3-1-2018

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MSU Digital Commons Citation

Yang, Jennifer and Merrill, Edward C., "Implicit Memory of Locations and Identities: A Developmental Study" (2018). *Department of Psychology Faculty Scholarship and Creative Works*. 270.
https://digitalcommons.montclair.edu/psychology-facpubs/270

Journal of Experimental Child Psychology 167 (2018) 162–179

Contents lists available at ScienceDirect

Journal of Experimental Child Psychology

journal homepage: www.elsevier.com/locate/jecp

Implicit memory of locations and identities: A developmental study

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ARTICLE INFO

Article history:
Received 9 September 2016
Revised 23 October 2017
Available online 22 November 2017

Keywords:
Implicit learning
Location
Identity
Visual search
Working memory
Children

ABSTRACT

Objects in the environment have both location and identity properties. However, it is unclear how these independent properties are processed and combined in the implicit domain. The current study investigated the development of the implicit memory of object locations and object identities, both independently and combined, and the relation between implicit memory and working memory (WM) for these properties. Three age groups participated: 6- and 7-year-old children, 9- and 10-year-old children, and adults. Children and adults completed a repeated search paradigm. In the learning phase, targets' locations were consistently predicted by both the identities and locations of the distracters. In the test phase, either both remained predictive or just the identities or just the locations of the distracters predicted the location of the target. All groups showed significant implicit learning when both the identities and locations of the distracters remained predictive. When only the locations but not the identities of the distracters were predictive, adults and 9- and 10-year-olds showed significant learning, whereas 6- and 7-year-olds did not. When only the identities but not the locations of the distracters were predictive, none of the groups showed significant learning effects. In evaluating the contributions of either visual or spatial WM to implicit learning and memory, we found that children with smaller visual WM exhibited larger implicit memory effects for object identities than

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https://doi.org/10.1016/j.jecp.2017.10.015

did children with larger visual WM. Taken together, the results indicate that children's ability to differentiate identity and location undergoes development even in the implicit domain.

Introduction

All objects in the environment afford at least two kinds of information for processing: information about their identity, such as shape and color, and information about their spatial location. The human brain seems to be able to integrate identity and location information rather seamlessly. However, object information and location information are generally mapped onto different neural pathways in the visual system (Haxby, Horwitz, Ungerleider, & Maisog, 1994; Pihlajamäki et al., 2005; Zachariou, Klatzky, & Behrmann, 2014). The identity information or object properties (e.g., shape, color) correspond to the "what" or ventral stream (occipitotemporal lobes). The spatial information (e.g., location, size) corresponds to the "where" or dorsal stream (occipitoparietal lobes). Research has demonstrated that these two systems are anatomically and functionally distinct for healthy young adults, young adults with intellectual disabilities, and healthy infants (Chinello, Cattani, Bonfiglioli, Dehaene, & Piazza, 2013; Haxby et al., 1994; Mareschal & Johnson, 2003; Paul, Stiles, Passarotti, Bavar, & Bellugi, 2002; Pihlajamäki et al., 2005; Woodcock, Humphreys, & Oliver, 2009). Whereas the majority of previous studies have focused on differences in explicit memory processing of identity versus location information, the goal of the current study was to investigate the development of implicit memory for object identities and object locations. Our study may help to illustrate whether the dissociation between object location and object identity memory is also present during implicit information processing activities and whether the ability to separate these two dimensions undergoes developmental change.

Identity and location memory

Generally speaking, research suggests that remembering object location information is more incidental and less effortful than remembering object identity information. Early theoretical perspectives actually proposed that location information may be encoded automatically (Ellis, Katz, & Williams, 1987; Hasher & Zacks, 1979, 1984). This relatively extreme position has not received much support in the literature in that location memory is influenced by several properties that affect effortful processing such as intention, competing tasks, and practice (Cestari, Lucidi, Pieroni, & Rossi-Arnaud, 2007; Naveh-Benjamin, 1987; Puglisi, Cortis Park, Smith, & Hill, 1985; Siemens, Guttentag, & McIntyre, 1989). However, it does seem that locations may be easier to remember than identities. A brief snapshot of a display may be enough for adult participants to register location memories of the items in the display, which can be viewed as one holistic visual pattern (Haladjian & Mathy, 2015). By contrast, identity memories of heterogeneous items in the display would require a series of eye movements examining each item in detail (Beck, Peterson, & Vomela, 2006; Hollingworth, 2007; Huang & Grossberg, 2010).

The difference between explicit object identity and object location memories is also evident in their developmental trajectories. In a typical study, researchers present child participants with objects in identifiable locations and then instruct them to explicitly recall identity information, location information, or both. Throughout childhood, although age differences always seem to be found for object identity memory, it is common to find similarities across age or smaller age differences for object location memory (e.g., Cestari et al., 2007; Heil & Jansen, 2008; Jansen-Osmann & Heil, 2007; Lange-Küttner, 2010; Pentland, Anderson, Dye, & Wood, 2003; Van Leijenhorst, Crone, & van der Molen, 2007). In addition, researchers generally agree that the ability to recall both location and identity information develops more slowly than the ability to recall either dimension separately for children aged 5–12 years (Cestari et al., 2007; Pentland et al., 2003; Schumann-Hengsteler, 1992; Siemens et al., 1989). For example, Cestari et al. (2007) suggested that memory retrieval for the combined information is relatively more difficult because it requires the integration of information acquired through two separate components of visuospatial memory.

Implicit memory of identity and location

Recent research has also indicated that both object identity and object location can be processed implicitly, or without conscious awareness and intention (e.g., Deroost et al., 2010; Jiménez & Méndez, 1999; Reber, 1992). However, little is known about the developmental trajectories associated with the implicit learning of object location versus object identity. This is important because in real-world settings implicit learning is an important mechanism for acquiring information from the environment. For instance, you might never intend to remember the exact layout of the supermarket that you frequent. However, shopping will be a lot faster and easier in a familiar store relative to a new store. That is likely because you were able to pick up information about the layout of the supermarket without intention and awareness. Because of this mechanism, we are able to free up more cognitive resources to do things that are more mentally consuming such as deciding what items to purchase.

