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Give Me a Hand: Adult Involvement During Object Exploration Affects Object Individuation in Infancy

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Abstract

The development of object individuation, a fundamental ability that supports identification and discrimination of objects across discrete encounters, has been examined extensively by researchers. There are significant advancements in infants' ability to individuate objects during the first year-and-a-half. Experimental work has established a timeline of object individuation abilities and revealed some mechanisms underlying this ability, however, the influence of adult assistance during object exploration has not yet been explored. The current study investigates the effect of adult involvement during object exploration on infants' object individuation abilities.

In Experiment 1a and 1b, we examined 9.5-month-old infants' colour-based object individuation following adult-assisted multisensory object exploration. Two components of adult interaction were of particular interest: facilitation of object manipulation (grasping, rotating, and attention-getting behaviours) and social engagement (smiling, pointing, attention-getting verbalizations, and object-directed gaze). Experiment 2a and 2b assessed these components with 4.5-month-olds to examine their impact across development. The results showed that after adult-guided object exploration, both 9.5- and 4.5-month-old infants successfully individuated previously undifferentiated objects. Results of Experiments 1b and 2b provide implications for the mechanisms underlying the scaffolding influence of adult interaction during infant behaviours.

Keywords

object individuation; multisensory exploration; social interaction; object manipulation; infancy

In the visual world, objects in motion create complex and dynamic scenes. To understand and successfully navigate this world, infants must develop the ability to perceive objects as distinct, bounded entities with perceptual properties that remain relatively stable across time and contexts. In infancy, this ability is often assessed through tests of *object individuation*, which is the ability to accurately detect whether an object currently in view is the same or a different object than one seen previously. Infants use a variety of information in the service of this ability, including spatial, temporal, and featural cues (Leslie, Xu, Tremoulet, &

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Scholl, 1998; Wilcox & Baillargeon, 1998a; Xu & Carey, 1996). Although infants are particularly sensitive to spatial and temporal cues, their utilization of object features, such as colour or pattern, to individuate objects is less reliable. The use of differences (or similarities) in object features for object individuation is important given that object features are often the only distinguishing factor available to identify or discriminate objects. Thus, learning to attend to object feature differences and use these differences as a basis for object individuation is critical to accurate perception of the world. The current study examines the development of this ability in infancy and the factors that may influence its expression. In particular, the research presented here explores the impact of adult-guided multisensory play on object individuation in order to develop a better understanding of the processes that shape the development of this essential skill.

Influences on Object Processing

Object individuation abilities are affected by infants' experiences with objects. For example, simply being given the opportunity to visually compare feature differences side-by-side (e.g., a dotted object next to a striped object) helps infants to individuate objects based on feature differences when they would have been unable to do so without this experience (Wilcox & Woods, 2011; Wilcox, Woods, Chapa, & McCurry, 2007). Furthermore, there is a growing body of research demonstrating that infants' *own* actions on objects are remarkably influential in guiding learning about objects, including object features and actions (e.g., Baumgartner & Oakes, 2013; Gerson & Woodward, 2013; Hauf, Aschersleben, & Prinz, 2007; Libertus & Needham, 2010; Sommerville, Hildebrand, & Crane, 2008). Multisensory object exploration (i.e., object exploration using touch and sight simultaneously) enhances infants' ability to use object features in the service of object individuation. Specifically, infants used colour differences (e.g., a green ball compared to a red ball) to individuate objects at 10.5 months and pattern differences (i.e., a dotted ball and a striped ball) to individuate objects at 5.5 months (Wilcox et al., 2007; Woods & Wilcox, 2013). Without visual-tactile multisensory experience, infants do not demonstrate these abilities until 11.5 and 7.5 months, respectively (Wilcox, 1999). Wilcox and colleagues (2007) proposed that infants benefitted from multisensory object exploration because multisensory experiences focus infants' attention to the explored object and encourage integration of feature information. However, the advantage of multisensory object exploration for individuation is limited; it is restricted to the few months prior to when infants demonstrate proficiency in the absence of multisensory experience with objects (i.e., visual experience only): while 10.5-month-olds benefitted from the multisensory experiences, 9.5-month-olds did not (Wilcox et al., 2007). Similarly, while 5.5-month-olds benefitted from the multisensory experiences, 4.5-month-olds did not (Woods & Wilcox, 2013).

One possibility is that this limitation is established by developmental constraints on infants' exploratory behaviours. Multisensory visuo-haptic exploration of objects occurs naturally at around 5 months of age (Gibson, 1988) and becomes increasingly sophisticated across development (McCall, 1974; Rochat, 1989; Streri, Pownall, & Kingerlee, 1993). With the onset of certain motor skills, such as the ability to reach for objects of interest or to sit unassisted, infants' exploratory behaviours are appreciably enhanced (e.g., Lobo & Galloway, 2013; Rochat, 1992). Experimental studies have confirmed that artificial

production of these developmental milestones similarly enhances infants' exploratory behaviours. For example, Needham, Barrett, and Peterman (2002) augmented infants' reaching and grasping skills through the use of 'sticky mittens'. After the mittens were removed, infants displayed more mature object exploration skills than their same-age counterparts who did not receive 'sticky mitten' experiences. Woods and Wilcox, (2013) provided postural support during object exploration to 5-month-olds who were not yet able to sit independently. The added support resulted in successful object individuation, presumably due to enhanced object processing during exploration.

