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Differences in means-end exploration between infants at risk for autism and typically developing infants in the first 15 months of life.

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Abstract

Our study compared means-end exploration in infants at-risk (AR) for autism and typically developing (TD) infants using a nested box paradigm. 16 AR and 16 TD infants were observed at 9, 12, and 15 months with follow-up at 18 and 24 months. We collected video data on three tasks involving retrieval of a small toy by opening – a) an opaque box, b) a transparent box, and c) two nested boxes. Dependent variables included hand bias, time to completion, bilateral hand use, problem solving strategies used, and tester assistance required. There were no group differences in terms of hand biases. Compared to TD infants, AR infants had lower bilateral hand use, poor problem solving, and required greater assistance. Both groups demonstrated age-related improvements in motor and cognitive skills. Means-end exploration provides a window into the bilateral coordination, motor planning/problem solving abilities of young infants at-risk for autism. Lastly, object retrieval tasks could serve as important learning contexts for at-risk infants.

Keywords

Object retrieval; means-end exploration; at-risk infants; autism; motor

Over the past few decades there has been a steady increase in research directed towards systematically studying the development of infants who have an older sibling diagnosed with Autism Spectrum Disorder (ASD). This group of at-risk (AR) infants is at a heightened risk to develop ASD or other more subtle delays in social communication, cognitive, and motor skills characteristic of the broader autism phenotype (Georgiades et al., 2013; Messinger et al., 2013; Pisula & Ziegler-Sadowska, 2015; Rogers, 2009). Specifically, approximately 20%

of AR infants develop an ASD diagnosis by 3 years of age and an additional 30% of AR infants develop features consistent with the broader autism phenotype (Bhat, Landa, & Galloway, 2011; Landa, Gross, Stuart, & Bauman, 2012; Ozonoff et al., 2011; Yirmiya, Gamliel, Shaked, & Sigman, 2007). Prospective longitudinal studies comparing AR infants to typically developing (TD) infants without a family history of ASD can help in identifying early markers of ASD and other developmental delays and have important implications for the initiation of early intervention services (Fein et al., 2013). Past work including our own research has identified atypicalities and delays in the perceptuo-motor domain including excessive visual exploration, poor grasping, immature postural control, poor use of motor skills during early infant-caregiver interactions, and an overall diminished movement repertoire in AR infants (Bhat, Galloway, & Landa, 2012; Bhat, Galloway, & Landa, 2010; Flanagan, Landa, Bhat, & Bauman, 2012; Focaroli, Taffoni, Parsons, Keller, & Iverson, 2016; Kaur, Srinivasan, & Bhat, 2015; Koterba, Leezenbaum, & Iverson, 2012; Landa & Garrett-Mayer, 2006; LeBarton & Iverson, 2016b; Libertus, Sheperd, Ross, & Landa, 2014; Nickel, Thatcher, Keller, Wozniak, & Iverson, 2013; Ozonoff et al., 2008; Srinivasan & Bhat, 2016; van Etten, Kaur, Srinivasan, Cohen, Bhat & Dobkins, 2017). In the current study, we extend this line of research to another early emerging skill, namely, object retrieval. Successful retrieval of objects from containers requires infants to plan and execute multiple steps in an appropriate sequence in order to reach the end goal and also requires the coordinated use of both hands (Bruner, 1970; Piaget, 1953; Woodward, 1971).

Previous work has suggested that fine motor delays are evident in AR infants within the first two years irrespective of their future diagnostic status (Bhat et al., 2011; Kaur et al., 2015; Landa & Garrett-Mayer, 2006; LeBarton & Iverson, 2013; Libertus et al., 2014). As early as 6 months, AR infants exhibit lower levels of manual and oral exploration of toys and instead engage in greater visual fixation on objects compared to their TD peers (Kaur et al., 2015; Koterba et al., 2012; Libertus et al., 2014). Similarly, Landa and Garrett-Mayer found fine motor delays on the Mullen Scales of Early Learning (MSEL) in a large cohort of AR infants at 14 months compared to low-risk TD infants (Landa & Garrett-Mayer, 2006). The low-levels of fine motor control early in life gradually change to stereotypical and repetitive movement patterns by the second year of life (Baranek, Parham, & Bodfish, 2005; Damiano, Nahmias, Hogan-Brown, & Stone, 2013; Ozonoff et al., 2008). For example, Damiano et al. reported greater rates and types of body-related and object-related repetitive and stereotyped movements in 15-month-old infant siblings at-risk for ASD compared to typically developing infants (Damiano et al., 2013). Fine motor delays/atypicalities in infancy also have implications for the development of more sophisticated motor skills such as tool use, imitation, and everyday functional and self-care skills. In addition, fine motor impairments have cascading adverse effects on other developmental domains including social communication and cognitive skills (Bhat et al., 2012; Iverson, 2010; Leary & Hill, 1996; LeBarton & Iverson, 2013; Leonard et al., 2014; Leonard, Elsabbagh, Hill, & BASIS team, 2014). The motor system provides infants with a rich repertoire of ways to explore, interact, and gain information about their bodies and their environment and facilitates further skill development (Bornstein, Tamis-LeMonda, Hahn, & Haynes, 2008; Bornstein, Hahn, & Suwalsky, 2013; Gottlieb, 1991; Libertus & Needham, 2011). For instance, object play allows infants to discover object properties and affordances, develop object segregation and

