DO VESTIBULAR INPUTS TRIGGER UPPER BODY RESPONSES DURING A SLIP?

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INTRODUCTION

After a slip is initiated, the body attempts to regain balance by generating postural responses at the knee, hip and shoulder (Cham and Redfern, 2002; Sandrian and Cham, 2007). Shoulder responses are of particular interest because previous research has indicated that the arm is used to brace the body for a fall during a severe slip, but moves the arm in the opposite direction in an effort to recover from a non-severe slip (Sandrian and Cham, 2007). However, it is not known what triggers these complex and rapid arm responses. We hypothesize that vestibular inputs sense the fall and trigger these responses.

The purpose of this study is to explore the association between changes in vertical head acceleration, which would be sensed by the vestibular system, and shoulder reaction moment onset time.

METHODS AND PROCEDURES

A total of 31 healthy subjects (13 older and 18 young) were recruited to take part in the study. Written informed consent was obtained prior to enrolment. Four subjects were not included in the analysis due to technical or testing problems. Subjects performed 2-5 baseline walking trials and then were unexpectedly slipped with a liquid glycerol contaminant. Subjects were harnessed to prevent injury. An eight-camera motion analysis system recorded whole body motion via a 79 marker set.

Shoulder moments and head acceleration were calculated from marker data. Shoulder moments were calculated by performing a distal to proximal inverse dynamics method from the hands up to the shoulders. Segment masses and moments of inertia were determined as per (de Leva, 1996). Head motion was tracked by generating a virtual head center of mass trajectory based on 4 markers placed on the head. Head marker data was filtered using a 2nd order butterworth filter with cutoff frequency of 10 Hz and then was twice differentiated via a 3-point method.

The two primary variables were the time of negative vertical head acceleration and the time of shoulder flexion moment deviation from baseline non-slip trials. Head acceleration time was determined to potentially result in a vestibular queue when vertical head acceleration switched from positive (up) to negative head acceleration (down). This time point, time of head acceleration direction change (THADC) was chosen as a measure of deviation from normal walking during the slip. In addition, the THADC was required to deviate from baseline dry walking trials. If THADC did not deviate from baseline walking, the trial was excluded. This measure therefore resulted in a time at which the fall could be sensed by the vestibular system. To determine shoulder moment reaction times, the flexion moment ipsilateral to the slip was analyzed. The ipsilateral flexion moment was chosen because its magnitude correlated best with slip severity (Sandrian and Cham, 2007).

Shoulder reaction time was identified as the time when the moment during the slip trial differed from the dry trials by 3 standard deviations. Standard deviations were calculated from the difference of the slip and dry trial for 0.5 sec before heel contact. When no shoulder reaction or very late reaction moments were found, the trials were not analyzed. A mixed model ANOVA was run with subject as a random effect; THADC, slip severity and THADC-slip severity interaction as the fixed effects on shoulder reaction time.

RESULTS

The timing of head acceleration direction change (THADC) was significantly correlated with shoulder reaction time ($p<0.05$). (Figure 1) The slope of the regression line is 0.84. The intercept of the line is 0.104 s, which is significantly different from 0 ($p<0.05$) On average, the THADC occurred 116 ms after heel contact, and the moment generation reaction time was 204 ms after heel contact. Slip severity did not significantly influence the relationship.

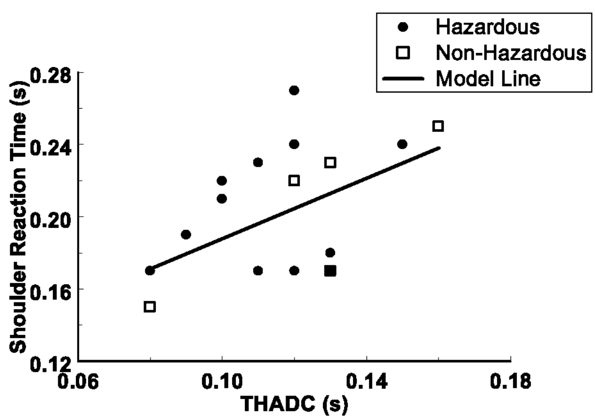

Figure 1. Shoulder reaction time plotted against THADC shows a positive correlation.

DISCUSSION AND SUMMARY

This study suggests that the vestibular system may play a role in sensing the fall and initiating the upper body postural response to a slip. The ANOVA further supports the claim. For example, if an upper body postural response only occurred after receiving vestibular input, the slope of the line between vestibular input time and reaction time would be 1. Our analyses revealed the slope of the line was near to that value. Furthermore, the intercept of the line, which would represent the time for signal processing, decision making, signal transition time and muscle activation, is 104 ms. Because of the proximity of the vestibular system, neural processing center and shoulder, a reaction in 104 ms is reasonable.

One limitation of this study was the measure of head acceleration and shoulder reactions. Future studies will include accelerometers to get more accurate acceleration profiles and shoulder EMG's for improved quantification of shoulder reaction onset.

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