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Research Article

Exploration of a Multisensory Toy in Children with and without Down Syndrome

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Abstract

Background: Early experiences with objects provide critical enrichment opportunities during development. However, infants and children with Down syndrome (DS) show reduced play with objects such as reduced manual exploration and greater visual exploration of objects. Therefore, the primary goal of the current study was to investigate whether experience with a multi-sensory toy would lead to an increase in the overall engagement and exploration of objects in children with DS. **Methods:** Twenty-eight children with 14 each in the DS (chronological age = 33.14 ± 4.15 months; mental age = 17.01 ± 1.55 months) and TD group (chronological age = 15.15 ± 1.74 months; mental age = 17.07 ± 1.84 months) participated in the study. Children were observed while playing with a multi-sensory toy offering tactile, visual, and auditory feedback at two time points during a single lab visit. Additionally, participants completed the cognitive and the fine motor subtests of Bayley Test of Infant Development- 3rd Edition (Bayley-III). **Results**: Both children with DS and TD children showed greater activation of the vibration plate offering tactile feedback compared to the sound, light, and null plates. The DS group showed no changes in activation of the sensory plates over the two time periods, whereas children in the TD group showed reduced activation of the vibration plate and increased activation of the sound plate during time 2 compared to time 1. Additionally, the DS group showed less variety in their exploration by reduced switching between different sensory plates during time 1 compared to TD group. Lastly, activation patterns differentially correlated with age, overall fine motor, and cognitive scores of children in both the groups. **Conclusion:** This study provides preliminary evidence for the use of sensory toys in infants and young children with DS. Specifically, tactile stimulation such as vibration may be especially engaging for young children with DS. We recommend that clinicians and researchers be cognizant of the preliminary nature of the study before generalizing the study results.

Keywords: Sensory toys; Object; Play; Exploration; Down syndrome; Tactile stimulation

Introduction

Object exploration in children with Down Syndrome

Exploring and playing with objects are integral parts of early development. Through these experiences, infants and young children learn about objects, they learn about their own abilities to create change in the physical world, and they exercise their hands and fingers, which likely results in improvements in their hand skills [1]. Over the first few years of life, infants show substantial changes in their exploratory behaviors [2]. In contrast, children with developmental disabilities such as Down syndrome (DS) play with objects less than typically developing (TD) infants [3-7]. DS is one of the most common chromosomal disorders with an estimated prevalence of 1 in 700 live births [8]. Less active object play in DS is evident as early as the infancy period and persists throughout the childhood period [9-12]. For example, infants with DS between 4- to 6-month-old showed more grasping failures and fewer exploratory behaviors including reaching, banging, and rotating during an object exploration task compared to chronological age-matched TD infants [10,12]. Similarly, school-aged children with DS were observed during a 2-minute free play with random set of toys such as plastic coins, bracelet bands, and paper cups [12]. During the play session, children with DS were less likely to initiate actions on new toys (i.e., previously unexplored toys) and less likely to show novel functional actions (i.e., previously undemonstrated functional actions) compared to mental-age matched TD children and children with other developmental disabilities [12]. These differences in engagement with objects may lead to fewer learning opportunities for children with DS.

Further, object play is associated with the development of several critical skills such as non-verbal language and adaptive behaviors in children with DS [11,13]. Specifically, the object retrieval strategies used by 34-month-old children with DS associated with their non-verbal behaviors. To elaborate, children with DS who had poor retrieval strategies (e.g., more reaching failures), showed fewer non-verbal behaviors in social contexts (e.g., less looking/pointing at objects and less requesting of social routines like tickling) [13]. Similarly, children with DS showed a positive correlation between their goal-directed actions on objects and daily living skills such as grooming and feeding [11]. Given the evidence for reduced object play in DS and its impact on the development of children with DS, there is a clear need to understand how to improve meaningful exploration of objects in infants and young children with DS.

