Postural Control in Down Syndrome: The Use of Somatosensory and Visual Information to Attenuate Body Sway

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The purpose of this study was to examine the effects of visual and somatosensory information on body sway in individuals with Down syndrome (DS). Nine adults with DS (19–29 years old) and nine control subjects (CS) (19–29 years old) stood in the upright stance in four experimental conditions: no vision and no touch; vision and no touch; no vision and touch; and vision and touch. In the vision condition, participants looked at a target placed in front of them; in the no vision condition, participants wore a black cotton mask. In the touch condition, participants touched a stationary surface with their right index finger; in the no touch condition, participants kept their arms hanging alongside their bodies. A force plate was used to estimate center of pressure excursion for both anterior-posterior and medial-lateral directions. MANOVA revealed that both the individuals with DS and the control subjects used vision and touch to reduce overall body sway, although individuals with DS still oscillated more than did the CS. These results indicate that adults with DS are able to use sensory information to reduce body sway, and they demonstrate that there is no difference in sensory integration between the individuals with DS and the CS.

Key Words: vision, light touch, sensory integration, relevant information, posture

Although it may appear simple, the maintenance of the upright position is a very complex task, achieved through an intricate and dynamic relationship between sensory information and muscle activation. Sensory information, mainly carried by the visual, somatosensory, and vestibular systems, provides the means to indicate the body’s relative position in the environment as well as the forces that act on it (Horak & Macpherson, 1996; Nashner, 1981). Muscle activation, based on sensory inputs, balances internal and external forces in order for the body to maintain or achieve a desired position. Therefore, in order to coordinate and control a multi-segmented body with many degrees of freedom, the postural control system must integrate sensory information that comes from multiple sources. How sensory information is used to regulate such a motor control system is still the motivation of many studies (Jeka, Kiemel, Creath, Horak, & Peterka, 2004; Oie, Kiemel, & Jeka, 2002; Peterka,
This issue becomes even more complex when a system shows functional differences, such as in the case of people with Down syndrome (DS).

A few studies have indicated that postural control in individuals with DS is different from that in control subjects (CS) (Vieregge, Schulze-Rava, & Wessel, 1996; Vuillerme, Marin, & Debú, 2001), and that these differences could be due to the use of sensory information (Butterworth & Cicchetti, 1978; Shumway-Cook & Woollacott, 1985; Wade, Emmerik, & Kernozek, 2000; Webber, Virji-Babul, Edwards, & Lesperance, 2004). However, many questions are still unanswered. For example, could individuals with DS use additional information to improve their postural control? In addition, is sensory integration different in individuals with DS as compared to a control group (CS)?

One of the first attempts to explain postural control differences in individuals with DS claims that they have difficulties integrating sensory information from various sources and that they are more dependent on visual information than on other modalities (Shumway-Cook & Woollacott, 1985). In fact, Butterworth and Cicchetti (1978), using a moving room, showed that infants with DS were more influenced by visual inputs than were individuals in their control group. Infants with DS displayed greater body sway and a higher number of falls than did infants without DS. Similarly, Wade et al. (2000) observed that the manipulation of visual information through the use of a moving room produced more instability during the upright stance for children with DS than for their peers without DS. Finally, Webber et al. (2004) revealed that, in the absence of visual information during the upright stance, adults with DS displayed higher body sway velocity than did the CS. At first glance, these results indicate that individuals with DS are more reliant on visual information in order to maintain the upright stance than are their peers without DS. However, Vuillerme et al. (2001) questioned this issue and examined the upright stance control of teenagers with and without DS, manipulating visual and somatosensory information. The results indicate that both groups employed comparable weighting of somatosensory and visual inputs, suggesting that postural control functioning in individuals with DS differs from their peers quantitatively rather than qualitatively (Vuillerme et al., 2001).