Implicit learning and memory of identities and locations can be studied using the contextual cueing paradigm (Chun & Jiang, 1998; Jiang & Chun, 2001). In a typical contextual cueing task, participants search for a target amid distracters in several displays. Unbeknownst to the participants, several displays are “repeated” displays, in which the relative locations of the distracters to the target (i.e., contexts) remain the same over trials. Because the same context is consistently paired with a single target location, the repeated displays are predictive of the target location. In “new” displays that are seen only once, the contexts are random from trial to trial. Because the context has not been seen previously, the new displays are not predictive of the target location. After a number of exposures to the repeated displays, participants can locate the target faster in those displays than in the new displays. Importantly, the researchers never asked participants to remember the context, and participants usually have no conscious awareness about the repetitions, indicating that contextual cueing is relatively implicit in nature (Chun & Jiang, 1998, 2003; Chun & Phelps, 1999; Jiménez & Vázquez, 2011; however, see Smyth & Shanks, 2008). Hence, in contextual cueing, participants have implicitly associated a target location with a set of distracters defined by their locations and/or identities.

The contextual cueing paradigm can elicit both location and identity effects, depending on which type of information about the distracters predicts the location of the target (Chun & Jiang, 1998, 1999). In particular, the observation of facilitation when distracter identities remain constant and distracter locations vary indicates contextual cueing based on distracter identity. Similarly, the observation of facilitation when distracter locations remain constant and distracter identities vary indicates contextual cueing based on distracter locations. Interestingly, these different implicit effects have been associated with the separate pathways for processing location and identity information. Following an extensive literature review, Huang and Grossberg (2010) proposed a model for the neural mechanisms of contextual cueing based on behavioral and neuroscience data. They suggested that the spatial (location) aspect of contextual cueing is linked to the dorsal “where” pathway, including regions such as posterior parietal cortex, parahippocampal cortex, and dorsolateral prefrontal cortex. The object (identity) aspect of contextual cueing is linked to the ventral “what” pathway, including regions such as anterior inferotemporal cortex, perirhinal cortex, and ventral prefrontal cortex.

Research using the contextual cueing task has suggested that, much like explicit memory, implicit memory for object identity and object location may also be processed via different pathways. For example, Endo and Takeda (2004) first presented participants both-repeated displays in the learning phase, where both the identities and locations of the distracters were predictive of the target identity and location. In the testing phase, the previously viewed both-repeated displays were altered so that only one dimension (either identity or location) was still predictive of the target, whereas the other dimension was rendered random and unpredictive. Participants showed significant learning when the test displays included new objects (i.e., different identities) in the same locations as the distracters on the both-repeated displays (i.e., *location-repeated* condition). However, participants showed no learning effects when the test displays preserved only the repeated identities but varied the locations of the distracters of the both-repeated displays (i.e., *identity-repeated* condition). Hence, when both identities and locations were predictive of the target during acquisition, participants were able to use preserved location information, but not preserved identity information, to locate the target during the test phase. This indicated that in repeated visual search, adult participants were able to extract location information, but not identity information, from the associations that were formed (see also Hollingworth, 2007). However, Endo and Takeda (2004) employed abstract contoured shapes that were unfamiliar and nameless, rather than identifiable objects, as search items. It is possible that difficulties in encoding the "identities" of these shapes may have precluded participants from effectively remembering identity information about the distracters. Using real-world, namable objects (e.g., chairs, coffee makers), Hout and Goldinger (2010) asked participants to search for new targets among repeated distracters. Search performance was facilitated when the identities of distracters were repeated, rather than varied, from trial to trial. Performance was the best when the repeated distracter identities were also consistently associated with repeated spatial locations. In addition, search performance was better when the distracter identities were repeated and the distracter locations varied compared with when the distracter locations were repeated and the distracter identity mapping varied. That is, the consistency of distracter identities benefited search performance more than the consistency of distracter locations. Taken together, when distracter identities are identifiable and can be easily coded, it appears that identity may play an important role in facilitating search for the target.

The current study

The goal of the current study, therefore, was to investigate the age-related changes in the acquisition of implicit memories of location and identity information. The flexible integration and separation of object location and object identity memories may require extended development. The memory of the identity and location of an object may be represented in a unified or holistic manner for children, particularly younger children (e.g., < 7 years; Barrett & Shepp, 1988; Lange-Küttner & Küttner, 2015; Shepp, Barrett, & Kolbet, 1987; Treisman, 1993, 2006). With increased age or repeated exposure, children may gradually be able to separate them into different dimensions (Barrett & Shepp, 1988; Shepp & Barrett, 1991; Shepp et al., 1987). However, because implicit memory processes are less affected by strategic and conscious differences (Chun & Jiang, 1998; Reber, 1992; Vickery, Sussman, & Jiang, 2010), they may undergo a different developmental course than that suggested by developmental changes in explicit memories.

The current study included three groups of participants: 6- and 7-year-old children, 9- and 10-year-old children, and adults. These ages were chosen for two reasons. First, Yang and Merrill (2014) found that children as young as 6 years exhibit basic implicit spatial learning in the contextual cueing paradigm (see also Yang & Merrill, 2015a, 2015b). Therefore, contextual cueing can be used to evaluate the research question in these age groups. Second, explicit memory research suggests that the age range of 6–10 years reflects an important transition period for the successful differentiation of identity and location information processing (e.g., Booth et al., 2000; Lange-Küttner & Küttner, 2015; Nelson et al., 2000; Passarotti et al., 2003; Thomas et al., 1999; Vuontela et al., 2009). Hence, it is reasonable to expect that if age-related differences in the processing of identity and location information are to be found in implicit learning, we would observe them during this developmental period.

Participants completed a modified contextual cueing task. In the learning phase of the task, they were presented with consistent associations between the target and both the identities and locations of the distracters. Then, in the test phase, the search displays were altered to assess the strength of association between target location and each individual dimension (i.e., location or identity) of the distracters. More specifically, the test displays either retained the identities of the distracters and varied their locations or retained the locations of the distracters and varied their identities. Although similar to Endo and Takeda (2004), our study differed in two key ways. First, in our study participants simply indicated the facing direction rather than the location of the target as in Endo and Takeda's study. Responding to locations may encourage participants to focus on processing location information and subject that information to more effortful and explicit processing. Our task should minimize explicit location processing and, thus, reflect a more implicit measure. Second, we used real-world namable objects (Hout & Goldinger, 2010) as search items instead of abstract contours (Endo & Takeda, 2004).

The real-world objects should be more engaging particularly to our young participants and can be encoded for identity more easily. The additional semantic and verbal cues associated with the search items may encourage deeper encoding and elicit greater learning of the identities of the distracters.