Interventions/techniques to improve object exploration

Several techniques have been proposed in the literature to provide enriched object-related experiences to infants and children with and without disabilities [14,15]. First, positioning/handling techniques can significantly improve an infants' ability to move body segments due to greater stability offered by the posture/position [16-18]. For example, premature infants who participated in a positioning intervention involving body flexion in supine, prone, or side lying showed greater exploratory movements of their body post-intervention such as greater hand to mouth, reaching and midline arm movements. This in turn significantly improved infants' ability to explore their environment including increased manipulation of toys [17]. In fact, these results have been replicated in children with other diagnoses including DS [19].

Second, scaffolding interventions such as scaffolding reaching using "sticky mittens" have been successful in improving the manual and visual exploration of objects in pre-reaching 2.5- to 3-month-old TD infants [20,21]. Specifically, caregivers were asked to engage in daily object play with their infant while the infant wore mittens with Velcro palms (sticky mittens), which allowed infant to "pick up" the Velcroed toy as they swiped at it. This brief 2-week intervention not only improved the reaching and grasping behaviors of infants, but also resulted in greater visual attention towards toys compared to infants who did not receive the training. These results have been successfully piloted in infants at-risk for developmental disabilities such as premature infants [22,23], and infants at higher genetic risk for Autism Spectrum Disorder (ASD) [24].

Lastly, rewarding feedback such as lights or sounds are usually effective in promoting exploratory movements in infants and children. For example, infants will work (e.g., by producing a certain pattern of sucking on a pacifier, or by moving a limb in certain way) to receive rewarding sights and/or sounds [25-28]. Similarly, preschoolers with ASD performed better in a task involving custom-made sensory objects compared to non-sensory objects. To elaborate, children with ASD showed better imitation of experimenter's actions on objects when it resulted in sensory feedback (light and/or sound) from the objects compared to objects producing no feedback [29]. Currently, there is a lack of evidence regarding the possible benefits of children with DS interacting with toys that offer systematic sensory feedback. Further, prior research does not offer comparison of sensory feedback across different modalities such as visual, auditory, and tactile in order to determine which sensory feedback might be most rewarding for young children with DS. On the other hand, evidence from the motor learning literature suggests a differential effect of sensory modality on the learning/performance of motor tasks such that neurotypical adults who engaged in a target selection task were quickest when provided with tactile feedback compared to visual, auditory, or no feedback [30]. In contrast, adults learning a novel gymnastic task showed superior performance during trials where sensory feedback was combined across modalities, i.e., visual and tactile feedback compared to visual only or tactile only trials [31]. Overall, toys offering sensory feedback could potentially be beneficial while practicing or learning new exploratory behaviors in young children with DS, however, current evidence limits our understanding and impact of sensory feedback in the DS population.

Goals of the current study

The primary goal of the current study was to investigate the use of a multisensory toy, i.e., a toy offering rich sensory feedback in visual, auditory, and tactile modalities in response to the exploratory behaviors of children with DS and mental-age matched TD children. Additionally, we were interested in examining the effect of repeated toy exposure on the child's exploratory behaviors by presenting the toy twice within the same testing session. We hypothesized that children with DS would spend similar amounts of time touching or grasping the toy compared to the TD children due to the contingent sensory reinforcement produced from the toy. However, children with DS will show no significant changes in their exploratory behavior between the two repeated presentations of the toy as they are usually less likely to initiate new actions on toys [12].

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Materials and Methods

Participants

Twenty-eight children participated in the study with 14 children each in the DS (chronological age = 33.14 ± 4.15 months; mental age = 17.01 ± 1.55 months) and TD group (chronological age = 15.15 ± 1.74 months; mental age = 17.07 ± 1.84 months; (Table 1). Parents of children in the DS group submitted a medical record confirming the genetic diagnosis of Trisomy 21. Parents of TD infants completed a brief screening to confirm absence of any birth/family/developmental history of delays. Additionally, all parents confirmed the absence of any physical/visual/hearing impairments which would impair study participation for their child. Participants in the DS group were recruited from local organizations, centers, and schools. TD infants were recruited through birth records obtained from state birth records and through word of mouth. The group demographics including the age, sex, ethnicity, and parents' age and education are provided in Table 1. Both groups were similar in terms of mental age, sex, and ethnicity, but differed in terms of parents' age and education (Table 1). The parents in the DS group were older with fewer years of education compared to the parents in the TD group. All parents signed the formal parental permission form approved by the university's Review Board before participating in the study.

