Motor Control, 2012, 16, 506-520

MOTOR CONTROL
Official Journal of ISMC
www.MC-Journal.com
ORIGINAL RESEARCH

Optic Flow Contribution to Locomotion Adjustments in Obstacle Avoidance

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Locomotion generates a visual movement pattern characterized as optic flow. To explore how the locomotor adjustments are affected by this pattern, an experimental paradigm was developed to eliminate optic flow during obstacle avoidance. The aim was to investigate the contribution of optic flow in obstacle avoidance by using a stroboscopic lamp. Ten young adults walked on an 8m pathway and stepped over obstacles at two heights. Visual sampling was determined by a stroboscopic lamp (static and dynamic visual sampling). Three-dimensional kinematics data showed that the visual information about self-motion provided by the optic flow was crucial for estimating the distance from and the height of the obstacle. Participants presented conservative behavior for obstacle avoidance under experimental visual sampling conditions, which suggests that optic flow favors the coupling of vision to adaptive behavior for obstacle avoidance.

Keywords: obstacle avoidance, optic flow, movement information, locomotion, visual sampling.

Locomotor skills in real environment present a high degree of complexity. To prevent individuals from losing their equilibrium and falling, a dynamic muscular synergy is involved to coordinate the different body segments efficiently. Stability during locomotion is maintained through reactive, predictive, and anticipatory strategies and involves the control of COM (position and velocity) within the changing and moving base of support (Patla, 2003). This complexity becomes even more apparent when one notes that the individual is constantly adapting to the environment, for example, avoiding other pedestrians on the sidewalk, holes and depressions in the uneven terrain or objects and furniture inside the house. This adaptive locomotor capacity depends on the skills to interact with the time-space constraints of the environment. For these constraints to be perceived and used by the locomotor control system, people need to be constantly aware of their current position in relation to objects and events around them. The visual system is the main responsible for this constantly updated information.

Vision provides indispensable information for the control of motor actions. The greatest and most relevant part of information from the environment is obtained

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and allows the control of the most varied movements in finely-tuned syntony with variations that constantly arise during body displacement (Patla, 1997; Lappe, Bremmer & van den Berg, 1999). Thus, providing precise current visual information on the time and spatial location of objects and events is an essential task that permits effective interaction with the environment during locomotor actions. This study acknowledges that information obtained by the visual system is highly efficient in controlling adjustments in locomotion obstacle avoidance actions and addresses the research challenge of precisely documenting the specific mechanisms of how vision is used to control locomotion. To understand the process of acquisition of visual information and how it is used favors the implementation of strategies that exploit the use of visual control in different contexts (educational, rehabilitation, robotics and training).

The concept and properties of optic flow were described initially by James J. Gibson (1950; 1966; 1979) and since then, theorists have discussed the concept and properties in detail (for example, Koenderink, 1986). Gibson (1950) initially noted that when an observer moves in the environment, there is a corresponding transformation in the environmental texture projected onto the retina. He called this transformation Optic Flow, which is based on the unvarying nature of the geometric relationship between the observer in movement and the environment. The optic flow provides the observer with information on the structure of the scene, object location and the observer's own movements in relation to objects. When an observer moves forward, the retinal image of the environment necessarily undergoes a continuous geometric transformation.

Since Gibson's theoretical formulations, optic flow has been noted for its importance in specifying direction to locomotion (Warren et al., 2001; Schubert et al., 2003), the distance of objects in relation to the observer (Tresilian, 1999; De Rugy et al., 2002), movement velocity (Prokop, Schubert & Berger, 1997; Lappe, Bremmer & van den Berg, 1999), and distance discrimination (Redlick, Jenkin & Harris, 2001; Frenz, Bremmer & Lappe, 2003). However, the relation between optic flow and locomotion adjustments in obstacle avoidance has not yet been well explored.

The presence of an obstacle in the path of progression offers an opportunity to verify the strategies used to solve the challenge imposed by the perturbation. The characteristics of the obstacle and its localization are first visually perceived for the appropriate body displacement that is then implemented. Modulating the length and width of steps to position the feet in correct relation to the obstacles is just one example of such adaptations. For this reason, an experimental situation was elaborated to verify the contribution of optic flow to adaptive locomotion by minimizing its effect. The stroboscopic lighting provides a brief visual sample of the environment at each flash. The flash duration is fixed but the experimenter can control the flash frequency rate (visual sample).