If the postural control functioning of individuals with DS and CS is based on the same control parameters, a possible cause for postural control differences between these two groups could be in how sensory information coming from many channels is used to properly modulate the motor control system. In fact, some studies have shown that individuals with DS seem to be unable to appropriately calibrate their motor action based upon available information. For example, when grasping an object, individuals with DS generate more force than is necessary (Cole, Abbs, & Turner, 1988), and they often must stop in front of obstacles before stepping over them (Virji-Babul & Brown, 2004). In addition, when available sensory information is reduced or conflicts, the performance of individuals with DS typically is more affected than for individuals in control groups (Vuillerme et al., 2001; Webber et al., 2004). Thus, what would happen if additional information was provided to them? Could individuals with DS use it to attenuate their body sway?

Lackner and collaborators (Holden, Ventura, & Lackner, 1994; Jeka & Lackner, 1994) showed that the information subjects gained by lightly touching a stationary surface with their fingertips helped improve their postural control, reducing body sway more than 60% when compared to the condition of not touching the surface.
According to these authors, changes in fingertip stimulation indicate that when the body oscillates, the postural control system uses this information to anticipate appropriate motor activity. Thus, the “light touch paradigm” allows us to examine whether the postural control system is able to extract this additional sensory information and use it to enhance postural control.

Since individuals with Down syndrome seem to have difficulty integrating sensory information in order to properly modulate motor control (Butterworth & Cicchetti, 1978; Cole et al., 1988; Virji-Babul & Brown, 2004; Wade et al., 2000), it seems logical to question whether they might be able to use light touch to enhance their postural control. In addition, would the use of this light touch have similar effects both with and without the input of visual information? Therefore, the purpose of this study was to investigate the effect of sensory information on the postural control of individuals with DS. Specifically, we examined the effect of visual and somatosensory information on the body sway magnitude of adults with DS. Although previous results indicate that individuals with DS might have difficulty integrating sensory information (Butterworth & Cicchetti, 1978; Cole et al., 1988; Virji-Babul & Brown, 2004; Wade et al., 2000), a recent study showed that individuals with DS are able to integrate sensory information from different sensory systems and reorganize balance control similar to that of their neurologically normal peers (Vuillerme et al., 2001). Thus, we hypothesized that individuals with DS would be able to properly integrate sensory information, light touch and vision, thereby promoting a reduction in body sway and enhancing postural control.

Methods

Participants

Nine adults with DS (four males and five females), 19–29 years of age ($M = 21$ years, $SD = 3.3$ years), and nine CS (four males and five females), 19–29 years of age ($M = 21.2$ years, $SD = 3.3$ years), participated in this study. The participants with DS were recruited from a special school (Infancy Rehabilitation Association of Limeira, SP, Brazil), and the CS were either undergraduate or graduate students at São Paulo State University (UNESP). All participants in both groups reported no known musculoskeletal injuries or neurological disorders (besides DS) that might affect their ability to maintain the upright stance, and all had normal or corrected-to-normal vision. Before the experimental procedures, participants (or parents of participants with DS) signed an informed consent form. All procedures were approved by the university’s institutional ethical review board.

Procedures

Data collection occurred at two different locations. Data from the participants with DS was collected at their school; data from the CS group were collected at the Movement Studies Laboratory, Institute of Bioscience, UNESP. The experimental protocol was exactly the same for both groups. Participants were positioned on a force plate (AMTI model OR6, Watertown, MA) 1 m away from a white wall,
and were asked to stand upright, with their feet parallel, at shoulder width. All participants wore regular shoes; high heels or other shoes that might compromise the upright stance were not allowed.

A touch device was used to provide the participants with additional sensory information. The touch apparatus consisted of a rectangular metal box with a circular (5 cm diameter) metal plate connected to strain gauges (Alfa Instruments model GL1) that acquired applied forces in the vertical and horizontal directions. The touch device was mounted on a tripod, allowing adjustment of its height to each participant’s hip joint. The device was positioned at the right side, at a distance so that the participant could comfortably touch the center of its metal plate with his or her fingertip with elbow flexed to approximately 165º.

