*Neuroscience* 145 (2007) 505–519

# TEMPORAL FACILITATION OF GAZE IN THE PRESENCE OF POSTURAL REACTIONS TRIGGERED BY SUDDEN SURFACE PERTURBATIONS

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**Abstract—Saccadic reaction times can be shortened by an additional sensory modality (e.g. auditory, tactile) presented in temporal proximity to the triggering cue. Whereas somatosensory cues given by sudden perturbations of the support surface can trigger appropriate postural adjustments to maintain upright stance, it is not known how gaze executions are affected by the dual task of maintaining upright balance while redirecting gaze. It was hypothesized that the onset latency of gaze movements toward visual targets will be shortened by sudden surface perturbations following visual target shifts to prompt a stable visual anchor for postural stabilization. Eight subjects stood on a movable platform with gaze fixated on a central target 2 m directly in front, and were instructed to shift their gaze to lateral targets located along a 63° arc to the right and left. The trials began with the central target lit followed randomly by either the right, left or center target. Fifty or 250 ms following this target shift, balance was perturbed by a sudden yaw movement of the support surface (15.5° over 210 ms at 130°/s), with no stepping or large arm reactions observed. The latency of the gaze shifts was significantly shortened (by ~72 ms) when executed simultaneously with a surface perturbation. A decrease in excitation latency was also observed in the cervical paraspinals and sternocleidomastoid muscles. Postural responses in the ankle and knee muscles were not affected by gaze shifts. Pelvic horizontal angular motion closely followed surface motion whereas head motion was influenced by gaze shifts. During the combined gaze shift and surface motion conditions, thorax movement excursion was larger and not correlated with either the surface motion or visual target shift. In conclusion, postural adjustments in response to sudden surface yaws facilitate voluntary gaze shift execution and this enhancement may result from the sensory fusion of somatosensory and visual information.** 

**Key words: oculomotor, postural control, saccades, reaction time, sensory fusion.**

Multisensory stimuli, such as visual–auditory cues, have been shown to reduce the onset latencies of saccadic eye movements (e.g. Corneil and Munoz, 1996; Frens and Van Opstal, 1998; Colonius and Arndt, 2001). This finding is supported by neurophysiological evidence of multisensory integration observed at the level of the superior colliculus (Meredith and Stein, 1986; Jay and Sparks, 1987a,b; Frens and Van Opstal, 1998). The combinations of somatosensory and visual cues (Groh and Sparks, 1996; Amlot et al., 2003) or visual and tactile stimulations (Diederich et al., 2003) have also been shown to decrease the onset of saccadic latencies. These intersensory facilitations appear to be even more marked when cues are provided in close temporal or spatial proximity (Colonius and Arndt, 2001; Amlot et al., 2003), supporting the concept of sensory fusion prior to sensorimotor integration when preparing and releasing a motor response.

Most studies of visuomotor control were performed sitting, with minimal demands of the CNS for postural control, yet visual tasks are generally executed in the context of a variety of complex static and dynamic postures. In fact, human postural control in itself is a task that requires sensorimotor integration, implying that multiple coordinate system transformations (sensory and motor) are required to integrate the visual, inertial and somatosensory information (Soechting and Flanders, 1992). Therefore, adding visual tasks to the regulation of upright standing posture increases task complexity as they must be integrated within an internal representation of the body in space to maintain postural equilibrium and achieve these visual task goals. Upright posture alone has been studied extensively and has been shown to require more cognitive resources, as observed in dual-task paradigms where performance of both the cognitive and postural tasks was affected (Kerr et al., 1985; Teasdale et al., 1993). Regardless, the effects of upright stance regulation on gaze control are not well understood.

Recent investigations on the control of balance during eye movements showed that in the absence of retinal slip, a significant sway, measured by the root-mean-square of the lateral displacement of the center of pressure (CoP), developed 2 s after subjects began smooth pursuit eye movements to track a visual target (Strupp et al., 2003; Glasauer et al., 2005). These findings support the interaction of oculomotor and postural control processes under

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*Abbreviations:* A/D, analog-to-digital; ANOVA, analysis of variance; AP, antero-posterior; CoM, center of mass; CoP, center of pressure; CP, cervical paraspinals; EMG, electromyography; EO, external abdominal oblique; ES, erector spinae; LED, light emitting diode; MG, medial gastrocnemius; ML, medio-lateral; RT, reaction time; SCM, sternocleidomastoid; S.E., standard error of the mean; ST, semitendinosus; TA, tibialis anterior; TWIN, time-window-of-integration; VL, vastus lateralis; VOR, vestibulo-ocular reflex.

0306-4522/07$30.00+0.00 
doi:10.1016/j.neuroscience.2006.12.027

static, unperturbed stance conditions. However, during dynamic balance control, it is unclear how these processes would interact.

Furthermore, it has been shown that the execution of rapid voluntary movements (other than oculomotor) can be influenced by multisensory stimuli. In a study by Dietz et al. (2000) that examined the interaction of anticipatory postural adjustments with voluntary movements, subjects were required to execute voluntary push or pull movements with their arms in the presence and absence of antero-posterior surface translations. They found that voluntary movement latencies were significantly shorter when preceded by surface perturbations, as shown by leg muscle activation related to focal arm movements. Similarly, Maki and McIlroy (1997) contrasted grasping responses executed in response to surface translations with those generated with a visual cue and observed earlier and less variable responses in the presence of surface perturbations.

