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The effects of object height and visual information on the control of obstacle crossing during locomotion in healthy older adults

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ABSTRACT

In order to safely avoid obstacles, humans must rely on visual information regarding the position and shape of the object obtained in advance. The present study aimed to reveal the duration of obstacle visibility necessary for appropriate visuomotor control during obstacle avoidance in healthy older adults. Participants included 13 healthy young women (mean age: 21.5 ± 1.4 years) and 15 healthy older women (mean age: 68.5 ± 3.5 years) who were instructed to cross over an obstacle along a pressure-sensitive pathway at a self-selected pace while wearing liquid crystal shutter goggles. Participants were evaluated during three visual occlusion conditions: (i) full visibility, (ii) occlusion at T-1 step (T: time of obstacle crossing), and (iii) occlusion at T-2 steps. Toe clearances of both the lead and trail limb (LTC and TTC) were calculated. LTC in the occlusion at T-2 steps condition was significantly greater than that in other conditions. Furthermore, a significant correlation was observed between LTC and TTC in both groups, regardless of the condition or obstacle height. In the older adult group alone, step width in the occlusion at T-2 steps condition increased relative to that in full visibility conditions. The results of the present study suggest that there is no difference in the characteristics of visuomotor control for appropriate obstacle crossing based on age. However, older adults may exhibit increased dependence on visual information for postural stability; they may also need an increased step width when lacking information regarding their positional relationship to obstacles.

1. Introduction

In addition to supporting postural stability, gait cycle modulation, and navigation, vision is essential for obstacle avoidance in environments in which humans must coordinate their movement in response to the presence or movement of other objects [1–4]. Crowded living spaces, uneven surfaces, and busy roadways require individuals to continually monitor and avoid obstacles along their paths [3]. In order to prevent trips and/or falls, sufficient toe clearance must be maintained while navigating such environments.

Previous studies examining the effect of visual field occlusion on obstacle avoidance determined that visual information is critical for navigating cluttered environments [5–9]. The visual system exerts feedforward control that allows one to adjust the toe clearance of the lead limb based on visual information obtained while approaching an object [5,7]. Timms et al. [10] further reported that visual information obtained at least two steps prior to reaching the obstacle is required to maintain appropriate toe clearance of the lead limb. In contrast, that of the trail limb depends on proprioceptive feedback from the lead limb, as the trail limb cannot be observed in the visual field [11,12]. However, results regarding the correlation between toe clearance of the lead and trail limbs remain inconsistent [5,7].

Because falls due to tripping increase with age, it is important to clarify potential alterations in visuomotor control experienced by older adults during obstacle crossing to reduce the risk of fall-related injuries. Published data indicate that older individuals increasingly rely on vision for the maintenance of postural stability, while experiencing both decreased gait velocity and longer reaction times in responding to visual stimuli [13–15]. In addition, prolonged single-leg positions are associated with the high risk of falling observed in older adults [12,16,17]. Uiga et al. [18] reported that older individuals tend to look downward more frequently and move their eyes more quickly than young people do. Nevertheless, no studies have investigated the duration of obstacle visibility required for obstacle avoidance.

Thus, we aimed to investigate differences in the duration of obstacle visibility required by younger and older participants for appropriate visuomotor control during obstacle avoidance, and to examine the potential mechanisms underlying these differences. We hypothesized

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that young people would determine the appropriate toe clearance based on visual information until two steps before the obstacle, while older individuals would require additional visual information. Thus, even if the field of vision is occluded just prior to the obstacle, they would be unable to plan movements in advance, resulting in higher toe clearance in an attempt to avoid objects of uncertain height.

2. Materials and methods

2.1. Participants

Twenty-eight healthy women were divided into two groups: a young adult group (n = 13; mean age = 21.5 ± 1.4 years (range = 19–23 years); mean height = 162.4 ± 3.1 cm; weight = 53.9 ± 6.2 kg) and an older adult group (n = 15; mean age = 68.5 ± 3.5 years (range = 63–74 years); mean height = 156.3 ± 4.7 cm; weight = 51.1 ± 4.2 kg). Since it is necessary to unify the participants' perception with respect to the height of a certain obstacle, only female participants were recruited to avoid drastic height differences among participants. Participants were recruited from the student population at Kobe University (young) or the Silver Human Resources Center (older). All participants exhibited normal vision, which was confirmed via an evaluation of past medical history, and could walk outdoors without glasses (normal vision and contact lenses only). No participants reported visual difficulties, including those associated with perception of distance, or any neuromuscular/orthopedic disorders that may have affected their participation in the study. Assessment of older participants using the Mini Mental State Examination (MMSE) revealed no significant decline in cognitive function (score = 28.6 ± 2.1, cut off point = 24) [19]. No participants in the older adult group had experienced a fall within the past 6 months.