The current study extends this body of work by assessing whether adult guidance during multisensory object exploration similarly augments infants' exploratory skills in a way that leads to accurate object individuation. Previous work provides evidence that active support or guidance from an adult during object exploration can lead to enhancements or changes in infants' own behaviours. For example, Lobo and Galloway (2008) found that when parents were instructed to engage in activities to improve motor skill (e.g., sitting up, maintaining posture) or object-oriented behaviours (e.g., reaching, haptic exploration), infants' object exploration behaviours were enhanced. In a similar intervention, the authors found that adult-guided enhancement of infants' motor behaviours at 2 months led to improved motor skills a full year later (Lobo & Galloway, 2012). Thus, the inclusion of adult assistance during multisensory object exploration may play a similar role by enhancing infants' motor skills during exploration, which may then lead to successful object individuation. Furthermore, adult assistance has the potential to uniquely impact infants' individuation abilities, as it combines manipulative assistance with another important learning mechanism: social engagement.

Learning About Objects Through Social Engagement

Social engagement is a powerful tool for learning. Infants as young as three months reliably use adults' eye gaze as a cue to direct their own visual attention (D'Entremont, Hains, & Muir, 1997; Hood, Willen & Driver, 1998), and use of this cue becomes more sophisticated over time (Morales et al., 2000). Beyond eye gaze, infants also track the motor actions of other individuals during joint play, directing their attention towards others' hand placement (Yu & Smith, 2013). Social engagement can be used as a tool to manipulate infants' early motor behaviours, such as handedness proclivity (Morange-Majoux & Devouche, 2014). Both naturalistic and experimental studies show that when mothers or other adults interact with infants, infants' exploratory behaviours are enhanced and attention becomes more focused than is observed during independent play (Lawson, Parrinello, & Ruff, 1992; Parrinello & Ruff, 1988). As infants develop and gain more social experience, the effect of social engagement increases; engagement with objects in the presence of a social partner becomes more focused and coordinated towards the end of the first year (Bakeman & Adamson, 1984).

Thus, it is reasonable to conclude that the social aspects of adult involvement during object exploration (i.e., gaze directing, modelling of exploration behaviours, and engagement in goal-oriented actions) may provide a unique boost to infants' attention and exploratory behaviours. If these behaviours lead to a more thorough appraisal of the objects, they may

indirectly enhance object individuation. Recent evidence suggests that the social context can indeed influence infants' object individuation abilities. Brower and Wilcox (2013) assessed infants' ability to use colour information for individuation following visual priming with or without the presence of an adult. The results demonstrate that the mere presence of a social partner during visual exposure enhances infants' use of colour for individuation. However, as of yet, no research has specifically examined how intentional, active adult guidance during infant object exploration may affect infants' capacity for individuating objects. Given the effect social interaction can have on behaviour and learning in a number of domains in infancy (see Striano & Woodward, 2012 for a review), it is likely that the social component of adult involvement during multisensory object exploration plays a significant role in the development of infants' object individuation abilities.

The Current Study

Both sophisticated object exploration behaviours and social interaction during exploration play major roles in infants' ability to process and learn about their world. The current study seeks to examine the effects of adult-assisted object exploration on infants' object individuation abilities. Evidence suggests that the addition of adult assistance during object exploration will support object manipulation (e.g., grasping and rotation) as well as provide social cues (e.g., attention directing) that will enhance infants' self-guided attention to and exploration of objects (e.g., Lawson et al., 1992; Parrinello & Ruff, 1988). The contribution of the current work is to examine the degree to which these factors (i.e., manipulation assistance and social cues) support object individuation at two distinct points in development: 4.5 and 9.5 months.

These two ages were specifically selected to expand on previous research demonstrating that solo multisensory exploration at these ages is insufficient for infants' individuation of objects based on specific features (Wilcox et al., 2007; Woods & Wilcox, 2013). Furthermore, 4.5- and 9.5-month-old infants each have a unique set of abilities that will allow us to clarify the mechanisms by which adult guidance is useful at these distinct ages. At 4.5 months, infants' ability to engage in multisensory object exploration is just emerging, and these skills are still relatively unsophisticated (Gibson, 1988). However, their attention to objects can be manipulated by something as subtle as an adults' eye gaze (D'Entremont, Hains, & Muir, 1997; Hood, Willen, & Driver, 1998). During joint play in which an infant, adult, and object are the 'players', these behaviours serve to focus attention towards the object, potentially giving the object priority over other elements of the environment. If the adult also boosts infants' manual object exploration, together these experiences provide highly supportive conditions for object learning. Nine-and-a-half-month-olds, in comparison, are considerably more advanced in motor and object manipulation skills (McCall, 1974), thus the added help with object manipulation may not be as valuable to infants in this age group relative to the younger infants. However, at 9 months, adult intervention during object play heightens attention to target and periods of joint attention robustly enhance object processing. (Cleveland & Striano, 2007; Parrinello & Ruff, 1988). If these supportive conditions facilitate object learning, we reason that infants of both ages may form the complete, persistent object representations that sustain accurate object individuation.

Thus, the current study examines how this support influences object individuation abilities. Experiment 1a assesses the effect adult assistance during object exploration has on subsequent object individuation of differently-coloured objects in 9.5-month-old infants. Experiment 1b assesses whether manipulative assistance or social engagement differentially impact infants' object individuation ability by manipulating the behaviours in which adults engage during object exploration (i.e., rotating objects, pointing at objects). Experiments 2a and 2b assess the influence of these same factors on 4.5-month-olds' use of pattern differences to individuate objects. The results demonstrate that adult engagement during object exploration has a positive effect on infants' ability to individuate objects. Furthermore, examination of manipulative assistance and social engagement in isolation reveals developmental asymmetries that illuminate the mechanisms responsible for this positive effect.

