International Conference on Virtual Rehabilitation 2011
Rehab Week Zurich, ETH Zurich Science City, Switzerland, June 27 - 29, 2011

Postural Responses of Adults with Cerebral Palsy to Combined Base of Support and Visual Field Rotation

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Abstract— **We employed a virtual environment to examine the postural behaviors of adults with cerebral palsy (CP). Four adults with CP (22-32 yrs) and 9 healthy adults (21-27 yrs) were tested in a Rod and Frame protocol. They then stood quietly on a platform within a 3-wall virtual environment. The platform was tilted 3° into dorsiflexion while in the dark or with pitch up and down visual field rotations at 30 and 45 °/sec. While the visual field rotated, the platform was held tilted for 30 sec and then slowly returned to a neutral position over 30 sec. Trials with the platform stationary were performed with the same visual field rotations. Center of pressure (CoP) was recorded and center of mass (CoM) was calculated. Angular deviations from the Rod and Frame test were larger in adults with CP suggesting that they are visually dependent. Adults with CP had difficulty maintaining balance when standing on a stationary platform with pitch upward rotation. When the platform tilted with visual field rotation, adults with CP took longer to stabilize themselves after the tilt and had larger CoM oscillations over the trial compared to dark. Plots of CoP revealed that side-to-side CoP increased on both a stationary and tilted platform when visual flow was presented suggesting that adults with CP are unstable with visual flow. Two adults with CP were wheelchair users and they exhibited even larger CoP RMS values indicating greater instability in adults with impaired ambulatory function.**

Keywords-Cerebral palsy; visual flow; ambulatory; visual dependence; balance

I. INTRODUCTION

While cerebral palsy (CP) is generally thought of as a disorder of childhood, the majority of individuals with CP live at, or near to, a full life expectancy [1]. In the US, approximately 1 million adults and children with CP live independently [2]. Clinical care of adults with CP lacks comprehensiveness with gaps in continuity of care in the transition to adulthood as well as an understanding of the impact of aging on their neuromotor system and functional status. Hence, adults with CP are a relatively underserved population [1]. Individuals with CP present with considerable functional heterogeneity and a marked decrease in functional status as they age into adulthood due to the development of secondary neuromuscular impairments [1]. This decrease in functional status is concurrent with documented deficits in somatosensory function [3], and poor control over the trunk muscles which has been documented in children with CP as young as three [4,5]. These additional factors, in the adult, can lead to balance instability and fear of falling that further contributes to lost function.

The loss of function as the child with CP ages into adolescence and young adulthood is well documented [6-16]. Day and colleagues [15] examined the changes in ambulatory ability of 7,550 children with CP (10 ± 0.9 years of age) and 5,721 adults with CP (25 ± 0.8 years of age) after a period of 15 years. For the children with CP, of those who had no trouble with ambulation, 23% declined in ambulatory function fifteen years later. Of those children with some ambulatory problems, 11% demonstrated a decline in ambulatory ability. Finally, of those children who were somewhat dependent upon wheelchairs to navigate in their environment, 34% became completely wheelchair dependent. The most commonly reported age-related change and secondary conditions for the adult with CP are pain, fatigue, spasticity, and muscle weakness [1]. All these factors can lead to decreases in activity. However, the loss of ambulatory ability may also be attributed to deficits in balance, which may contribute to a heightened risk of falls [1]. Higher fall risk could further restrict activity levels, contributing to increases in body mass and loss of muscle strength in the adult with CP.

While we are aware of no literature that examines the risk of falls in the adult with CP, we do know that falls can result in significant injury. For example, in the geriatric population, of those who fall, 20-30% sustain injuries that reduce mobility and independence [17], or result in admission to long-term care facilities [18]. Instability resulting in falls is the leading cause of injury related death and of nonfatal injury in the US [19-23]. To prevent such falls, the dynamic process of

This work was supported by NIH grant AG26470 from the NIA, H133F100010 from NIDRR and Temple University Faculty Senate Seed Money.

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maintaining an upright posture is vital to health and independent function.