Participants also completed visuospatial working memory (WM) tasks to help evaluate the relationship between implicit learning and WM. WM provides the repository to filter out irrelevant information and extract meaningful information before processing into long-term memory (Baddeley, 1992, 1998; Manginelli, Baumgartner, & Pollmann, 2013a; Manginelli, Langer, Klose, & Pollmann, 2013b). Previous literature holds that implicit memory and WM are largely independent. In fact, WM is generally considered highly explicit in nature. However, adult studies of implicit spatial learning and visuospatial WM indicate that the two may be related. For example, concurrent WM tasks in the testing phase, but not in the learning phase, interfered with the observation of implicit spatial learning in adults (Manginelli et al., 2013b; Travis, Mattingley, & Dux, 2013; Vickery et al., 2010). Manginelli et al. (2013a) also found that WM-related brain regions were involved in contextual cueing. More specifically, the activation of the dorsal WM-related brain areas (e.g., intraparietal and transverse occipital sulci) was correlated with the magnitude of the contextual cueing effects, thereby implying that they have a role in maintaining the implicit memory templates for the contextual cueing effects. The ventral WM-related brain areas (e.g., temporoparietal junction) were activated for the repeated displays relative to the new displays, thereby implying their role in capturing bottom-up attention by the repeated/memorized displays in producing contextual cueing effects.

In Yang and Merrill (2015b), younger children, but not older children, were unable to acquire implicit spatial learning when the repeated displays were interspersed with a large number of new displays during acquisition. The authors suggested that this may be due to young children's smaller visuospatial WM capacities. With a smaller WM capacity, younger children would be less able to recognize and retrieve repeated spatial templates experienced many trials ago. To our knowledge, no studies have directly examined whether children's WM capacities would limit their implicit spatial learning. The current study did just that. In our study, evaluating age-related WM differences may help to explain any observed differences in the implicit learning of identities and locations across ages (Couperus, Hunt, Nelson, & Thomas, 2011; Yang & Merrill, 2015b). In addition, because visuospatial WM can be further distinguished into both a visual component and a spatial component (Logie, 1995; Smith & Jonides, 1999), we included a visual WM task and a spatial WM task. This may help to clarify whether the identity and location processing is modular in children (Lange-Küttner & Friederici, 2000), in which case WM should relate to implicit learning only if it is in the same domain.

Method

Participants

We recruited 31 college students, 33 younger children (6- and 7-year-olds), and 33 older children (9- and10-year-olds). Children were recruited from local elementary schools. Two children from the 6- and 7-year-old group and two children from the 9- and 10-year-old group failed to complete the visual search task and were removed from the study. The final sample consisted of 31 college students (18–20 years old; 15 women and 16 men), 31 younger children (18 boys and 13 girls; M_{age} = 7.06 years, SD = 0.64, range = 6.0–8.0), and 31 older children (16 boys and 15 girls; M_{age} = 10.03 years, SD = 0.56; range = 9.08–11.0). College students were paid $4, and children were given small gifts for their participation. All the recruitment and testing procedures followed the institutional review board guidelines of the university.

General procedures

Adult participants were tested individually in our lab at the university. Child participants were tested individually in our lab, at their school, or at their home at the convenience of the parents. Participants first completed the contextual cueing task, followed by the two WM tasks. The testing procedure with breaks included took about 30 min for adults and 40–60 min for children.

Contextual cueing

Materials. A total of 57 unique black and white images were selected from Snodgrass and Vanderwart (1980) and used as the search items. All items had clear features and were easily identifiable by children. The motorcycle image was designated as the target (see Fig. 1). The rest of the images

