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Visual and somatosensory contributions to infant sitting postural control

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Visual and somatosensory contributions to infant sitting postural control

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ABSTRACT

There are a limited number of studies that have investigated sitting posture during infancy and the contribution of the sensory systems. The goal of this study was to examine the effects of altered visual and somatosensory signals on infant sitting postural control. Thirteen infants (mean age ± SD, 259.69 ± 16.88 days) participated in the study. Initially, a single physical therapist performed the Peabody Developmental Motor Scale to determine typical motor development. Then the child was placed onto a force platform under four randomized conditions: (a) Control (C) – sat independently on the force plate, (b) Somatosensory (SS) – Sat independently on a foam pad (low density), (c) Visual (VS) – sat independently on the force plate while the lights were turned off creating dim lighting, and (d) Combination of b and c (NVSS). Center of pressure (COP) data from both the anterior-posterior (AP) and the medial-lateral (ML) directions were acquired through the Vicon software at 240 Hz. The lights off conditions, both VS and NVSS, lead to increased Root Mean Square (RMS) and Range values in the AP direction, as well as increased Lyapunov Exponent (LyE) values in the ML direction. Altered visual information lead to greater disturbances of sitting postural control in typically developing infants than altered somatosensory information. The lights off conditions (VS and NVSS), unveiled different control mechanisms for AP and ML direction during sitting. Thus, the present findings confirm the dominance of vision during the early acquisition of a new postural accomplishment.

KEYWORDS

Motor development; center of pressure; sensory

1. Introduction

Postural control is an essential component of motor skill development from birth onwards. Postural responses develop in a clear cephalocaudal progression (Woollacott and Shumway-Cook 1990). At birth infants are helpless and rely on their caregivers not only for their basic needs but also for altering posture positions. They are placed in a supine and prone position while in bed or during tummy time. They stand upright while being held or in certain baby equipment. Different postures allow infants to explore gravity, practice activation of the muscles controlling head movement and to discover ways to maintain steady head posture. Postural control follows a cephalo-caudal progression of development, and as the lower trunk and pelvis control is achieved infants can sit independently for short periods of time. Besides gravity and dynamic musculoskeletal body changes, infants are required to integrate a wealth of sensory information to maintain upright posture.

The main sensory systems that contribute to the control of posture are the visual, somatosensory, and vestibular systems which develop throughout childhood (Forssberg and Nashner 1982; Shumway-Coo and Woollacott 1985). At birth, it is suggested that the vestibular system counting the semicircular canals, otolith organs and myelination of the vestibular nerve is similar to adults physiologically (Bergstrom 1973; Dayal et al. 1973). The visual system is not fully mature until 4 years of age, while components of the system, such as binocular vision and stereoacuity are mature around 5 and 7 months of age respectively (Brecelj 2003; Neuringer and Jeffrey 2003). Furthermore, magnetoencephalography studies have shown that the functioning of both the primary and secondary somatosensory areas are not adult-like at birth, while myelination of the system still occurs during infancy and synapse elimination continues well into adolescence (Nevalainen et al. 2014). Since there is relative maturity of the sensory systems we would expect that infants would be able to maintain sitting posture, which develops between 5–8 months of age, and postural sway would slightly vary across conditions in which these sensory systems are challenged. However, there is a limited number of studies that investigated sitting posture during infancy and the contribution of the sensory systems.