A critical barrier to reducing falls and fall-related injury is identifying the mechanisms behind the falls. Falls have been reported as occurring most frequently during ambulation [24] but these are not always correlated with obvious environmental causes such as uneven surfaces and obstacles. Lengthened response latencies, reduced segmental motion, and muscle weakness [25-29] are all factors that have been identified as contributors to falls. Diminished or disrupted responses to sensory information that also occur with aging [30-35] may be potential factors in adults with CP as well, and need to be further explored as related to falls. Although various risk factors have been identified in healthy elderly adults, less is known about such risk factors for falls in adults with CP. What is evident is that all of these factors are present in adults with CP, and could also contribute to increased instability that would precipitate reduced functional activity.

In this paper, we present a pilot study that investigated the postural responses of adults with CP using a paradigm that has distinguished responses between healthy young and elderly adults. Responses of adults with CP and adults with typical development (TD) were assessed while they were standing on a support surface that tilted and viewing a visual scene that rotated in the same and opposite direction of the surface tilt.

II. METHODS

A. *Subjects*

Nine adults with TD (21-27yrs), and 4 adults with spastic diplegic CP (22-32 yrs) gave informed consent to participate as approved by Temple University IRB. All of our adults with CP had a plantar flexion contracture of the ankle ranging from 5-10 deg as measured with goniometer when lying supine. Two of the adults with CP used a wheelchair in their everyday environment and 2 adults with CP were ambulatory. One of adults with CP, who was a wheelchair user, was only able to complete half of the tilt trials due to instability.

B. *Rod and Frame Test*

To assess whether this sample of adults with CP were more visually dependent than the adults with TD, each subject completed the Rod and Frame test [36-40]. Subjects were standing freely in the upright position in the dark. They were instructed to look straight ahead at a projection screen that displayed a luminous frame tilted 22.5° clockwise or counterclockwise from horizontal. A projected rod was digitally rotated from an initial position of 20° or 45˚ from vertical or horizontal. Subjects verbally identified when they perceived the rod as reaching pure vertical or horizontal (reached 90˚). Absolute angular deviations of the rod were calculated as the value of the position given by the subject subtracted from 90° (pure vertical or horizontal). For instance, if the absolute angular deviation was calculated as 5˚, then the subject indicated that the rod had reached pure vertical (90˚) when the rod was actually located at either 95˚ or 85˚.

C. *Postural Task*

Subjects were instructed to look straight ahead with feet placed a comfortably distance apart but side-by-side, arms at their sides and maintain an upright posture. After standing quietly for 5 sec, the support surface tilted 3°in dorsiflexion at a constant velocity of 30°/sec, remained tilted for 30 sec, and then slowly returned to neutral over a 30 sec period at a constant velocity of 0.1°/sec (Fig. 1). The slow return of the platform was chosen to be below the thresholds of vestibular detection but at the thresholds of proprioceptive detection [41]. The visual field was either dark or rotated in continuous upward or downward pitch at the same velocity as the platform (30°/sec) or faster (45°/sec). Onset of visual field rotation and support surface tilt was synchronized and visual field motion was maintained throughout the trial. Five trials were conducted in which the support surface was stationary for each visual condition. A total of 10 trials were performed and these trials were randomized across direction and velocity of support surface and visual scene.

Figure 1. 3-wall virtual environment displayed to subjects standing quietly on the dynamic platform.

D. *Data Collection*

Subjects stood within a virtual environment composed of three transparent 1.2 m x 1.6 m screens placed 90 cm in front and to the right and left of a 3-degree of freedom platform (Neurocom International Inc., Clackamas OR) that contained integrated dual triaxial force plates (AMTI, Watertown, MA, Fig. 1). Specialized software calculated center of pressure (CoP) from the force plate output. Two Panasonic PT-D5600U DLP-based projectors located behind each screen projected a full-color workstation field (1024x768 stereo) at 60 Hertz (Hz) onto each screen. Polarized filters placed in front of the projector provided left eye and right eye views of the image on each screen, and passive stereo glasses delivered the correct view to each eye. Three dual processor computers created the imagery projected in the virtual environment and were synchronized via the CAVELib application (MechDyne, Virginia Beach, VA). Three-dimensional kinematic data from the body was collected using a Motion Analysis (Santa Rosa, CA) 6-camera infrared Hawk system sampling at 120 Hz.

E. *Data analysis*

Center of mass (CoM) of the body was calculated from marker displacement in the anterior-posterior (AP) direction. Center of pressure was measured from the dual force plates at 200 Hz and analyzed in both AP and lateral planes. A root means squared (RMS) measures of CoP in the AP and lateral plane were calculated over a 20 sec period that encompassed the sustained tilt period (10-30sec after the tilt) and over the 25 sec period that contained the platform return to neutral (35 -60 sec after the tilt). All adults with CP were compared to adults with TD. To examine differences within the adults with

CP due to ambulation in their environment, RMS of CoP was compared between adults with CP who were wheelchair users and adults with CP who were ambulatory.