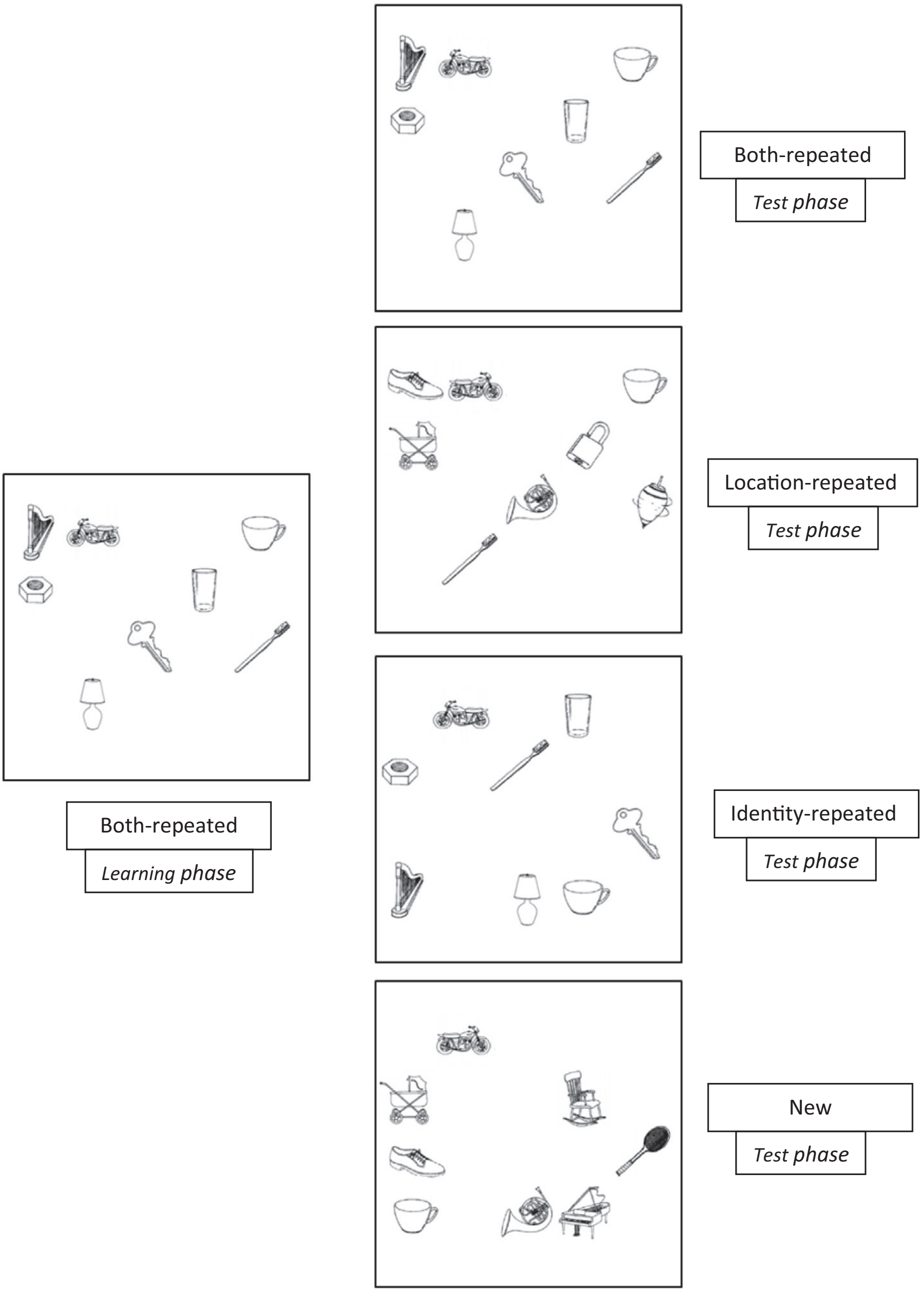


Fig. 1. Example displays. The both-repeated acquisition display is on the left. The target was the motorcycle. The pictures on the right were presented in different test conditions based on the both-repeated picture on the left.

(e.g., broom, brush, crown, train) were used as distracters. Each search display was composed of seven randomly selected distracters and the target in an invisible 5×5 grid.

Four different types of displays were created. One type was designated the both-repeated displays. These displays included eight configurations randomly generated for each participant at the start of the experiment. Four target locations (one in each quadrant of the display) were randomly assigned to the eight configurations, such that two displays were paired with each target location. This merely simplified the counterbalancing procedure and did not affect the main variables. These configurations were repeated throughout the experiment and used as the both-repeated displays. In the both-repeated displays, both the identities and locations of the distracters predicted the target. The second type of display was the location-repeated displays. In these displays, the locations of the distracters were identical to those of the both-repeated displays. However, the identities of the distracters were randomly selected from the pool of 56 search items anew for each trial. Hence, in location-repeated displays, only locations of the distracters predicted the target. The third type of display was the identity-repeated displays. In these displays, the identities of the distracters were identical to those in the both-repeated displays. However, the locations of the distracters were randomly selected from the 24 possible locations on the invisible grid (excluding the target location) anew at each trial. Hence, in the identity-repeated displays, only the identities of distracters predicted the target. The fourth type of display was the new displays. In the new displays, both the identities and locations of the distracters were randomly selected for each trial. Hence, in the new displays, neither the identities nor locations of the distracters predicted the target. The target locations in these four conditions were the same. Thus, any difference between conditions should not be attributed to the repetition of target locations but rather the context. The both-repeated displays were used in the acquisition and testing phases. The location-repeated, identity-repeated, and new displays were used only in the testing phase. See Fig. 1 for examples of four types of displays in the testing phase, which were constructed based on the repeated display in the learning phase.

Procedures. The task was programmed in Matlab PsychToolbox 3.0.12. All the stimuli were presented in a 15.6-in. Lenovo laptop computer. Participants were told that they would be playing an “I spy” computer game. In this game, participants needed to find the target motorcycle, decide which way it was facing, and press the corresponding key on the keyboard. Both speed and accuracy were emphasized. On each trial, there was a fixation cross presented for 750 ms, followed by a blank screen for 750 ms. Then, the search display appeared and participants pressed the key on the computer keyboard indicating whether the target was facing left (z) or right (m). The search display stayed on the screen until participants made a response, followed by a blank screen for 750 ms before the start of the next trial. All participants received 4 trials of random configurations as practice prior to the start of the experimental trials. Only after making sure that the participants understood the task would the experimenter administer the task.

The contextual cueing task was composed of a learning phase and a testing phase. The learning phase consisted of 10 blocks of 16 both-repeated displays. Within each block, each of the eight repeated configurations appeared twice (i.e., once with the target facing left and once with the target facing right). Hence, each repeated configuration was repeated 20 times altogether in the learning phase. The test phase was composed of two blocks. Each block consisted of 16 both-repeated, 16 location-repeated, 16 identity-repeated, and 16 new displays. In the example of Fig. 1, the picture on the left was repeated 10 times with the target facing left and 10 times with the target facing right in the learning phase. Each picture on the right was repeated two times with the target facing right and two times with the target facing left in the test phase. A flowchart depicting the sequence of events within each trial in the learning and test phases can be found in Appendix A. Trials within each block were randomized. Breaks were offered after every two blocks in the learning phase and between blocks in the test phase. Participants were given as much time as they needed at each break. To further encourage the youngest participants, they also earned one sticker after each break for a total of seven stickers.

Explicit memory test. After the test phase, there was an explicit memory test. Participants were presented with 8 both-repeated displays and 8 newly created displays. They were asked to decide whether they had seen them in the search task.

Working memory

We constructed two visuospatial WM tasks—one for location (spatial WM) and one for identity (visual WM)—both patterned after Simmering (2012). The order of the two WM tasks was counterbalanced between participants. Because two tasks were similar in format, the experimenter made sure that the participants understood the instructions before the start of each task.

Spatial WM. This was a change detection task (Simmering, 2012; Simmering, Miller, & Bohache, 2015). Participants first saw an array of shapes in different locations and were asked to decide whether a second array was identical to or different from the first one. Within each trial, there was first a fixation cross lasting for 1000 ms, followed by a blank screen for 1000 ms. Then, participants saw some shapes in different locations for 500 ms. After a delay of 1500 ms, participants saw the second array of shapes, which stayed on the screen until participants made a response. For half of the trials one shape changed its location to a previously unoccupied location, and for the other half all the shapes remained in the same locations. Participants pressed “q” for same array and “p” for different array. The shapes were randomly drawn from a set of eight different shapes (see Fig. 2) with replacement. Their locations were randomly drawn from a 6×6 invisible grid. The background was black, and the shapes were white. There were five set sizes ranging from 2 to 6. Each set size had 4 trials within each of the three blocks. Trials within each block were randomized. Participants completed a total of 60 trials. Before the formal testing, participants first practiced 4 trials with a set size of 2.

Visual WM. The visual WM used the exact same stimuli as in the spatial WM. However, in half of the trials one shape changed to a different shape, whereas in the other half all the shapes stayed the same. The locations of the shapes did not change. Everything else was the same as in the spatial WM. Participants also completed 60 trials plus the 4 practice trials.

