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Walking combined with reach-to-grasp while crossing obstacles at different distances

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ABSTRACT

Background: Obstacle avoidance and object prehension occur regularly in real-world environments (walking up/down steps and opening a door). However, it is not known how walking and prehension change when there is an increase in the level of difficulty of the walking task.

Research question: We investigated the changes in walking and reach-tograsp when performing these two motor skills concomitantly in the presence of an obstacle on the ground positioned in different locations in relation to the object-to-be-grasped.

Methods: Fifteen young adults walked and grasped a dowel placed on a support with the obstacle positioned at the step before (N-1), during (N) and after (N + 1) the prehension task.

Results: The prehension task did not affect leading limb obstacle negotiation. Toe clearance and maximum toe elevation were lesser at obstacle position N + 1 than at obstacle position N-1 when combining grasping and obstacle-crossing task for the trailing limb. Step width increased in the presence of the obstacle-crossing task independent of obstacle location. The correlation between foot position before the obstacle and toe clearance revealed that the addition of the prehension task disrupted the relationship between these variables for the trailing limb. Foot placement and limb elevation were unaffected by the prehension task. The reaching component was unaffected by the increased level of difficulty of the walking task. The grasping component was affected by the increased level of difficulty of the walking task, as the time to peak grip aperture occurred earlier in the presence of the obstacle at position N, and may indicate a cautious strategy to grasp the dowel successfully.

Significance: Our results showed that prospective control is affected after the prehension since the attention to grasping may have impaired the acquisition of visual information for planning the trailing limb elevation.

1. Introduction

Although prior studies have investigated walking and reach-to-grasp separately [1,2], these two skills are often performed concomitantly. We previously investigated these combined tasks and showed that changes in walking are dependent on manual task difficulty [3,4]. For the most difficult manual tasks, participants reduced step velocity and increased margins of stability [3,4] but did not change coordination necessary to implement the grasping while walking [5]. Moreover, reaching duration and peak grip aperture velocity decreased in the presence of walking [3,4].

It is currently not clear how this combined task is modulated when there is an increase in the level of difficulty of the walking task, such as during obstacle negotiation. Obstacle avoidance and object prehension occur regularly in real-world environments, such as walking up/down steps and opening a door. Locomotion requires an intermittent visual scanning of the environment to control foot placement before the obstacle and limb elevation to deal with an obstacle [6–9]. As the control of obstacle crossing while walking and reach-to-grasp share similar neural areas that contribute to the planning and execution of these movements [10,11], the simultaneous control of both tasks may be affected and the behavioral changes in either walking or reach-to-grasp may capture this influence.

The obstacle avoidance depends on vision to pick up information

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about obstacle location and size [8,12]. The initial part of obstacle clearance for the leading limb (from toe-off to foot over the obstacle) is controlled in a feedforward manner, whereas the latter part (from maximum clearance to the ground) is controlled in an online feedback-based manner [8,13]. Different studies have shown that leading and trailing limbs are independently controlled [6,8,14]. The control of the trailing limb throughout the step over the obstacle is based on feedforward visual information acquired during the approach phase [8,14]. Then, what may happen with the control of obstacle crossing when visual attention is shared with the reach-to-grasp task? To investigate this issue, we positioned obstacles at the step before, during and after the reach-to-grasp task. When obstacle negotiation and reach-to-grasp are simultaneous, the need to share visual attention between these tasks may influence how these two movements are controlled. For obstacles located at both the step before and after the reach-to-grasp task there would be enough time to pick up visual information to appropriately control both walking and reach-to-grasp tasks without interference.

An accurate foot placement before the obstacle is important to allow enough time to flex the limb and clear the obstacle [7]. The existence of a correlation between toe-obstacle horizontal distance and toe clearance represents an association between the visual and other kinesthetic inputs for the control of limb elevation, particularly for the trailing limb for which control depends on visual information acquired during the approach phase and kinesthetic inputs from the leading limb during obstacle avoidance [8]. The presence of the reach-to-grasp task may disrupt this association and compromise obstacle avoidance.

We aimed to investigate the changes in walking and reach-to-grasp when these two motor skills were combined in the presence of an obstacle positioned in different locations in relation to the object-to-be-grasped. We hypothesized: (1) For the obstacle located at the step of the reach-to-grasp task, the leading limb obstacle-crossing variables would be affected by the grasping task, especially the online control component. For the obstacle located before and after the reach-to-grasp task, the obstacle-crossing variables would be unaffected because the grasping task should not influence the feedforward and online control mechanisms. (2) The trailing limb obstacle-crossing variables would be unaffected by the presence of the reach-to-grasp task for all obstacle locations. Although participants may rely more on an online control mechanism to control arm-hand configuration to grasp the object at the same time they are stepping over the obstacle, the control of the trailing limb is still predicted to occur on the basis of feedforward visual information acquired during the approach phase. (3) Both reaching and grasping components would be affected by the obstacle at the location of the reach-to-grasp task compared to the obstacle before and after because of the division of visual attention.