III. RESULTS

A. Rod and Frame

Adults with CP had larger errors during the Rod and Frame test for both vertical and horizontal alignment (Fig 2). Average absolute angular deviation in horizontal was 8.2 deg and 5.4 deg in vertical for adults with CP. Average absolute angular deviation was 2.2 deg in horizontal and 2.4 deg in vertical for adults with TD. The larger deviations suggest that adults with CP are more visually dependent than adults with TD.

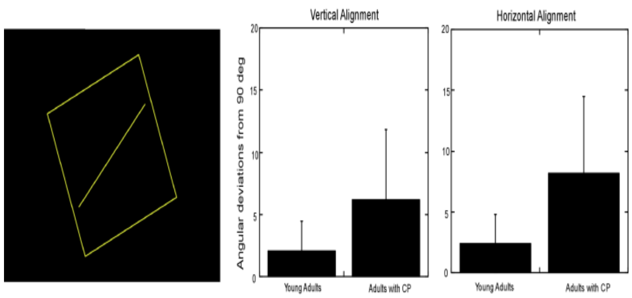

Figure 2: *Left:* Picture of Rod and Frame experiment. *Right:* Average angular deviations for young adults and adults with CP for vertical and horizontal alignment

B. Stationary support: CoM and CoP responses

Differences in quiet stance were evident when subjects stood on a stable surface in the dark. Adults with CP shifted their CoM forward while adults with TD remained mostly neutral or shifted slightly backwards over the 65 sec period when in the dark. Visual flow in the pitch up and down directions were chosen because they shift perception of verticality upwards or downwards resulting in compensatory displacement of the subject's body in the direction of the changing perception (i.e., forward shift in body displacement with pitch downward rotation and backwards shift in the body with pitch upward rotation). During the trials with visual flow, adults with CP demonstrated larger CoM and CoP excursions in the direction of visual flow than adults with TD when on the stationary surface with more extreme shifts from initial stance occurring during the upward pitch of the visual field (Fig. 3). Adults with TD demonstrated a more forward CoM displacement during the pitch downward rotation compared to in the dark when on a stationary support surface. In contrast, CoP and CoM responses to the pitch down rotations were similar to responses when standing in the dark in adults with CP.

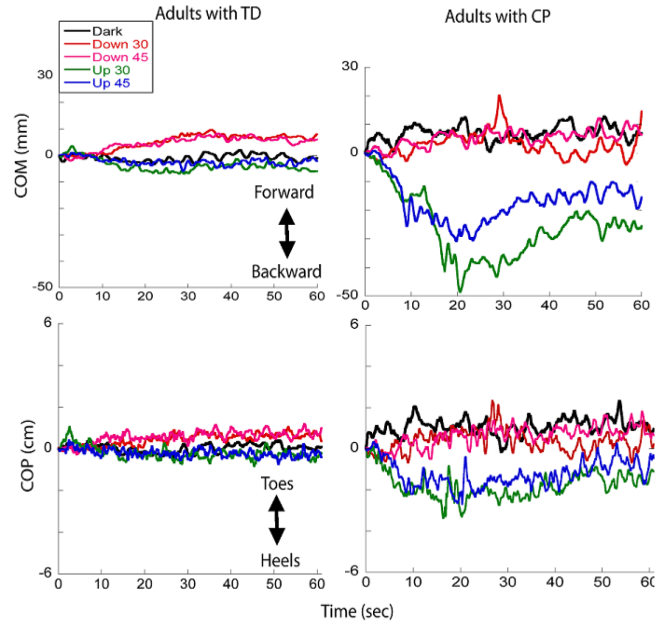

Figure 3: Average CoM (top) and CoP (bottom) responses in the AP direction of adults with TD (left) and adults with CP (right) while standing on a stationary platform and immersed visual flow

C. Tilt perturbation: CoM and CoP responses

During the trials that involved the platform tilt, adults with CP took longer to recover from the tilt than adults with TD when the tilt was combined with visual field motion in either velocity or direction. Adults with TD appear to restabilize after the onset of the tilt within 2 seconds. Adults with CP took about 2 seconds to reorient to vertical when in the dark but approximately 4 seconds to align to vertical with visual field rotation (Fig 4A). This delayed recovery affected subsequent postural responses in adults with CP, emerging as larger excursions and more frequent oscillations in CoM and CoP over the sustained tilt period than adults with TD (Fig 4B). As the platform returned to neutral, adults with CP demonstrated a backwards shift in CoM and CoP with all conditions of visual field motion compared to when in the dark (Fig 4B). In contrast, adults with TD shifted their responses forward with pitch downward rotation and slightly more backwards with pitch upwards rotation when compared to in the dark.