Results

In the following analyses, Bonferroni corrections were used whenever post hoc tests were conducted. In addition, we used multivariate analysis of variance (MANOVA) instead of analysis of variance (ANOVA) when both between-participant and within-participant factors were involved. Relative to ANOVA, MANOVA does not require the assumption of sphericity (O’Brien & Kaiser, 1985) and is more suitable for the data of the current study (see also Jiang & Chun, 2001).

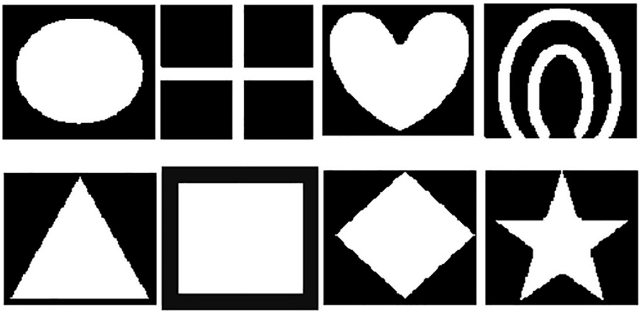


Fig. 2. Eight shapes used in the WM tasks.

Contextual cueing

All participants in the final sample completed the contextual cueing task. We excluded incorrect trials and trials with a reaction time (RT) beyond 3 standard deviations of an individual's mean. This resulted in the removal of fewer than 2% of the trials for each age group. Average RTs within each block in the learning phase and within each condition in the test phase were calculated and used in the following analyses. We first analyzed the learning phase and then the test phase. In the test phase, if participants exhibited significant learning of the distracters' identities, locations, or both, then RTs should be faster in the corresponding repeated conditions than in the new displays.

Learning phase

We conducted a 3 (Group: younger children, older children, or adults) × 10 (Block) MANOVA on the RTs in the learning phase (see Fig. 3). The main effect of group was significant, $F(2, 90) = 81.65$, $p < .001$, $\eta_p^2 = .65$, with college students being faster than 9- and 10-year-olds, who in turn were faster than 6- and 7-year-olds. The main effect of block was also significant, Wilks' $\lambda = .35$, $F(9, 82) = 17.12$, $p < .001$, $\eta_p^2 = .65$, with RTs decreasing over blocks. Tests of within-participant contrasts indicated a significant linear trend, $F(1, 90) = 50.11$, $p < .001$, $\eta_p^2 = .36$.The interaction was significant, Wilks' $\lambda = .66$, $F(18, 164) = 2.13$, $p = .007$, $\eta_p^2 = .19$. Adults exhibited a relatively smaller and more consistent improvement in RT performance across blocks than the other two groups.

Test phase

We conducted a 3 (Group: younger children, older children, or adults) × 2 (Block) × 4 (Condition: both-repeated, identity-repeated, location-repeated, or new) MANOVA on RTs in the test phase. The main effect of group was significant, $F(2, 90) = 95.35$, $p < .001$, $\eta_p^2 = .68$. The main effect of condition was significant, Wilks' $\lambda = .44$, $F(3, 88) = 36.73$, $p < .001$, $\eta_p^2 = .56$. The interaction between group and condition was significant, Wilks' $\lambda = .86$, $F(6, 176) = 2.38$, $p = .031$, $\eta_p^2 = .08$. All the other effects were not significant.

For each age group, we conducted a one-way repeated-measures ANOVA examining the implicit memory effects. Because the main effect of block was not significant in the overall analysis, we averaged the RTs in two blocks. For adults, the main effect of condition was significant, $F(3, 90) = 23.39$, $p < .001$, $\eta_p^2 = .44$. Post hoc tests suggested faster RTs in the both-repeated condition (661 ms) than in the new condition (706 ms), $p < .001$. RTs were also faster in the location-repeated condition (685 ms) than in the new condition, $p = .015$. There was no difference between RTs in the identity-repeated condition (707 ms) and those in the new condition. Hence, adult participants demonstrated significant contextual cueing effects in the both-repeated and location-repeated displays.

For 9- and 10-year-olds, the main effect of condition was significant, $F(3, 90) = 15.51$, $p < .001$, $\eta_p^2 = .34$. Post hoc tests suggested significantly faster RTs in the both-repeated condition (973 ms) than in

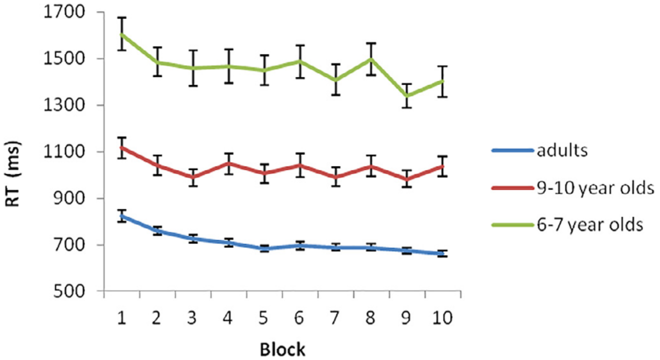


Fig. 3. RT (in milliseconds) in the learning phase for the three age groups. Error bars show standard errors.

the new condition (1067 ms), $p < .001$. In addition, RTs were also faster in the location-repeated condition (1014 ms) than in the new condition, $p = .003$. No difference was found between the identity-repeated condition (1041 ms) and the new condition. Hence, like adults, 9- and 10-year-olds could separate location information from the combined locations and identity information implicitly.

For 6- and 7-year-olds, the main effect of condition was significant, $F(2.17, 65.23) = 6.64$ (Greenhouse–Geisser method), $p = .002$, $\eta_p^2 = .18$. Post hoc tests found significantly faster RTs in the both-repeated condition (1383 ms) than in the new condition (1501 ms), $p < .001$. Neither the identity-repeated condition (1441 ms) nor the location-repeated condition (1447 ms) significantly differed from the new condition.

Explicit memory test

Total accuracy in identifying whether a display had been repeated was subject to a one-way ANOVA. The main effect of group was not significant, $F(2, 90) = 0.21$, $p = .81$, indicating similar explicit memory recall among the three groups (57.49% for 6- and 7-year-olds, 60.15% for 9- and 10-year-olds, and 59.90% for adults). Hence, differences found in the implicit learning results cannot be attributed to a difference in explicit awareness among groups.