The most widely studied sensory modality in infancy is the visual system. Through a series of moving room experiments, it was determined that infants increase their postural sway and tip over (Lee and Aronson 1974; Bertenthal et al. 1997, 2000). It was also found that there is a relationship between visual input and trunk sway during sitting in typically developing infants, which changes according to the visual stimulus (frequency of the room) (Barela et al. 2000). Bertenthal et al. (2000) investigated the developmental changes in the coordination of perceived optical flow and postural control in infants aged 5-, 7-, 9-, and 13-months sitting on a force platform in a moving room. This study found that even before infants were able to sit independently, they begun to visually modulate their postural response (Bertenthal et al. 2000). Lejeune et al. (2006) also utilized the moving room paradigm but found that pre-locomotor infants show minimal postural compensation to movement in the periphery of the visual field. When visual input is absent and without excluding the effect of the vestibular system, children tend to demonstrate well-organized postural responses. For example, infants from the age of four months present appropriate muscle responses to sitting and standing platform perturbations (Woollacott et al. 1987). In addition, children and infants lightly touching a contact surface have been shown to couple with the tactile stimulus (Metcalfe and Clark 2000; Barela et al. 2003). More recently, another study challenged infant sitting posture by having the infants sit in three different foam surfaces with varying densities (Kokkoni et al. 2017). The authors concluded that either infants do not rely on somatosensory information to control sitting posture or are able to down-weight that sensory modality and rely on vision and vestibular information alternatively (Kokkoni et al. 2017).

Infant sitting is a critically important milestone as it is the first vertical position achieved by the infant and allows for increased interactions with caregivers and objects in the immediate environment. It is not only important for the succession of later milestones, such as crawling and walking, but also for the development of cognitive and social behaviour (Libertus and Violi 2016). One of the most comprehensive and unobtrusive ways to examine sitting posture in infants, is with centre of pressure (COP) data through a force platform (Kyvelidou et al. 2013, 2017). Linear and nonlinear measures of COP allow to describe the amount of sway but also the temporal organization of the postural patterns (Kyvelidou et al. 2013, 2017) and it has been used widely the past 15 years. It is expected that the evaluation of COP measures during sitting posture in infants and under altered sensory conditions may give us an additional insight into the organization and development of sitting posture.

Therefore, the overall goal of this study was to examine the effects of altered visual and somatosensory signals on infant sitting postural control. First, to determine the effect of visual information on infant sitting postural control we modified vision by turning off the lights during data collections. We hypothesized that the modification of visual information would lead to increased values of linear and nonlinear measures of COP. Second, to examine the effect of somatosensory information on infant sitting postural control we modified this modality by changing the sitting surface composition with a foam pad. Based on the previous study by Kokkoni et al. (2017), we did not expect any changes due to the altered somatosensory information. However, we wanted to examine whether we could replicate their results as well as investigate the effect of altering both visual and somatosensory information in infants.

2. Methods

2.1. Participants

The participants in this study were 15 typically developing infants. Two out of the 15 infants were excluded from the analysis either due to insufficient collected data or technical problems. Therefore, the total number of typically developing infants who met the entry criteria and completed data collection was 13 infants (mean age ± standard deviation, 259.69 ± 16.88 days). Infants were recruited from employee announcements at the campus of the University of Nebraska at Omaha and at the Munroe-Meyer Institute, University of Nebraska Medical Center. Prior to participation an informed consent was signed by the parents of the infants. The study was approved by the Institutional Review Board of the University of xxxx Medical Center.

The inclusion criteria for entry into the study for the typically developing infants were: (a) a score on the Peabody Gross Motor Quotient within 0.5 SD of the mean, (b) age of between seven and nine months at the time of data collection, and (c) the ability to sit independently without the use of hands (Stage 3 of sitting). The exclusion criteria were: (a) a score on the Peabody Gross Motor Quotient of greater than 0.5 SD below the mean, (b) diagnosed visual and hearing deficits, (c) diagnosed musculoskeletal problems, (d) an acute ear infection, history of chronic ear infections, tubes in the ears, or history of dizziness and (e) medications that could potentially affect the child's balance.

