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# Postural control adaptation to optic flow in children and adults with autism spectrum disorder

Yi Huey Lim<sup>a,\*</sup>, Hoe C. Lee<sup>a</sup>, Torbjörn Falkmer<sup>a,d</sup>, Garry T. Allison<sup>b</sup>, Tele Tan<sup>c</sup>, Wee Lih Lee<sup>a</sup>, Susan L. Morris<sup>b,\*</sup>

<sup>a</sup> School of Occupational Therapy, Social Work and Speech Pathology, Faculty of Health Sciences, Curtin University, GPO Box U1987, Perth, WA, 6845, Australia

<sup>b</sup> School of Physiotherapy and Exercise Science, Faculty of Health Sciences, Curtin University, GPO Box U1987, Perth, WA, 6845, Australia

<sup>c</sup> School of Mechanical Engineering, Faculty of Science and Engineering, Curtin University, GPO Box U1987, Perth, WA, 6845, Australia

<sup>d</sup> Pain and Rehabilitation Centre, Department of Medical and Health Sciences, Linköping University, SE-58183, Linköping, Sweden

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## ABSTRACT

**Background:** Sensory reweighting is important for humans to flexibly up-weight and down-weight sensory information in dynamic environments. There is an element of time involved in the sensory reweighting process. A longer time spent on sensory reweighting may increase the destabilizing effect of postural control. Individuals with autism spectrum disorder (ASD) are reported to have poor postural control. It is uncertain if a different sensory reweighting process underlies the postural control deficit in children and adults with ASD.

**Research question:** To explore the sensory reweighting capability in ASD, the present study examined whether the temporal domains of postural control differed in children and adults, with and without ASD under various optic flow conditions.

**Methods:** Thirty-three children (8–12 years old) and 33 adults (18–50 years old) with and without ASD underwent quiet standing in six radial optic flow conditions. Each condition lasted for 60 s and was shown twice to all participants. For each optic flow condition, changes in postural response within-trial and between-trials were measured.

**Results:** Under various optic flow illusions, both children with and without ASD took a longer time to restore their posture compared with adults with and without ASD. Nonetheless, all groups demonstrated comparable abilities to adjust their posture to one that is close to the baseline position after one exposure to the optic flow stimulation.

**Significance:** The present study showed that the temporal domains of postural control under different optic flow conditions were similar between individuals with and without ASD from the same age group. The ability to down-weight visual information efficiently comes with the developmental progression of the sensory reweighting system. These findings suggest that the sensory reweighting process does not elucidate the postural control deficits in individuals with ASD and thus alternative explanations to determine the underlying mechanism for postural instability are needed.

## 1. Introduction

In the course of a day, humans experience a number of sensory changes in their environment; one moment they may be walking on a well-lit path, the next in a dimly lit alley. This change in the visual environment introduces incongruent visual input to the postural control system, which prompts a re-estimation of the body orientation to prevent postural instability [1]. The ability to form an estimation requires the process of sensory reweighting: the timely selection and re-weighting of the most reliable source of sensory information to control

the position of the body [2,3]. During this process, a shift in the relative contributions of the sensory systems occurs as the central nervous system relies less on the sensory system that receives incongruent information and more on the other sensory systems with reliable information; thereafter, inputs from the different sensory systems are reintegrated for use in motor planning and execution [1,3,4]. The estimation of body orientation during sensory changes in the environment does not happen instantly; rather there is a time delay because the central nervous system takes time to reweigh and reintegrate sensory information [5]. A longer time delay during sensory reweighting may

\* Corresponding authors.

E-mail addresses: [Yihuey.lim@postgrad.curtin.edu.au](mailto:Yihuey.lim@postgrad.curtin.edu.au) (Y.H. Lim), [S.morris@curtin.edu.au](mailto:S.morris@curtin.edu.au) (S.L. Morris).

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have a destabilizing effect on postural control [6]. However, time delay reduces as sensory reweighting becomes more efficient through prior experiences and practice [7].