All participants provided written informed consent prior to participation. The present study was approved by the ethics committee at our institution (2014 acceptance number: 118) and conformed to the tenets of the Declaration of Helsinki.

2.2. Protocol

We evaluated the physical function of all participants using the Timed Up & Go test (TUG) and Sit to Stand test (STS). In the TUG, mobility was assessed by measuring the time required to stand up from a standard armchair, walk a distance of 3 m, turn around, walk back to the chair, and sit down again. A pressure-sensing mat (T.K.K.5806: Takei Equipment Co., Ltd., Tokyo, Japan) located on the seat of the chair was used to collect data. In the STS, participants were asked to stand up 10 times with their arms folded on the same pressure-sensing mat. Each assessment was performed twice, and the shorter times were chosen as the representative values for each participant.

Participants were then asked to walk along a pathway containing an obstacle at a self-selected pace, cross over the obstacle, and continue walking for at least five additional steps (Fig. 1). Gait analysis equipment (Walk Way MW-1000: Anima Co., Ltd.) was placed along the walking path, which contained one of three different styrofoam obstacles (depth = 5 cm, width = 70 cm, heights = 2.5 cm, 5 cm, and 10 cm) that had been colored red to improve visibility. Obstacles remained unfixed to prevent falls associated with contact. Movements were recorded using a digital camera (HDR-CX590 V: SONY Corp., Tokyo, Japan) located alongside the obstacle.

Participants were instructed to cross obstacles with their right foot first so that the right leg was defined as the lead limb. Start position was four or five steps away from the obstacle, and participants were allowed to practice and determine their start positions prior to beginning the experiment [10]. They were also instructed to keep the same walking pace throughout the experiment.

Participants wore liquid crystal shutter goggles (S-13031 Takei equipment Co., Ltd.) to allow adjustments to the degree of visual field occlusion (graying of visual field), and walked along a pressure-sensing mat (30 cm × 30 cm) that recorded the pressure associated with each heel contact. The mat was adjusted according to the initial position and walking pattern of each participant. To avoid the influence of stride adjustments, the mat was covered with a thin sheet so that participants could not determine its position. Older participants were equipped with a harness in order to prevent the occurrence of falls. We further confirmed that the harness had no effect on walking speed.

Participants were asked to cross obstacles under three different, randomly ordered visual conditions: (i) full visibility, (ii) occlusion at T-2 steps, and (iii) occlusion at T-1 step, where T refers to the time of obstacle crossing (Fig. 2). Participants underwent three trials for each condition and each obstacle height (18 perturbed and 18 unperturbed). To avoid the influence of fatigue, participants were provided adequate opportunities for rest as necessary. The fear of visual-field occlusion was evaluated by inquiry.

2.3. Data analysis

The trial data were converted to image data using motion analysis software (Media Blend: DKH. Co., Ltd, Tokyo, Japan.). Toe clearance of the lead limb (LTC) was defined as the vertical distance from the front edge of the obstacle to the large toe of the lead limb during obstacle crossing. Toe clearance of the trail limb (TTC) was defined as the vertical distance from the front edge of the obstacle to the large toe of the trail limb.

Secondary outcome measures included trail foot placement, step length, step width, walking speed, and crossover time for the lead limb. Step length and step width were measured at the point at which the lead limb crossed over the obstacle. Trail foot placement, defined as the distance from the first toe of the left foot to the obstacle at the final step, was calculated using motion analysis software. Other measures were automatically calculated by the gait analysis equipment.

Group differences in the results of the TUG and STS were analyzed using independent samples *t*-tests. Obstacle-crossing parameters were analyzed using a mixed-design analysis of variance model (ANOVA) for

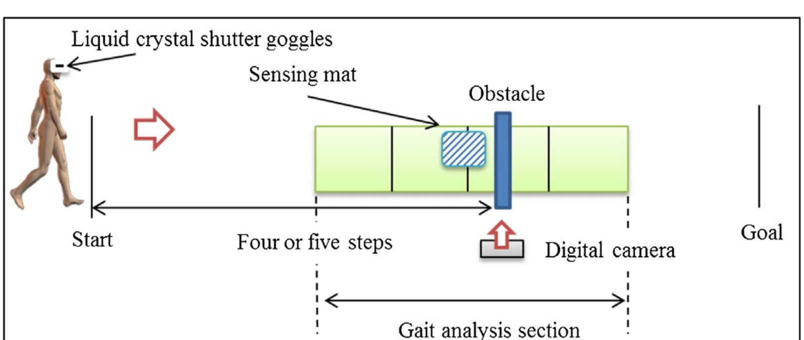

Fig. 1. Experimental environment. The mat was covered with a sheet in order to prevent adjustments in stride that may have occurred due to the perception of the mat.