Experiments using stroboscopic light, aiming to minimize the optic flow, have been designed for tasks of static balance (Amblard, Cremieux, Marchand & Carblanc 1985; Cremieux & Mesure, 1994; Robertson, Collins, Elliott & Starkes, 1994), handgrip (Lyons, Fontaine & Elliott, 1997; Buekers & Helsen, 2000) and locomotion (Assaiante, Marchand & Amblard, 1989; Azulay, Mesure, Amblard, Blin, Sangli & Pouget, 1999). As a basic assumption of these experiments, the optical flow can be corrupted by the use of low frequency of stroboscopic light.

Each flash of light provides brief static visual samples of environment, providing only information on position and orientation. Accordingly, the speed movement or approach of an object must be evaluated through the changes in extent and location of objects and events in the environment.

What has been observed in studies with human locomotion (Assaiante, Marchand & Amblard, 1989; Azulay, Mesure, Amblard, Blin, Sangli & Pouget, 1999) and locomotion in cats (Sherk & Fowler, 2001) is that the image movement generated by the displacement (optic flow) helps in performing the task.

Assuming the reasoning of these studies, that when the visual information of movement is broken (stroboscopic lighting effect), the information flow is minimized and only static samples can be used. Thus, comparison of the locomotor behavior of the participants between normal conditions and stroboscopic lighting may make it possible to answer the following questions: Is optic flow crucial for locomotion adjustments to step over obstacle? What is the contribution of optic flow to locomotion adjustments to step over obstacle? What are the strategies used by the locomotor control system to overcome lack of information in optic flow?

Another point of interest is whether the characteristics of the obstacle can also influence behavior: Does the height of the obstacle influence the demand for information from the optic flow? Studies show that obstacles at knee-height increased biomechanics demand, especially in the control of body segments when compared with obstacles at ankle-height, where the modulations required from the effector system are lower (Patla, Prentice & Gobbi, 1996; Patla, Adkin, Martin, Holden & Prentice, 1996). Patla, Adkin, Martin, Holden and Prentice (1996) also observed that the demand for visual sampling is differentiated in relation to the height of the obstacle.

Therefore, the objective of this study was to investigate the contribution of optic flow to the task of stepping over obstacles of different heights.

As optic flow is necessary for adaptive locomotion, we expected that a lack of optic flow in static visual sampling would affect the amplitude of the participant behaviors in relation to the distance (horizontal and vertical) of the participant's feet from the obstacle. That is, if the quality of visual information is reduced, the margin of safety to be taken is increased (larger distances between the feet and the obstacle). Aside from this, this influence was expected to be inversely proportional to the frequency of static visual sampling. In the varied sampling conditions, the height of the obstacle was expected to influence the strategies adopted during step-over.

Method

Participants

10 young adult volunteers of both genders (age: 281 ± 15 months; height: 164.55 ± 5.31 cm; weight: 57.83 ± 8.82 Kg), with no neuromuscular impairments or visual limitations that were not corrected by corrective lenses and without history of convulsion or dizziness in stroboscopic environments were selected. All these data were collected through individual interviews. All participants in the study signed a free and informed written term of consent approved by the local ethics committee.

Procedures

The participants wore a pair of soft antiskid stretch shoes covered in Velcro. Battery powered light emitting diodes (LED) were placed at two anatomical points on the feet (5th metatarsal and lateral face of the heel). Each participant performed the following protocol:

1) *Anthropometric Measurements:* body mass, height and length of right lower limb segments (ankle height and length of leg and thigh) were obtained. The lengths of the lower limbs (total height of the ankle, length of the leg and thigh length) were used for the standardization of data. This allowed customizing the height of the obstacle for each participant.
2) *Task:* The participant was instructed to walk a distance of 5 m at their preferred speed, step over an obstacle and continue walking for three more meters. Four digital video cameras (JVC, model GR—DVL 9800) were distributed bilaterally along the walkway (8m × 1.4m), and recorded the LED trajectories at a frequency of 60 Hz, with manual focus and shutter speed of 1/250 (Figure 1). A clapboard was used to synchronize the sound and video of the four video cameras.

The heights of the obstacles were individualized for each participant, with the low obstacle corresponding to the height of the ankle and the high obstacle corresponding to the height of the knee. The manipulation of the visual sampling frequency was done by an analogically regulated stroboscopic lamp (Party Light PL50). The stroboscopic lamp was positioned on the ceiling of the laboratory exactly above the obstacle.