	Down syndrome (DS)	**Typically developing (TD)**	***P* (Chi-square/t-test)**
Chronological Age (Months)	33.14 ± 4.15	17.01 ± 1.55	0.001
Mental Age (Months)	15.15 ± 1.74	17.07 ± 1.84	ns
Sex	7F; 7M	6F; 8M	ns
Ethnicity	8W; 1B; 3H; 2M	11W; 1B; 1H; 1M	ns
Mother's Age (Years)	35.86 ± 1.86	32.21 ± 0.91	ns
Mother's Education (Years)	15.43 ± 0.53	18.29 ± 0.7	0.003
Father's Age (Years)	37.77 ± 2.1	33.14 ± 1.07	0.05
Father's Education (Years)	14.86 ± 0.65	17.71 ± 0.62	0.004

Table 1: Group Demographics; F = Female, M = Male, W = White, B = Black, H = Hispanic, M = Multiracial, ns = *p*-value not significant.

Procedure and experimental task

Children sat on their parent's lap around a semi-circular table, with the experimenter seated across the table and directly in front of the child. A multisensory object producing three different modes of sensory feedback (i.e., tactile, visual, and auditory) was presented to children. The object was a rectangular board with 5 small individual plates glued on top, a vibration plate (offering tactile feedback), a light plate (visual feedback), a sound-knob and a sound-roller plate (auditory feedback), and a null plate (no sensory feedback). Vibration, light, and null plates produced sensory feedback on pressing the plates, the sound-knob required pulling the knob and sound-roller required rotating the roller. This object examined the sensory preferences of children by offering multiple opportunities for sensory exploration that were all readily available at the same time. However, we recognize that the object properties such as placement of sensory plate on the object (e.g., vibratory and sound roller were in the first row, and light, sound knob and null plate were in the second row) could confound the results of the study, and these were considered during analysis and interpretation of study results.

The experimenter briefly demonstrated how to activate the object before presenting it to the child, e.g., placing their own hand on the vibration plate or rotating the knob plate. The object was presented twice for 45-seconds each (Time 1 and Time 2). In between the two presentations, children completed other study tasks such as the Bayley Test of Infant Development- 3rd Edition. The repeated presentation of the multisensory object allowed us to examine the time course of self-directed learning in children with and without DS within the context of an object exploration task. We video recorded the children throughout the session for later coding of their behavior.

Coding of experimental task

A behavior coding software, [32] was used to code the child's interaction with the object using a custom coding scheme. Datavyu is an open-source coding software which offers frame-by-frame analysis of video recordings. Trained research assistants coded the behavior. Pearson's correlations were used to establish inter-rater reliability between the primary coder and a second coder by working on a randomly selected 25% of the dataset. Inter-rater reliability scores were greater than 90% for the coded behavior.

Manual exploration (activation and touch)

We were interested in analyzing the manual exploration of the multisensory by children with DS and TD children. Manual exploration is defined as any contact with the toy using fingers, palm, or whole hand. Coders were instructed to mark the start and stop time of each manual contact using the Datavyu software. Start time was marked as soon as the child contacted the multisensory object using their fingers, palm, or whole hand and stop time was marked when the child's hand was no longer touching the multisensory object. Any manual contact with the sensory plates of the object is referred to as ***"activation"*** in the manuscript as it indicated child's intent to activate the sensory plate and receive feedback. On the other hand, any manual contact with the sides or the rectangular board of the object is referred to as ***"touch"*** as it indicated child's intent to simply touch the multisensory object. In other words, touch was a measure of non-purposeful object exploration as manually contacting the sides of the object would result in no sensory feedback. We were also interested in examining the sensory preferences of children when multiple opportunities for seeking sensory feedback were available at the same time. To analyze this, the coders further categorized the activation behavior based on the type of sensory plate (i.e., vibration, light, sound-knob, sound-roller, null) activated by the child. We are reporting on the percent duration of behavior during time 1 and time 2 which was calculated using the formula = [total behavior in seconds/total time in seconds] x 100.