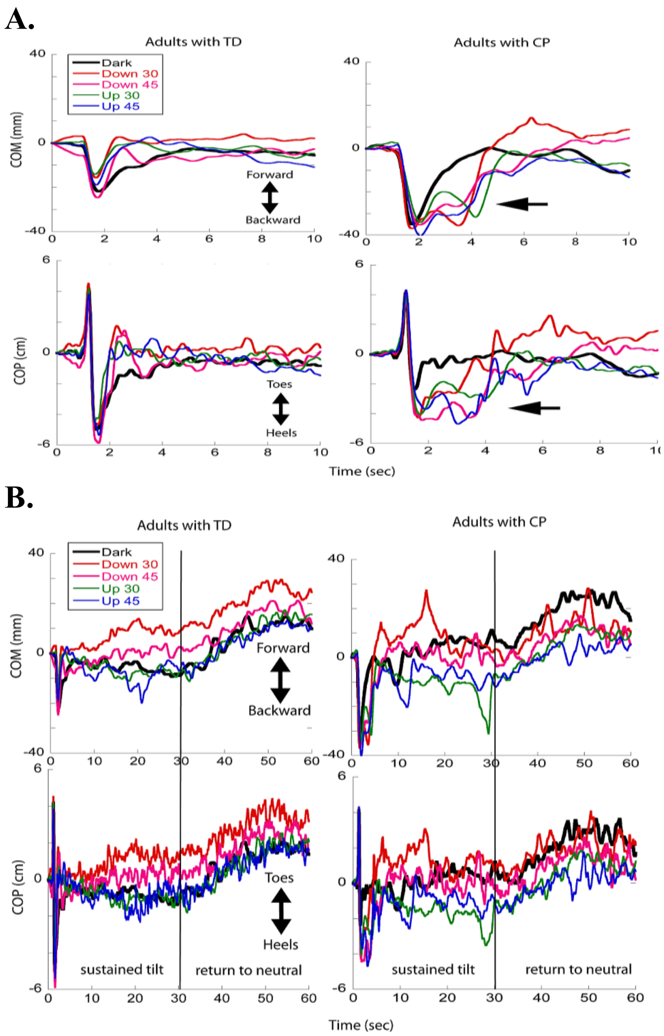

Figure 4: **A.** Average CoM (top) and CoP (bottom) responses of adults with TD (left) and adults with CP (right) in the AP direction during the initial 10 seconds of the trials with a tilt perturbation. Arrows indicate the delay in restabilizing in adults with CP with visual flow. **B.** Average CoM (top) and CoP (bottom) responses of adults with TD (left) and adults with CP (right) during the entire task for trials with the tilt perturbation. Black vertical line indicates when the platform returned to neutral position For both figures, responses during dark trial are black, pitch down 30˚/sec are red, pitch down 45 ˚/sec are pink, pitch up 30 ˚/sec are green and pitch up 45 ˚/sec are blue.

D. CoP responses in ML and AP

Plots of the AP CoP against side-to-side CoP revealed that although the primary response was in the AP plane, adults with TD had increased medial-lateral (ML) sway when the support surface tilted compared to when the surface was stationary (Fig 5). There did not appear to be any difference in the CoP plots due to velocity of the visual field motion. Some of the adults with TD demonstrated a response to the direction of visual flow but this was not consistent in all of the subjects. In contrast, adults with CP had a large ML component in the CoP both on the stationary platform (Fig 6A) and when the platform was tilted suggesting that they may be more unstable than adults with TD (Fig 6B). When the platform was tilted, stronger responses to visual flow were found for 30°/sec compared to 45°/sec rotation in both directions for adults with CP.