The longer the body is in an unstable position, the higher the likelihood of a potential fall [8]. Some children and adults with autism spectrum disorder (ASD) have been reported exhibiting clumsiness in walking, gross motor skills, and poorer standing postural control compared with their typically developing (TD) peers [9,10]. With the developmental progression of the sensory system influencing the maturation of the postural control system [11], investigations into the effect of altered sensory information on the spatial domains of postural control in both children and adults with ASD have been conducted to understand the mechanism underlying postural control deficits in the ASD population [12]. However, the temporal domains of postural control following a sensory change have not been examined, and thus it is uncertain whether a different sensory reweighting process underlies postural control deficits in individuals with ASD. The consideration to take an alternative approach from the existing investigations arose from increasing evidence of a different sensory regulatory mechanism in children with ASD compared with TD children, often classifying them as being over- or under-responsive to sensory input, or a seeker of sensory input [13,14]. Sensory regulation refers to the process in which the central nervous system organizes all the sensory information [15], and thus issues with sensory regulation in individuals with ASD may reflect issues with prior processes concerning sensory reweighting and sensory integration. The inability to down-weight incongruent sensory information efficiently could lengthen time delay in the sensory reweighting process [6], resulting in a posture that is unstable; hence, investigation of the time taken to restore balance in incongruent sensory conditions may elucidate the mechanism of postural instability in children and adults with ASD.

Existing studies have used a variety of incongruent sensory conditions to assess the temporal domains of postural control in TD individuals; one of which is the use of visual motion [16,17]. Visual motion, such as optic flow, can induce strong postural responses [18]. For instance, Lee and Aronson [18] used the moving room paradigm to create an optic flow illusion effect for participants standing on stationary ground; as the room moved forward, the participants perceived a backward motion of his/her body relative to the environment and counteracted the backward motion by oscillating forward in sync with the motion of the room. The unconscious adjustment of the participants' body was a result of the misguided visual information from the optic flow illusion. In addition to the direction of the optic flow, optic flow illusions with diverse dimensions of the visual field have been found to change the evoked postural response of the observer, particularly optic flow perceived in the full, central and peripheral visual field [19,20].

The sensory reweighting processes in younger and older adults have been examined using the temporal domains of postural control. Previous research considered how postural responses changed within a trial over multiple time intervals [16,17]. Some studies compared the temporal patterns of postural restoration between younger and older adults and found that sensory reweighting was associated with age, whereby younger adults required a lesser amount of time to restore postural stability than older adults [16,17]. One study considered how postural responses reduced with exposure to repeated incongruent sensory conditions: habituation [17]. When postural responses between trials are compared, younger adults showed the greatest reduction in postural response than older adults after the first exposure to an incongruent sensory condition [17]. In contrast, older adults required additional exposures to the same incongruent sensory condition to reduce their postural response. Similarly, the age of a person appears to be a critical factor in learning the appropriate response to a misguided sensory input and updating the internal model of the body during exposure to repeated incongruent sensory conditions. Interestingly, little is currently known about the differences in the sensory reweighting

process between children and adults. It might be expected that children take longer to restore their balance since the postural control system becomes mature and more efficient only when the sensory systems are fully developed in adolescence [11].

Sensory reweighting is important so that humans can flexibly up-weight and down-weight sensory information in dynamic environments. Children and adults may demonstrate different sensory reweighting abilities for postural control due to the developmental progression of the sensory reweighting system [11]. The first aim of the present study was to examine whether the time taken to restore postural stability in response to optic flow conditions, varying in flow directions and visual field dimensions, differed between children and adults, with and without ASD. We hypothesized that the time taken to restore postural stability would be longer in individuals with ASD than in their TD counterparts. In addition, we hypothesized that the time taken to restore postural stability would be longer in children with ASD than in adults with ASD. The second aim was to examine whether the reductions in postural response between trials to optic flow stimulation differed between children and adults, with and without ASD. We hypothesized that the reductions in postural response between trials would be smaller in individuals with ASD than in their TD peers.

## 2. Methods

The present study was part of a series of experiments to investigate the effect of visual information on postural control in individuals with ASD [21,22]. Further details of the study methods can be found elsewhere [22].