EXPERIMENT 1A

In Experiment 1a, we assessed 9.5-month-old infants' individuation of solid-coloured objects following adult-assisted multisensory object exploration. When adults interact with infants during object exploration, they enrich the multisensory experience through both social interaction and assistance manipulating objects. Our primary goal was to assess the relative importance of these two aspects of adult engagement in forming infants' object representations. To do so, it was important first to establish that infants are capable of individuating objects based on colour differences following a multisensory exploration experience with adult assistance. To date, studies on the influence of multisensory object exploration on object individuation abilities have demonstrated that 9.5-month-olds do not benefit from such experiences (Wilcox et al., 2007). Therefore, in Experiment 1a, we provided infants with object exploration sessions in which an adult was highly socially engaged with the infant during object exploration and also assisted the infant in object manipulation. Our hypothesis was that if the 9.5-month-olds benefitted from adult involvement during object exploration, they would successfully individuate objects based on colour differences.

The object individuation assessment, the Narrow-Screen task (Wilcox & Baillargeon, 1998a; 1998b), involves comparing looking times of infants who see an occlusion event using a narrow screen with those of infants who see the same event with a wide screen. One object moves behind the screen and is then replaced by an object that differs in some way (e.g., colour, shape, etc.). If infants detect the difference and individuate the objects, they should find the narrow-screen event, in which the screen is too narrow to hide two objects simultaneously, unexpected as indicated by longer looking times. Infants who see the event with a wide screen, in which there is room to hide two objects, should find the event less interesting and look for a shorter duration relative to those who see the narrow screen. Conversely, if infants fail to detect the change in objects, there should be no statistically significant difference in looking times between infants who see the narrow screen event and those who see the wide screen event. Therefore, our more specific hypothesis was that following the adult-assisted object exploration trials, infants who see the narrow-screen test event will look longer than infants who see the wide-screen test event.

Method

Participants—Sixteen 9.5-month-olds (8 F) completed the experiment. Infants were pseudo-randomly assigned to one of two conditions based on screen size during the test trials (narrow or wide). In this and the following experiments, infants were healthy, full-term, with no family history of colorblindness. Infants were Caucasian (93%), Caucasian and Hispanic or Latino (3%), Caucasian and Native American (1%), or ‘other’ (3%). All parents had a high school diploma, and 86% of participants had at least one parent with a college degree. Parent information was collected from local birth announcements or the Department of Health, and parents were invited to participate by letter or phone.

Apparatus and stimuli—The apparatus, a wooden cubicle $105 \times 60 \times 25$ cm, sat atop a 72 cm high table. The back wall was neutral-coloured and the floor was gray laminate with a recess, 11 cm wide $\times$ 14 cm deep, in the centre. Centred on the floor rested a gray felt platform 60×15 cm with an 11 cm gap at the location of the recess. The gap and recess provided space for an experimenter to switch two objects behind an occluding screen (see Figure 1). A neutral board covered the apparatus stage between trials. Canvas-covered frames located to either side of the apparatus concealed two observers.

Two Styrofoam balls, one red and one green (equiluminant), measuring 10.25 cm in diameter were used during the familiarization and test events (see Figure 2). A 2 cm high fringe-covered slit ran along the back wall of the apparatus. The slit allowed a concealed experimenter to move the objects across the platform using Plexiglas handles that were attached to each ball.

The familiarization screen was a 30×41 cm yellow poster board. The narrow test screen was 16×41 cm, and the wide test screen was 30×33 cm. Both were dark blue poster board with gold stars.

Events and procedure—Infants’ ability to individuate the objects based on colour differences was assessed using the Narrow-screen task (Wilcox & Baillargeon, 1998a; 1998b). The task is the most frequently used method to study object individuation in infants younger than 10 months (Wilcox & Baillargeon, 1998b; Wilcox & Woods, 2009); thus, we used this assessment to allow more effective comparison to other studies. Each infant participated in two object exploration trials, followed by six familiarization trials, and one of two four-trial test events (narrow or wide screen).

Object exploration trials—Prior to testing, infants participated in two 60-second multisensory object exploration trials, giving the infants the opportunity to see and touch objects identical to those used during the familiarization and test trials. These trials were similar to those used by Wilcox et al. (2007, Experiment 2) except that an experimenter actively facilitated infants’ visual and manual exploration of the objects (see Figure 3). Infants were shown the green ball first, then the red ball. The objects were never seen together. Trials were video recorded for behavioural coding.

Upon presenting the object to the infant and ensuring that the infant had seen it, the experimenter first slowly moved the object up and down twice from the infant’s eye level to

the experimenter's eye level. This specific type of movement was selected based on evidence that movements used by parents include high amplitude and repetition and are useful for infants when learning about object features (Koterba & Iverson, 2009). The experimenter then handed the object to the infant for multisensory exploration. The experimenter was instructed to facilitate the infant's natural exploration activities as much as possible (e.g., helping the infant lift the object, rotating the object in the infant's hand). The rotation was specifically employed to allow the infant to see the surface features of the object from multiple views. Experimenters also socially engaged the infant through behaviours such as vocalizations (e.g., 'Look what you have!'), pointing, and tapping and scratching the surface of the object, and initiating joint attention using behaviours such as looking and smiling at the infant. Specific phrases were used to ensure that the experimenters never labelled the objects or used language that indicated a particular number of objects.