2. Methods

2.1. Participants

Fifteen healthy young adults participated in this study (26.7 ± 4.9 years; 1.73 ± 0.05 m; 74.2 ± 18.0 kg). Thirteen participants were right-handed and two were left-handed. The ethics committee of the University of Massachusetts Amherst approved all study procedures.

2.2. Procedures

We placed passive reflective markers on anatomical landmarks to define a 15-segment biomechanical model (Fig. 1), three markers for reaching and grasping analyses (thumbnail, right wrist and the index fingernail, Fig. 1), one marker on the top of the dowel and another one at the base of the obstacle. Markers were tracked and collected at 120 Hz by an 11-camera movement analysis system (Oqus 3-series, Qualisys AB, Gothenburg Sweden).

Participants performed three walking tasks at their preferred pace: 1) walking combined with reach-to-grasp; 2) walking with obstacle negotiation; and 3) walking with obstacle negotiation combined with reach-to-grasp. In task 1, participants walked on an unobstructed walkway and grasped the dowel (aluminum cylinder, diameter: 5 cm, height: 12 cm, mass: 150 g), placed on a support surface adjusted to participants' greater trochanter height and located ∼3.5 m from the starting position. For tasks 2 and 3, we placed the obstacle (height: 10 cm; width: 60 cm) in one of three positions: one step before the dowel location (N-1), at the step corresponding to the dowel location (N) and one step after the dowel location (N + 1, Fig. 1). In tasks 2 and 3, participants walked and crossed the obstacle without and with grasping the dowel, respectively. They walked until the end of the walkway without stopping while grasping the dowel and crossing the obstacle. All participants grasped the dowel on the right side and held it walking until the end of the walkway.

Participants performed five trials in each of the three walking tasks. They performed the tasks in separate blocks with obstacle position randomized within each block for tasks 2 and 3. The order of blocks was randomly assigned to each participant.

2.3. Data analysis

The three-dimensional coordinates of the markers were digitally filtered with a 4^{th} order Butterworth filter (8 Hz cut-off frequency). The computation of the obstacle crossing variables (leading and trailing limbs) were divided into three phases (Fig. 1): before crossing (toe-obstacle anterior-posterior horizontal distance), crossing (toe clearance and maximum toe elevation), and after crossing (obstacle-heel anterior-posterior horizontal distance). Stride length, duration, and velocity were computed for the stride over the obstacle for leading and trailing limbs (Fig. 1). Step width was computed for the step over the obstacle.

The interval between reaching onset [3] and dowel contact was used to calculate the reaching and grasping variables. Dowel contact was defined when the velocity in the AP direction of the marker on the dowel crossed the threshold of 0.2 m/s [15]. The reaching variables were movement time (temporal difference between reaching onset and dowel contact), peak wrist velocity (maximum value obtained in the resultant wrist velocity curve), and time-to-peak wrist velocity (adjusted to movement time). For the peak wrist velocity, we used the relative position of the right wrist to the right iliac crest (i.e., relative to the person's body position in space [16]). The grasping variables were peak grip aperture (maximum distance between the markers on thumb and index finger), time-to-peak grip aperture (adjusted to movement time), peak grip aperture velocity (maximum value obtained in the resultant velocity curve of the thumb-finger distance), and time-to-peak grip aperture velocity (adjusted to movement time).

2.4. Statistical analyses

For the walking variables, we conducted two-way MANOVA (task [with and without grasping] x obstacle position [N-1, N, and N + 1]) with repeated measures in both factors for the following set of dependent variables: 1) toe-obstacle and obstacle-heel horizontal distances; 2) toe clearance and maximum toe elevation. We used two-way ANOVA (task x obstacle position) with repeated measures for both factors for the following dependent variables: step width; stride length and velocity. For the reach-to-grasp variables, we conducted one-way MANOVA (four conditions [walking and grasping without obstacle, walking and grasping with obstacle at positions N-1, N, and N + 1]) with repeated measures for the following set of dependent variables: 1) movement time, peak wrist velocity, and time to peak wrist velocity; and 2) peak grip aperture, time to peak grip aperture, peak grip aperture velocity, and time to peak grip aperture velocity. We used post-hoc tests with Bonferroni adjustments. We also ran correlation analyses between toe-obstacle horizontal distance and toe clearance for both the leading and trailing limbs in each experimental condition. The level of significance was set at 0.05 (trends reported at 0.10).