memory skills, and learn advanced problem solving skills (Bertenthal & Clifton, 1998; Klatzky & Lederman, 1992; Lederman & Klatzky, 1987; Needham, 2001; Needham, Barrett, & Peterman, 2002). Additionally, as infants engage in object play with caregivers they learn various social communication skills such as joint attention, turn taking, pretend play, and object labels (Bakeman & Adamson, 1984; Bruckner & Yoder, 2007; Haebig, McDuffie, & Weismer, 2013; Iverson & Wozniak, 2007; Iverson, 2010; Klatzky & Lederman, 1992; Lifter & Bloom, 1989; McDuffie, Lieberman, & Yoder, 2012). In fact, early fine motor skills predict expressive language skills at 36 months and academic achievement in school-age children (Bornstein et al., 2013; Cameron et al., 2012; Grissmer, Grimm, Aiyer, Murrah, & Steele, 2010; LeBarton & Iverson, 2013). Overall, there is considerable evidence emphasizing the role of early fine motor skills in facilitating multisystem development in infancy and early childhood.

Our lab has previously investigated fine motor skills, namely object exploration in AR infants in the first 15 months of life. We found that compared to TD infants, AR infants had reduced grasping at 6 months and reduced purposeful dropping at 9 and 12 months (Kaur et al., 2015). In this study, we extend our line of research to another early-emerging, object-related functional skill, object retrieval, that also requires significant bilateral fine motor control and motor planning/problem solving. Object retrieval is a means-end exploratory behavior involving deliberate and intentional execution of a sequence of intermediate steps as a means to achieve an end goal (Piaget, 1953; Willatts, 1999; Woodward, 1971). Typically developing infants begin to demonstrate such means-end behaviors around seven to eight months during simple problem solving tasks but continue to refine these skills up to the end of the second year (Bruner, 1970; Willatts, 1997). As mentioned earlier, successful and efficient object retrieval-based means-end tasks require optimal sequencing/problem-solving skills and motor coordination to understand means-end relationships and execute the appropriate steps necessary to search and retrieve objects (Bruner, 1970; Piaget, 1953; Willatts, 1999). In a developmental study, infants between 6 and 17 months were observed as they attempted to retrieve a toy placed inside a box with a transparent lid (Bruner, 1970). 6 to 8-month old infants were mostly unsuccessful in retrieving the objects whereas, 9 to 11-month-old infants could retrieve the object using unimanual strategies. Furthermore, 12 to 14-month old infants had just begun to use bimanual strategies and finally by 15–17 months infants seemed to use more efficient and well-dissociated bimanual strategies to achieve their end goal (Bruner, 1970). Similarly, in terms of problem-solving skills, prior to 8 months of age, TD infants may be aware of their end goal but have difficulties planning sequential steps to get to the end goal (Baillargeon, 1993; Willatts, 1999). Overall, the developmental trajectory of means-end behaviors requiring object retrieval has been well-studied in TD infants.

In contrast to studies in TD infants, there is a remarkable dearth of corresponding literature on means-end development in AR infants. As discussed above, AR infants as a group demonstrate delays/atypicalities in reaching, grasping, and object manipulation skills (Kaur et al., 2015; Koterba et al., 2012; Nickel et al., 2013; Ozonoff et al., 2008). Moreover, young children with ASD also demonstrate deficits in executive functioning that interfere with their problem-solving abilities during goal-directed tasks (McEvoy, Rogers, & Pennington, 1993; Pennington & Ozonoff, 1996). Given the presence of the aforementioned impairments in AR

infants that are also pre-requisite for successful means-end problem solving, it would be worthwhile to investigate the trajectory of such behaviors in AR infants compared to TD infants. In the present study, we assessed means-end behavior in AR and TD infants at 9, 12, and 15 months using a set of three incremental object retrieval tasks developed by Goubet and colleagues (Goubet, Rochat, Maire-Leblond, & Poss, 2006; Srinivasan, Nguyen, Kaur, & Bhat, 2015). We systematically coded hand biases, bilateral hand use, types of problem solving strategies employed, amount of assistance required as well as total time required for each task in both groups. We hypothesized that AR infants would have significant delays/deficits in object retrieval skills compared to TD infants at all ages.

Methods

Participants

12 infants at risk for developing ASD (AR infants; 11 Caucasian and 1 African-American; 11 infant siblings of children with ASD and 1 preterm infant) and 11 typically developing infants (TD infants; 10 Caucasian and 1 of mixed ethnicity) with no family history of ASD or prematurity participated in the study. All families belonged to upper-middle or upper class based on socioeconomic status (see Table 1 for demographic details) (Hollingshead, 1975). Infants were observed during means-end tasks at 9, 12, and 15 months (see Table 1). Infants were recruited through online announcements as well as phone calls and fliers sent to autism centers, schools, early intervention clinics, and ASD advocacy groups. The preterm infant received an ASD diagnosis before three years of age and the older siblings of all other AR infants met criteria for ASD. For all infants, the ASD diagnosis was confirmed using the the Autism Diagnostic Interview-Revised (ADI-R) (Lord, Rutter, & Couteur, 1994), clinical judgment, and/or medical records. Infants with significant birth history including low birth weight, birth asphyxia, head injury, genetic disorders, hearing or vision impairment, and orthopedic diagnoses were excluded from the study. All infants were recruited in the study following written parental consent approved by the Institutional Review Board at the University of Connecticut.