2.2. Procedures

The sessions lasted 45 minutes to one hour. A standard set of infant toys was used for distraction and comfort, accompanied by a DVD player, which presented infant movies. All attempts were made to maintain a calm, alert state by allowing the infant to eat if hungry, be held by a parent for comforting, or adapting the temperature of the room to the infant's comfort level. The first part of the session included the performance of the Peabody Developmental Motor Scale-2 by a single physical therapist experienced in administering this test. This standardized test is norm-and criterionreferenced, which examines gross motor function in children from birth to 83 months (Folio and Fewell 2000). After the child was undressed (naked), the infant was placed by their guardian or the experimenter on the top of a force plate that was covered with a special pad for warmth which was securely adhered with tape on the force plate. The baby was placed on the force plate in the sitting position in the middle of the plate when calm and happy (Figure 1). The investigator and the parent remained at one side and in front of the infant respectively during all data collection to assure the infant did not fall or become insecure. Four conditions were performed randomly: (a) Control (C, Figure 1(A)) – sat independently on the force plate, (b) Somatosensory (SS, Figure 1(B)) – Sat independently on a foam pad (low density) while on the force platform, (c) Visual (VS, Figure 1(C)) – sat independently on the force plate while the lights were turned off creating dim lighting, and (d) Combination of b and c (NVSS, Figure 1(D)) – sat independently on a foam pad while the lights were turned off creating dim lighting. Trials of sitting behaviour were performed until data from three trials (3 8.3sec) per condition met predetermined criteria (Table 1), or until the infants were not willing to continue. The selection of the number and length of trials was based on previous studies that have validated this experimental protocol. For the SS and NVSS condition, a foam pad (18.25 20 3 inch) and low density (12 kg/m3) was used to alter somatosensory information.

2.3. Instrumentation, materials, and measurement

For data acquisition, infants sat on an AMTI force plate (Watertown, MA), interfaced to a computer system running Vicon data acquisition software (Lake Forest, CA). COP data from both the anterior-posterior (AP) and the medial-lateral (ML) directions were acquired through the Vicon software at 240 Hz. This frequency was selected based on frequency analysis and the duration that infants can sit independently at such an early age. No filtering was performed on the data because such a procedure can affect the nonlinear results (Stergiou et al. 2004). Video of each trial was collected using a Sony Digital Handycam with 0 Lux Nightshot (Model DCRTRV30 NTSC) (Model 5100 HS) interfaced with a Panasonic Digital AV Mixer (Model WJ-MX30). The camera was positioned to record a sagittal view of the subject (Figure 1).