Switches

Next, we coded the switching behavior, i.e., the total number of times the child switched to a different sensory plate. For example, if the sequence of plate activation was sound --> vibration ---> light --> light, this was coded as 2 switches as the last switch from the light plate to retouching it would not be counted as switch to a different plate. Switching could reflect a process of comparison as well as a measure for variety in exploratory behaviors, as higher frequency of switches could indicate the process of comparing or exploring different forms of sensory modalities during a given time period. We are reporting on percent switches during time 1 and time 2 using the formula = [total number of switches/total number of manual contacts with the sensory plates] x 100.

First exploration

Object properties could impact exploration, for example, children would probably first explore the sensory plate which is closest to them. To explore this further, we looked at the group differences for first exploration, i.e., the first sensory plate activated by children upon object presentation by the experimenter during time 1 and time 2. We are reporting on the total number of children in the DS and TD group who had similar first exploration during time 1 and time 2.

Bayley Test of Infant Development- 3rd Edition (Bayley-III)

The Bayley-III is a standardized measure to assess the cognitive, motor, language, socio-emotional, and adaptive behaviors of infants and young children between 1 and 42 months of age [33]. It is reported to have high reliability (internal consistency among domains ranges between 0.83 and 0.93) and moderate validity (confirmatory factor analysis of domain structure ranges between 0.50 and 0.79). We used two subtests of the Bayley-III: cognitive and fine motor. The cognitive subtest assesses the problem-solving, concept formation, and memory through tasks such as completing puzzles, matching, and counting. The fine motor subtest assesses use of fingers and hand for object manipulation such as reaching/grasping, stacking blocks, and drawing shapes. The subtest raw scores can be converted to scaled scores and age equivalents based on the scoring norms. The age equivalents of the cognitive subtest were used to match the children on their mental age across the DS and the TD groups (Table 1). The raw scores of both of the subtests were used to examine the effect of cognitive and fine motor skills on the child's performance during the experimental task. One child with DS did not complete the cognitive and fine motor subtest due to non-compliance with the experimenter during the session; their experimental data were included in the final sample despite these missing data.

Statistical analysis

Touch and activation

A repeated measures analysis of covariance (ANOVA) was conducted for the percent duration of total touch and total activation with behavior type (touch, activation) and time period (time 1, time 2) as within-subjects factors, and group (TD, DS) as between-subjects factor. Another repeated measures ANOVA was run for different categories of activation behavior with sensory plate type (vibration, light, sound-knob, sound-roller, null) and time period (time 1, time 2) as within-subjects factors, and group (TD, DS) as between-subjects factor.

Switches

A repeated measures ANOVA was conducted for the percent switch behavior with time period (time 1, time 2) as within-subjects factors, and group (TD, DS) as between-subjects factor. For all ANOVA models, the data was checked for parametric assumptions using the Mauchly's Test of Sphericity and Greenhouse-Geisser corrections were applied in case of violations. The ANOVA main and interaction effects were further examined using post-hoc t-tests, which included both between-group and within-group comparisons.

First exploration

We conducted a Multinomial Logistic Regression to determine the effect of group and time period on the first sensory plate explored by children in the DS and TD group.

Correlations

We conducted pairwise Pearson's correlations to examine the association of age, Bayley-III cognitive and fine motor scores with the percent duration of activation of sensory plates. We are reporting on both the direction (negative, positive) as well as the magnitude of correlations (weak ≤ 0.3, moderate ≤ 0.5, strong ≥ 0.7). Significance was set at $p \leq 0.05$ for all the comparisons, and p values between 0.05 and 0.1 were considered as statistical trends.

Results

Touch and activation of multisensory object

The repeated measures ANOVA for the total touch and activation indicated a main effect of behavior type (F (1, 26) = 28.6, $p < 0.01$, partial $h^2 = 0.52$) and no effect of group or time period ($p > 0.05$). Overall, irrespective of the group and the time period, children spent more time in purposeful manual exploration by activating the sensory plates (60.91 ± 5.41%) compared to touching the non-sensory parts of the object (17.01 ± 2.87%; $p < 0.01$).