Four experimental conditions were employed: (1) no vision and no touch (NVNT); (2) vision and no touch (VNT); (3) no vision and touch (NVT); and (4) vision and touch (VT). In the vision condition, participants were asked to look at a target, a red circle 12 cm in diameter, which was fixed 1 m in front of the subject at eye level. In the no vision condition, participants wore a black cotton mask to cover their eyes. In the no touch condition, participants’ arms hung loosely at their sides. In the touch condition, the right index finger contacted the touch apparatus as the left arm hung passively. Despite the different body orientation between the touch and no touch conditions, Lackner, Rabin, and DiZio (2001) have demonstrated that this different arm position does not produce significant body sway variability during the upright stance.

In order to avoid mechanical stabilization of posture, participants were limited to 2 N of vertical force on the contact surface, which was monitored on-line throughout the trial. While previous studies (Holden et al., 1994; Jeka & Lackner, 1994) limited the contact force to 1 N, we increased this force in the present study to a limit of 2 N because individuals with DS had difficulties applying force on the touch surface below 1 N. According to Holden et al. (1994), even 2 N of contact force still would provide very little mechanical support during the upright stance. When participants applied force above this limit, the experimenter instructed the participant to decrease the applied force without losing contact with the touch apparatus. In order to increase the number of trials performed by the participants, two blocks were collected, with the four experimental conditions randomized within each block. Each trial lasted 20 s, with a brief resting interval between trials.

Before each trial, participants were asked to assume a comfortable upright stance and maintain this position as stable as was possible. In all trials, one experimenter was positioned behind the participants to assist them and prevent falls. Once the participant stood quietly, data acquisition was initiated. A practice trial in the touch condition was given to demonstrate to the participant the amount of force that could be applied.

Force plate and touch device data were sampled at 100 Hz, using a custom-written data acquisition program (LabVIEW, version 7, National Instruments Corp., Austin, TX). Center of pressure (CP) data were acquired for the medial-lateral (ML) and anterior-posterior (AP) directions. Although touch force data were collected for vertical and horizontal (anterior-posterior and medial-lateral) directions, we present force values only for the vertical direction in the present study.
Data Reduction

Two dependent variables were chosen to describe the participants’ postural behavior: mean sway amplitude and speed of CP, for both ML and AP directions. The mean sway amplitude was calculated by fitting and subtracting a first order polynomial from the signal, and then calculating the mean sway variance as the standard deviation of the signal. The mean sway speed was obtained by dividing the sum of displacement values, in each direction, by the total time of each trial. In the touch trials, the average force was calculated by obtaining the mean of vertical force that was applied throughout the trial to the contact surface.

Statistical Analysis

The statistical analyses employed were two multivariate analyses of variance (MANOVAs) and one analysis of variance (ANOVA). Both MANOVAs had as factors the two groups, the two vision conditions, and the two touch conditions, with these two last factors treated as repeated measures. The dependent variables for the MANOVAs were the mean sway amplitude and speed, respectively, for the ML and AP directions. When necessary, follow up univariate analyses and Tukey (HSD) post hoc tests were employed. In order to meet the MANOVA’s assumptions, the mean sway amplitude values were transformed to a natural logarithm, and the mean sway speed values were transformed to $\log_{10}$.

The ANOVA was employed to verify any difference in the amount of applied force to the contact surface and had as factors the two groups and the two vision conditions, with repeated measures on the last factor. The dependent variable was the amount of applied force. When necessary, Tukey (HSD) post hoc tests were employed. In all comparisons, the alpha level was set at .05, and all analyses were performed using SPSS for Windows, version 10.0 (SPSS, Inc., Chicago, IL).

Results

Applied Force

Figure 1 depicts the amount of force applied to the contact surface for both groups. All participants applied force levels below 2 N, except two participants with DS who applied forces between 2 and 3.6 N. Univariate analysis revealed effect for group, $F(1, 16) = 67.21, p < .001$. Participants with DS applied higher force levels to the contact surface than did the CS.