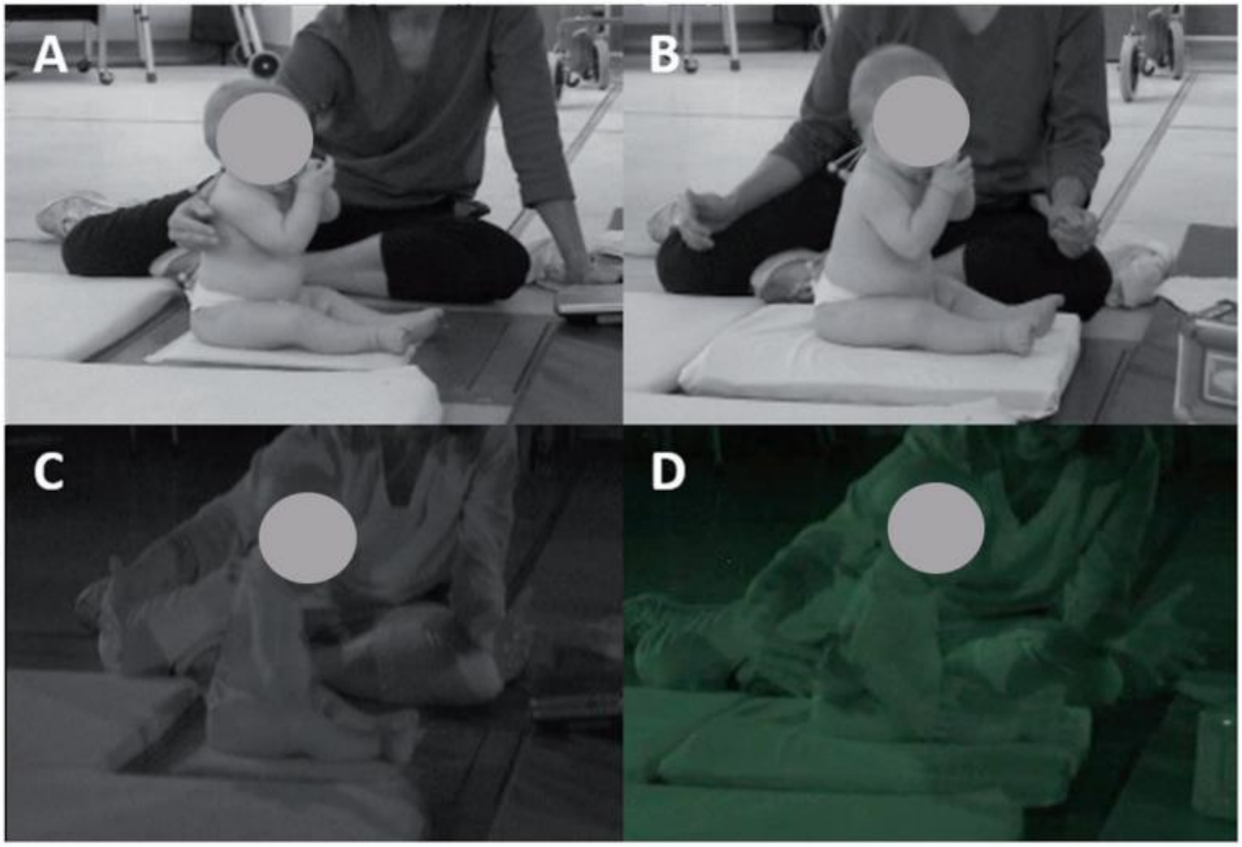

Figure 1. (A) Experimental set up in the control “C” condition. The infant is sitting on the force plate. (B) Experimental set up in the somatosensory (SS) condition. The infant is sitting on a foam support surface. (C) Experimental set up in the lights off (VS) condition. The infant is sitting on the force plate while dim light conditions are in effect. (D) Experimental set up in the combination (NVSS) condition. The infant is sitting on a foam support surface while dim light conditions are in effect.

Table 1. Criteria for using acceptable trials of infant sitting behaviour.

Sitting Criteria
Infant did not move the arms (not reaching, holding an object, or flapping their arms)
Infant did not vocalize or cry
Infant was not in the process of falling
Trunk was not inclined more than 45 degrees to either side
Not being touched
Sat independently without the use of hands

2.4. Data analysis

Linear measures of the variability present in postural sway were calculated from the selected trials using customized MATLAB software (Mathworks, Natick, MA) from the COP time series (Harbourne and Stergiou 2003). The linear measures calculated were the root-mean-square (RMS) and the maximum minus minimum (range) for the AP and the ML directions, as well as the length of the path traced by the COP (sway path).

In addition, three nonlinear measures of variability were calculated from the selected trials: the approximate entropy (ApEn), the largest Lyapunov exponent (LyE), and the correlation dimension (CoD) for both the AP and the ML directions. Nonlinear measures of the variability present in postural sway were calculated from the COP time series as described by Harbourne and Stergiou (2003).

Table 2. Mean and standard deviation (SD) values of linear and nonlinear measures for both the anterior-posterior (AP) and medial-lateral (ML) direction across sensory conditions.