Future outcomes

We tracked infant outcomes by emailing parents around infants' second birthday and using parent questionnaires at 18 and 24 months. We provided the Ages and Stages Questionnaire, 3rd edition (ASQ-3) (Squires & Bricker, 2009) and the Modified Checklist for Autism in Toddlers (M-CHAT) (Robins, Fein, Barton, & Green, 2001) to parents at 18 and 24 months. The ASQ-3 is a developmental screener to assess motor, social, and cognitive delays in infants between 1 month and 5.5 years of age (Squires & Bricker, 2009). Scores falling 2SDs below the mean were considered as developmental delays. The M-CHAT is a screening questionnaire for ASD where failure on 3 or more items or 2 or more critical items is suggestive of a high risk for developing ASD (Robins et al., 2001). We have ASQ-3 and M-CHAT data from all TD infants and 11 out of the 12 AR infants. In the TD group, none of the infants reported any delays on the ASQ-3 or failed on the M-CHAT at 18 and 24 months. In the AR group, at 18 months, 7 infants had delays on the ASQ-3 and 6 infants failed on the M-CHAT. At 24 months, 5 AR infants had delays on the ASQ-3 and 3 infants failed on the M-CHAT. Based on parent reports, none of the TD infants had any diagnoses at 2 years. In

the AR group, 2 infants were diagnosed with ASD and three other infants were diagnosed with language delays. Further, 4 AR infants were receiving early intervention services as reported by parents at infants' second birthday. Therefore, overall, in the AR group, 5 out of 12 infants developed future delays/diagnoses (2 ASD, 3 language delays) or were receiving early intervention services (1 child with language delay was not receiving services) based on developmental follow-up within the first 2 years.

Procedures

The Means-End Paradigm: Each infant was seated upright in a booster seat with the tester on one side. The experimental paradigm consisted of three tasks of increasing complexity. In task 1, infants were asked to retrieve a small toy animal from an opaque square box as shown in the first image in Figure 1. In task 2, infants were asked to retrieve the same toy from a smaller transparent cylindrical box (see the second image in Figure 1). Lastly, in task 3, the toy animal was placed in the transparent box, which was placed within the square opaque box (see the third image in Figure 1). Tasks 1 & 2 were both 3-step tasks but they differed in the bimanual strategies that infants would need to use to retrieve the toy from the box. Task 1 involved a larger opaque box that required asymmetrical hand use for opening. Step 1 of Task 1 involved opening the box by stabilizing the box with one hand and opening the lid with another. The second step in Task 1 was to remove the toy animal from the box. By the end of step 2, if the toy was not already in the infant's hand then the infant had to grasp the toy fallen onto the seat tray. For example, younger infants would fling the container by grabbing the lid with one hand and the toy would fall out onto the seat tray. In these instances, grasping of this fallen toy was considered step 3 of Task 1. In contrast, Task 2 involved a transparent container that required more symmetrical hand use for opening. Step 1 of Task 2 involved pulling apart the lid from the container base. The next step in Task 2 required the infants to show asymmetrical hand use by grasping the open container with one hand and scooping out the toy animal using fingers. At the end of step 2 of Task 2, if the toy was not in the infants' hands then the infant had to grasp the toy fallen onto the seat tray. For example, younger infants would open the lid and dump the toy onto the seat tray and grasping of the dumped toy was then considered step 3 of task 2. Furthermore, in Task 1 the large opening of the opaque box allowed the infant to use their entire hand to remove the toy from the box (see first image in Figure 1). In contrast in Task 2, the small opening of the transparent box required the infants to use their fingers in a coordinated fashion to retrieve the toy from the box. Task 3 combined both tasks 1 & 2 and involved five steps. Step 1 of Task 3 involved stabilizing the opaque box with one hand and opening the lid with another. The second step in Task 3 involved removing the transparent container from the opaque box. The third step of Task 3 involved pulling apart the lid from the container base. The fourth step of Task 3 involved asymmetrical hand use by grasping the open container base with one hand and scooping out the toy animal with the other hand. If the infant dumped the toy on the seat tray then the fifth step of Task 3 involved grasping the fallen toy.

Each task was considered complete, when the infant was able to retrieve the toy placed within the box/boxes. Prior to beginning the tasks, the tester presented the toy animal on the tray of the booster seat and let the infant reach, grasp, and explore the toy for 10 seconds. The tester then placed the toy in the opaque/transparent box based on the task. The tester

shook the box and presented it on the tray to the infant saying, “Where is the sheep? Can you find the sheep?” If the infant seemed to have difficulties completing the task (i.e. more than 3 failed attempts to open box), the tester provided verbal and/or gestural prompts to redirect the infant’s attention to the box. Examples of verbal prompts include, “Can you get the sheep out?” etc., while pointing to the box to indicate that the toy was inside the box. After a three-minute period, if the infant was not able to retrieve the toy, the tester provided manual assistance to help the child complete the task. All testers were blinded to the grouping of infants and their future outcomes. Moreover, in order to avoid experimenter bias, all testers conducted behavioral tasks according to a standard testing protocol. Testers used a stopwatch to ensure that the amount of opportunity provided was equal across infants. All visits were videotaped for further behavioral coding of the data.

Behavioral coding: A custom coding scheme was developed to assess the means-end performance of all infants. Specifically, we assessed multiple qualitative variables for each of the three tasks: a) total number of strategies used (all possible qualitative strategies attempted by infants for each task), b) hand use patterns (unilateral and bilateral strategies employed by infants to complete tasks), c) hand biases based on the reach-grasp actions scored within the hand use data, and d) tester assistance required (whether or not infant could complete the task independently). In addition, we also assessed the time taken by the infant to complete each of the three tasks. Table 2 provides a detailed description of the coding scheme used for the study.