WM analysis

Two children in the 9- and 10-year-old group did not complete the WM tasks due to time constraints of the testing session. Hence, all analyses involving WM excluded their data. Two children in the 6- and 7-year-old group completed only the visual WM task but not the location WM task. One 9-year-old completed only the visual WM task but not the spatial WM task. One adult completed the spatial WM task but not the visual WM task. Their data were included in the descriptive analyses but were not included in the ANOVAs after deleting missing data listwise. Following the procedure of Simmering (2012) and Simmering et al. (2015), we calculated capacity estimates $K_{\max}$ for each participant in each WM task. $K_{\max}$ encompasses performance across set sizes and represented one single value. It avoided the potential pitfalls of analyzing performances only at lower set sizes where children were just able to perform, whereas adults performed at ceiling. To obtain $K_{\max}$, we first obtained K at each set size for each participant: $K = \text{SS} * (\text{H} - \text{FA})/(1 - \text{FA})$, where SS refers to set size, H refers to hit rate, and FA refers to false alarm rate (Pashler, 1988). Each participant's maximum K across set sizes was then selected as WM capacity $K_{\max}$.

We first compared three age groups within each WM condition (see Table 1). For visual WM, one-way ANOVA suggested that the main effect of group was significant, $F(2, 87) = 37.60$, $p < .001$, $\eta_p^2 = .46$. Adults had a significantly larger WM capacity than 9- and 10-year-olds, who in turn had a larger capacity than 6- and 7-year-olds, *ps* < .01. For spatial WM, the main effect of group also was significant, $F(2, 88) = 6.19$, $p = .003$, $\eta_p^2 = .13$, with adults exhibiting a significantly larger WM capacity than both 9- and 10-year-olds and 6- and 7-year-olds, $ps \leq .01$, who did not differ from each other.

WM and implicit learning

We then examined whether WM capacity could explain individual differences in the implicit learning effects of children. We did not include adults in the analysis because as a group their performance

Table 1
WM performance.

		n	Mean	SD	Min	Max
Visual WM	Adults	30	4.28	0.55	3.20	5.00
	9- and 10-year-olds	29	3.66	0.78	2.00	5.00
	6- and 7-year-olds	31	2.73	0.76	0.75	4.17
Spatial WM	Adults	31	4.91	0.27	4.00	5.00
	9- and 10-year-olds	28	4.46	0.71	2.00	5.00
	6- and 7-year-olds	29	4.46	0.66	3.00	5.00

Note. The maximum possible score for visual and spatial WM capacities was 5.

on spatial WM was near ceiling. For the analysis, we disregarded age and categorized the child participants into high and low groups for visual and spatial WM separately. This was done because approximately half of the child participants performed at ceiling in the spatial WM test and, hence, correlations using raw scores would be misleading. Pertinent to the current study, for spatial WM those with a capacity of 5 (i.e., ceiling) were categorized as the higher WM group (31 participants) and those with a capacity of less than 5 were categorized as the lower WM group (28 participants). For visual WM, only 2 participants performed at ceiling. A median split was conducted so that those with a capacity higher than 3.00 were categorized as the higher group (28 participants) and those with a capacity equal to or lower than 3.00 were categorized as the lower group (31 participants). Counts in each WM category are in Table 2.

Next, we analyzed how WM group membership was related to the individual differences in children's implicit learning performances. To control for the different baseline RTs across participants, we combined RTs in the two testing blocks and calculated percentage of facilitation (PoF) for each repeated condition (e.g., Jiang, Song, & Rigas, 2005; Yang & Merrill, 2014) for the child participants. PoFs were used to evaluate the relations between implicit learning and WM. The PoF formula for the both-repeated condition was

$$\frac{\text{RT of new displays} - \text{RT of both-repeated displays}}{\text{RT of new displays}}.$$

PoFs of the identity-repeated and location-repeated conditions were calculated similarly. PoF is a better measure than the raw RT difference between the repeated and new displays because it takes into account overall RT differences when determining the magnitude of contextual cueing. Darby, Burling, and Yoshida (2014) found that for 8- to 12-year-olds, baseline search speed modulates the magnitude of contextual cueing effects (i.e., raw RT difference between repeated and new displays). Because individuals with longer RT baselines have more room to improve, it is possible for them to demonstrate larger raw RT differences. However, it does not necessarily mean that they have demonstrated larger learning effects. In contrast, PoF values do a better job by adjusting for baseline RTs, particularly relevant in the current developmental study (Yang & Merrill, 2014).

Although the group analyses of contextual cueing in the identity-repeated condition were not significant, there was wide variability in performance, indicating that there may have been individual differences in implicit learning in this condition. Hence, we decided to examine its relationship with WM to determine whether it can account for any systematic individual differences in the expression of contextual cueing, where some individuals do and some do not exhibit contextual cueing. For the age range of the children in our study, there were also great variations of WM abilities within each age group (see Fig. 4 and Table 2). For instance, although a greater number of older children than younger children were in the high spatial/high visual WM group and the reverse pattern was found in the low spatial/low visual WM group, there were also some younger children in the both high groups and some older children in the both low groups. Age, as a demographic factor, captures only a certain amount of individual differences in ability. WM, as a cognitive factor, can mediate the age effect on cognitive function (de Ribaupierre & Lecerf, 2006; Fry & Hale, 1996). Children with the same WM capacities may be more alike in performing certain cognitive tasks than children of the same ages. Hence, WM may be better able to account for the individual differences in implicit learning than age.

Table 2
Counts of child participants in different WM groups.

	Higher spatial WM	Lower spatial WM	Total
Higher visual WM	16 (4)	12 (3)	28
Lower visual WM	15 (12)	16 (12)	31
Total	31	28	59

Note. The number of younger children in each WM subgroup is listed in parentheses.

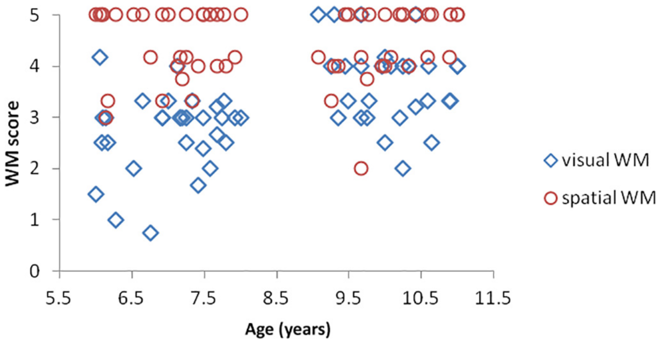


Fig. 4. Scatterplot of WM scores as a function of age and two WM types.