Familiarization and test events—Following object exploration, infants moved to an adjacent room for six familiarization trials and four test trials. Infants sat on a parent's lap facing the apparatus, approximately 80 cm away from the objects. White noise (35 dB) masked movement of the objects.

Familiarization trials began with the green ball resting to the left of the familiarization screen and the red ball hidden in the recess. The ball remained stationary until the observers indicated the infant had looked at it for at least 1 second. The experimenter then moved the green ball to the right at 12 cm per second until it was hidden behind the screen. While still hidden, the green ball was exchanged for the red ball. The red ball then emerged to the right of the screen and came to rest for 1 second at the right side of the platform. This single trajectory lasted 5 seconds, during which the object spanned 60 cm. The trajectory was reversed and the sequence continued until the trial ended (see Figure 4). The trial ended if the infant looked for 60 seconds or looked away for 2 consecutive seconds after reaching the minimum looking criteria (10 cumulative seconds).

After familiarization, half the infants saw a narrow-screen test event and half saw a wide-screen test event. The minimum looking time during the test trials was 5 seconds, which is sufficient time for the infant to see a single trajectory. In all other ways, the test events were identical to the familiarization event.

Two naïve observers monitored infants' looking through small viewing holes in the canvas panels located to either side of the apparatus. Observers pressed a button on a gamepad when the infant was looking at the event. A computer programme recorded the infants' looking times and calculated observer agreement for each tenth of a second. The primary observer's data were used for analysis. Interobserver agreement for Experiments 1a and 1b averaged 90% per test trial per infant.

Results and Discussion

Mean scores for familiarization and test were analysed separately (see Figure 5), each using a one-way Analysis of Variance (ANOVA) with screen size (narrow or wide) as a between-subjects factor. Results for the familiarization trials showed no statistically discernable differences, $F(1, 14) = 0.15$, $p = .70$, $\eta_p^2 = .01$, (narrow screen, $M = 28.47$, $SD = 5.91$; wide

screen, $M = 27.13$, $SD = 7.79$) suggesting that infants' looking times did not differ during this phase.

Preliminary analyses of test trial data revealed heterogeneity of variance, so data were square root transformed.¹ Means reported below are prior to transformation to allow more effective comparisons. Results based on the transformed data revealed that the 9-month-old infants looked longer at the narrow-screen event ($M = 16.03$, $SD = 4.36$) than the wide-screen event ($M = 11.18$, $SD = 1.84$), $F(1, 14) = 7.90$, $p = .01$, $\eta_p^2 = .36$. These results suggest that infants who received adult assistance during object exploration, rich in both social interaction and assistance manipulating the objects, subsequently individuated the objects based on colour differences.

EXPERIMENT 1B

Experiment 1a revealed that 9.5-month-old infants individuated objects based on colour when previously provided the opportunity to explore the objects with assistance of an adult. In Experiment 1b, we investigated the relative importance of the type of adult involvement during object exploration. In one object exploration treatment, an experimenter engaged infants through social interaction, but provided no assistance physically exploring the objects. For the other treatment, an experimenter aided infants in their manipulation of the objects, but provided no social interaction.

Research has demonstrated that infants' exploratory and manipulation behaviours facilitate attention to and processing of objects (e.g., Gibson, 1988; Ruff, 1984), but that these behaviours do not develop until around 5 months of age (Gibson, 1988), and change very little after about 8 months of age (McCall, 1974). Therefore, 9.5-month-olds, who are already skilled at object manipulation, are unlikely to benefit from assistance in manual exploration of the objects. Our first hypothesis, therefore, was that when assistance physically exploring the objects was withdrawn and only social interaction was available to enrich the object exploration experience, the 9.5-month-olds' ability to individuate the objects would not be adversely affected; they would benefit from the social interaction-only experience.

Conversely, we expected the withdrawal of social interaction to be detrimental. Engagement with objects in the presence of a social partner becomes more focused and coordinated towards the end of the first year (Bakeman & Adamson, 1984). If social interaction is important to enhance object exploration, withdrawal of it will adversely affect the experience. Thus, our second hypothesis was that when social interaction was withdrawn and only assistance manually exploring the objects remained to facilitate object exploration, the 9.5-month-olds would not benefit from object exploration.

¹Means and standard deviations for the test trials of Experiment 1a (9.5-month-olds) after transformation were $M = 3.96$, $SD = 0.57$ (narrow screen) and $M = 3.33$, $SD = 0.28$ (wide screen). Means and standard deviations after transformation for the test trials of Experiment 1b for the main effect of screen were $M = 4.37$, $SD = 1.16$ (narrow screen), and $M = 3.64$, $SD = 0.67$ (wide screen). For individual conditions, they were $M = 4.28$, $SD = 0.62$ (social interaction only, narrow screen), $M = 3.44$, $SD = 0.48$ (social interaction only, wide screen), $M = 4.46$, $SD = 1.58$ (manipulation assistance only, narrow screen), and $M = 3.84$, $SD = 0.80$ (manipulation assistance only, wide screen).

Method

Participants—Thirty-two 9.5-month-olds (17 F) were pseudo-randomly assigned to one of four conditions formed by crossing object exploration treatment (social interaction-only or manipulation assistance-only) with screen size during the test trials (narrow or wide).

Apparatus, stimuli, events, and procedure—The apparatus and stimuli for Experiment 1b were identical to those of Experiment 1a. The events and procedure were also identical with the exception of the object exploration phase, described below.