The repeated measures ANOVA for the percent duration of activation of sensory plates indicated a significant main effect of sensory plate (F (4, 104) = 7.91, $p < 0.01$, partial $h^2 = 0.23$) and 3-way time x sensory plate x group interaction (F (4, 104) = 3.55, $p < 0.01$, partial $h^2 = 0.12$). We further analyzed the 3-way interaction using post-hoc t-tests. During time 1 and time 2, the DS group showed greater activation of the vibration plate compared to all other plates except the sound-roller plate (Figure 1A; $p < 0.05$). Similarly for time 1, the TD group showed greater activation of the vibration plate compared to all other plates, whereas, for time 2, the TD group showed greater activation of the vibration and sound-roller plate compared to light and null plate (Figure 1B; $p < 0.05$). Comparing activation of plates across time 1 and time 2, the DS group showed no changes in activation (Figure 1A). In contrast, the TD group significantly increased the activation of vibration plate and decreased the activation of sound-roller plate from time 1 to time 2 (indicated by dotted lines in Figure 1B; $p < 0.05$) (Figure 1A, 1B).

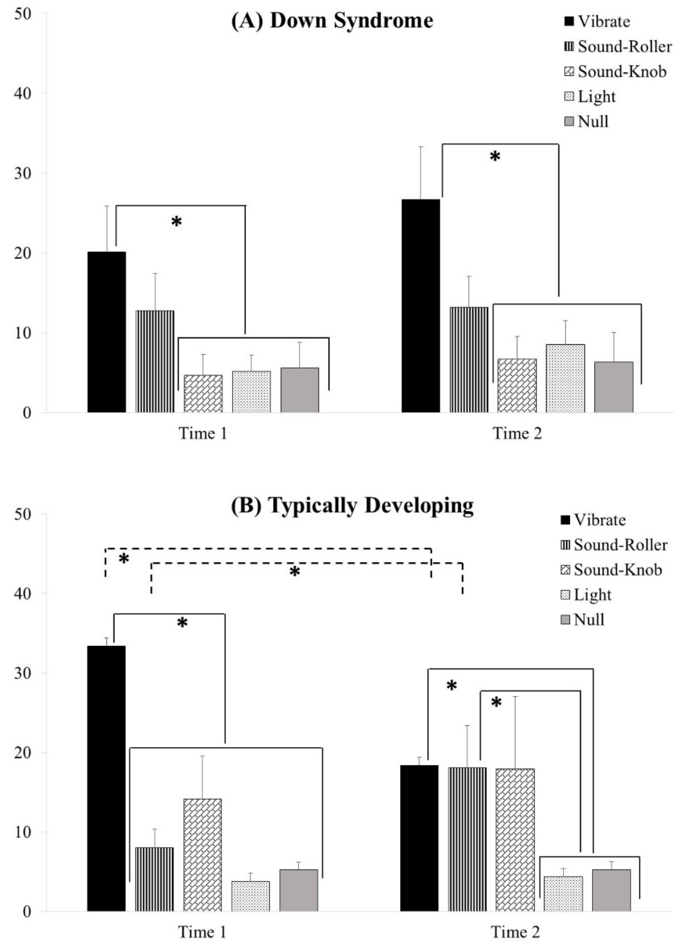

Figure 1: Percent duration of activation patterns for different plates of the multisensory toy in the (A) Down Syndrome, and (B) typically developing group.

Note: Solid lines indicates differences in activation of the plate within time period 1 and 2, whereas dashed lines indicate differences in activation between time 1 and time 2. * indicates $p < 0.05$

Switches

The repeated measures ANOVA for percent switches indicated a significant main effect of time (F (1, 26) = 21.07, $p \leq 0.01$, partial $h^2 = 0.45$) and 2-way time x group interaction (F (1, 26) = 11, p

< 0.05, partial $h^2 = 0.3$). We further analyzed the 2-way interaction using post-hoc t-tests. The DS group had fewer percent switches compared to the TD group during time 1 ($p < 0.05$, Figure 2) indicating that children with DS showed fewer switching between sensory plates compared to the total number of times they manually contacted or touched the sensory plates. However, between the two time periods, children with DS increased their percent switches from time 1 to time 2 ($p < 0.05$, Figure 2). TD group on the other hand showed similar percent switches during time 1 and 2 (Figure 2).

