gorska, T., Lundberg, A., & Petterson, L.-G. (1984). Visually guided switching of forelimb target reaching in cats. *Acta Physiologica Scandinavica*, *120*, 151–153.
- Bonnard, M., & Pailhous, J. (1993). Intentionality in human gait control: modifying the frequency-to-amplitude relationship. *Journal of Experimental Psychology: Human Perception and Performance*, *19*, 429–443.
- Brenner, E., & Smeets, J. B. J. (2003). Perceptual requirements for fast manual responses. *Experimental Brain Research*, *153*, 246–252.
- Carlton, L. G. (1981). Processing visual feedback information for movement control. *Journal of Experimental Psychology: Human Perception and Performance*, *7*, 1019–1030.
- Carson, R. G., Chua, R., Goodman, D., Byblow, W. D., & Elliott, D. (1995). The preparation of aiming movements. *Brain and Cognition*, *28*, 133–154.
- Chen, H. C., Ashton-Miller, J. A., Alexander, N. B., & Schultz, A. B. (1991). Stepping over obstacles: Gait patterns of healthy young and old adults. *Journals of Gerontology: Medical Sciences*, *46*, M196–M203.
- Chen, H. C., Ashton-Miller, J. A., Alexander, N. B., & Schultz, A. B. (1994a). Age effects on strategies to avoid obstacles. *Gait and Posture*, *2*, 139–146.
- Chen, H. C., Ashton-Miller, J. A., Alexander, N. B., & Schultz, A. B. (1994b). Effects of age and available response time on ability to step over an obstacle. *Journals of Gerontology: Medical Sciences*, *49*, M227–M233.
- Chou, L. S., & Draganich, L. F. (1997). Stepping over an obstacle increases the motions and moments of the joints of the trailing limb in young adults. *Journal of Biomechanics*, *30*, 331–337.
- Day, B. L., & Brown, P. (2001). Evidence for subcortical involvement in the visual control of human reaching. *Brain*, *124*, 1832–1840.
- Day, B. L., & Lyon, I. N. (2000). Voluntary modification of automatic arm movements evoked by motion of a visual target. *Experimental Brain Research*, *130*, 159–168.
- Den Otter, R., Geurts, A. C. H., Duysens, J. (2003). Step characteristics of stroke patients in obstacle avoidance. Program No. 824.10. *Abstract Viewer/Itinerary Planner*. Washington, DC: Society for Neuroscience.

- Elble, R. J., Sienko-Thomas, S., Higgins, C., & Colliver, J. (1991). Stride dependent changes in gait of older people. *Journal of Neurology*, 238, 1–5.
- Finley, F. R., Cody, K. A., & Finizie, R. V. (1969). Locomotor patterns in elderly women. *Archives of Physical Medicine and Rehabilitation*, 50, 78–84.
- Patla, A., Beuter, A., & Prentice, S. (1991). A two stage correction of limb trajectory to avoid obstacles during stepping. *Neuroscience Research Communications*, 8, 153–159.
- Patla, A. E., Prentice, S. D., Rietdyk, S., Allard, F., & Martin, C. (1999). What guides the selection of alternate foot placement during locomotion in humans? *Experimental Brain Research*, 128, 441–450.
- Paulignan, Y., MacKenzie, C., Marteniuk, R., & Jeannerod, M. (1990). The coupling of arm and finger movements during prehension. *Experimental Brain Research*, 79, 431–435.
- Paulignan, Y., MacKenzie, C., Marteniuk, R., & Jeannerod, M. (1991). Selective perturbation of visual input during prehension movements. *Experimental Brain Research*, 83, 502–512.
- Perfliev, S. N., Petterson, L. G., Varfolomeev, A. (2003). Cortical activity during updating of ongoing reaching in the cat. Program No. 708.11. *Abstract Viewer/Itinerary Planner*. Washington, DC: Society for Neuroscience.
- Pisella, L., Grea, H., Tilikete, C., Vighetto, A., Desmurget, M., Rode, G., et al. (2000). An 'automatic pilot' for the hand in human posterior parietal cortex: Toward reinterpreting optic ataxia. *Nature Neuroscience*, 3, 729–736.
- Prablanc, C., & Martin, O. (1992). Automatic control of trajectory of a pointing movement in response to a change in target location. *Journal of Neurophysiology*, 67, 455–469.
- Schillings, A. M., Van Wezel, B. M. H., & Duysens, J. (1996). Mechanically induced stumbling during human treadmill walking. *Journal of Neuroscience Methods*, 67, 11–17.
- Schillings, A. M., Van Wezel, B. M. H., Mulder, T. H., & Duysens, J. (1999). Widespread short-latency stretch reflexes and their modulation during stumbling over obstacles. *Brain Research*, 816, 480–486.
- Soechting, J. F., & Laquaniti, F. (1983). Modification of trajectory of a pointing movement in response to a change in target location. *Journal of Neurophysiology*, 49, 548–564.
- Varraine, E., Bonnard, M., & Pailhous, J. (2000). Intentional on-line adaptation of stride length in human walking. *Experimental Brain Research*, 130, 248–257.
- Weerdesteyn, V., Nienhuis, B., Mulder, Th., & Duysens, J. (in press). Older women strongly prefer stride lengthening to shortening in avoiding obstacles. *Experimental Brain Research*.
- Weerdesteyn, V., Schillings, A. M., Van Galen, G. P., & Duysens, J. (2003). Distraction affects the performance of obstacle avoidance during walking. *Journal of Motor Behavior*, 35, 53–63.
- Weerdesteyn, V., Sierevelt, I., Nienhuis, B., Duysens, J. 2001. Obstacle avoidance strategies of elderly. In: J. Duysens, B.C.M. Smits-Engelsman, H. Kingma, H. (Eds.), *Control of posture and gait* (pp. 170–174). Amersfoort.
- Zelaznik, H. N., Hawkins, B., & Kisselburgh, L. (1983). Rapid visual feedback processing in single-arm movements. *Journal of Motor Behavior*, 15, 217–236.