Manipulation-only object exploration trials—The manipulation-only object exploration trials were the same as the object exploration trials of Experiment 1a except that the experimenter provided only manual assistance to infants during object exploration with minimal social interaction. This was accomplished by concealing the experimenter behind a screen. The experimenter moved and rotated objects via dowel rods that were secured to the back of each object in the same manner as the movements in Experiment 1a (Figure 3). The upper section of the screen had a peep-hole through which the experimenter observed the infant and the lower section was a curtain through which the experimenter presented the objects. The sequence of movements and manipulations were the same as those of the procedure of Experiment 1a; upon presenting the object to the infant, the experimenter moved the object slowly up and down twice from the infant's eye level to the experimenters eye level, then moved the object closer to the infant for exploration. While allowing the infant to explore in as natural a manner as possible, the experimenter rotated the object and tapped or scratched it using an extendable hand-like tool. When the trial ended, the experimenter drew the object behind the curtain. The second trial was conducted in the same manner using the second object.

Interaction-only object exploration trials—The interaction-only object exploration trials were identical to the object exploration trials of Experiment 1a except that the experimenters engaged in social interaction while providing no manual assistance in exploration (see Figure 3). Objects identical to those used in Experiment 1a were presented to the infant and placed directly in the infants' grasp for exploration. For the duration of each 60-second trial, the experimenter executed social interaction behaviours that included looking and pointing at the object, calling the infant's name, and using attention-getting phrases such as, 'Look what you have!' The experimenter did not help the infant hold or manually explore the object, but did return the object to the infant if it was dropped. When the trial ended, the experimenter retrieved the object from the infant. The second trial was conducted in the same manner using the second object.

Results and Discussion

Mean scores for familiarization and test were analysed separately. Because our primary research questions involved specific contrasts of group means (i.e., comparing narrow- and wide-screen looking times within conditions), we elected to conduct multiple planned comparisons, using the Bonferroni correction to control family-wise error rates (Bonferroni, 1937). This approach is regarded as appropriate and adequately conservative to detect between-group differences (Hancock & Klockars, 1996). In the manipulation assistance

condition, results for familiarization indicate that infants look equally whether subsequently tested with the narrow screen ($M = 32.63$, $SD = 8.57$) or the wide screen ($M = 26.65$, $SD = 8.49$), $F(1, 14) = 1.96$, $p = .18$, $\eta_p^2 = .12$. Similar results were obtained in the social interaction condition, with infants looking equally long whether subsequently tested with the narrow screen ($M = 30.78$, $SD = 6.28$) or the wide screen ($M = 27.93$, $SD = 10.50$), $F(1, 14) = 0.43$, $p = .52$, $\eta_p^2 = .03$. This outcome was to be expected because all infants saw the same familiarization event.

Preliminary analyses of test trial data revealed heterogeneity of variance, so data were square root transformed.¹ Means reported below are prior to transformation to allow more effective comparisons. Planned comparisons revealed that the 9.5-month-olds who received social interaction, but no assistance manipulating the objects during multisensory object exploration looked longer at the narrow-screen event ($M = 18.69$, $SD = 5.64$) than the wide-screen event ($M = 12.07$, $SD = 3.44$), $F(1, 14) = 8.88$, $p = .01$, $\eta_p^2 = .38$. In contrast, infants who received assistance only in manipulating the objects without the social input from the adult looked about equally at the narrow ($M = 18.32$, $SD = 8.68$) and wide-screen events ($M = 14.32$, $SD = 4.82$), $F(1, 14) = 0.98$, $p = .33$, $\eta_p^2 = .06$. These results suggest that when assistance manipulating the objects was withdrawn leaving only the social elements of adult engagement, the 9.5-month-olds later individuated the differently coloured objects. However, when social interaction was withdrawn during the object exploration period, infants showed no evidence of subsequently individuating the objects.

Additional Analyses

Given that past studies have demonstrated that the duration of looking and touching objects during multisensory exploration appears to influence subsequent individuation of those objects (Wilcox et al., 2007; Woods & Wilcox, 2013), we further examined infants' exploratory behaviours. Videos of the object exploration trials were available for 45 of the infants from Experiments 1a and 1b; videos were not available for 3 infants due to parents' request or equipment malfunction. Videos were coded for duration of looking at and touching the objects. Furthermore, in order to assess the effect of multimodal exploration, simultaneous looking and touching was also calculated. The Observer® XT 9.0 software by Noldus was used for coding. Coder reliability averaged 95%. Behaviour duration was calculated for each of the two object exploration trials then averaged across trials for each infant. Mean durations were analysed using a multivariate analysis of variance (MANOVA) with exploration trial type (full assistance, manipulation only, or interaction only) as a between-subjects factor.

Analyses revealed a main effect of object exploration treatment for duration of looking, $F(2, 42) = 10.15$, $p < .001$, $\eta_p^2 = .33$. Planned comparisons revealed that 9.5-month-old infants looked significantly longer at the objects during the object exploration trials when provided with solely manipulative assistance ($M = 42.05$, $SD = 8.08$), as compared to those who received full assistance ($M = 33.34$, $SD = 8.58$) or social interaction only ($M = 29.03$, $SD = 8.30$). Touching durations, however, did not differ between conditions, all $p > .05$, $\eta_p^2 < .09$ (full assistance, $M = 39.90$, $SD = 11.87$; manipulation only $M = 36.49$, $SD = 13.10$; interaction only $M = 45.40$, $SD = 13.01$). For duration of simultaneous looking and

touching, analyses revealed a main effect, $F(2, 42) = 4.45$, $p = .02$, $\eta_p^2 = .18$. Planned comparisons revealed that infants spent far less time engaging in simultaneous looking and touching during object exploration trials when provided with solely manipulative assistance ($M = 9.31$, $SD = 5.84$), as compared to infants who received full assistance ($M = 15.32$, $SD = 5.83$) or social interaction only ($M = 15.52$, $SD = 7.28$).