Each of the means-end tasks had multiple components and each step was coded for all the aforementioned variables. To elaborate, Tasks 1 and 2 involved a total of 3 discrete steps – open opaque/transparent box, remove toy, and grasp toy (if the toy had fallen out of the box and onto the seat tray). Task 3 involved a total of 5 steps – open opaque box, remove transparent box, open transparent box, remove toy, and grasp toy (if the toy had fallen out of the box and onto the seat tray). A full score was given for the grasp toy component if the infant had simultaneously removed and grasped the toy. We summed all the component step scores to obtain a score for each of the tasks on each variable. Finally, for each variable, we calculated a total score that was obtained by summing the scores across all three means-end tasks. For instance, as shown in Table 2, hand use was scored on a scale of 0 to 3. Tasks 1 & 2 had 3 steps each, therefore, for each of these tasks, the maximum possible hand use score (by summing across component steps of the task) was 9. For task 3 which had 5 steps, the maximum possible hand use score (by summing scores across all 5 steps) was 15. For all 3 tasks combined with a total of 11 steps, the total possible hand use score an infant could obtain was 33. Similarly, for the tester assistance variable scored on a scale of 0 to 2, the total possible score an infant could obtain summed across all 3 tasks (11 steps) was 22. For the total number of strategies and time to completion variables, coders kept track of the number of strategies attempted to accomplish each of the tasks and the time taken to complete each task respectively. Given the nature of these variables, there was no upper limit for these two outcome measures.

As mentioned earlier, we used the hand use patterns to identify infants’ hand biases at each visit. We specifically used the “grasp toy” component from each of the three tasks for this scoring. The hand bias ratio was calculated by using the formula: $\text{Right grasps} / (\text{Right} + \text{Left})$

Grasps). Note that we provided infants a total of 3 opportunities to reach for the toy across the 3 tasks at a given visit. To be clear, if 3 out of 3 reaches were right-handed, the hand bias ratio would be 1, if 2 out of 3 reaches were right-handed, the ratio would be 0.66, if 1 out of 3 reaches was right-handed then the ratio would be 0.33, and if none of the reaches were right-handed, the ratio would be 0. So infants with ratios of 0.66 and 1 were termed as having a “right-hand bias” and infants with a ratio of 0 and 0.33 were considered as having a “left-hand bias”. Moreover, by examining infants’ hand bias ratios across the 9-, 12-, and 15-month visits, we classified their overall developmental hand bias pattern as one of the following: right hand bias, left hand bias, or switching hand bias. Infants who consistently used their right or left hand to grasp the toy across all three ages were classified as having a ‘right’ or ‘left’ bias respectively. Infants who changed their hand biases over time across the three visits were said to have a ‘switching’ hand bias (left-right-left or right-left-right or right-right-left, left-left-right, etc.; Table 3 outlines the age-related changes in hand biases of infants in both groups).

All coders were blind to the grouping of the child as well as their future outcomes. A single coder coded all the videos after establishing intra-rater reliability of over 90% and inter-rater reliability with a second coder of over 85% for all variables using 20% of the dataset.

Statistical analysis

We confirmed that our data met assumptions for parametric statistics including normality and homogeneity of variances. We conducted repeated measures MANCOVA to identify developmental trends and group differences in means-end performance for the different qualitative variables. We used visit (9 month, 12 month, and 15 month) and variable type (hand use, total number of strategies, and tester assistance) as our within-subjects factors, group (TD and AR infants) as a between-subjects factor, and developmental hand bias as a covariate. We used ANCOVAs as well as dependent (to assess developmental trends) and independent (to assess group differences) *t* tests to conduct post-hoc testing of significant main effects and interactions from the omnibus MANCOVA. In all the individual ANCOVAs conducted, we added developmental hand bias as a covariate in the analysis. In case of significant main effects and interactions between factors, we further examined the significant interactions only. We assessed the time to completion variable separately by conducting another repeated measures ANCOVA with visit (9 month, 12 month, and 15 month) as the within-subject factor, group (TD and AR infants) as the between-subject factor, and hand bias as a covariate. We report effect sizes in the form of partial eta-squared values (η_p^2) and standardized mean difference (SMD) values using Hedges’s *g* (Hedges, 1981). We also report confidence intervals around SMD values for significant within-group and between-group differences. Statistical significance was set at $p = 0.05$ and statistical trends are reported at $p < 0.1$.

Results

Qualitative variables

Our omnibus MANCOVA for all qualitative variables indicated a significant main effect of variable type (Pillai’s trace = 0.85, $F(2, 19) = 54.69$, $p < 0.001$) as well as significant

interaction effects of variable type $\times$ group (Pillai's trace = 0.43, $F(2, 19) = 7.16$, $p = 0.005$), visit $\times$ group (Pillai's trace = 0.31, $F(2, 19) = 4.23$, $p = 0.03$), variable type $\times$ developmental hand bias (Pillai's trace = 0.49, $F(2, 19) = 9.03$, $p = 0.002$), variable type $\times$ visit (Pillai's trace = 0.79, $F(4, 17) = 16.01$, $p < 0.001$), and variable type $\times$ visit $\times$ group (Pillai's trace = 0.46, $F(4, 17) = 3.61$, $p = 0.026$). We further analyzed the significant 3-way interaction using ANCOVAs and t tests. For the time to completion variable, our ANCOVA revealed a significant main effect of visit only ($F(1.57, 31.52) = 4.97$, $p = 0.012$, $\eta_p^2 = 0.20$). Below, we present results of our post-hoc analyses for each variable in terms of both developmental trends and group differences.