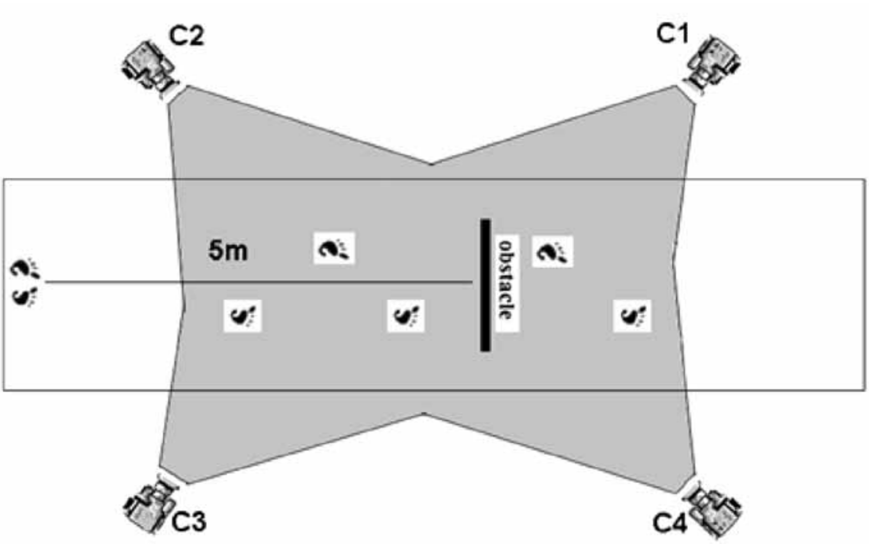

Figure 1 — Illustration of experimental setup: positioning of the cameras, obstacle and starting point for locomotion. The shaded area represents the camera zone. C1, C2, C3 and C4 represent the video cameras.

Verification of the frequencies' consistency could be manipulated by a counter pulse, a voltmeter and a chronometer. The voltmeter was used to assess the magnitude of the voltage at each frequency. The counter pulse and marking of the measured time recorded the shots per minute. Furthermore, a digital video camera at a frequency of 120Hz was positioned beside the support of the stroboscopic lamp to capture the audio signal triggered by the relay time. Through these audio signals the consistency of the intervals between flashes was confirmed (~500ms to ~250ms to 2Hz and 4Hz). This procedure was repeated on 5 other opportunities and similar results were obtained. The duration of the stroboscopic light was verified using a digital camcorder to 120Hz through number of frames in which the environment is illuminated by a flash and determined as less than 16ms.

The trials were presented by combining the visual sampling conditions (static: 2 samples/second and 4 samples/second and dynamic sampling) and obstacle height (high obstacle corresponding to the knee and low obstacle corresponding to the ankle), for five trials per condition, totaling 30 trials. The normal laboratory illumination allowed the dynamic sampling (optic flow influence) and the stroboscopic light provided static sampling at 2 and 4Hz. The trials were performed in two sets. The first set constituted the dynamic sampling and was randomized only for obstacle height (10 trials). The second set constituted the static sampling trials that were randomized for frequency and obstacle (20 trials). This division of trials into two blocks was performed to avoid constant changes in camera focus and also for the comfort of participants.

The frequencies of 2 and 4 Hz were chosen based on the results of Assaiante et al. (1989). The authors found that tasks requiring precise positioning of the feet during locomotion were successful when visual samples were above 3Hz. Thus, this study chose to study one frequency above and one frequency below from that studied by the authors. In addition, the study by Assaiante et al. (1989) did not evaluate kinematic characteristics of the task, only mean velocity.

The heights of the obstacles (ankle and knee) were chosen considering the requirements of modulation. The obstacle corresponding to the knee requires greater biomechanics demand, especially in relation to the control of body segments. Patla et al. (1996b) evaluated the effects of body scale on the participants' decision to bypass or overcome obstacles of different heights. When the height of the obstacle corresponds to the knee, the locomotor system is brought to a critical state, increasing the task demands and enabling a higher risk of failure. Moreover, high obstacles increased demand for visual sampling when compared with low obstacles (Patla et al., 1996a). The height corresponding to the ankle characterizes a height easily found in everyday locomotion and usually requires no decision on bypass or diverting. Manipulating these two independent variables, this study advances the knowledge of how the task demands can affect the adaptive locomotor behavior when information from optical flow is changed.

The images were captured by a video board (PINNACLE, Studio DV, Version 1.05.307) coupled to a computer. A metallic frame in the form of a parallelogram (975mm × 560mm × 720mm) was used to calibrate the camera zone. The photometric procedure was performed with Digital Video for Windows Software (Barros et al., 1999). MatLab software (The Matworks Inc., 1998—version 5.3) was used to calculate the dependent variables.