The results of these analyses indicate that the outcome of Experiment 1 is not simply due to longer looking at or touching the objects. Infants' touching was largely the same across treatments and differences in looking at the objects were counter to what would be expected to lead to the outcomes observed. That is, the 9.5-month-olds spent less time visually attending to the objects during the object exploration trials that led to successful individuation (full assistance and interaction-only conditions) relative to the object exploration trials that did not (manipulation-only condition). However, the results of the multisensory object exploration (simultaneous looking and touching) indicate that the type of support experimenters provide uniquely influences these behaviours. Specifically, when social interaction alone or full assistance was provided, infants spent a greater amount of time in multimodal object exploration.

Taken together, the results of Experiment 1 identify social interaction as a particularly influential component of adult assistance for 9.5-month-olds and suggest that the advantage may be the result of an increase in the amount of time spent in multisensory object exploration. When provided only social interaction, 9.5-month-olds still demonstrate successful individuation based on colour differences. However, when provided only manipulative assistance, the ability to individuate is not demonstrated. Is this a persistent developmental trend, or might these results be unique to 9.5-month-old infants? To test this question, the same methods and experimental manipulations were conducted with 4.5-month-old infants, exploring whether and how adult assistance impacts individuation of objects based on pattern.

EXPERIMENT 2A

In Experiment 2a, we assessed 4.5-month-old infants' use of objects' surface pattern differences to individuate objects following adult-assisted object exploration. Our primary goal was to determine whether adult assistance during object exploration has the same impact on 4.5-month-olds as it does on 9.5-month-olds.

Method

Participants—Sixteen 4.5-month-old infants (8 F) were pseudo-randomly assigned to either the narrow- or wide-screen conditions.

Apparatus, stimuli, events, and procedures—The events used in Experiment 2a were identical to those used in Experiment 1a with the exception of the objects used. The 4.5-month-olds saw two green balls, one painted with red, yellow, and blue dots, and the other painted with red, yellow, and blue stripes (see Figure 2). The dotted ball replaced the green ball of Experiment 1a and the striped ball replaced the red ball. Also, because 4.5-month-olds are typically unable to sit up without support, they were placed in a Bumbo™ seat

during object exploration. Interobserver agreement across Experiments 2a and 2b averaged 89% per test trial per infant.

Results and Discussion

Mean looking times during familiarization and test trials were analysed separately, in the same manner as Experiment 1a (see Figure 5). Results revealed no statistically discernable differences during familiarization trials, $F(1, 14) = 0.01$, $p = .89$, $\eta_p^2 = .001$, (narrow screen, $M = 29.81$, $SD = 14.06$; wide screen $M = 29.06$, $SD = 8.68$).

Preliminary analyses revealed test data were not normally distributed, so data were square root transformed. Means are reported prior to transformation to enable effective comparisons.² Analyses indicated that infants who saw the narrow-screen event ($M = 32.92$, $SD = 8.89$) looked longer than infants who saw the wide-screen event ($M = 19.96$, $SD = 7.20$), $F(1, 14) = 9.39$, $p = .008$, $\eta_p^2 = .40$. This outcome suggests that following the adult-assisted multisensory object exploration, the 4.5-month-olds individuated the objects based on pattern differences.

EXPERIMENT 2B

The primary goal of Experiment 2b was to determine whether the distinct components of adult-assisted object exploration (social interaction and manipulation assistance) differentially influenced 4.5-month-olds' individuation of objects based on pattern differences. While the results of Experiment 2a mirrored those of Experiment 1a, we did not expect this pattern to extend to Experiment 2b. Specifically, we believed that for 4.5-month-olds, both support in object exploration and social engagement are necessary to sufficiently alter their exploratory behaviours in a way that leads to subsequent individuation. Thus, the withdrawal of either manipulation assistance or social engagement would be detrimental.

Method

Participants—Thirty-two 4.5-month-old infants (19 F) were pseudo-randomly assigned one of four conditions formed by crossing treatment during object exploration (social interaction-only or manipulation assistance-only) with screen size used during the test trials (narrow or wide).

Apparatus, stimuli, events, and procedures—Experiment 2b was identical to Experiment 1b, except that the dotted ball and striped ball from Experiment 2a were used, and infants were provided postural support.

²Means and standard deviations for the test trials of Experiment 2a (4.5-month-olds) after transformation were $M = 5.68$, $SD = 0.85$ (narrow screen) and $M = 4.40$, $SD = 0.82$ (wide screen). Means and standard deviations after transformation for the test trials of Experiment 2b for the main effect of treatment were $M = 5.77$, $SD = 1.57$ (manipulation only), and $M = 4.45$, $SD = 0.58$ (social interaction only). Means for individual conditions were $M = 4.26$, $SD = 0.64$ (social interaction only, narrow screen), $M = 4.64$, $SD = 0.47$ (social interaction only, wide screen), $M = 6.32$, $SD = 1.12$ (manipulation assistance only, narrow screen), and $M = 5.21$, $SD = 1.83$ (manipulation assistance only, wide screen).