Note also that the following PoF analyses were not contingent on PoFs being greater than 0 (i.e., significant implicit learning). They were conceptually comparable to the RT contrasts between the repeated displays and the new displays. Therefore, a PoF below 0 simply reflects longer RTs in the repeated condition than in the new condition.

For each repeated condition, we conducted a 2 (Visual WM: high or low) × 2 (Spatial WM: high or low) analysis of covariance (ANCOVA) with age group as a covariate. None of the effects was significant for PoFs of the both-repeated and location-repeated conditions. However, for the PoF of the identity-repeated condition, the main effect of visual WM was significant, $F(1, 54) = 5.74$, $p = .02$, $\eta^2_p = .10$, with larger PoF values for those with lower visual WM capacities (adjusted estimate $M = .054$, $SE = .014$) than for those with higher visual WM capacities (adjusted estimate $M = .002$, $SE = .015$). As a follow-up, a one-sample t test suggested that for children with lower visual WM, their identity-repeated PoF was significantly different from 0, $t(31) = 3.60$, $p = .001$. In other words, children with lower visual WM demonstrated significant identity contextual cueing effects.

Discussion

In this study, we investigated implicit memory for identities and locations of objects among 6- and 7-year-old children, 9- and 10-year-old children, and adults. In addition, the role of WM in producing these memories was investigated. All three age groups exhibited significant implicit learning when both the identities and locations of the distracters were predictive of the target location. This result essentially replicates previous studies evaluating contextual cueing effects in children and adults (e.g., Merrill, Conners, Yang, & Weathington, 2014; Yang & Merrill, 2015a; Yang & Merrill, 2015b). However, when only the locations of the distracters were predictive of the target in the test phase, adults and 9- and 10-year-olds showed significant implicit learning, whereas 6- and 7-year-olds did not. In addition, when only the identities of the distracters were predictive of the target in the test phase, none of the three age groups showed significant implicit learning. Hence, across the different age groups, we observed both similarities and differences in the implicit learning of object identities and locations. We also found that WM was related to individual differences in implicit learning above and beyond the effect of age for the children.

Implicit learning of object identities and locations

Using real-world namable objects as stimuli, we obtained results that were similar to those found for adults by Endo and Takeda (2004). When distracter identities and locations varied in combination, all three age groups exhibited significant implicit learning. This is consistent with several previous studies supporting the view that contextual cueing is a relatively robust form of learning for children and adults (Dixon, Zelazo, & De Rosa, 2010; Merrill et al., 2014; Yang & Merrill, 2014, 2015a, 2015b).

However, when distracter identities and locations were tested individually, there was a dissociation of contextual cueing effects for object identities versus object locations. Adults and older children, but not younger children, demonstrated contextual cueing effects for object locations, and none of the age groups did so for object identities. To be sure, the fact that we observed greater and more robust contextual cueing in the both-repeated condition relative to either feature independently indicates that both identity and location information about the distracters contribute to the production of contextual cueing effects. Furthermore, the repetition of the heterogeneous and complex real-world objects provided additional benefit to the implicit spatial learning effects (see also Merrill et al., 2014), which were bigger in this study than is typically found in studies with homogeneous distracters (e.g., Chun & Jiang, 1998). Notably, the difference between the combined effects and independent effects was especially clear for the younger children. It is possible that a memory association generated by two sources of information (i.e., locations and identities) is more easily retrieved than one generated by a single source (e.g., Paivio, 1990). A response predicted by two sources of information may also generate greater confidence than a response generated by a single source. Whatever the explanation, it is clear that both identity and location information contribute to the production of contextual cueing effects in the both-repeated condition for all participants regardless of age.

When information about distracter locations and information about distracter identities were tested separately, we found that location information was more likely to produce contextual cueing than identity information. In particular, our results indicated that location information alone was sufficient to produce contextual cueing effects for 9- and 10-year-olds and adults. Neither of these groups exhibited contextual cueing when only identity information was available. Nevertheless, it may be that some child participants are more likely to exhibit contextual cueing for identity than others (as discussed later). Previous studies also indicate that identity contextual cueing effects occur in more limited conditions than location contextual cueing effects (Chun & Jiang, 1999; Endo & Takeda, 2004; Hout & Goldinger, 2010). Huang and Grossberg (2010) suggested that location contextual cueing is expressed more strongly because in the early phase of scene analysis spatial cues can be processed in parallel as global gist reflected in a single overall configuration. In contrast, because object identities need to be processed one at a time in a series of eye fixations, contextual cueing based on identity information would be expected to accrue more slowly and not be as strong. Hence, it is more difficult to acquire identity contextual cueing than to acquire location contextual cueing. Our study also suggested that this was true regardless of whether the distracter identities were identifiable, as in our study, or abstract contours, as in Endo and Takeda (2004).

There was also an age difference in the degree to which distracter locations independently produced implicit spatial learning. Adults and 9- and 10-year-olds demonstrated significant implicit learning of distracter locations, whereas 6- and 7-year-olds did not exhibit significant implicit learning. Even though location information and identity information may be processed separately, an object's identity and location memories seem to be accessed holistically by young children (Lange-Küttner & Küttner, 2015; Treisman, 1993, 2006). The ability to access these features independently appears only with increasing age. Because of this, the younger children's memory of the repeated displays may be more rigid than memories for adults and older children. Hence, any alteration of the remembered displays may have resulted in the younger children treating them as new. Therefore, younger children did not show location contextual cueing effects when assessed independent of object identity.

WM and implicit memory

Our results also indicate that a complex relationship exists between WM capacity, a general factor underlying cognitive development (e.g., Bjorklund & Harnishfeger, 1990; Egami et al., 2015; Simmering, 2012), and implicit learning in children. On the one hand, we observed a basic level of independence between working memory and implicit learning in two of our conditions. For the both-repeated conditions, where significant implicit learning was found for all participant groups, neither visual WM nor spatial WM was able to account for any individual differences. Similar results were also found for location contextual cueing effects. This confirms the robustness of contextual cueing effects and supports the view that basic implicit learning mechanisms are generally independent of one's working memory limits (e.g., Vickery et al., 2010). Furthermore, it appears that encoding a single overall spatial configuration does not tax working memory resources in a way that produces individual differences (Manginelli et al., 2013a, 2013b).