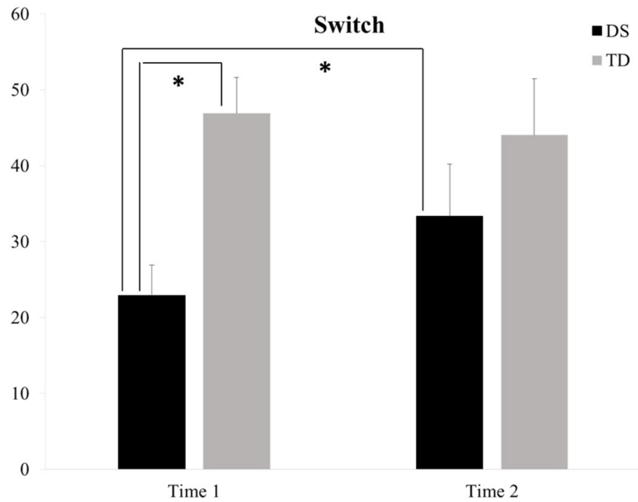

Figure 2: Percent switches seen while exploring the multisensory toy in children with Down Syndrome and typically developing children; * indicates $p < 0.05$.

First exploration

The regression model conducted on the first plate explored by children was not statistically significant (χ^2 (8) = 3.37, $p = 0.91$) for group and time period and explained only 6.5% (Nagelkerke R^2) of the variance in the model. Table 2 reports the number of children who first explored a similar type of sensory plate. Irrespective of the group and time period, greater number of children explored the vibration and sound-roller plate first compared to other plates (Table 2). This indicates that object properties such as the placement of sensory plates on the multisensory toy could impact exploration, however, we would like to emphasize that this did not contribute to any group differences as both children with DS and TD children were equally likely to first explore the vibration and sound plate compared to other plates.

Time	Group	Sensory Plates (Total # out of 14)				
		Vibration	Sound-Roller	Sound-Knob	Light	Null
Time 1	DS	7	6	0	0	1
	TD	6	5	2	1	0
Time 2	DS	9	3	1	1	0
	TD	6	5	2	0	1

Table 2: First exploration of sensory plates; DS = Down syndrome, TD = Typically Developing.

Correlations of activation with age and Bayley-III subtests

Pearson's correlations were conducted to better understand the relationship of the age and Bayley-III cognitive and fine motor subtest scores with the activation behavior. For the DS group, age (r = 0.58 or moderate correlation) and fine motor scores (r = 0.64 or moderate correlation) were *positively* correlated with the activation of the sound-roller plate during time period 1 ($p < 0.05$). For the TD group, age (r = -0.62 or moderate correlation), cognitive (r = -0.60 or moderate correlation), and fine motor scores (r = -0.72 or strong correlation) were *negatively* correlated with the activation of the sound-knob plate during time period 2 ($p < 0.05$). Additionally, age (r = 0.62 or moderate correlation) and cognitive scores (r = 0.60 or moderate correlation) in the TD group were *positively* correlated with the activation of the light plate during time period 1 ($p < 0.05$).

Discussion

Summary of results

The current study expanded on the existing work to investigate how young children with Down syndrome (DS) would explore a multisensory toy (i.e., a toy producing tactile, auditory, and visual feedback). This toy was presented twice to children with DS and a group of mental age-matched TD children. In general, children in both the groups spent more time purposefully exploring the sensory plates (i.e., total activation of sensory plates) compared to non-purposeful exploration (i.e., touching the non-sensory parts of the object). This partly aligns with our study hypothesis as we expected sensory objects could be engaging for children and resulting in similar amount of exploration across the DS and TD groups. A closer look at the activation of different sensory plates indicated that both children with DS and TD children spent more time activating the vibration plate compared to the sound, light, and null plates. However, from time 1 to time 2, the TD group reduced the activation of the vibration plate and increased the activation of the sound-roller plate, but similar changes were not seen in the DS group.

In terms of percent switches, the DS group showed less variety in their exploratory behaviors by doing fewer switches between different sensory plates compared to the total number of times they touched/contacted the sensory plates during time 1. However, during time 2, the DS group seems to have caught up to the TD group by increasing the percent switches from time 1 to time 2.

