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Short communication

Do characteristics of a stationary obstacle lead to adjustments in obstacle stepping strategies?

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ABSTRACT

Navigating cluttered and complex environments increases the risk of falling. To decrease this risk, it is important to understand the influence of obstacle visual cues on stepping parameters, however the specific obstacle characteristics that have the greatest influence on avoidance strategies is still under debate. The purpose of the current work is to provide further insight on the relationship between obstacle appearance in the environment and modulation of stepping parameters. Healthy young adults ($N = 8$) first stepped over an obstacle with one visible top edge ("floating"; 8 trials) followed by trials where experimenters randomly altered the location of a ground reference object to one of 7 different positions (8 trials per location), which ranged from 6 cm in front of, directly under, or up to 6 cm behind the floating obstacle (at 2 cm intervals). Mean take-off and landing distance as well as minimum foot clearance values were unchanged across different positions of the ground reference object; a consistent stepping trajectory was observed for all experimental conditions. Contrary to our hypotheses, results of this study indicate that ground based visual cues are not essential for the planning of stepping and clearance strategies. The simultaneous presentation of both floating and ground based objects may have provided critical information that lead to the adoption of a consistent strategy for clearing the top edge of the obstacle. The invariant foot placement observed here may be an appropriate stepping strategy for young adults, however this may not be the case across the lifespan or in special populations.

1. Introduction

To successfully update gait patterns and avoid an obstacle, the visual system must accurately identify obstacle spatial parameters; such as height and position of the obstacle relative to the environment [1,2]. Different obstacle constructs are common in daily living, requiring task specific modulation to produce an efficient and safe stepping strategy [2–4]. It is currently unknown if obstacle stepping strategies are planned in order to clear the highest point of an obstacle or if a greater emphasis is placed on the aspect of the obstacle in contact with the ground. The purpose of the current work was to present a novel paradigm to address this question and to this end we monitored obstacle stepping parameters while crossing a stationary "floating" obstacle while simultaneously manipulating location of a second ground-based reference object. This manipulation allowed us to test whether stepping kinematics were altered based on the changing ground reference, or were held relatively constant in relation to the stationary obstacle. It was *hypothesized* that manipulation of the ground reference object location would induce changes in stepping strategies regardless of the constant position of the stationary obstacle, as previous work has suggested that ground based obstacle cues result in more successful obstacle avoidance strategies [4].

2. Methodology

2.1. Participants

Eight right foot dominant [5] healthy young adults participated in this study (mean age 20.78 ± 0.83 years, mean height 173.10 ± 5.88 cm and mean mass 65.89 ± 9.99 kg); the University Research Ethics Board approved the procedures. All had normal or corrected vision and were free from any self-reported neuromuscular conditions or injuries that would affect their walking ability.

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2.2. Experimental set up

Kinematic data were collected at 100 Hz (Optotrak Model 3020, Northern Digital Inc., Waterloo, ON, Canada) using rigid marker triads fixed to the head, trunk, pelvis and feet and anatomical landmarks (e.g. heels, toes) were digitized [6]. The height of this "floating" obstacle was fixed at 20 cm for all participants. The ground reference object was placed in parallel below the obstacle, on a light grey floor. The obstacle with one visible top edge ("floating" obstacle) was kept stationary for the entire experiment; the position of the ground reference object was manipulated by the experimenters (see Fig. 1 for obstacle details and the experimental conditions).

2.3. Experimental procedure

Participants walked barefoot along an 8 m walkway at a comfortable, self-selected pace in normal ambient light conditions, and stepped over the obstacle with their dominant foot first; no further instructions were given as to how subjects should step over the obstacle. Participants were allotted 4–6 practice trials followed by 8 collected "control" trials stepping over the "floating" obstacle with no ground reference object. A block randomized trial presentation was then executed (8 trials per obstacle location); subjects were asked to turn away from the path and experimenters moved the ground reference object to 1 of 7 different possible positions (Fig. 1) prior to the start of each trial.

2.4. Data analyses

Data was analyzed using Visual3D software (C-Motion Inc., Germantown MD). Missing kinematic data were interpolated and filtered using a dual-pass low-pass Butterworth filter (f_c = 6 Hz). All kinematic outcome measures were calculated in relation to the stationary obstacle. Take-off distance (TOD) was calculated as the horizontal distance between the trail foot first metatarsal and obstacle; landing distance (LD) was the horizontal distance between lead heel and obstacle. Minimum lead clearance (MLC) and minimum trail clearance (MTC) were the minimum distances between either the first metatarsal or heel and the top of the obstacle for the lead and trail limbs, respectively. Velocity was calculated as the first derivative of the weighted center of mass position (head, trunk, pelvis; modified model [7]) at instantaneous heel contact two steps before (Vel OBS-2), one step before (Vel OBS-1), and at obstacle crossing (Vel OBS-xing). Variability for all measures was the standard deviation within participants across the 8 trials for each condition.