As voluntary movements seem to be executed earlier in the presence of somatosensory stimulation, such as support surface perturbations, similar enhancements may be observed with voluntary gaze shifts. The idea of sensory fusion (Colonius and Arndt, 2001; Amlot et al., 2003) or parallel processing of sensory information which takes into account all available and relevant cues to achieve multiple task goals may explain the temporal facilitations observed in dual-task paradigms. The present study examined the coordination and control of visuomotor and postural responses during standing while executing saccadic gaze shifts (visual perturbation) toward space-fixed lateral targets in the presence or absence of sudden support surface movements. Movement of the supporting surface provides predominantly a somatosensory perturbation while also affecting the visual and vestibular systems, although the degree to which these other systems are involved in triggering the postural reaction remains unclear (Runge et al., 1998; Carpenter et al., 2001; Zettel et al., 2005). It was hypothesized that, in accordance with the concept of sensory fusion, a support surface perturbation (predominated by somatosensory stimuli) presented in temporal proximity to a visual target step stimulus will affect gaze redirection rather than a triggered postural reaction induced by surface movement and result in temporal facilitation of gaze movements toward the new visual target.

## EXPERIMENTAL PROCEDURES

### Subjects

Eight healthy subjects (28±2 years) participated in this study. The subjects had no prior history of neurological diseases, diabetes, and rheumatic or orthopedic conditions that could contribute to postural instability or movement dysfunction. All subjects were right handed as assessed by the Edinburgh Handedness Inventory (85±11%) (Oldfield, 1971). Informed written consent was obtained from the subjects prior to their participation in the study. Ethics approval was obtained from the institutional review board.

### Experimental setup and protocol

As depicted in Fig. 1A, the subjects stood in the middle of a movable platform in a step-stance position, with the left foot in front, to increase postural difficulty (by decreasing lateral stability). The subjects' feet were positioned symmetrically around the surface's axis of rotation and were the same for all trials. Three visual green light emitting diode (LED) targets were placed at eye level: one central target located 2 m directly in front of the subject, and two lateral targets located along a 63° arc to the right and left of the central target. The trials began with the central target lit and the support surface at a neutral position orienting toward the central target (Fig. 1A, $T_1$). Following a variable period of 1.0–3.8 s (to avoid subject anticipation), the subjects were randomly presented with one of three stimuli for target fixation: (1) central LED OFF, right ON; (2) central LED OFF, left ON; (3) central ON, left/right OFF (Fig. 1A, $T_2$). The subjects were instructed to fixate their gaze on the lit target and to shift gaze as rapidly as possible when the target location changed. The room lights were dimmed to minimize visual interference and enhance the target visibility. Fifty milliseconds ($n=5$) or 250 ms ($n=3$) following the target shift, balance was perturbed by a sudden yaw movement of the support surface (Fig. 1A, $T_3$) presented randomly in different directions (right or left yaw or none). An interstimulus interval of 250 ms was used for the first three subjects tested. This time interval was selected based on the study by Dietz et al. (2000) in which different time intervals were compared between the presentation of a go signal for initiating a voluntary handle push or pull and the onset of a surface translation. An interstimulus interval of 250 ms had the most marked effects in reducing the onset latency of the anticipatory postural adjustments. However, Colonius and Diederich (2004) showed that the earlier a tactile cue accompanying visual stimulus was presented, the shorter the ensuing saccadic reaction time (RT). Thus, to assess whether a shorter time interval between target presentation and surface motion would lead to even shorter gaze onset latencies, we reduced the interval to 50 ms in the last five subjects tested.

Surface yaw motions were 15.5° in amplitude and 210 ms in duration, with a peak velocity of 130°/s, and peak acceleration of 480°/s$^2$ in either direction. None of the subjects tested responded with stepping or large arm reactions to recover balance. Five trials per condition, presented in random order, were collected for each subject (3 target×3 surface=9 conditions×5 trials=45 trials per subject). Prior to data collection, subjects were exposed to several surface perturbations and visual target shifts to familiarize them with the experimental protocol and to avoid learning effects.

### Measurements

Three-dimensional body kinematics were acquired using a six-camera Vicon 512 system (Vicon Peak, Oxford, UK). Forty-six reflective markers were placed bilaterally on specific anatomical landmarks on subjects' head, shoulders, thorax, pelvis, lower limbs and the movable surface to record whole-body kinematics along with surface perturbations, as illustrated in Fig. 1A. The marker positions were tracked in real time by a 100 Mb Ethernet link, sampled at 250 Hz. Body segment angles (head, thorax and pelvis) and center of mass (CoM) location were computed with the Vicon Plug-In-Gait model using marker positions and subjects' anthropometric measurement (height, mass and joint widths). Marker positions, segment angles and CoM were then imported into the Matlab software and low pass filtered at 15 Hz for subsequent analysis, using a 4th order, dual-pass Butterworth filter for zero phase lag.

Eye movements were tracked using an EyeLinkI Gaze Tracking system (SensoMotoric Instruments GmbH, Berlin, Germany), consisting of two high-speed cameras mounted on a headband to track pupil movements relative to the subject's head. The EyeLinkI system was also connected through a 100 Mb Ethernet link and