Total strategies

The ANCOVA suggested significant main effects of visit ($F(2, 40) = 3.93$, $p = 0.028$, $\eta_p^2 = 0.16$) and group ($F(1, 20) = 7.19$, $p = 0.014$, $\eta_p^2 = 0.26$) as well as a visit $\times$ group interaction ($F(2, 40) = 4.63$, $p = 0.015$, $\eta_p^2 = 0.19$). Further evaluation of the visit $\times$ group interaction suggested that after controlling for hand bias patterns, TD infants explored greater number of problem solving strategies to complete the means-end tasks at 9 months compared to AR infants (see Figure 2; SMD = 1.01, CI = 0.14 to 1.88). As seen from individual data in Figure 3A, the majority of the AR infants who later developed delays/diagnoses used fewer problem-solving strategies compared to the TD group average at all ages. In terms of developmental changes, TD infants reduced the overall number of strategies used from 9 to 12, 12 to 15, and 9 to 15 months (see Figure 2; SMD range = 0.72 to 1.68, CI range = -0.04 to 2.78). In contrast, AR infants demonstrated a protracted trajectory, with a significant decrease in total number of strategies employed between 9 and 15 months (see Figure 2; SMD = 0.92, CI = 0.13 to 1.69).

Hand use

The ANCOVA suggested significant main effects of group ($F(1, 20) = 6.00$, $p = 0.024$, $\eta_p^2 = 0.23$) and visit ($F(2, 40) = 12.93$, $p < 0.001$, $\eta_p^2 = 0.39$). In terms of group differences, after controlling for hand bias patterns of infants, AR infants had lower hand use scores across all visits, suggesting less bilateral hand use compared to TD infants (see Table 4A; SMD = 0.53, CI = -0.30 to 1.36). Moreover, individual data suggested that the majority of the AR infants who later developed delays/diagnoses received lower hand use scores than the TD group average across all ages (see dotted lines in Figure 3B). In terms of developmental changes, after controlling for hand bias patterns, infants in both groups increased hand use scores suggesting better bilateral hand use from 9 to 12 months and 9 to 15 months with a similar trend also observed from 12 to 15 months (see Table 4B; SMD range = 0.43 to 3.35, CI range = 1.65 to 4.51).

Tester assistance

The ANCOVA indicated significant main effects of group ($F(1, 20) = 4.56$, $p = 0.045$, $\eta_p^2 = 0.19$) and visit ($F(2, 40) = 7.26$, $p = 0.002$, $\eta_p^2 = 0.27$). Post-hoc testing suggested that overall, even after controlling for hand bias patterns, AR infants required greater tester assistance to complete the means-end tasks across all visits compared to TD infants (see Table 4A; SMD = 0.53, CI = -0.31 to 1.36). Furthermore, as seen in Figure 3C, the majority of the AR group required greater assistance compared to the TD group average especially at

9 and 12 months of age. In terms of developmental changes, infants in both groups reduced the amount of tester assistance required to complete the tasks from 9 to 12 and 9 to 15 months (see Table 4B, SMD range = 0.72 to 1.02, CI range = 0.23 to 1.56).

Time to completion

Post-hoc testing of the main effect of visit suggested that irrespective of group, infants significantly reduced the time to complete the means-end tasks from 9 to 15 months and 12 to 15 months with a similar trend from 9 to 12 months (see Table 4B; SMD range = 0.90 to 1.58, CI range = 0.38 to 2.25).

Discussion

Summary of results

In this study, we aimed to identify early signs of developmental delay in at-risk infants. Our past work has shown that compared to TD infants, AR infants demonstrate atypical manual, oral, and visual exploration of objects over the first 15 months of life (Bhat et al., 2010; Kaur et al., 2015). In the current study, we compared the developmental trajectory of another early-emerging functional skill, i.e. object retrieval, at 9, 12, and 15 months between AR and TD infants. Past work has shown clear associations between hand biases and object manipulation skills; infants with stable hand biases demonstrate more sophisticated object management, tool use, and manual skills compared to infants with inconsistent hand biases (Kotwica et al., 2008; Marcinowski et al., 2015; Fraz et al., 2014; Michel et al., 2016). In the current study, we found group differences in object retrieval even after controlling for developmental changes in hand biases of infants. At all visits, AR infants had poor bilateral hand use scores and required greater tester assistance to retrieve objects compared to their TD peers. Moreover, AR infants used fewer problem-solving strategies at 9 months compared to TD infants. With increasing age, both groups showed improved bilateral hand use, a decrease in the total number of strategies and tester assistance required to complete tasks, as well as a progressive decrease in the time required to retrieve objects. Below we discuss possible reasons for group differences and developmental findings of our study.