	Control condition (C)		Somatosensory condition (SS)		Visual condition (VS)		Combination condition (NVSS)	
Linear measures	Mean	SD	Mean	SD	Mean	SD	Mean	SD
RMS AP (mm)	6.55	5.31	7.91	6.03	9.66	7.58	9.39	5.00
RMS ML (mm)	6.92	3.78	7.09	2.52	7.40	2.39	9.66	3.51
Range AP (mm)	32.17	16.80	39.55	27.50	42.46	24.76	47.95	22.44
Range ML (mm)	36.84	23.12	35.73	12.18	35.36	9.53	47.57	16.58
Sway Path (mm)	1147.43	356.97	991.64	182.42	973.64	299.64	1070.29	293.78
Nonlinear measures								
LyE AP	0.080	0.011	0.086	0.013	0.087	0.019	0.087	0.012
LyE ML	0.076	0.016	0.080	0.012	0.090	0.008	0.090	0.009
ApEn AP	0.380	0.149	0.355	0.083	0.323	0.118	0.353	0.080
ApEn ML	0.338	0.146	0.332	0.090	0.344	0.078	0.335	0.059
CoD AP	3.946	0.419	3.910	0.405	3.942	0.294	3.859	0.482
CoD ML	3.988	0.484	4.040	0.415	4.008	0.276	3.746	0.438

RMS: Root Mean Square; LyE: Lyapunov Exponent; ApEn: Approximate Entropy; CoD: Correlation Dimension

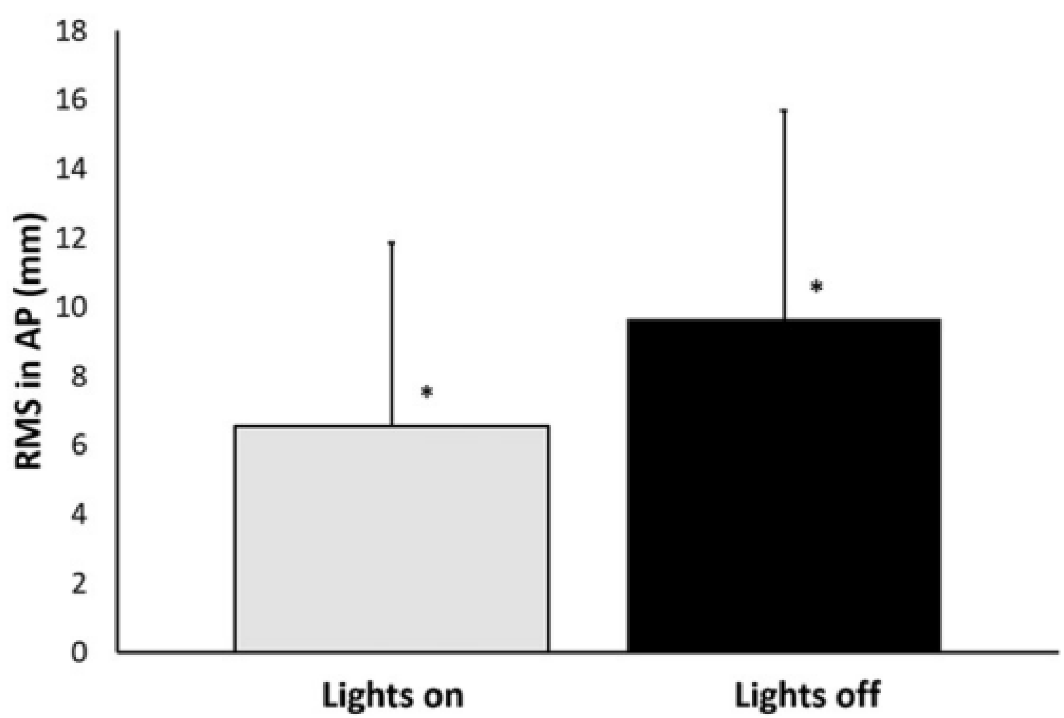

Figure 2. Root mean square in the anterior-posterior (AP) direction presented statistically significant main effect of vision. Specifically, the combination and dim lighting conditions (VS, NVSS) presented statistically significant greater values than the control (C) and the somatosensory (SS) condition. *Asterisk indicates statistically significant differences.