Results and Discussion

Looking times were analysed in the same manner as Experiment 1b. Planned comparisons revealed that infants in the manipulation assistance condition, $F(1, 14) = 1.97, p = .18, \eta_p^2 = .12$, and social interaction condition, $F(1, 14) = 1.82, p = .19, \eta_p^2 = .11$, looked equally long during familiarization, whether subsequently tested with the narrow screen or wide screen (manipulation assistance, narrow screen, $M = 38.02, SD = 11.96$; manipulation assistance, wide screen, $M = 30.81, SD = 8.19$; social interaction, narrow screen, $M = 29.93, SD = 9.52$; social interaction, wide screen, $M = 34.42, SD = 8.47$).

Preliminary analyses revealed that test data were not normally distributed, so data were square root transformed. Means are reported prior to transformation to enable effective comparisons.² Planned comparisons indicated that infants who received only manipulation assistance during object exploration, $F(1, 14) = 2.09, p = .17, \eta_p^2 = .13$, or only social interaction during object exploration, $F(1, 14) = 1.82, p = .19, \eta_p^2 = .11$, looked about equally at the two events (manipulation assistance, narrow screen, $M = 41.08, SD = 13.65$; manipulation assistance, wide screen, $M = 30.19, SD = 19.09$) social interaction, narrow screen, $M = 18.55, SD = 5.42$; social interaction, wide screen, $M = 21.81, SD = 4.27$), suggesting that when the 4.5-month-olds received only manipulation assistance or only social interaction during the object-exploration phase, they did not subsequently use the objects' pattern differences for individuation.

Additional Analyses

Videos of the object exploration trials of 46 infants from Experiments 2a and b were coded in the same manner as those for Experiments 1a and b. For two infants, videos were not available due to equipment malfunction or parent request. Analyses revealed a main effect of object exploration type for duration of looking, $F(2, 43) = 7.82, p = .001, \eta_p^2 = .26$, in which infants who received only social interaction during the object exploration trials ($M = 36.20, SD = 11.85$) looked at the objects for a shorter duration than infants in both the full-assistance, ($M = 49.50, SD = 11.25$) and the manipulation-only ($M = 48.84, SD = 7.65$) object exploration trials. The 4.5-month-olds' duration of touching did not differ between conditions, $F(2, 43) = 0.66, p = .52, \eta_p^2 = .03$ (full assistance, $M = 38.87, SD = 10.38$; manipulation only $M = 39.06, SD = 10.74$; interaction only $M = 35.13, SD = 10.68$). Analyses did reveal a main effect for duration of multisensory exploration (simultaneous looking and touching), $F(2, 43) = 5.36, p = .008, \eta_p^2 = .19$. Planned comparisons revealed that infants spent more time engaged in multisensory object exploration when provided with full assistance ($M = 25.65, SD = 10.01$), as compared to those provided with solely manipulative assistance ($M = 13.93, SD = 8.52$). Amount of time engaged in multisensory exploration in the interaction-only condition did not significantly differ from other conditions ($M = 18.63, SD = 11.30$).

The results of these analyses partially mirror those in Experiment 1. The duration of looking or touching *alone* did not explain the effect of adult involvement on infants' subsequent object individuation. However, infants who successfully individuated (full assistance) spent the greatest amount of time engaged in multisensory object exploration. These results

suggest that one way in which adult involvement may impact subsequent individuation is by enhancing the multisensory experience.

GENERAL DISCUSSION

The goal of this study was to assess the impact of adult involvement on infants' ability to individuate objects based on feature differences. Previous research has definitively established the importance of infants' own actions on objects for their learning about these objects (e.g., Baumgartner & Oakes, 2013; Gerson & Woodward, 2013; Hauf, Aschersleben, & Prinz, 2007; Libertus & Needham, 2010; Sommerville, Hildebrand, & Crane, 2008). Experimental work has shown that external manipulations can successfully augment infants' object-oriented motor behaviours using both motor and social influences (Lobo & Galloway, 2008; 2012; Needham, Barrett, & Peterman, 2002; Woods & Wilcox, 2013). The current study included two experiments to examine how adult involvement during multisensory object exploration impacts infants' own exploratory skills and subsequent object individuation at distinct developmental time points.

As predicted, following adult-guided object exploration, both 9.5- and 4.5-month-old infants individuated objects based on colour and pattern, respectively, following adult-assisted multisensory object play. These results add to our understanding of young infants' capacities for object individuation by demonstrating this skill at ages when infants have been previously unsuccessful. Subsequent experiments examined isolated components of adult assistance (manipulative assistance vs. social interaction) in order to assess whether the findings in Experiments 1a and 2a could be explained by a particular set of adult behaviours. The differing result of these manipulations across the two ages revealed an interesting pattern that highlights the interaction of developmental stage and experience on object processing. The 9.5-month-old infants successfully individuated objects based on colour following social interaction, but not manipulation assistance. Conversely, 4.5-month-olds failed to individuate objects following either condition. The utility of these experimental manipulations becomes evident when comparing infant behaviours during object exploration across conditions. Examinations of the behaviours in which infants engaged during the object exploration trials show that infants generally engaged in longer durations of multisensory object exploration (simultaneous looking and touch) during conditions in which they successfully individuated objects than in conditions in which they failed. There were no such consistent differences in examinations of unimodal tactile or visual exploration that could explain the pattern of results in test trials. As such, it appears that certain types of adult guidance scaffold infants' multisensory exploratory behaviour in a meaningful way.