In terms of first exploration, irrespective of the group and time period, a greater number of children first explored the vibration or sound-roller plate compared to other sensory plates indicating that object properties such as placement of sensory plates similarly impacted the exploration of children in the DS and TD group. Lastly, for the associations of activation with age, Bayley-III cognitive, and/or fine motor scores, the DS group showed a positive correlation during time 1 whereas the TD group showed a negative correlation during time 2 with the activation of the sound plates. Additionally, the TD group showed a positive correlation of age and cognitive scores with the activation of the light plate during time 1.

Sensory feedback from the multisensory object

In general, children in both groups preferred the tactile feedback produced from the vibration plate compared to auditory/visual feedback from the sound/light plates. Touch sensation is the first to develop in utero and is among the primary sensory modalities' infants use to explore objects' properties (e.g., size, weight, texture) in the surroundings. In fact, premature infants who received early tactile stimulation in the form of skin-to-skin contact with their mothers showed long-term gains including greater exploration of toys, better engagement with mothers, as well as behavior/emotion regulation at 6-months of age compared to infants in the control group [34,35]. So, one possibility is that greater activation of the vibration plate in the current study was due to its calming/soothing effect on infants [36]. This result could have possible implications for clinicians/therapists during intervention planning and toy selection for the DS population. For example, toys producing tactile stimulation could be used to support compliance and maintain child's interest especially while teaching complex, multi-step tasks. However, these results are exploratory and so we recommend further investigation into the role of tactile stimulation on teaching new skills/behaviors to children with DS.

Another possible interpretation of these data is that participants may have simply been seeking to maximize (or minimize) the intensity of the sensory stimulation they received as they explored the multisensory object. To address this possibility, we gave the object to college-aged students (n = 10; average age = 19.8 years), asked them to explore the sensory feedback from the object plates. The experimenter explained to the participants that there were five plates to manipulate and asked the participant to rank the intensity of the sensory feedback of the plates from 1 to 5, with "1" being the most intense sensory feedback and "5" being the least intense. The results indicated that the sound-roller (average score = 1.8) and vibration plate (average Score = 2.1) ranked most intense and did not significantly differ in their scores, while the light plate (average score = 3.7) and null plate (average score = 5) produced the least intense sensory feedback. These data provide additional information to help interpret the study results. Children in both groups activated the modality that produced the most intense sensory feedback, i.e., the vibration plate (although the sound-roller may have been equally engaging, it was explored more only by the TD group during time 2, see discussion below). This result indicates it may be important to assess the overall intensity of the sensory feedback provided by a toy to optimize engagement.

Furthermore, it is possible that the placement of sensory plates on the multisensory toy resulted in greater activation of vibration plate as it was closer to children. Our results for first exploration indicated that greater number of children first touched the vibration or sound-roller plate which are placed closest to the child on the multisensory toy. However, this could only partly explain the child's exploration of the toy as both groups primarily activated the vibration plate and not the sound-roller which was also closer to them compared to the other sensory plates.

Group differences in exploration of the multisensory object

In terms of group differences, the DS group showed fewer percent switches during time 1 compared to TD group. In fact, the DS group switched between different sensory plates only 23% out of the total manual contacts with the plates, compared to 47% by the TD group. This result highlighted a crucial difference in object play of children with DS, i.e., a tendency to demonstrate more repetitive and less varied play behaviors [12,6,7]. For example, [12] indicated that school-aged children with DS are limited in their use of novel objects or demonstration of novel actions while playing with a set of toys compared to mental-age matched TD children and children with other developmental disabilities. Venuti et al. 2009 [7] also indicated that 3-year-old children with DS showed limited demonstration of simple actions (i.e., actions involving a single object such as dialing a telephone) and complex actions (i.e., actions involving two or more objects such as putting handset on a telephone base) while playing with a set of toys.

Similarly, in the current study, less switching by the DS group compared to TD group during time 1 could indicate reduced variety in play behaviors or reduced ability to engage in a sensory comparison process and it was not until time 2 that the DS group increased their switching behavior. Interestingly, increased switching by the DS group during time 2 did not change their activation patterns as children with DS continued to show greater activation of the vibration plate during time 1 and time 2. In contrast, the TD group showed greater variety in exploratory behaviors during both time 1 and time 2 by switching between different sensory plates. Additionally, during time 2, TD children changed their activation patterns as well by reducing the activation of the vibration and increasing the activation of the sound-roller plate.