Group differences in object retrieval

Object retrieval means-end tasks provide a window into motor and cognitive development in infancy (Bojczyk & Corbetta, 2004; Willatts, 1999). Successful object retrieval requires strong fine and gross motor skills including proficiency in reaching towards objects, using both hands in coordinated and complementary ways to manipulate objects skillfully, as well as a stable sitting posture to allow free use of arms (Bojczyk & Corbetta, 2004; Bruner, 1970; Fagard, 1994; Lobo & Galloway, 2008; Piaget, 1953; Willatts, 1999). As mentioned previously, hand biases in infancy and early childhood also influence object manipulation skills (Michel et al., 2016). TD infants with stable hand use patterns show greater proficiency in manual skills such as stacking blocks, managing and interacting with multiple objects simultaneously, and bimanual object transfer skills (Marcinowski, 2015; Kotwica et al., 2008). In addition to motor skills, for successful object retrieval, infants need to plan goal-directed action sequences that act as a *'means'* to reach an *'end'*-goal (Piaget, 1953; Willatts, 1999). This may involve exploring multiple movement solutions and figuring out

the best strategy to achieve their final goal. Infants also need to inhibit certain predominant responses such as directly reaching for a toy instead of opening the lid of a transparent box, or using the two hands in a symmetrical manner instead of a dissociated pattern (Bojczyk & Corbetta, 2004; Diamond, 1991). The above-mentioned pre-requisite motor and cognitive skills that underlie object retrieval are the very skills impaired in infants and children at-risk for autism possibly contributing to group differences observed in our study. Below we discuss each of these factors briefly.

Fine and gross motor skills in at-risk infants

There is substantial evidence for the presence of fine-motor delays in at-risk infants and young children with ASD (Damiano et al., 2013; Focaroli et al., 2016; Gernsbacher, Stevenson, Khandakar, & Goldsmith, 2008; Kaur et al., 2015; Koterba et al., 2012; Landa & Garrett-Mayer, 2006; Leonard et al., 2014; Leonard, Elsabbagh et al., 2014; Libertus et al., 2014; Lloyd, MacDonald, & Lord, 2013; Ozonoff et al., 2008). For instance, a landmark prospective study comprising 87 high-risk infants found both fine- and gross-motor delays in infants who eventually developed an ASD diagnosis compared to an unaffected group as early as 14 months (Landa & Garrett-Mayer, 2006). Our own recent work suggests that at-risk infants as a group demonstrated poor early grasping, reduced dropping, and excessive visual and oral exploration of objects between 6 and 15 months compared to their low-risk peers (Kaur et al., 2015). Poor fine motor skills limit infants' active exploration of objects and in turn may impact their ability to discover means-end relationships (Lobo & Galloway, 2008). In line with our previous work, we found that AR infants as a group demonstrated poor means-end performance compared to the TD group even after controlling for the effects of hand biases during object retrieval. In fact, bilateral hand use was reduced as early as 9 months in the AR group and these group differences continued to persist at 15 months. Libertus and colleagues also found fine motor delays pertaining to bilateral hand use, object exploration, and grasping on the MSEL in at-risk infants at 6 months of age (Libertus et al., 2014). Our findings also fit with the broader literature on fine motor coordination impairments at later ages in at-risk populations and young children with ASD (Barbeau, Meilleur, Zeffiro, & Mottron, 2015; Focaroli et al., 2016; Fournier, Hass, Naik, Lodha, & Cauraugh, 2010; Provost, Lopez, & Heimerl, 2007; Provost, Heimerl, & Lopez, 2007; Sacrey, Germani, Bryson, & Zwaigenbaum, 2014). In addition to fine motor impairments, poor gross motor skills including trunk instability can also impair object retrieval skills in infants (Lobo & Galloway, 2008). At-risk infants exhibit gross motor deficits including delayed sitting and standing as well as fewer advanced postures during naturalistic play (LeBarton & Iverson, 2016a; Nickel et al., 2013; Bhat, Galloway, & Landa, 2012). Postural immaturity in sitting can limit infants' active exploration of objects using both hands and thereby negatively impacting means-end performance. Overall, delayed/atypical fine and gross motor skills in the AR group may have contributed to their poor means-end performance compared to the TD group.

Executive functioning/Cognitive flexibility in at-risk infants

Delays in executive functioning including planning, problem solving, impulse control, cognitive flexibility, generativity and focused attention have been demonstrated in children with ASD as early as 3 years of age (Adrien, Rossignol-Deletang, Martineau, Couturier, &

Barthelemy, 2001; Diamond, 2013; Happé, Booth, Charlton, & Hughes, 2006; Hill, 2004; Holmboe, Fearon, Csibra, Tucker, & Johnson, 2008; Hughes, Russell, & Robbins, 1994; Hughes, 1996; McEvoy et al., 1993). However, recently, atypical executive functioning such as poor response inhibition and working memory have also been demonstrated in 24-month-old at-risk infants irrespective of their outcome diagnoses (St John et al., 2016). Similarly, during a computer-based task, at-risk infants demonstrated poor response inhibition compared to low-risk infants at 9 months of age (Holmboe et al., 2010). Poor response inhibition can impair infants' ability to purposefully complete intermediate steps as a means to get to their final goal. In our study, we found that the AR group employed fewer problem-solving strategies (both in total number and variety) at 9 months compared to the TD group. In other words, AR infants engaged in fewer object retrieval attempts suggestive of low task persistence, and also showed limited diversity in the strategies explored to accomplish the end goal compared to TD infants. Atypical executive functioning in cognitive flexibility (ability to explore diverse problem-solving strategies) and generativity (ability to generate multiple solutions) have been well documented in older individuals with ASD (Hill, 2004). However, our study suggests that the precursors of these later cognitive skills may well lie in infancy and could possibly be tapped by behavioral paradigms such as means-end tasks. Lösche reported similar results where 22 to 30-month-old children with ASD performed fewer exploratory actions on objects within naturalistic settings compared to TD children (Lösche, 1990). Moreover, between 31 and 42 months, the ASD group engaged in repetitive, primitive sensorimotor actions compared to their TD peers who explored diverse action possibilities during means-end tasks (Lösche, 1990). Variability in sensorimotor exploration is a hallmark of a healthy perception-action system and allows infants to learn to adaptively match their actions to object properties (Hadders-Algra, 2010; Lobo, Kokkoni, de Campos, & Galloway, 2014). Our findings suggest that at-risk infants demonstrate a diminished sensorimotor repertoire as early as 9 months, which in turn could have negative implications for future development within the motor, social communication, and cognitive domains.