In previous studies of the influence of multisensory object exploration on object individuation, Wilcox et al. (2007) proposed that infants benefitted from multisensory object exploration because multisensory experiences encourage integration of feature information and serve to focus infants' attention to the object in a way that is not possible through unimodal exposure. This proposal was based on research by Lorraine Bahrick and her colleagues (Bahrick, 2001; Bahrick & Lickliter, 2000; Bahrick, Lickliter, & Flom, 2004), who suggested that multisensory experiences promote the formation of multisensory object representations that are more detailed and robust than unisensory object representations

formed via exposure in a single modality. Even intermodal relations (i.e., linking the tactile experience of shape to colour) can be facilitated through multisensory exposure (Bahrick, 1994; Hernandez-Reif & Bahrick, 2001). While our 4.5-month sample is younger than those in previous studies, it is possible that the same principle applies during adult-guided multisensory exploration. Thus, when infants engaged in longer durations of multisensory object explorations, they were able to form more sophisticated and enduring representations of the target objects, enabling successful individuation of those objects in the subsequent task.

The effectiveness of particular conditions on subsequent individuation was influenced by infants' age and developmental abilities. The impact of adult assistance on enhancing infants' object exploration is only useful when objects can be skillfully manipulated. For the 4.5-month-olds, the social cues made available in the current study, when isolated (i.e., interaction-only condition), were not sufficient to result in object individuation. Similarly, assistance in manipulating objects was not sufficient to promote object feature-based object individuation when isolated (i.e., manipulation-only condition). That is not to say, however, that these components are not important to infants' effective object exploration. In fact, we argue that it is the influence of these forms of assistance in concert that allows infants of any age to successfully individuate objects based on feature differences. While younger infants are not as sophisticated as their older counterparts in the utilization of social cues, they do attend to and make use of this interpersonal information (D'Entremont et al., 1997). In order for the benefits of social engagement to result in object individuation, however, skilled object manipulation was also necessary. Therefore, the 4.5-month-old infants needed both components of adult assistance to support object processing.

When skilled object manipulation is not a challenge, social engagement plays a fundamental role in increasing attention and focus to target objects at both ages. Research by Reid and colleagues (2004) shows that 4-month-old infants experience enhanced neural processing of objects that are the target of an adult's eye gaze. This study provides clear neurological evidence that infants are sensitive to the attentional signals provided during adult-infant interactions and that gaze cues convey information about what is important to attend for further processing. Wu and colleagues (2011) similarly demonstrated enhanced attention and accuracy in 9-month-olds during a target identification task when a social cue was added. These studies show that one way adult involvement may facilitate object processing is by filtering out 'noise' within object processing tasks thereby supporting focus to the object and the features that are most relevant to the task. In the current study, the adult experimenters' attention to the features of the objects may have provided a cue as to what was important to attend to during haptic exploration, ostensibly resulting in a more complete representation of the object, including its colour and pattern, which in turn resulted in formation of a new object representation when the features differed.

Multisensory object exploration occurs naturally, frequently, and has a profound effect on infants' perception and knowledge of objects (e.g., Gibson, 1988; Ruff, 1984; Wilcox et al., 2007; Woods & Wilcox, 2013). However when infants are at the lower end of their ability to deploy attention efficiently to target objects, solo multisensory experience may not be sufficient. Vygotsky (1978) proposed that every learner has a zone of proximal development

that represents what they are unable to achieve on their own, but can achieve if given the proper support. In many interactions, this support takes the form of scaffolding, in which the more skilled individual provides guidance and support in the domains in which the learner is not yet adept. The addition of a skilled adult experimenter during object exploration provided scaffolding, raising infants to a level of exploratory and attentional skill they would not be able to achieve on their own. This study also informs our understanding of the developmental limitations or biases in the type of support provided. While social support alone influenced object individuation abilities of 9.5-month-olds, this same type of support was not sufficient for the individuation abilities of 4.5-month-olds. For the adult-assisted object exploration to be effective, the support provided needed to be appropriately matched to the developmental skills and abilities of the learner.

The results of the current study directly apply to our understanding of the developmental trajectory of object individuation abilities in the first year, and the factors that shape it. However, these findings have broader implications for the impact of adult-guided learning on a number of early skills. Because adult involvement acts to enhance object individuation by changing *infant* behaviours, it stands to reason that this involvement and its effects on multisensory exploration by infants would generalize to other skills, such as object representation, categorization, or word learning. Future research should assess whether the scaffolding effects of adult guidance on multisensory exploration extend to enhancements in learning in other domains. Overall, the results of this study add to a growing literature on the true skills and abilities of young infants when examined in appropriately supportive contexts (Cleveland & Striano, 2007; Lawson, Parrinello, & Ruff, 1992; Needham, Barrett, & Peterman, 2002; Woods & Wilcox, 2013; Wu, Gopnik, Richardson, & Kirkham, 2011).

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Figure 1.
Schematic drawing of the apparatus, narrow-test screen, and objects as seen from the infants' (a) and experimenter's (b) point of view.

Figure 2.
Photos of the objects seen by the 4.5-month-olds (a, b) and 9.5-month-olds (c, d) in Experiments 1 and 2. Objects were never seen together.

Figure 3.

Presentation of the object during the full-assistance object exposure trials of Experiment 1a and the social interaction-only and manipulation-only object exposure trials of Experiment 1b.

a. Familiarization Event **b. Narrow-Screen Test Event** **c. Wide-Screen Test Event**

Figure 4. Object motion sequence during familiarization (a), narrow-screen (b), and wide-screen (c) test trials of Experiments 1 and 2.

* Significance at $p < .05$

Figure 5.

Mean looking times with standard error bars during the familiarization and test trials of Experiments 1a and 2a, prior to transformation, as a function of screen size used during the test trials.