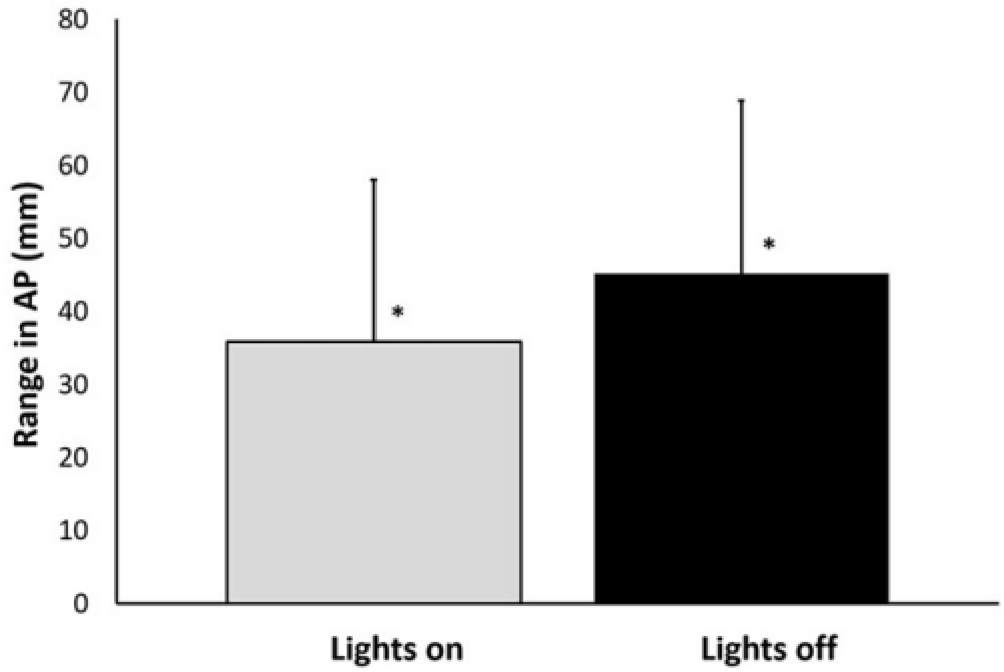

Figure 3. Range in the anterior-posterior (AP) direction presented statistically significant main effect of vision. Specifically, the combination and dim lighting conditions (VS, NVSS) presented statistically significant greater values than the control (C) and the somatosensory (SS) condition. *Asterisk indicates statistically significant differences.