The x, y and z coordinates from each LED were filtered utilizing a fourth-order Butterworth digital filter with a cutoff frequency of 5 Hz. The x-axis corresponded to the anterior-posterior displacement, the y-axis corresponded to the vertical displacement and the z-axis corresponded to the midlateral displacement. The vertical speed of the LEDs was used to identify the events: heel-strike and toe-off. These events were identified for the leading leg (L), as well as the trailing leg (T). Leading leg (L) was defined as the first leg to overcome the obstacle and the trailing leg (T) was defined as the second leg to overcome the obstacle. From those events, the following dependent variables were determined: foot placement before obstacle (FTPL-L and FTPL-T) and toe clearance (TC-L and TC-T). The foot placement before obstacle was measured by the difference of coordinates in "x" between the obstacle and the fifth metatarsal, when the foot loses touch with the ground to address the obstacle. The toe clearance was measured by the difference of coordinates in "y" between the fifth metatarsal and the top edge of the obstacle when the fifth metatarsal is vertically aligned to the obstacle (Pieruccini-Faria et al., 2006). All kinematics analysis was accompanied by visual verification of the image collected.

Statistical Analysis

Of the 300 trials, 287 trials were analyzed. Ten trials were discarded because it was impossible to distinguish which LEDs were lit and three trials were discarded because the captured image was blurry. The mean values for each dependent variable were statistically analyzed by *two way* ANOVA, for factors of visual sampling conditions at three levels (dynamic; static at 2Hz; and static at 4Hz) and obstacle conditions at two levels (low and high obstacle). The factors were treated as repeated measures. Tukey Method was employed when ANOVA proved the main effect of visual sampling or interaction between factors. All of the statistical procedure was performed utilizing SPSS software (SPSS for Windows, version 10.1) and the level of significance was set at 0.05.

Results

Table 1 presents ANOVA results and level of significance for each dependent variable.

Table 1 ANOVA Results and Significance Levels for the Main Effects of Visual Sampling and Obstacle Height and Interaction Between Factors by Dependent Variable.

Dependent Variables	Visual sampling	Obstacle height	Interaction
FTPL-L	$F_{2,18} = 7.304$; $p < 0.005$*	$F_{1,9} = 0.140$; $p = 0.71$	$F_{2,18} = 2.366$; $p = 0.12$
FTPL-T	$F_{2,18} = 1.827$; $p = 0.19$	$F_{1,9} = 2.547$; $p = 0.14$	$F_{2,18} = 4.627$; $p < 0.02$*
TC-L	$F_{2,18} = 54.221$; $p < 0.001$*	$F_{1,9} = 28.614$; $p < 0.001$*	$F_{2,18} = 0.966$; $p = 0.4$
TC-T	$F_{2,18} = 3.117$; $p = 0.06$	$F_{1,9} = 69.637$; $p < 0.001$*	$F_{2,18} = 1.527$; $p = 0.24$

Note: * Indicates Significant Difference.

For FTPL-L, ANOVA showed the main effect of visual sampling and Tukey Method identified the difference between the dynamic visual sampling and the two static visual sampling rates. No difference was identified between the static visual sampling rates at 4Hz and 2 Hz. At both static visual sampling rates (2 Hz and 4Hz), the participants increased FTPL-L at approximately 7cm when compared with dynamic visual sampling (Figure 2A).

For FTPL-T, ANOVA did not reveal the main effect of visual sampling and the obstacle but did show an interaction between factors. Tukey method identi-