### 2.1. Participants

Fifteen children with ASD (3 females, mean age = 9.7 years, range 8–12 years, mean height = 142.7 cm, mean weight = 35.6 kg), 18 TD children (6 females, mean age = 10 years, range 8–12 years, mean height = 143.4 cm, mean weight = 35.7 kg), 15 adults with ASD (3 females, mean age = 23.5 years, range 18–50 years, mean height = 177.9 cm, mean weight = 79.1 kg), and 18 TD adults (1 female, mean age = 27 years, range 18–37 years, mean height = 175.8 cm, mean weight = 74.9 kg) completed the study. Participants were included in the study if they have normal to corrected-to-normal vision and no history of neurological disease or physical abnormalities. Participants with ASD had a confirmed diagnosis of ASD. There were no statistically significant differences between children with and without ASD and adults with and without ASD in gender, age, height, and weight. The study was performed in accordance with the guidelines of the Helsinki Declaration and was approved by the Human Research Ethics Committee of Curtin University (HR28/2016). All of the participants and parents/caregivers gave informed consent/assent to participate in the study.

### 2.2. Equipment

The participants stood barefoot on an AMTI AccuGait force platform (Advanced Mechanical Technology Inc., Watertown, MA, USA) that was positioned 2-meters in front of a 4-meter half-dome concave screen. The Projection Design F35 projector (Projectiondesign, Gamie Fredrikstad, Norway) projected dot patterns that were adapted from previous studies [20,23]: 5000 dots that moved either forward to the front of the 'tunnel paradigm' (contraction) (Fig. 1A) or backward (expansion) (Fig. 1B) at a speed of 20 m/s. The six experimental conditions were: (1) full visual field (FV) contraction, (2) central visual field (CV) contraction, (3) peripheral visual field (PV) contraction, (4) FV expansion, (5) CV expansion, and (6) PV expansion. An SMI RED250Mobile remote eye tracker (SensoMotoric Instruments, Germany) was placed 60-centimeters from the participants and was used to measure their eye gaze during each trial.

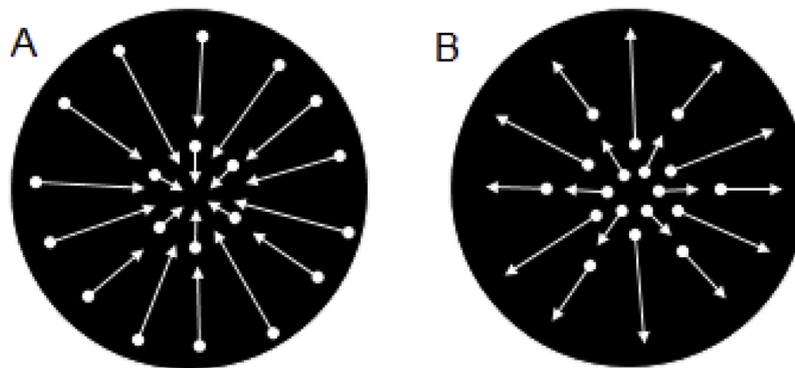


Fig. 1. Illustrations of stimuli: (A) full visual field contraction and (B) full visual field expansion.

### 2.3. Procedure

Participants stood still on the force platform with their bare feet placed together. They had to look at the center of the screen throughout the trial. A target point was shown on the screen for 5 s before the start of the trial. At trial commencement, an experimental stimulus that lasted for 60 s was introduced to the participant. Each experimental condition was shown twice and the order of the conditions was randomly assigned. There was a one-minute rest between trials.

### 2.4. Postural control measurements

Postural responses only in the anteroposterior direction were considered because the optic flow stimulation employed in the present study was designed to induce body movement in the anteroposterior direction [24]. Postural responses were measured as the average deviation of the center-of-pressure from the baseline position in the anteroposterior plane (COP<sub>y</sub>). The baseline position indicated the average center-of-pressure position two-seconds before the start of the visual stimulation. Based on previous literature [18,25], movement of COP<sub>y</sub> can be expected in the anterior direction with contraction radial optic flow and in the posterior direction with expansion radial optic flow. COP<sub>y</sub> was synchronized with the eye-tracking data, where COP<sub>y</sub> with a gaze fixation percentage less than 90% was excluded from analysis. The gaze fixation percentage was calculated on the duration of fixated gaze within the predefined region that is 10° from the center of the screen. Values of COP<sub>y</sub> were obtained for three 20-seconds time interval during the trial (Period 1: 0–20 s; Period 2: 21–40 s; Period 3: 41–60 s).