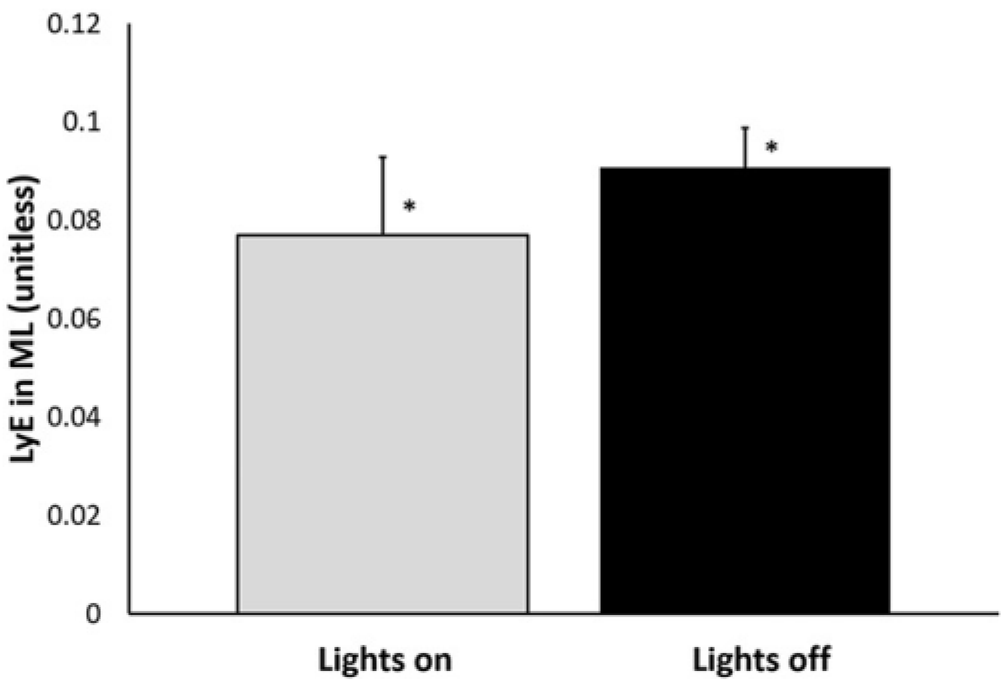

Figure 4. Lyapunov exponent in the medial-lateral (ML) direction presented statistically significant main effect of VISION. Specifically, the combination and dim lighting conditions (VS, NVSS) presented statistically significant greater values than the control (C) and the somatosensory (SS) condition. *Asterisk indicates statistically significant differences.

2.5. Statistical analysis

All results from the three individual trials were averaged for each infant for all conditions and for all linear and nonlinear parameters. The means of the linear and nonlinear measures were compared using a two by two (visual and somatosensory) fully repeated measures ANOVA model. In interactions that resulted in a significant F ratio ($p< .05$), we used a Tukey multiple comparison test to identify the location of the significant differences. We also computed the eta squared to determine the effect size when appropriate. All statistics were performed using SPSS statistical software (16.0 student version, Prentice-Hall, Inc.).

3. Results

The mean values of all measures across all conditions are presented in Table 2.

3.1. Linear measures

No significant interactions were found between the two factors for any of the linear measures examined. There was a main effect of vision for both RMS (f(1, 12) ¼ 9.671, p ¼ .009, g2 ¼ 0.44) and Range (f(1, 12) ¼ 6.419, p ¼ .026, g2 ¼ 0.34) in the AP direction. The RMS (Figure 2) and Range (Figure 3) in the AP direction presented significantly greater values in the VS and NVSS condition in comparison to the C and SS condition. There was no main effect for the distortion of somatosensory information in any of the linear measures investigated.

3.2. Nonlinear measures

No significant interactions were found between the two factors for any of the nonlinear measures examined. There was a main effect of vision for LyE (f(1, 12) ¼ 8.677, p ¼ .012, g2 ¼ 0.42) in the ML direction. The LyE in the ML direction (Figure 4) presented significantly greater values in the VS and NVSS condition in comparison to the C and SS condition. There was no main effect for the alteration of somatosensory information in any of the nonlinear measures investigated.

4. Discussion

The purpose of this study was to determine the effect of altered visual and somatosensory information on sitting postural sway in typically developing infants. We found that among all measures investigated, RMS and Range in the AP direction as well as LyE in the ML direction presented greater values when infants sat in the lights off conditions (VS and NVSS). In addition, we observed large effect sizes (g2), which suggests that the differences observed were very robust. No differences were observed for the main effect of somatosensory information or significant interactions.

The absence or altered visual information appeared to have the greatest effect on infant sitting posture, which confirms the dominance of vision during the early acquisition of a new postural accomplishment. The presentation of increased postural sway under altered visual information is also similar to standing postural control studies in children between 5 and 15 years old (Mallau et al. 2010) and similar to standing (Casselbrant et al. 2001) and sitting (Bertenthal et al. 1997) infant studies. Foudriat et al. (1993) suggested that in children younger than 3 years old there is a vestibular-visual control of standing posture which also confirms our results during sitting, since the interaction term did not reveal any significant differences. Interestingly, the lights off conditions (VS & NVSS) may have revealed a breakdown or in contrast an inherent mode of how infants control AP and ML components of sitting posture with two different mechanisms. Specifically, AP sway was controlled by increased sway shifts that the infant performed in that direction whereas ML control was regulated by increased stochastic components. Partially, these results are in agreement with Kurz et al. (2013) in which children with and without balance impairments increased the stochastic components of their postural sway when vision was absent (Kurz et al. 2013).

