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How do age and nature of the motor task influence visuomotor adaptation?

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ABSTRACT

Visuomotor adaptation with prism glasses is a paradigm often used to understand how the motor system responds to visual perturbations. Both reaching and walking adaptation have been documented, but not directly compared. Because the sensorimotor environment and demands are different between reaching and walking, we hypothesized that characteristics of prism adaptation, namely rates and aftereffects, would be different during walking compared to reaching. Furthermore, we aimed to determine the impact of age on motor adaptation. We studied healthy younger and older adults who performed visually guided reaching and walking tasks with and without prism glasses. We noted age effects on visuomotor adaptation, such that older adults adapted and re-adapted slower compared to younger adults, in accord with previous studies of adaptation in older adults. Interestingly, we also noted that both groups adapted slower and showed smaller aftereffects during walking prism adaptation compared to reaching. We propose that walking adaptation is slower because of the complex multi-effector and multi-sensory demands associated with walking. Altogether, these data suggest that humans can adapt various movement types but the rate and extent of adaptation is not the same across movement types nor across ages.

1. Introduction

A majority of daily walking involves navigation of complex environments and is highly dependent on visual guidance. Humans can flexibly adapt their walking patterns to visual distortions, which are easily created with gaze-shifting prism glasses. In this paradigm, individuals rapidly alter motor output based on trial-to-trial feedback, eventually establishing a new visuomotor mapping. While many studies of human prism adaptation focus on the upper extremity [1–4], adaptation is also observed during saccades [5,6], lower extremity movements [7], and walking [8–10]. Some have compared movement types in the context of generalization or how the type of movement or task generalizes to another [7,8,10]. However, no study has yet to determine if adaptation is similar in rate and extent across different adapted tasks, or if the type of movement influences how it is adapted (e.g., upper limb movements are adapted faster than lower limb movements). It is obvious that the demands associated with upper extremity movements and walking are quite different. Based on the model of visuomotor coordination proposed by Redding and Wallace [11], we propose that walking adaptation involves many more subsystems than reaching adaptation, resulting in slower error-correction processes. The behavioral consequence of this is slower adaptation during walking. In order to support or refute this hypothesis, we herein compare adaptation of reaching to adaptation of walking.

A secondary aim of this paper was to determine the effects of aging on motor adaptation of reaching and walking. Normal aging involves a myriad of changes in the nervous system that affect visuomotor adaptation, including degradation of sensory receptors and atrophy of the frontal cortex and cerebellum [12,13]. Older adults respond poorly to changes in their environment, which may underlie the high incidence of falls and movement-related injuries in this population. Indeed, existing data indicate that older adults adapt slower to visual perturbations but show similar if not larger aftereffects compared to younger adults [14,15]. Strategic control processes, which are important during adaptation but not for expression of aftereffects, are thought to be impaired in older

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adults and account for slower adaptation. However, the available literature has focused primarily on upper-extremity adaptation in older adults. The additional challenges, mainly balance and coordination, during walking may further impair older adults' ability to adapt their walking pattern, but this has not been studied.

In this experiment, we evaluated visuomotor adaptation to prism glasses in healthy older and younger adults during reaching and walking. Our goal was to examine the effects of both age and motor task on the properties of visuomotor adaptation. In accord with previous studies, we predicted older adults would adapt slower but have similar aftereffects compared to younger adults during both tasks. Furthermore, we postulated that because walking is more demanding than reaching, adaptation rates during walking would be slower compared to reaching for all participants.

2. Materials and methods

2.1. Participants

Young ($n = 15$, 7 male, mean age 25.0 ± 5.83 years) and old ($n = 18$, 9 male, mean age 70.1 ± 7.27 years) adults participated. Younger adults were recruited from the student cohort at the Washington University School of Medicine Program in Physical Therapy. Older adults were recruited using a volunteer database provided by the Department of Psychology at Washington University. All participants had normal neurological function, 20/40 vision or better without the aid of glasses, and were not cognitively impaired (Mini-mental status exam $\geq$26). Participants provided written consent before participation and were compensated for their time, travel, and effort. All procedures were approved by the Human Research Protection Office at Washington University School of Medicine in St. Louis.

2.2. Tasks and procedures

Participants completed 70 visually guided reaching and walking trials in the Locomotor Control Laboratory at Washington University School of Medicine in St. Louis. Each task was divided into three phases: baseline (10 trials), adaptation (40 trials), and post-adaptation (20 trials).