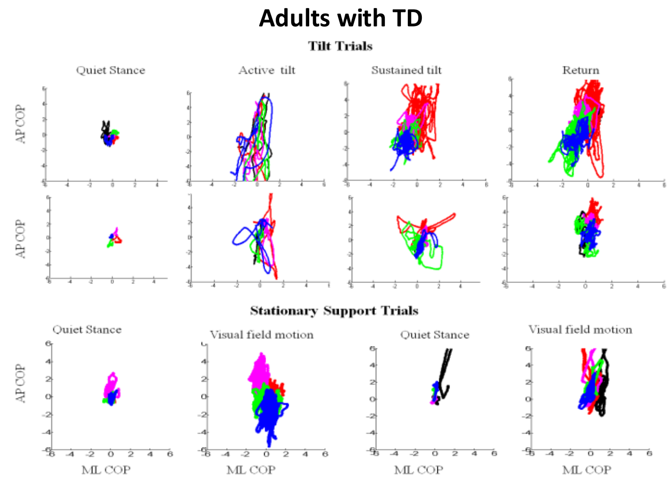

Figure 5: AP CoP plotted against side-side (ML) CoP for 2 young adults during the tilt (top 2 graphs) and during stationary support trials. Reponses during Dark trial are black, pitch down 30 deg/sec are red, pitch down 45 deg/sec are pink, pitch up 30 deg/sec are green and pitch up 45 deg/sec are blue.

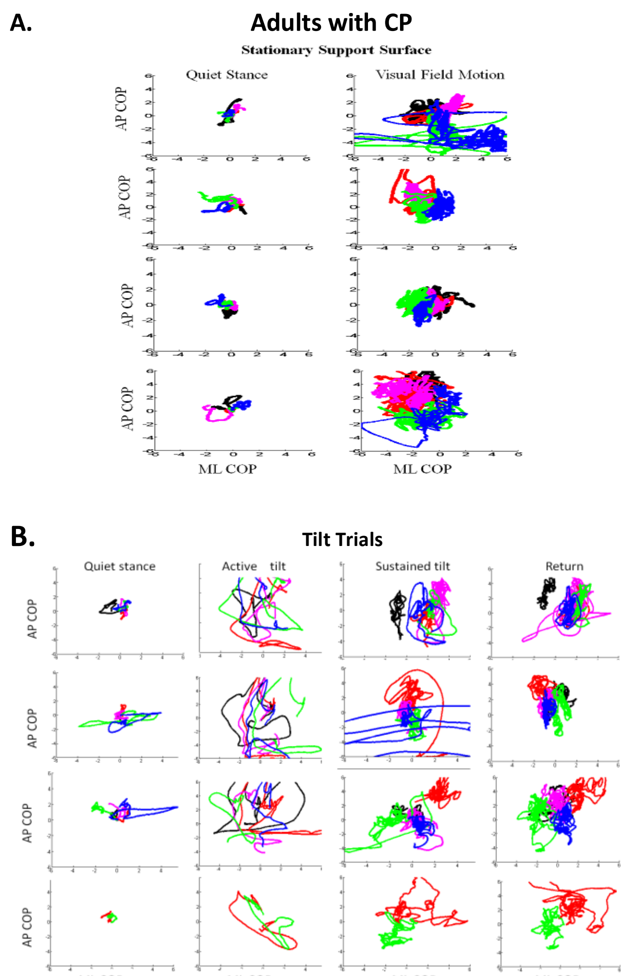

Figure 6: AP CoP plotted against side-side (ML) CoP for all 4 adults with CP during stationary support surface (A) and during the tilt trials (B). Responses during dark trial are black, pitch down 30 deg/sec are red, pitch down 45 deg/sec are pink, pitch up 30 deg/sec are green and pitch up 45 deg/sec are blue.

E. Adults with CP : wheelchair users vs ambulatory

When the support surface tilted, adults with CP who used a wheelchair appeared to shift their CoP more in the direction of visual flow than those adults with CP who were ambulatory for both AP and lateral plane of CoP (Fig. 7). Although the CoP responses in the AP plane appear to be different between ambulatory adults and wheelchair users, the RMS of CoP in AP plane did not. However, RMS of the CoP in the lateral plane did show differences with wheelchair users having larger RMS values over the sustained tilt and the return to neutral with visual flow and when in the dark.