Another important result is the positive correlation of DS group's age and fine motor scores with the activation of sound-roller plate during time 1. The activation of sound plates could have been motorically challenging for children with DS. To elaborate, the activation of the sound-roller plate required rotating the handle (relatively complex motor skill) compared to simple touching or tapping of the vibration and light plates. Given that motor and cognitive delays are among the most common characteristics of DS [37, 38], it is possible that children with DS with relatively superior fine motor skills were more successful in activating the sound-roller plate during time 1. This explanation could also hold for the TD group, whose activation of the sound-knob plate during time 2 was negatively correlated with the participant's age, fine motor, and cognitive scores. In other words, children with less well-developed motor/cognitive skills required more time to learn the activation of the sound-knob plate and were more successful during time 2.

Lastly, we would like to acknowledge the differences in family demographics. Paternal age was significantly higher, and maternal/paternal education years were significantly lower in the DS group compared to the TD group. Several studies examined the association of socioeconomic status (SES) such as parents' education and income with the child's development including cognitive and social-emotional development [39]. Specifically, low maternal/paternal education is associated with poor academic performance and lower IQ scores in their children, possibly due to lack of resources, stimulating environment, as well as differences in parenting styles and attitudes [40,41]. Research has also demonstrated less effective object exploration in infants residing in lower SES households compared to those living in higher-SES households [42]. However, if we follow the cut-offs for low and high SES in the above-mentioned studies, a majority of the DS families in our study sample could qualify for high SES. For example, the [42-57] considered families with 2+ years of college education as high SES, and 11 out of the total 14 DS families in our sample had 12+ years of education and would thus fall under the high SES category (see Table 1 for average parent education years). We would recommend further investigation of family factors (e.g., parents' occupation, education) and neighborhood factors (e.g., geographic location) on child's exploration and manipulation of objects, especially focusing on intersectional factors that could exist for children with disabilities living in lower-SES households.

Limitations

There are some limitations of the current study which should be kept in mind when generalizing the results. First, there are limitations regarding our sample. Our sample size was relatively small with total of 14 children in each group. Also, because we matched our groups on mental age, the children in the TD group were significantly younger than the children in the DS group. It is possible that the additional months/years of life experiences and interactions with objects/social partners in children with DS might have given an advantage to the DS group and masked group differences that could have been obtained in a chronological age-matched comparison. We would recommend future studies be conducted with larger sample sizes and chronological- and mental-age matched control groups of children with other developmental disabilities for better understanding of DS-specific behavioral phenotypes.

Second, we used a single multisensory toy offering sensory (light, sound, vibration plates) or no feedback (null plate). Moreover, object properties such as the placement of the sensory plates and the process required to activate the plates could have confounded our interpretations of sensory preferences among children. However, our analysis indicated no effect of group and time period on the differential exploration of the multisensory object based on object properties, e.g., no group differences for the first plate explored by children. For future studies, we would recommend examining the performance of children for a variety of exploratory behaviors and problem-solving strategies while playing with sensory and non-sensory objects.

Conclusion

The primary purpose of the study was to compare the object play of children with DS and mental-age matched TD children using a multisensory toy offering visual, auditory, and tactile feedback. Children with DS demonstrated repetitive activation of the vibration plate and TD children demonstrated activation of variety of plates including the vibration and the sound plates. This result highlighted a specific deficit in the object play of children with DS related to the tendency to demonstrate repetition and lack of variety in their play behaviors.

As discussed earlier, we are seeking factors that could lead infants and young children with DS to explore objects more actively. From the current study, we conclude that objects providing tactile feedback (such as vibration) in response to their actions may help engage young children with DS in object exploration. Additionally, sensory preferences could also depend on the intensity of the feedback provided by the toys. Overall, our study provided much-needed preliminary evidence for the use of sensory toys in children with DS, along with the need of future studies to further examine the use of sensory toys in children with DS.

Conflict of Interest

All authors declare no conflicts of interest.

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