Altered somatosensory information did not appear to have any effect on infant sitting posture. One could argue that our sample size was small, and thus we did not have enough power to achieve statistical significance. However, apriori power analysis revealed that in order to achieve 80% power, a total sample of 12 subjects were needed to detect a large effect size between conditions. In addition, these results agree with Kokkoni et al. (2017) even though we used a foam pad with lower density. Patel et al. (2008) suggested that adults standing on soft foam surface may be more capable in extracting sensory information about body orientation and thus apply corrective body movements to restore body equilibrium in comparison to firmer foam surface. Similarly, infants in this study may have been able to extract more sensory information and adapt their sitting posture without major disturbances in their postural sway. The lack of differences under the altered somatosensory condition may also be attributed to the increased sensory-motor experiences (Corbetta and Snapp-Childs 2009) that the infants have sitting on various surfaces. From the onset of sitting, infants are accustomed to sitting on carpets, beds, and couches which may have trained them in employing postural corrections for both AP and ML directions in a way to resolve the sensory conflict produced by altered somatosensory information through a continuous perception action loop. The infants in our study were experienced sitters, meaning they were sitting independently for at least 2 months. It is possible that the increased time spent in different surface contexts might have enhanced the perception of somatosensory information, similar to older infants during reaching (Corbetta and Snapp-Childs 2009). An alternative explanation could be that infants are downweighting somatosensory information for the control of sitting posture and rely mostly on visual and vestibular information.

The fact that we did not have any interaction effects limits our discussion about sensory-reweighting during sitting in infants. In condition NVSS, both visual and somatosensory information was altered, but not eliminated or distorted as it is the case with the sensory organization test with the Neurocom or the Clinical test of sensory organization and balance. However, for most of the measures, the combination condition lead to increased postural sway though not significantly greater than the other conditions. Since there is a lack of sensory tests for infants and children in general it would be important to discover innovative ways of eliminating visual and somatosensory information to assess for sensory dependencies or aversions in those populations that are in need of such evaluations, such as those with autism, sensory-motor disorders, and others.

Infants are born with the capacity to explore their environment through the senses (Gibson 1997). They take advantage of the incoming sensory information and act appropriately based on the task demands, the environmental conditions as well as their individual constraints. Through this perception-action relationship they learn quickly to establish models of behaviour and respond appropriately to future movement challenges. For example, our findings confirm that infants are most sensitive to the visually restricted environment when sitting independently. As such, this finding is consistent with those from previous studies suggesting that perception of visual information is accessible at very young ages (Bertenthal et al. 1997, 2000). We believe that through active exploration infants gain knowledge of how their actions produce changes to the incoming sensory information and vice versa, and create a sufficient internal model for the control of sitting posture as has been shown previously with standing posture and walking (Metcalfe and Clark 2000).

4.1. Limitations

A limitation to our study is that we used only one low density foam to challenge the somatosensory system. Even though Kokkoni et al. (2017) used three different foam support surfaces with varying densities, it is possible that using foam pads with different density properties may elicit changes in the postural control system of typically developing infants. In addition, the current paradigm was not able to create faulty visual and somatosensory signals to examine the contribution of the vestibular system to infant sitting posture.

5. Conclusions

Based on the results from the present study we can conclude that altered visual information leads to greater disturbances of sitting postural control in typically developing infants than altered somatosensory information. The lights off conditions (VS and NVSS), unveiled different control mechanisms for AP and ML direction during sitting. Future studies targeting somatosensory and visual adaptation in infants and longitudinal designs that explore the sensory contributions during the development of sitting could provide greater insight into how infants are able to achieve independent sitting posture.

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Disclosure statement

Anastasia Kyvelidou declares no conflict of interest. Nick Stergiou receives royalties from Human Kinetics and CRC Press.

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