Mean Sway Amplitude

Figure 2 depicts CP mean sway amplitude in the ML and AP directions for both groups and in all experimental conditions. MANOVA revealed effect for group, Wilks’ lambda = .371, $F(2, 15) = 12.72, p < .01$; vision, Wilks’ lambda = .467, $F(2, 15) = 8.554, p < .01$; and touch, Wilks’ lambda = .1, $F(2, 15) = 67.68, p < .001$. MANOVA also revealed group and vision interaction, Wilks’ lambda = .602, $F(2, 15) = 4.95, p < .05$, and group and touch interaction, Wilks’ lambda = .524, $F(2, 15) = 6.80, p < .01$. 
For the ML direction (Figure 2, top panel), univariate analysis revealed effect for group, \( F(1, 16) = 27.04, p < .001 \); touch, \( F(1, 16) = 119.08, p < .001 \); group and touch interaction, \( F(1, 16) = 8.44, p < .05 \); and group and vision interaction, \( F(1, 16) = 7.42, p < .05 \). Post hoc tests for group and touch interaction indicated that touch reduced body sway only for participants with DS, but did not reveal any difference for group and vision interaction. For the AP direction (Figure 2, bottom panel), univariate analysis revealed effect for group, \( F(1, 16) = 14.47, p < .01 \); vision, \( F(1, 16) = 10.446, p < .01 \); and touch, \( F(1, 16) = 62.86, p < .001 \). Participants with DS oscillated more than did the CS, and, for both groups, vision and touch reduced body sway.

**Mean Sway Speed**

Figure 3 shows CP mean sway speed in the ML and AP directions for both groups and in all experimental conditions. MANOVA revealed effect for group, Wilks’ lambda = .303, \( F(2, 15) = 17.25, p < .001 \); vision, Wilks’ lambda = .389, \( F(2, 15) = 11.79, p < .01 \); and touch, Wilks’ lambda = .099, \( F(2, 15) = 68.13, p < .001 \). MANOVA also revealed a group and touch interaction, Wilks’ lambda = .532, \( F(2, 15) = 6.60, p < .01 \).

For the ML direction (Figure 3, top panel), univariate analysis indicated effect for group, \( F(1, 16) = 8.04, p < .01 \); vision, \( F(1, 16) = 10.08, p < .01 \); touch, \( F(1, 16) = 120.1, p < .001 \); and a group and touch interaction, \( F(1, 16) = 13.29, p < .01 \). Participants with DS showed higher mean sway speed than did the CS. With vision, both groups reduced body sway speed. Post hoc tests for group and touch
interaction indicated that touch reduced mean sway speed only for participants with DS. For the AP direction (Figure 3, bottom panel), univariate analysis indicated effect for group, $F(1, 16) = 11.19, p < .001$; vision, $F(1, 16) = 24.92, p < .001$; and touch, $F(1, 16) = 38.21, p < .001$. The participants with DS showed higher mean sway speed than did the CS. For both groups, vision and touch reduced body sway speed.
Postural Control in Down Syndrome

Discussion

The purpose of this study was to investigate the effects of visual and somatosensory information on body sway magnitude of adults with DS. The results indicated that individuals with DS exhibited larger body sway than did the CS in all experimental conditions. However, the adults with DS used somatosensory information from the

Figure 3—Mean (± SD) body sway speed (cm/s) in the (a) medial-lateral and (b) anterior-posterior directions for the Down syndrome group (DS) and control subjects group (CS) across no vision and no touch (NVNT), vision and no touch (VNT), no vision and touch (NVT), and vision and touch (VT) experimental conditions.

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touching of a stationary surface, and dramatically reduced body sway variability. Moreover, the effects of light touch and visual information together on their body sway question any difference in sensory integration ability in the adults with DS. Taking these results together, we suggest that individuals with DS might have difficulties extracting the most relevant information needed to modulate the motor control system; however, when sensory information is enhanced, they can improve their postural control.

Our finding that the adults with DS swayed more than did the individuals without DS is in accordance with previous results (Aruin & Almeida, 1997; Vieregge et al., 1996; Webber et al., 2004). Yet, while these studies, along with ours, reveal that individuals with DS present higher body sway than do their peers without DS, there still is no agreement in the explanations for such a difference in motor performance. For example, Vieregge et al. (1996) suggested that a global cerebral dysfunction is responsible for diminished postural stability in individuals with DS, while Webber et al. (2004) suggested that it is due to greater stiffness of the postural muscles. Although we do not discard any of these explanations, we also suggest that individuals with DS sway more than CS because they have difficulty extracting the relevant information from the many available possibilities and using it to properly modulate the motor control system. However, when sensory information was enhanced through the touching of a stationary surface, as in the current study, body sway was reduced to approximately that of the CS levels.