Need for assistance in at-risk infants

We found that the AR group required greater assistance during object retrieval compared to the TD group. The tester provided manual assistance during each task if the infant could not complete the task independently. We noticed that several AR infants did not persist with the task as discussed earlier and were either distracted or fussy after a short period necessitating tester assistance for task completion. Even older children with ASD require significant tester assistance and prompting to redirect their attention towards tasks at hand (MacDuff, Krantz, & McClannahan, 2001). Overall, multiple early motor and cognitive impairments in AR infants could have contributed to the group differences observed in our study.

Developmental trends in object retrieval

Infants in both groups improved means-end performance from 9 to 15 months in terms of greater bilateral hand use, decrease in number of strategies employed, and reduction in time required to complete tasks. These changes could be attributed to age-related improvements in motor and cognitive skills in both groups. For instance, developmental literature on the emergence of role-differentiated bimanual manipulation (RDBM) suggests that until around 11 months, during tasks requiring use of both hands, infants typically either use only one

hand, or recruit both hands in a symmetrical and undifferentiated fashion. By around 13–14 months they start to use arms in a dissociated manner although precise and efficient complementary use of hands continues to develop over the 2nd year (Babik & Michel, 2016; Birtles et al., 2011; Kimmerle, Ferre, Kotwica, & Michel, 2010; Michel, Ovrut, & Harkins, 1985; Goldfield & Michel, 1986; Ramsay & Weber, 1986). Specifically, Kimmerle et al (2010) reported that TD infants begin to show hand preferences/biases during RDBM at around 13 months of age; however, even at this age RDBMs form only about 20% of infants' manual repertoire. In addition, a recent study by Babik & Michel (2016) also suggests that hand preferences/biases of TD infants for complex RDBMs such as removing/inserting things, similar to those performed in our study, become consistent by about 13–14 months. So it was not surprising to see the rapid increase in bimanual strategies without a clear hand bias in the infants in our study because RDBMs were still novel and emerging skills.

Age-related improvements in executive functioning, motor planning/problem solving abilities may have contributed to the reduction in the total strategies explored during retrieval tasks. The greatest variability and variety in oral, haptic, and visual exploration of objects is reported in the second half of the first year; thereafter, as infants discover object affordances, they learn to appropriately adapt and match actions to object properties (Lobo et al., 2014). In fact, repeated exposure to object retrieval tasks in TD infants has shown to enhance task performance compared to control infants who were not provided similar experiences (Bojczyk & Corbetta, 2004). With improvements in bimanual control and problem solving abilities, infants may have required progressively shorter times to complete tasks across visits. Similar improvements in movement times were observed during object transportation tasks from 18 to 36 months in at-risk and low-risk infants (Focaroli et al., 2016).

Clinical Implications

In terms of early detection, our results suggest that means-end tasks such as object retrieval may serve as a valuable naturalistic play paradigm to identify early motor delays in high risk populations. In recent times there is growing awareness regarding the utility of behavioral paradigms in addition to standardized tests to identify early delays/atypicalities in at-risk populations (Kaur et al., 2015; Libertus et al., 2014; Lobo & Galloway, 2013; Nickel et al., 2013; Ozonoff et al., 2008; Srinivasan & Bhat, 2016). Nevertheless, given our small sample size we recommend rigorous studies with larger samples to systematically establish the diagnostic utility of the current paradigm. Based on our preliminary findings, means-end tasks may be a valuable tool to assess bilateral hand use and problem solving skills in at-risk infants. Lastly, behavioral performance of infants during such paradigms can be carefully analyzed to identify targets for early intervention.

Object retrieval and more generally means-end tasks may also serve as paradigms to train motor and cognitive skills in infancy including bimanual control, motor planning and sequencing, problem solving, and cognitive flexibility (Bojczyk & Corbetta, 2004; Bruner, 1970; Esseily, Nadel, & Fagard, 2010; Fagard, Rat-Fischer, Esseily, Somogyi, & O'Regan, 2016; Willatts, 1999). For instance, with repeated exposure to object retrieval tasks from 6.5

months of age, TD infants were able to successfully retrieve objects from boxes 1.5–2.5 months prior to control infants (Bojczyk & Corbetta, 2004). Similarly, two weeks of scaffolded reaching experiences using ‘sticky mittens’ in 3-month old AR infants led to advancements in their grasping skills (Libertus & Landa, 2014). Repeated active experiences with means-end tasks may also facilitate infants’ understanding of the goal-directed nature of means-end, and more generally tool use tasks performed by self and others (Gerson, Bekkering, & Hunnius, 2015; Rat-Fischer, O’Regan, & Fagard, 2014; Sommerville & Woodward, 2005; Sommerville, Hildebrand, & Crane, 2008).