### 2.5. Statistical analyses

Group comparisons for participant characteristics were performed with Fisher's exact test on the gender variable, Mann-Whitney *U* test on the age variable, and independent samples *t*-test on the height variable. A linear mixed model, with a random effect of the participant, was used to investigate the effect of Group (children with ASD, TD children, adults with ASD, or TD adults), Period (1, 2, or 3), and Trial (1 or 2) on COP<sub>y</sub> separately for each experimental condition. The interaction terms were retained if the *p*-value was considered significant. Post hoc pairwise comparisons were performed using least squares means of fixed effects and least square mean differences of fixed effects. All significances were set at  $\alpha = 0.05$  and a more stringent *p*-value of 0.01 was used for pairwise comparisons to reduce the chance of a type I error. All analyses were performed using SPSS 24 (IBM Corp., USA).

## 3. Results

### 3.1. Within-trial changes in COP<sub>y</sub>

For the FV contraction condition, the linear mixed model analysis indicated a significant Group  $\times$  Period interaction,  $F(6, 235.198) = 4.466, p < 0.0001$ . Post hoc within-group pairwise comparisons showed that, in response to the stimulus, all groups displayed a strong anterior movement of COP<sub>y</sub>; in particular, adults from both ASD and TD groups displayed a posterior movement of COP<sub>y</sub> toward the baseline position by Period 2 ( $p < 0.0001$ ) (Fig. 2A). In contrast, TD children displayed a posterior movement of COP<sub>y</sub> only in Period 3 ( $p < 0.0001$ ). No significant change in COP<sub>y</sub> was detected for children with ASD between Period 1, 2, or 3.

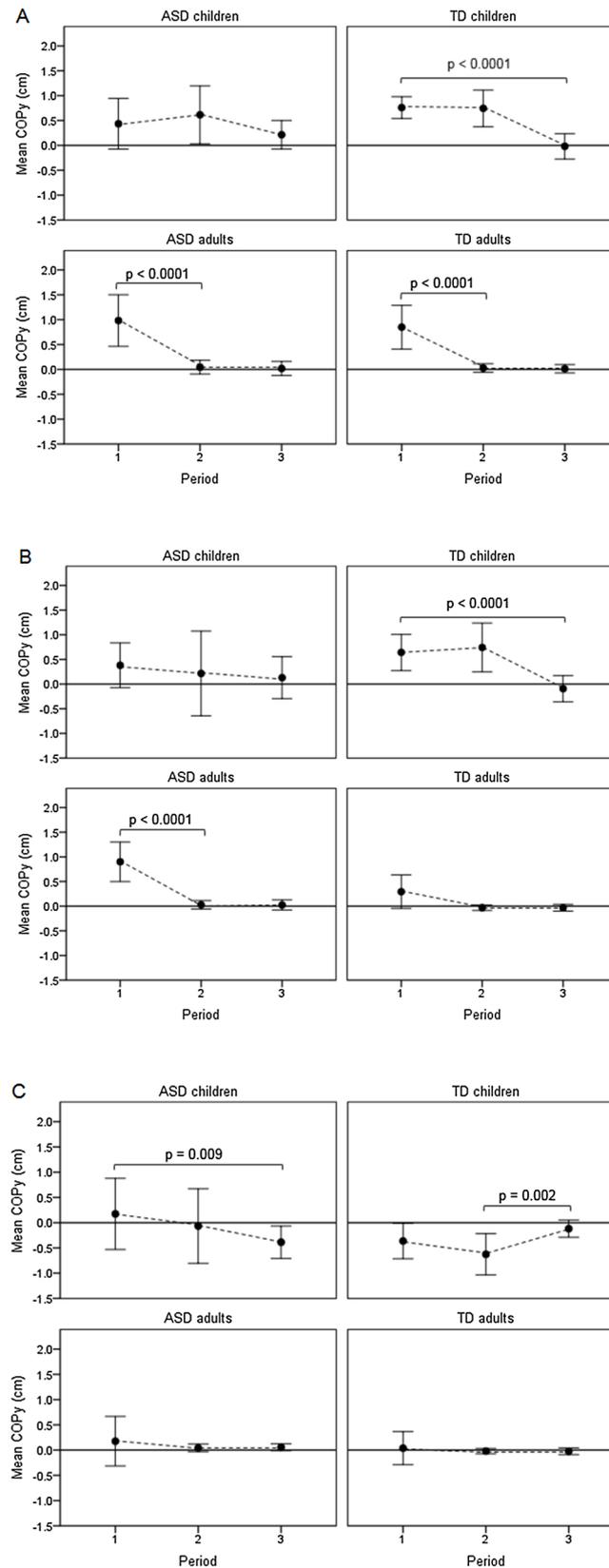
For the PV contraction condition, the linear mixed model analysis indicated a significant Group  $\times$  Period interaction,  $F(6, 231.078) = 3.804, p = 0.001$ . The between-group pairwise comparison showed that adults with ASD displayed a larger anterior movement of COP<sub>y</sub> than that of TD adults in response to the stimulus ( $p = 0.0007$ ) (Fig. 2B). The within-group pairwise comparison for adults with ASD showed a posterior movement of COP<sub>y</sub> toward the baseline position by Period 2 ( $p < 0.0001$ ). In contrast, for TD children, posterior movement of COP<sub>y</sub> toward the baseline position did not occur until Period 3 ( $p < 0.0001$ ). No significant change in COP<sub>y</sub> was detected for children with ASD and TD adults between Period 1, 2, or 3.