For the reaching task, participants reached and pointed to a visual target with their dominant arm as quickly as possible using a laser pointer. Participants stood 1.6 m from a large piece of paper hung on a wall. A 5 cm $\times$ 5 cm crosshair served as the target and was positioned at each participant's shoulder height. After each reach, the experimenter marked the position of the reach end point on the paper to allow feedback regarding reach accuracy. During baseline, reaching occurred without vision (eyes closed). During adaptation, participants reached while wearing eyeglass frames containing 30-diopter rightward-shifting prism lenses (Fresnel Prism and Lens Co, Bloomington, MN). They also wore modified, lens-free safety goggle frames over the prisms to obscure peripheral vision and ensure gaze was directed through the prism lenses. Eyes remained open throughout the adaptation phase. For post-adaptation, prisms were removed and reaching was completed without vision. For all trials, participants viewed their performance after each reach before completing the next trial.

The walking task required participants to walk forward on a path to a visual target on the floor (white piece of tape, 0.3 m long). Participants were instructed to stop with the arches of their feet resting in the middle of the tape. After each trial, the participant turned around and completed the next trial in the opposite direction. Walking was completed with the same phases and vision restrictions as in the reaching task. In addition, participants were fitted with a platform extending forward from the chest to limit vision of the feet and target during adaptation. Participants were instructed to first look at the target then look straight ahead while walking. However, we ensured that each participant was able to view the position of the feet relative to the target after each adaptation trial. Walking position was measured using an 8-camera motion capture system (Motion Analysis Corp, Santa Rosa, CA). Reflective markers were placed bilaterally on the greater trochanters and on the left scapula (offset marker). The midpoint of the pelvis markers was used to represent walking trajectory.

2.3. Data analysis

Reaching errors were calculated by measuring the horizontal distance from reach end point to center of the target. Absolute error was converted to an angular error using trigonometric calculations. Data measured using motion capture were processed for discontinuities and digitally low-pass Butterworth filtered (cut-off of 6 Hz). Walking errors were calculated from the difference in walking trajectory endpoint and center of walking target. These distances were also converted to angular errors. We defined rightward errors as positive and leftward errors as negative.

Trial-to-trial angular error curves for each phase were plotted for each task, and then averaged across all participants. We analyzed four characteristics of prism adaptation: magnitude of the adaptation (M_{adap}), magnitude of the aftereffect (M_{ae}), rate of adaptation (R_{adap}), and rate of post-adaptation (R_{post}). M_{adap} was defined as the difference in angular error between the first adaptation trial and the average of the last five adaptation trials. M_{ae} was defined as the angular error during the first post-adaptation trial [2]. Although M_{ae} is simply a magnitude, we present it as negative to indicate direction of the error and not to confuse it with M_{adap}. Adaptation and post-adaptation curves were fitted by a monotonic exponential function, allowing for estimation of the curve decay constant. We used built-in Matlab (R2011b, Mathworks Inc., Natick, MA) data fitting functions to fit curves during adaptation and post-adaptation phases to the form $y = A^{*}\exp(-b^{*}t) + c$, where A is a scaling constant, b is the decay constant, t is the trial number, and c is the horizontal asymptote. R_{adap} and R_{post} were defined as *1/b* for the exponential fit of adaptation and post-adaptation curves, respectively. We limited the range of b to 0.025–1 for adaptation fits and 0.05–1 for post-adaptation fits, which translates to a range of 1–40 for R_{adap} and 1–20 for R_{post}. These ranges reflect the minimum and maximum possible adaptation rates given the number of trials in each phase. Goodness-of-fit was determined by visual inspection in conjunction with R^2 values. Several fits from each group fit poorly to the exponential function, resulting in inaccurate parameter estimates. Specifically, three reaching adaptations (1 old, 2 young), three walking adaptations (1 old, 2 young), 1 reaching post-adaptation (old) and six walking post-adaptations (3 young, 3 old) were deemed poor fits. We excluded these from analysis of R_{adap} and $R_{post.}$ Subsequent analyses showed their inclusion did not change interpretation of the data. Finally, to quantify trial-to-trial variability, we calculated the standard deviation of the last five trials of each phase.

To examine the effects of age and task on the four adaptation variables, we used a mixed-effects ANOVA with between-groups effect of Group (young vs. old) and within-groups effect of task (reaching vs. walking) using SPSS v21 (IBM Corp, Chicago, IL). Because walking speed may affect magnitude or rate of adaptation and aftereffects, we included walking speed as a covariate in the ANOVA model. We also performed a 3-way ANOVA (task-phase-Group) to compare changes in variability across the experiment. If a main effect was present, post hoc t-tests were used to compare group differences within each task. Statistics were considered significant if $p < 0.05$.