Limitations

Our study was limited by a small sample size and hence needs to be replicated with larger samples. In fact the variability in the current sample may have contributed to the wide confidence intervals obtained around our calculated effect size estimates. We confirmed our group trends with an in-depth analysis of individual data, however, further studies should confirm our findings using homogenous samples. Although object retrieval tasks seem to be a promising paradigm to pick up early motor delays in at-risk populations, more rigorous work pertaining to assessment of task sensitivity and specificity is required with larger samples to establish the clinical and diagnostic utility of this paradigm. Moreover, we assessed object retrieval skills over a limited period of time without further follow-up at later ages. Our results are based on behavioral coding of video data. We unfortunately did not employ kinematic measures to conduct more fine-grained analyses of movement patterns of infants during retrieval tasks. We had limited data to assess hand biases, specifically, when infants were reaching and grasping for the toy, which did not allow us to reliably measure hand biases/preferences. In the future, we plan to further assess hand biases across all bimanual actions to examine the differential roles of the primarily acting versus stabilizing hands through additional behavioral coding. Lastly, although we clearly defined the conditions for tester intervention during the task, we could not strictly control for this. Tester involvement may therefore have contributed to some variation in performance between infants.

Conclusions

We compared object retrieval skills in a group of infants at-risk for developing autism and TD low-risk infants from 9 to 15 months of age. At-risk infants as a group had reduced bilateral hand use and required greater tester assistance to successfully retrieve objects at all ages compared to the control group. They also engaged in fewer problem solving strategies during object retrieval at 9 months of age. Both groups demonstrated developmental trends of improved bilateral hand use as well as reduction in total attempted strategies, tester assistance required, and time required in completing tasks. Overall, means-end tasks requiring object retrieval seem to be a promising paradigm to identify early developmental delays in at-risk infants. Moreover, given the skills underlying successful object retrieval, such tasks could be used by clinicians and caregivers to promote motor and cognitive development during early infancy in various at-risk populations, especially, infants at-risk for ASD.

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Figure 1:
Experimental setup for the three means-end tasks

Figure 2: Group differences and developmental trends in the total number of strategies used during means-end tasks. * indicates $p < 0.05$. The * within a black box indicates a significant group difference. The black * indicates a developmental difference between two ages for the group indicated. The black line indicates the TD group whereas the grey line indicates the AR group.

Figures 3A, 3B, and 3C:

Individual data on total strategies, hand use, and tester assistance in AR infants. Solid grey lines indicate data from individual AR infants and grey dot-dashed lines represent data from AR infants with future ASD diagnoses/other delays. Solid black lines indicate the TD group average. Group data were not shown for these variables because group differences were present at all ages.

Table 1:

Demographic characteristics of participating infants

Variables	Gender	Socioeconomic status Mean(SD)	Age Mean(SD)		
			9m	12m	15m
AR Group	2F, 10M	50.86 (13.68)	9.61 (0.54)	12.93 (0.84)	15.48 (0.95)
TD Group	4F, 7M	55.56 (10.06)	9.9 (0.48)	12.81 (0.53)	15.77 (0.64)
Test statistic & <i>p</i> values	$\chi^2 = 1.15, p = 0.28$	$t(18) = 0.86, p = 0.40$	$t(19.89) = 1.74, p = 0.10$	$t(21) = -0.40, p = 0.70$	$t(20) = 0.82, p = 0.42$

Table 2:

Coding scheme for means-end behaviors

Variable	Coding Scheme	Range of variable
Hand use	0 – Task not completed 1 – Unilateral strategies used (for e.g. dumping toy with one hand, fingering toy with one hand to get it out of the box, lifting lid with one hand to open box) 2 – Bilateral symmetrical strategies used (for e.g. opening opaque box like a book using two hands, pulling apart the lid and container base of the transparent box symmetrically with two hands) 3 – Bilateral asymmetrical hand use (for e.g. holding opaque box with one hand and lifting lid with the other hand, opening the lid of the opaque box with one hand and removing toy from within the box with the other hand, holding the container base of the transparent box with one hand while pulling out the toy with the other hand)	0–33 points
Total number of strategies	Total number of strategies used per task (a sum of all repetitions of all different types of strategies employed)	No upper limit
Tester assistance	0 – No assistance required 1 – Partial assistance required (for e.g. tester holds the box so that the child can open it using one hand) 2 – Total assistance from tester required to complete task (for e.g. tester opens box for the child and child simply picks up the toy from the box or seat tray)	0–22 points
Time to completion	Time between tester placing box on infant's seat tray to the point where the infant retrieved the toy from the box	No upper limit

Each of these variables were coded for each of the three tasks

Table 3:

Developmental hand bias patterns of infants

Hand bias patterns	% of TD infants	% of AR infants
Right hand bias	9.09	8.33
Left hand bias	45.45	41.67
Switching bias	45.45	50

Table 4A:

Group differences in means-end performance

Scores	TD infants Mean (SD)	AR infants Mean (SD)
Hand use	18.60 (5.58) *	15.49 (5.71)
Tester Assist	1.49 (2.01) *	3.18 (3.83)

* $p < 0.05$

Table 4B:

Developmental trends in means-end performance

Time/Scores	9 months Mean (SD)	12 months Mean (SD)	15 months Mean (SD)
Time to completion (seconds)	109.91 (30.61) ^{a†}	91.89 (34.38) ^{b*}	59.83 (20.21) ^{c*}
Hand use	11.36 (2.74) ^{a*}	18.70 (4.83) ^{b†}	20.86 (4.69) ^{c*}
Tester Assist	4.47 (3.50) ^{a*}	1.87 (2.32)	0.78 (2.51) ^{c*}

*
 $p < 0.05$,†
 $p < 0.1$;^a
9 to 12 months,^b
12 to 15 months,^c
9 to 15 months