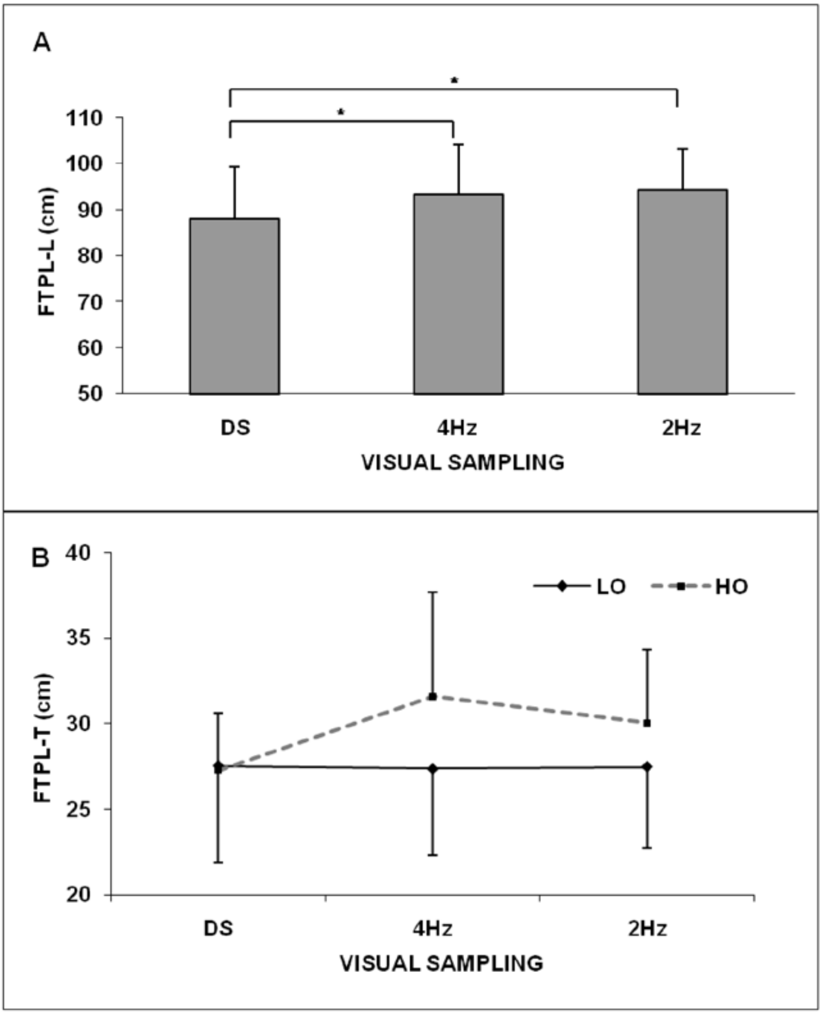

Figure 2 — Means and standard deviations of FTPL-L (A) by visual sampling conditions and FTPL-T (B) by visual sampling and obstacle conditions. The asterisk indicates significant differences. (DS= dynamic visual sampling; 4Hz= static visual sampling at 4Hz; 2Hz= static visual sampling at 2Hz; HO= high obstacle; LO= low obstacle).

fied the differences between low and high obstacles at the static visual sampling rates. For dynamic visual sampling, FTPL-T showed no difference for either obstacle height. During static visual sampling, the trailing leg was positioned approximately 4cm farther away from the low obstacle than from the high obstacle (Figure 2B).

For TC-L, ANOVA identified the main effect of sampling (Figure 3A) and the obstacle (Figure 3B). Tukey method identified the difference between the dynamic visual sampling and the two static visual sampling rates. No difference was identified between the static visual sampling rates of 4Hz and 2Hz. At the static visual sampling rates (4Hz and 2Hz), the participants increased TC-L in approximately 4 cm when compared with dynamic visual sampling (Figure 3A). The participants adopted a greater margin of safety for the high obstacle. Mean values of 9cm (low obstacle) and 15cm (high obstacle) were identified (Figure 3B). For TC-T, ANOVA revealed only the main effect of the obstacle. The participants also adopted a greater safety margin for the high obstacle for the trailing leg. Mean values of 13cm (low obstacle) and 26cm (high obstacle) were identified (Figure 3C).

Discussion

The aim of this study was to investigate the contribution of optic flow in locomotion adjustments when subjects avoided the obstacle in the walkway. These results have implications for the perceived magnitude of self-motion, the use of self-motion information for spatial updating and the geometry of extrapersonal space perceived from optic flow. These questions were speculated when the optic flow was suppressed or their effect minimized for the stroboscopic light and the locomotion adjustment was measured. The principal findings were: (1) Information on orientation and position were sufficient for locomotor adjustments control; and (2) Optic flow contributes to the precision of locomotion adjustments. These two topics are discussed below.

Information on Orientation and Position Were Sufficient for Locomotor Adjustments Control

The optic flow information was not crucial for precise gait adaptation to step over the obstacle. Static visual sampling was sufficient to visualize the trajectory of self-motion. The employed protocol included the time and distance limits that could be achieved without visual information (respectively, ~5m and ~8s; Lee, Lishman & Thomson, 1982; Thomson, 1983).

Patla et al. (1996a) documented the characteristics of self-selected visual sampling by the participants. Their participants used eyeglasses with crystal liquid lenses and the frequency, location and duration of the visual sampling during the execution of the task of stepping over the obstacle were controlled. The results showed a visual sampling pattern rate of approximately 0.5–1.0 samples/second. Two sampling strategies were evident: 1) one visual sampling at each stride with a long duration (~500ms); or 2) one visual sampling at each step with a short duration (~250ms). No stride phase was identified where the necessity for visual sampling was critical. In addition, the amount of visual samples did not exceed one sampling in each step.