For the FV expansion condition, the linear mixed model analysis indicated a significant Group  $\times$  Period interaction,  $F(6, 256.724) = 2.318, p = 0.034$ . The within-group pairwise comparisons showed that COP<sub>y</sub> of children with ASD deviated away from the baseline position over time, whereby COP<sub>y</sub> movement was more posterior in Period 3 than in Period 1 ( $p = 0.009$ ) (Fig. 2C). In contrast, TD children displayed a posterior movement of COP<sub>y</sub> in Period 1 and 2, then changed to the anterior direction toward the baseline position in Period 3 ( $p = 0.002$ ). No significant change in COP<sub>y</sub> was detected for ASD and TD adults between Period 1, 2, or 3. In addition, no significant interaction terms and main effects of Group and Period were observed in the CV contraction, CV expansion, and PV expansion conditions.

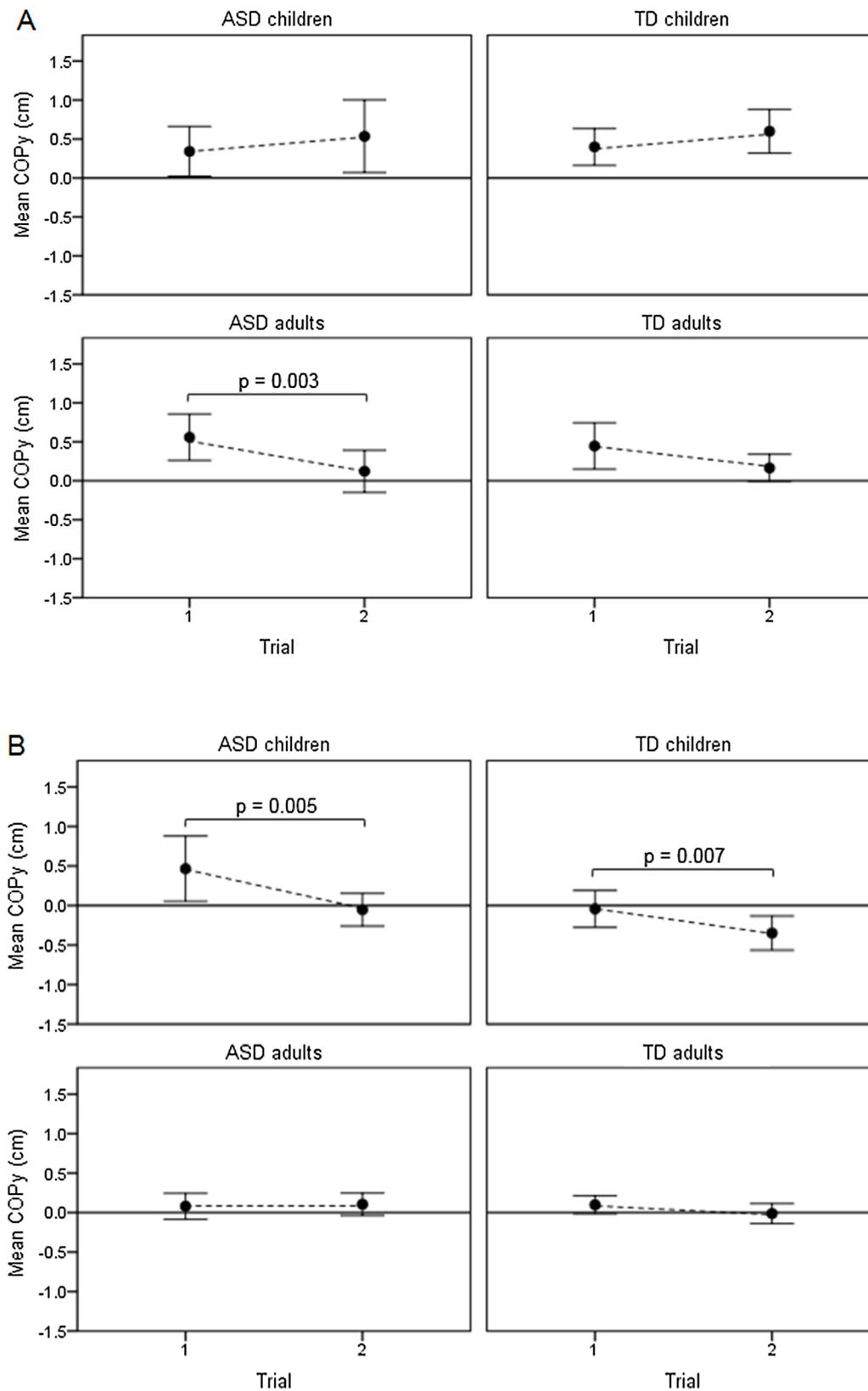
### 3.2. Between-trial changes in COP<sub>y</sub>

For the FV contraction condition, the linear mixed model analysis indicated a significant Group  $\times$  Trial interaction,  $F(3, 266.789) = 4.520, p = 0.004$ . Post hoc within-group pairwise comparisons showed a significant reduction of postural response between Trial 1 and 2 for adults with ASD ( $p = 0.003$ ) (Fig. 3A). Further analysis of the effect of Period and Trial on COP<sub>y</sub> in adults with ASD showed that the difference occurred only in Period 1 ( $p = 0.005$ ). No significant reduction in COP<sub>y</sub> between Trial 1 and 2 was detected for children with ASD, TD children, and TD adults.