2.5. Statistical analyses

Two multivariate ANOVAs were performed with obstacle condition as the factor for the mean measures of both the distance (TOD, LD, MLC, MTC) and velocity measures (Vel OBS-2, Vel OBS-1, Vel OBS-xing). Similarly, two multivariate ANOVAs were performed on the variability of the distance and velocity measures. Significance was set at $p < 0.05$.

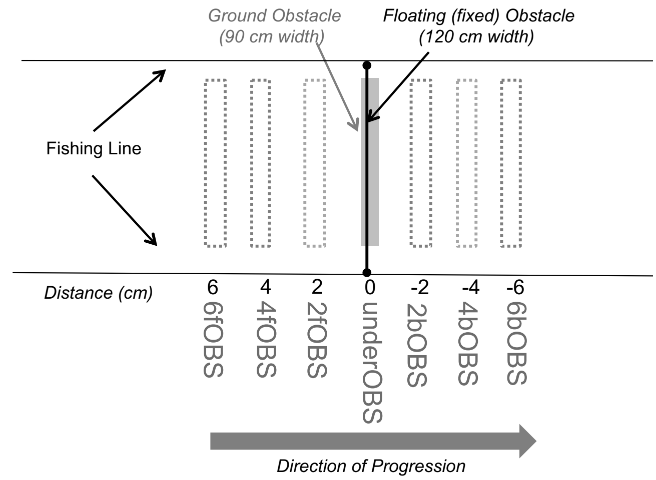

Fig. 1. Schematic diagram (overhead view) illustrating the possible obstacle locations for the experiment. The "Floating" obstacle (black wooden dowel; 1 cm diameter × 120 cm long) was suspended from the fishing line (20 cm above travel path for all participants); to reduce visual information about its position in space, only the top edge was visible upon obstacle approach. A second obstacle (black plywood; 4 cm tall × width 1.25 cm × 120 cm long) was positioned at one of seven different locations to create a ground reference object; directly under the suspended obstacle (underOBS), and either 2, 4, or 6 cm in front (2fOBS, 4fOBS, 6fOBS) or behind the floating obstacle (2bOBS, 4bOBS, 6bOBS). The ground reference object was moved forward and behind the floating obstacle in a randomized order.

3. Results

3.1. Obstacle contacts

The obstacle was contacted 4 times (total of 512 trials processed); once each for the 2 cm behind and 4 cm in front OBS, and twice when the block was positioned directly under the obstacle.

3.2. Kinematic results

Mean ± standard error values are presented in Table 1 for all kinematic variables. No significant effects were detected for any of the calculated measures for either the means or variability about the means. The TOD, MLC and MTC mean values are presented in Fig. 2 for illustrative purposes only.

Table 1
Mean ± standard errors for the obstacle stepping parameters. No statistical differences between the control condition or 7 different ground reference object locations were detected in any measure ($p > 0.05$).

Parameter	Control	6fOBS	4fOBS	2fOBS	UnderOBS	2bOBS	4bOBS	6bOBS
Vel OBS-2 (m/s)	1.15 ± 0.08	1.20 ± 0.09	1.17 ± 0.08	1.16 ± 0.08	1.16 ± 0.10	1.17 ± 0.08	1.18 ± 0.09	1.18 ± 0.07
Vel OBS-1 (m/s)	1.16 ± 0.07	1.17 ± 0.10	1.17 ± 0.08	1.15 ± 0.09	1.19 ± 0.07	1.15 ± 0.09	1.13 ± 0.11	1.15 ± 0.09
Vel OBS-xing (m/s)	0.94 ± 0.08	0.94 ± 0.10	0.95 ± 0.09	0.97 ± 0.09	0.96 ± 0.09	0.98 ± 0.08	0.94 ± 0.10	1.00 ± 0.08
TOD (m)	0.28 ± 0.03	0.30 ± 0.03	0.31 ± 0.02	0.30 ± 0.02	0.28 ± 0.02	0.29 ± 0.02	0.29 ± 0.02	0.28 ± 0.02
LD (m)	0.24 ± 0.06	0.22 ± 0.02	0.21 ± 0.03	0.21 ± 0.02	0.23 ± 0.02	0.23 ± 0.04	0.21 ± 0.02	0.24 ± 0.02
MLC (m)	0.14 ± 0.02	0.13 ± 0.02	0.13 ± 0.02	0.13 ± 0.02	0.13 ± 0.02	0.13 ± 0.02	0.13 ± 0.02	0.14 ± 0.02
MTC (m)	0.18 ± 0.02	0.17 ± 0.02	0.18 ± 0.02	0.16 ± 0.02	0.15 ± 0.02	0.16 ± 0.02	0.17 ± 0.02	0.16 ± 0.02

Vel OBS-2, Vel OBS-1 and Vel OBS-xing: velocity 2 or 1 steps prior or at obstacle crossing; TOD: take-off distance; LD: landing distance; MLC: minimum lead clearance; MTC: minimum trail clearance.