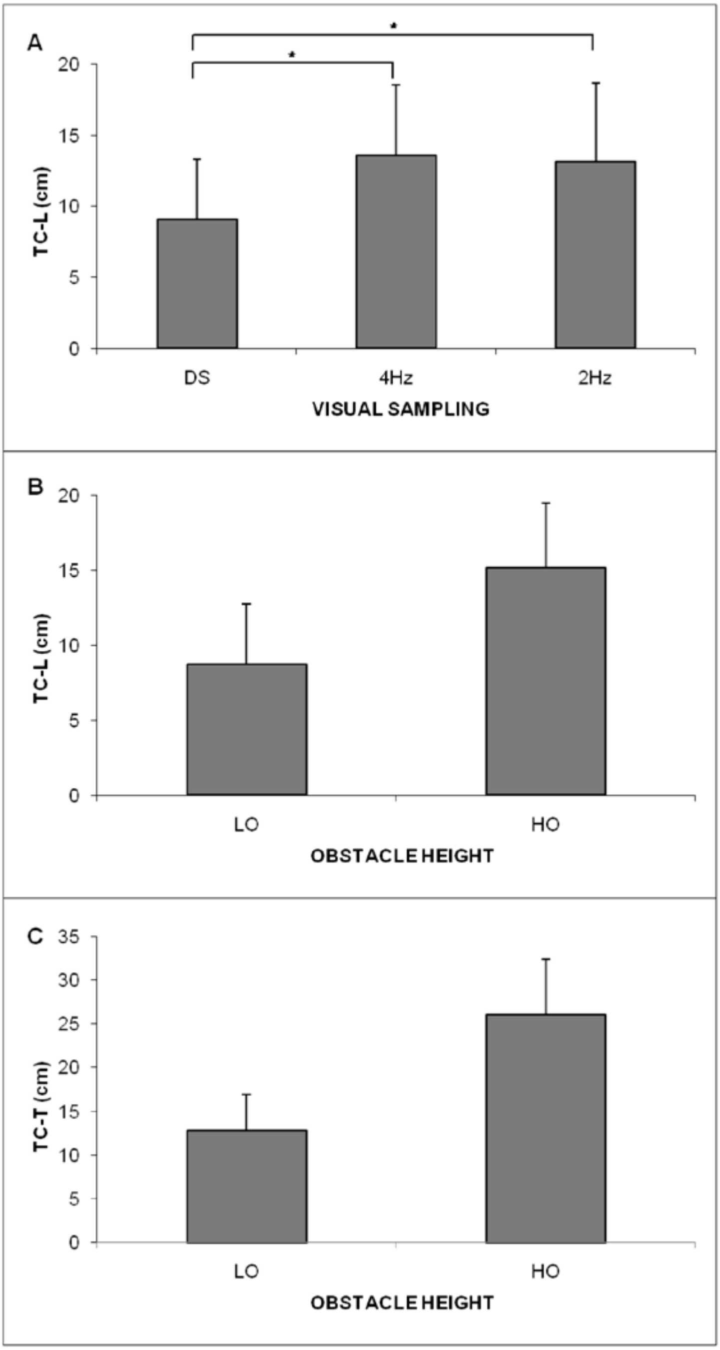

Figure 3 — Means and standard deviations for TC-L by visual sampling conditions (A) and by obstacle height (B); and TC-T by obstacle conditions (C). The asterisk indicates significant differences. (DS= dynamic visual sampling; 4Hz= static visual sampling at 4Hz; 2Hz= static visual sampling at 2Hz; HO= high obstacle; LO= low obstacle).

Patla & Vickers (1997) used an “eye tracker” to monitor the eye travel in surveying the visible area in the task of stepping over an obstacle and revealed that the participants: i) fixed their eyes intermittently on the obstacle only in the approach phase but not during the crossing phase; and ii) spent the majority of the time (~40%) in travel fixation in the direction of locomotion, approximately two steps ahead (Patla & Vickers, 1997; Hollands, Patla & Vickers, 2002). While these studies show that vision is used intermittently, the information of optic flow is still present. However, during stroboscopic illumination the field of optic flow is eliminated or their effect minimized, and only intermittent hints are available for direction and position. The participants do not need to continually visualize the environment; brief and periodic visualizations are sufficient for correct direction and execution of locomotor adjustments tasks.