For the CV contraction condition, the linear mixed model analysis



**Fig. 2.** The average deviation of the center-of-pressure from the baseline position in the anteroposterior plane (COPy) over Period 1, 2, and 3 for children with autism spectrum disorder (ASD), typically developing (TD) children, adults with ASD, and TD adults in (A) FV contraction, (B) PV contraction, and (C) FV expansion conditions. A positive value indicated the anterior movement of COPy relative to the baseline position. Error bars represent 95% confidence interval.



**Fig. 3.** The average deviation of the center-of-pressure from the baseline position in the anteroposterior plane (COPy) in Trial 1 and 2 for children with autism spectrum disorder (ASD), typically developing (TD) children, adults with ASD, and TD adults groups in (A) FV contraction and (B) CV contraction conditions. A positive value indicated the anterior movement of COPy relative to the baseline position. Error bars represent 95% confidence interval.

indicated a significant Group  $\times$  Trial interaction,  $F(3, 281.556) = 2.633, p = 0.05$ . The within-group pairwise comparisons showed a significant reduction of postural response between Trial 1 and 2 for both ASD and TD children ( $p < 0.007$ ) (Fig. 3B). No significant reduction in COPy between Trial 1 and 2 was detected for ASD and TD adults. In addition, no significant interaction terms, main effects of Group and Trial were observed in the CV contraction, PV contraction, FV expansion, and PV expansion conditions.