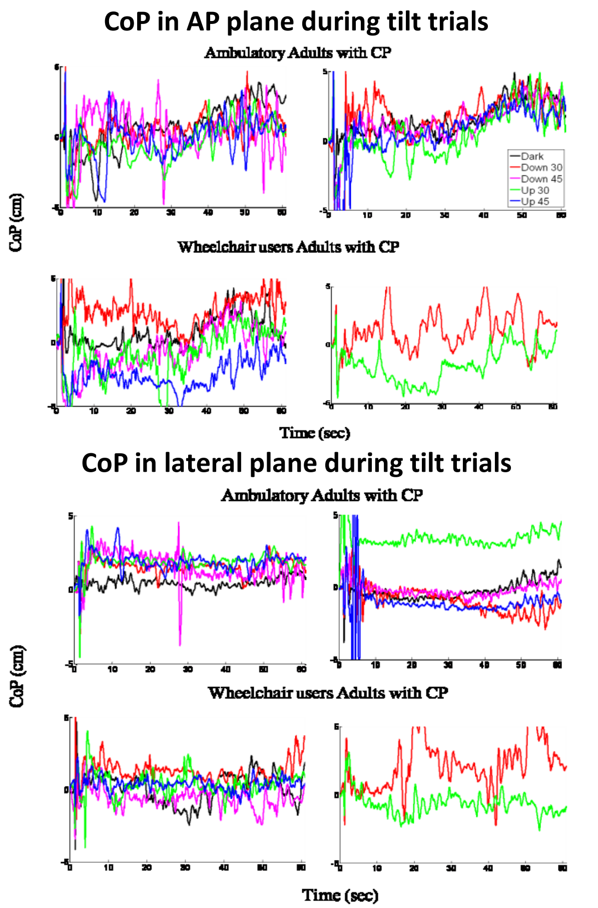

Figure 7: CoP responses over time in the anterior-posterior and medial-lateral planes for adults with CP who are ambulatory and adults with CP who use wheelchairs. Dark trial are black, pitch down 30 deg/sec are red, pitch down 45 deg/sec are pink, pitch up 30deg/sec are green and pitch up 45 deg/sec are blue.

IV. Discussion

Adults with CP had larger visual errors on the Rod and Frame test suggesting that they were more visually dependent than adults with TD. This increased visual dependence could explain their increased instability with visual flow on a stationary surface and difficulty realigning to vertical after the support surface tilted with visual flow. However, the results of the Rod and Frame do not explain the postural responses found with visual flow in the pitch downward direction. Adults with CP had larger responses emerging when the visual scene rotated upwards but not as strong when the visual scene rotated in the pitch downward direction when standing on the stationary platform. Smaller responses in the forward direction may have been due to the plantar flexion contracture of the ankle in our adults with CP group. When the visual scene rotated downwards, adults with CP may have reached their limit of ankle joint motion and were not able to produce any more dorsiflexion at the ankle with the visual scene rotation. When the visual scene moved upwards, the limited motion of the ankle may also have put adults with CP at a disadvantage because they would not have had the flexibility in their ankles to compensate with a forward sway thereby resulting in a larger displacement backwards. In fact, almost all of the adults with CP needed help from the spotter to maintain upright during the pitch upward rotations. The inability to appropriately correct for backwards motion of the CoM may also indicate that adults with CP may have weaker ankle muscle responses or have difficulty integrating visual and proprioceptive information which has been well documented in children with CP [42-48].

Even though both the mechanical and visual disturbances were in the sagittal plane, adults with TD demonstrated increased sway in the lateral plane when the platform tilted. Adults with CP, however, demonstrated increased lateral sway with visual rotation for both stationary and tilted platform and had larger lateral sway when compared to adults with TD. Within the adult CP group, individuals who used a wheelchair had larger lateral sway both with and without the presence of a visual flow field. Previous studies have shown that increased lateral sway is a predictor of future falls within a group of elderly fallers [49]. The increased lateral sway in adults with CP suggests that they are at greater risk of falls and that decreased ambulation can lead to more unstable postural responses.

In this paper, we have presented a pilot study that investigated postural responses of adults with CP and found that these individuals are highly unstable when immersed in a visual flow field. Implications of this finding are that adults with CP may refrain from ambulating in a busy environment because they experience more instability, which will then limit their social and functional activities. We plan expanding this sample size to determine the reliability of these results and to explore whether increased exposure to visual field motion will produce postural accommodations in this population.

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