Optic Flow Contributes to the Precision of Adaptive Locomotion

Research studies have shown that the relative distance from the obstacle is a robust characteristic, and that it is difficult for the height of the obstacle to affect it (Patla & Rietdyk, 1993; Gonçalves, Moraes & Gobbi, 2000; Krell & Patla, 2002; Mohagheghi, Moraes & Patla, 2004). In the current study, foot placement before obstacle of neither leading leg nor trailing leg was altered by the height of the obstacle, remaining at mean values of 88cm and 27cm, respectively. Note that even when stepping over obstacles that require different biomechanical demands, the foot placement before obstacle for either leg was not affected. This robust characteristic was also encountered by Gonçalves, Moraes and Gobbi (2000) who found no differences in foot placement before obstacle even when the height of the obstacle was above the knee, a height which is considered critical for the participants to choose whether to step over or go around an obstacle (Patla, Prentice & Gobbi, 1996).

However, in the absence of optic flow (stroboscopic lighting), this robust relationship in the approximation distances was altered. Participants adopted a greater distance from the obstacle with the leading leg when the optic flow was absent. For the trailing leg, the participants adopted a greater distance from high obstacle, but for lower obstacle distances were similar to the distances with the presence of optic flow. Two aspects may explain this data. The first refers to an increase in time that the static visual sampling can be evaluated. Assaiante, Marchand and Amblard (1989) explain that the reduction of velocity in locomotion on different surfaces with stroboscopic lighting can also increase the available time period. The second explanation refers to imprecision in the detection and localization of the obstacle. In research studies that manipulate the visual availability during the approach phase (Patla, 1997; 1998; Mohaguegui, Moraes & Patla, 2004; Patla, Davies & Niechwiej, 2004) or in cases where the visualization of the limb is not available during the step-over (Patla, 1998; Mohaguegui, Moraes & Patla, 2004), imprecise perception of the obstacle is employed to explain these data. Both explanations suggest that optic flow facilitates obtaining precise information about the obstacle features, such as distance and position.

The vertical distance between the toe and the obstacle is the main kinematic parameter used to identify adaptive locomotor strategy and the success of the action (Patla et al., 1996b; Patla et al., 1996c; Krell & Patla, 2002). This parameter is considered a margin of sufficient and adequate safety during step over by both legs and is great enough to avoid contact with the obstacle and adequate to guarantee stability and dynamic locomotor equilibrium (Chen et al., 1991).

Normally, leading toe clearance is finely adjusted in relation to the height of the obstacle (Patla & Rietdyk, 1993; Patla et al., 1996a; Patla et al., 1996b; Patla, Davies & Niechwiej, 2004). However, findings for this syntonic relationship have been contradictory. In the current study it can be observed that the participants increased the safety margin for a high obstacle, that is, the smaller distance between the foot and the top edge of the obstacle when the foot is vertically aligned with the obstacle (Patla & Rietdyk, 1993). For the leading leg, mean values of 9cm for a low obstacle and 15cm for a high obstacle were in accordance with previous findings, which identified a margin of safety that fluctuated at around 10cm (Patla & Rietdyk, 1993). The increase in the margin of safety for the leading leg, in function of the height of the obstacle was also previously found (Patla & Rietdyk, 1993; Patla, Prentice & Gobbi, 1996; Patla, Davies & Niechwiej, 2004). However, this increase was not always identified (Patla et al., 1996c; Mohagheghi, Moraes & Patla, 2004). These contradictory results may be related to differences in the experimental protocols, where the height of the obstacle was not individualized to the anthropometric characteristics of each participant. Similar to the leading leg, the trailing toe clearance increased significantly with the increase in obstacle height (13cm for a low obstacle and 26cm for a high obstacle). The differences between legs may be discussed in relation to the consequence of error. The higher obstacle presents a greater risk of error, requiring the locomotor system to adopt a safer strategy (Patla & Rietdyk, 1993; Patla, Prentice & Gobbi, 1996; Patla, Davies & Niechwiej, 2004). Aside from this, tripping over a higher obstacle can trigger more dangerous consequences than tripping over a lower obstacle (Patla et al., 1996a).

The results also demonstrated the effect of sampling for leading toe clearance. When optic flow was absent or their effect minimized, participants adopted a greater distance from the obstacle, independent of the height of the obstacle. This effect was expected because the leading leg would be visually guided during the stepping over of the obstacle. The differences found between legs may be explained by the "online" adjustments driven by vision and the stability of the body in relation to the center of mass during the step over. First, the leading leg can be visually guided during overtaking. On the other hand, the support leg is not visually guided. Second, when the leading leg is vertically aligned with the obstacle, the center of the body mass is still projected before the obstacle. This configuration is considered unstable and errors at this moment can be disastrous. On the other hand, when the trailing leg is vertically aligned with the obstacle, the projection of the center of the body mass is away from the obstacle. This configuration can be considered more stable and reactive control is normally sufficient to avoid falling if the individual trips at this moment (Perry & Patla, 2001).

