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Stride cycle influences on goal-directed head movements made during walking

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Abstract

Horizontal head movements were studied in six subjects as they made rapid horizontal gaze adjustments while walking. The aim of the present research was to determine if gait cycle events alter the head movement response to a visual target acquisition task. Gaze shifts of approximately 40° were elicited by a step change in the position of a visual target from a central location to a second location in the left or right horizontal periphery. The timing of the target position change was constrained to occur at 25%, 50%, 75% and 100% of the stride cycle. The trials were randomly presented as the subjects walked on a treadmill at their preferred speed (range: 1.25–1.48 m/s, mean: 1.39 ± 0.09 m/s). Analyses focused on the movement onset latencies of the head and eyes and on the peak velocity and saccade amplitude of the head movement response. The head and eye movement onset latencies were not affected by either the direction of the target change or the point in the gait cycle during which the target relocation occurred. However, the presence of an interaction between the gait cycle events and the direction of the visual target shift for both the amplitude and peak velocity of the head movement response indicates that the head movement responses to visual target changes can be influenced by the phase of the gait cycle during which the target relocation takes place.

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1. Introduction

Making gaze shifts to visually fixate objects peripheral to the progression of travel is common as we walk. When these gaze adjustments are sufficiently large, a head rotation must accompany the eye movements to achieve the goal. Investigations using seated subjects have demonstrated that the movement characteristics (i.e. amplitude and peak velocity) of these head rotations vary between subjects and conditions [1]. Two such conditions are the magnitude of the required gaze adjustment and the initial starting position of the head. Although a large body of literature exists relating to gaze re-fixations while seated, visual target acquisition has not been systematically investigated under more dynamic conditions. It is therefore unknown whether the lessons learned about gaze control from seated subjects can be directly extrapolated to conditions when a subject is walking. Prior to a more exhaustive investigation comparing seated or standing gaze adjustments to those performed while walking, it is necessary to determine whether the cyclical processes present during locomotion impose sources of variability that must be controlled for experimentally.

The head translates and rotates in a periodic fashion during locomotion. Reports vary regarding the magnitude of these periodic head movements but the phase relationship between these movements and ongoing gait events is consistent [2–9]. In the sagittal plane for example, the head pitches upward as the body translates down during each step. Yaw head movements counter the lateral translations of the body in a similar way. It is believed that these movements are largely the result of reflexive mechanisms [10,11], implying the presence of a periodic activation of the neck musculature. Because the head movement made in a gaze re-fixation would likely utilize many of the same muscles, an

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interaction between the naturally occurring cyclical processes and the voluntary head rotation may affect the dynamics of the head movement response.

Regardless of the control mechanism (i.e. reflexive, voluntary, or passive inertial), the cyclical head movements also suggest a periodic modulation in vestibular stimulation. Bent and colleagues found differences in lower body gait parameters that were dependent on when in the gait cycle a vestibular stimulus was given [12]. This phase-dependent vestibular-induced alteration in gait function indicates that there may be an optimal time during the gait cycle to make a voluntary head movement that could impart a similar vestibular disturbance. Differences in the gait disturbances imparted by voluntary versus unexpected head turns imposed during walking led Vallis and Patla to conclude that the central nervous system partially nullifies the sensory input created by voluntary head turns [13]. In addition to this proposed use of efferent copy to minimize the vestibular disturbance, a strategy of triggering head movements to coincide with phases of the gait cycle where the vestibular information is less important could also be used. Such a strategy would affect the timing of the head movement response in a visual target acquisition task. Differences in the response timing may also result from interactions with other ongoing activities. Lajoie et al. showed that reaction time was dependent on when in the gait cycle the stimulus was presented [14]. While this investigation used an auditory stimulus and utilized a response action that is not nearly as common during walking as the acquisition of peripheral visual targets, part of both activities is the perception of the stimulus. It is possible that the shock wave that is transmitted to the head following each heel strike creates a modulation in visual perception during the gait cycle. The presence of such could also create a gait cycle-dependent effect on the response timing of a target acquisition task performed while walking.

Through measures of eye and head movement onset latency and head movement kinematics, the goal of the present research was to assess whether the execution of a target acquisition task while walking is performed consistently, regardless of when in the gait cycle a visual stimulus appears in the periphery. In addition to providing preliminary data regarding the performance of this everyday activity, knowledge of whether gait cycle-dependent variation is present in such a task will provide the necessary background to properly develop future investigations comparing walking and seated gaze adjustment performance.

2. Methods

2.1. Subjects

Six healthy males in the age range from 26 to 35 (mean 31 years ±4) served as subjects for this study. None of the subjects had complaints of neck soreness at the time of the test and none had any history of vestibular disease. The experiment protocol was approved by the University of Massachusetts' Human Subjects Review Committee and all subjects gave their written informed consent prior to participation.

2.2. Testing conditions

2.2.1. Walking speed

The subjects, all wearing a similar type jogging shoe, were tested as they walked on a motor-driven treadmill (Accumill P, Pacer Fitness Systems Inc., Irving, TX) at their preferred walking speed. The subject-specific speeds were established using an interactive method defined in Holt et al. [15] which resulted in speeds ranging from 1.25 to 1.48 m/s (mean 1.39 ± 0.09 m/s).

2.2.2. Visual targets

Visual targets were presented on a rear-projection screen (Da-Lite Screen Company Inc., Warsaw, Indiana) that was placed between the subject and an LCD projector (Sharp, Model: XG-E670U, Mahwah, New Jersey). The screen was perpendicular to the walking direction at a distance of ~110 cm from the subject's nasal bridge. The targets, consisting of alpha-numeric characters, were controlled by custom software (LabVIEW; National Instruments Corp., Austin, TX.). When presented directly in front of the subject, the visual targets subtended a visual angle of $\sim 1.3^\circ$.

A data trial consisted of a single gaze re-fixation task. During each of the 14 s trials, a series of visual targets was initially presented in the center of the subject's field-of-view at a height that was perceived by them to be eye level. The target series was created using random selections from a "pool" that contained 24 upper-case characters (*O* and *I* were excluded) and eight numerals (0 and 1 were omitted). At the designated time, this series was extinguished and a similar series of targets drawn from a pool containing only the 24 characters was displayed at the same height, but 1 m to the left or right of the central location. These lateral locations required a gaze compensation angle of $\sim\pm 40^\circ$ for visual fixation. With the exception of the first target to appear in the lateral position, the display duration for each of the sequentially displayed characters was randomly determined using a finite set of duration times that fell at 50 ms intervals from 400 to 700 ms. This was done to prevent entrainment of the subject's stride to the visual stimulus. To account for the approximate 500 ms response time of the gaze adjustment, the first lateral target remained visible for 900 ms for all data trials.

At the conclusion of each trial the subject's recollection of the number of numerals that appeared in the central position, as well as the first letter seen in the lateral position, was compared to the actual values. While the successful identification of the first lateral target was used as an inclusion criterion for acceptable data trials, the primary

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