In fact, we agree with Vuillerme et al. (2001) that postural control functioning in individuals with DS differs from CS quantitatively rather than qualitatively. Despite the difference in greater body sway, individuals with DS and CS are similarly affected by the absence of visual information: they both increased body sway amplitude and speed. Again, this finding corroborates similar results from Vuillerme et al. (2001) and Webber et al. (2004).

Another finding of this study was that the touch effect in body sway reduction of individuals with DS occurs in both directions (ML and AP), even though it was more effective in the ML than in the AP direction. The sensory information provided by the touch was sufficient to stabilize body sway in the ML direction. In this case, touch information allowed greater body sway reduction than did the visual information. On the other hand, this did not happen in the AP direction. In the AP direction, the touch and visual information reduced body sway similarly. This probably happened because the touch device was placed at the participant’s side. The external reference provided by the contact surface carries information relative to body sway, depending on the position at which the touch bar is positioned (Jeka, Ribeiro, Oie, & Lackner, 1998). Since the touch bar was placed at the participant’s side in the present study, the touching of the stationary surface was more useful for attenuating body sway in the ML direction.

A more interesting finding, perhaps, was that individuals with DS can use additional sensory information to improve their postural control. Similarly to CS, individuals with DS reduced body sway amplitude and speed when light touch was available. Moreover, when sensory information was enhanced, in this case by touching a stationary surface, individuals with DS were the most affected by the additional information. This finding raises several issues. First, it may indicate that when sensory information is not enhanced, the postural control system of
individuals with DS might have difficulties extracting the most relevant sensory information from the many available options. Consequently, their performance would be affected. This seems to happen also with children without DS (Barela, Jeka, & Clark, 2003). Second, the fact that postural control in individuals with DS can be improved when additional information is provided might demonstrate that the system itself is not functionally compromised. That is, adults with DS can improve postural control as long as they have enough sensory information. Finally, as demonstrated by our findings, the postural control of individuals with DS differs from CS not qualitatively, but rather quantitatively. It can be improved as additional sensory information is made available to the system.

Another indication that individuals with DS might have difficulties in using the available sensory information to modulate the motor control system arises from the amount of force the participants with DS applied to the stationary surface. While the CS applied forces below 0.5 N, participants with DS applied forces around 1.5 N. Using a grip paradigm, Cole et al. (1988) observed that, when asked to grip and lift objects, adults with DS exerted about three times the static grip forces than a control group. Similarly, it seems that participants with DS also need to apply more force on a stationary surface in order to capture sensory information from the fingertip required to decrease body sway variability and improve postural control. Therefore, it appears that adults with DS may not use the available sensory information to modulate the motor control system as do CS.

Finally, our overall results support the suggestion by Vuillerme et al. (2001) that the postural control system of individuals both with and without DS are based on the same control parameters. We observed in the present study that the postural control system of participants with DS, as well as the CS, responded similarly to sensory manipulations, with differences only in magnitude. When either visual information or somatosensory information was provided, participants in both groups decreased their overall body sway. This suggests that adults both with and without DS use a comparable re-weighting process for somatosensory and visual inputs, although one source might contribute more than the other in controlling the motor system, and, consequently, to the overall performance of the postural control system. The individuals with DS, for example, appeared less stable than the CS, perhaps because they had difficulties extracting the relevant information to perform the task. Yet, when additional sensory information was provided, they took advantage of it, dramatically decreasing body sway and reaching values close to those observed for the CS. This supports the findings that individuals with DS might need a longer period of practice than individuals without DS (Latash, Almeida, & Corcos, 1993; Polastri & Barela, 2005) in order to successfully use sensory inputs, and, hence, modulate their motor control systems.

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