These results suggest that participants were also imprecise in detecting the height of the obstacle. The alternative, in this case, was to adopt a greater safety margin to guarantee the success of the action. Notably, the magnitude of the safety margin found in the current study was greater in comparison with other studies that have manipulated visual information during stepping over obstacles.

An intriguing finding in the current study was that the static visual sampling frequencies of 2Hz and 4Hz were not different from each other. Assaiante, Marchand

and Amblard's (1989) results demonstrated a linear decrease in the mean velocity of displacement as a function of the increased frequency of static visual sampling at 3Hz and above and they suggested that the interval between samples is critical for the success of locomotion. The hypothesis of coincidence states that the increase in the static sampling frequency increases the probability of visual sample and the demand for sample will coincide, and consequently, better performance will be observed. Although locomotor behavior has been inferred from mean velocity, in the current study only the spatial parameters were measured and found to be similar at frequencies of 2Hz and 4Hz. Sherk and Fowler (2001) evaluated the same frequencies for cats and also identified no differences in the precision of paw placement during locomotion on uneven terrain. However, Sherk and Fowler (2001) observed significant differences between dynamic visual sampling and static visual sampling. These results suggest that new studies should manipulate a greater number of static visual sampling frequencies to evaluate the relation between locomotor behavior and terrain.

Three issues were raised in this study. The first addresses whether optical flow is crucial for locomotor adjustments during obstacle avoidance. This study verified that optic flow produced by the displacement of the image in the retina is a rich source of information for precisely guiding adaptive movements. However, it was not critical to the success of the task. The second question asks what was the contribution of optic flow for adjustments in locomotion during obstacle avoidance. The results suggest that flow information facilitates accurate identification of distance and height of the obstacle, because the distances to the obstacle were increased. The third issue is related to the strategies used by the locomotor control system to overcome lack of information to optic flow. The participants adopted a conservative strategy, i.e., increased the distance of approach of the obstacle and the elevation of the legs during overtaking of the obstacle.

Another point of interest was whether the obstacle height can also influence the demand for information from the optic flow. The results showed that the height of the obstacle affects the parameter toe clearance of both legs, with corroborating findings in the literature. However, this effect was not influenced by visual manipulation.

In future investigations, the greatest challenge will be to identify the roles of diverse sensory information and delineate the transformation of sensory information into appropriate motor response (Dickinson et al., 2000). The simultaneous availability of multiple sources of information (Gibson, 1979) and the existence of different possibilities of neuromuscular configurations for each movement (Bernstein, 1967) are indications of the complex nature of the relationship between perception and action.

The results of the current study are in accordance with the findings in the research literature, which demonstrates that optic flow facilitates adaptive modulations in locomotor behavior. However, only the effects on task performance were identified. Many characteristics of the acquisition of visual information in different contexts (sports, rehabilitation and robotics) still need to be explored and continue to challenge research on visual control of motor skills. The results of this study indicate three aspects to consider in the research design of further investigations. The first approach is controlling when and where each visual sample is made available during execution of the task to verify if participants are regulating the execution of their actions in synchrony to the frequency of static visual sampling. While no relation was observed between obtaining the visual sample and any specific event in the step cycle (Patla et al., 1996a; Patla & Vickers, 1997), externally stimulated visual sampling may reveal such synchronization. The second aspect refers to defining new parameters, such as describing the steps before the obstacle as an approximation phase and establishing the time parameters of each of the phases of gait (single support, double support and swing) to verify any effects on the dynamics of the task. The third approach is to analyze eye movements to document any active searching for relevant environmental information that influences or determines the actions. For example, under stroboscopic light, eye movements would be expected to synchronize to the rate of visual sampling.

Conclusion

The results presented strengthen the role of optic flow as inherent in guiding locomotion. Although static, the visual samples provided sufficient cue information for adaptive locomotor behavior to infer position and direction and change the adjustments to the distance from the obstacle, just as when dynamic (continuous) visual samples of optic flow were available for adaptive adjustments. Therefore, we may conclude that the information is used to precisely detect the characteristics of the obstacle and visually control the crossing over obstacles.

Acknowledgments

We are grateful to the people who gave their time and effort to participate in this study, and thanks to Frederico Pieruccini Faria and Carolina Rodrigues Alves Silveira for the help with data collection, and thanks to Edson Menuchi for the help in creating and producing the active markers used in this study.

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