#### 4. Discussion

The present study explored the sensory reweighting capability for postural control in children and adults, with and without ASD. The analysis of the temporal domains of postural control showed no difference in the time taken to restore postural stability between ASD and TD groups in response to the various optic flow conditions. Instead, the time taken to restore balance was longer in children with and without ASD than in adults with and without ASD. Furthermore, all groups showed similar abilities to reduce their heightened postural responses after repeated exposure to the optic flow stimulus. These findings suggest that the sensory reweighting process of individuals with ASD in the present study appears to follow the normal developmental progression of TD individuals.

The first hypothesis that the time taken to restore postural stability will be longer in individuals with ASD when compared with their TD peers was not supported in the present study. However, the second hypothesis that the time taken to restore postural stability will be longer in children with ASD than in adults with ASD was supported. The results showed that whenever a strong postural response was induced by optic flow stimulation at the start of the trial, children in the ASD and TD groups required on average an additional 20 s, compared with adults in the ASD and TD groups, to reweigh the sensory information and to return to postural stability. The stronger postural responses were observed mostly in the contraction radial optic flow conditions likely because it is an optic flow direction that does not occur frequently [22]. Despite previous literature indicating a different sensory regulation mechanism in individuals with ASD [13,14], the sensory reweighting process in those with ASD do not appear to be different from their TD counterparts in the present study. Instead, how individuals reweigh sensory information in the presence of incongruent visual information seemed to be determined by the developmental maturation of the sensory reweighting system. Older children and adults who have a mature sensory reweighting system reweigh sensory information faster than younger children [26,27]. These findings suggest that it is possible for individuals with ASD to experience normal development of the sensory reweighting process as TD individuals.

The third hypothesis that the reductions in postural response between trials would be smaller in children and adults with ASD than in TD children and adults was not supported. All of the groups mostly displayed a reduced postural response after the first exposure to the optic flow stimulation and thus showed similar capability in updating the internal model of their body. This ability to update the internal model is also manifested in other motor skills such as upper limb control. Gidley Larson, Bastian, Donchin [28] found no difference in the adjustment of arm movement over time between ASD and TD children during two novel motor learning tasks, indicating that children with ASD were able to update the internal model of their body the same way as TD children. However, other studies have argued that the updating of the internal model in ASD may be atypical especially when there is misguided somatosensory information in the environment because individuals with ASD tend to rely more on information from the somatosensory system than from the visual system [29,30]. Nevertheless, the present finding suggests that children and adults with ASD have the capability to update the internal model of their body appropriately in the presence of incongruent visual information.

The present study had limitations. Firstly, the study considered age

groups rather than using age as a covariate in the analysis of the study. Secondly, the results pertaining to the children participants represented only those between 8–12 years old and thus cannot be generalized to all children with ASD. Future investigations could include using children across a wider age range to yield a comprehensive understanding of the sensory reweighting process for postural control in individuals with ASD across the developmental progression.

In summary, the temporal domains of postural control under various optic flow conditions were not different between individuals with and without ASD if they were within the same age group. Individuals with ASD were able to down-weight visual information that is incongruent, a process that seems to become more efficient with the approaching of adulthood. Additionally, individuals with ASD were able to reduce their postural responses appropriately to repeated optic flow exposures, suggesting a successful update of their internal model for postural control. While these findings have broadened the understanding of the sensorimotor process in individuals with ASD and may have implications for ASD interventions, alternative explanations are required to determine the underlying mechanism for postural instability in individuals with ASD. Given that the complexity of sensory reweighting for postural control may increase in a more complex environment, there is future scope for a comprehensive investigation of the sensory reweighting process of individuals with ASD in two or more incongruent sensory environments.

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#### Authors' contribution

YHL participated in the conception and design of the study, acquisition of data, analysis and interpretation of the data, and drafting of the manuscript. HCL, TF, GTA, TT, WLL, and SLM participated in the design of the study, interpretation of the data, and drafting of the manuscript. All authors read and approved the final manuscript.

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