Our results did indicate a relationship between WM and the implicit learning of identities. This is true in spite of the fact that identity contextual cueing was not significant overall. Previous studies on young adults suggested that presenting a concurrent spatial WM task in the testing phase, but not in the learning phase, can reduce contextual cueing effects (Manginelli et al., 2013a; Travis et al., 2013; Vickery et al., 2010). This suggests that WM capacity limits do not restrict *learning* the repeated contexts per se. Instead, WM is involved in the retrieval, maintenance, and/or use of the previously learned contexts, hence *expressing* the implicit learning of the context (Manginelli et al., 2013a, 2013b). Our results suggest that a smaller WM capacity may actually be beneficial for exhibiting the implicit learning of distracter identities, at least for our child participants.

It may seem counterintuitive that smaller WM capacity is associated with larger, rather than smaller, implicit learning effects. Traditionally, larger WM capacity is associated with greater learning. Nonetheless, there are at least two ways that smaller WM capacity can positively affect implicit learning. First, in our task participants needed to search for the target and were never explicitly instructed to pay attention to either the identities or locations of the distracters. Hence, the learning of the distracter identities or spatial layouts was likely a byproduct of the search activity itself. Having a small visual WM capacity may have resulted in a less well-organized visual search (Woods et al., 2013), causing children with smaller WM capacity to dwell longer on each distracter and/or revisit the same distracters multiple times (Shen, McIntosh, & Ryan, 2014). As a result, the processing of the distracter identities would be more likely to be encoded into memory. Second, Hout and Goldinger (2010) reported that the incidental memory of distracter identities was better when adult participants searched under a high working memory load. They suggested that a reduced ability to block out the processing of the distracters resulted in more encoding of distracter information into memory (Lavie & de Fockert, 2005). It is well documented that search facilitation in contextual cueing is contingent on attending to the relevant features of the distracter items (e.g., Jiang & Leung, 2005; Makovski & Jiang, 2007). Hence, larger contextual cueing effects may be observed in children with low visual WM capacity if they had more difficulty in filtering out distracter information and, therefore, encoded the identities of the distracters to a greater degree than those with high visual WM capacity. This extends and complements the research on the relationships between WM capacity and contextual cueing reported by Manginelli et al. (2013a, 2013b).

Conclusions

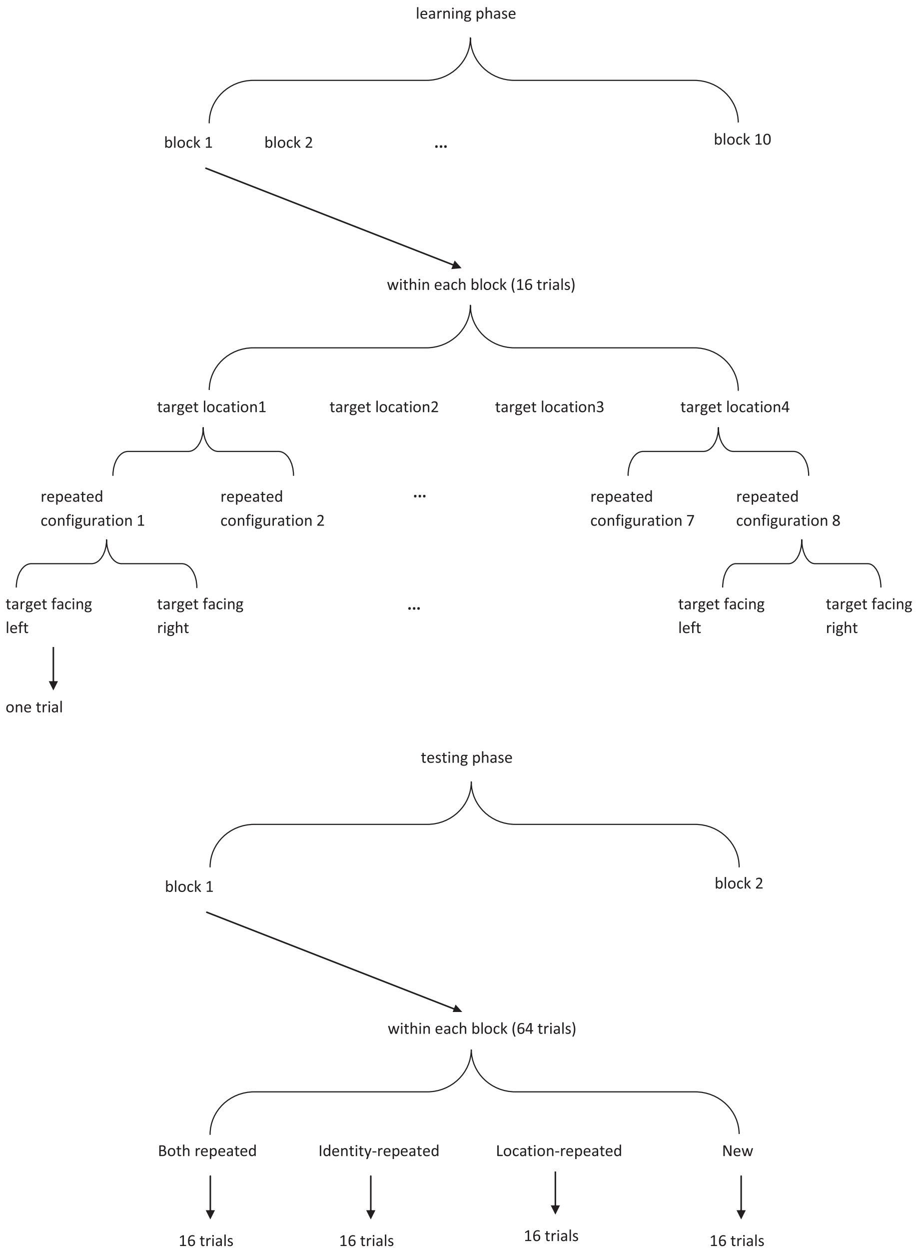
As a multifaceted entity, memory is a cornerstone of human cognition. The current study contributes to understanding not only the dissociations between object identity and object location memories but also the dynamics between working memory and implicit memory in children. Interestingly, there was a nuanced developmental difference in implicit memory, such that younger children were less likely to exhibit location-specific contextual cueing after learning in conditions where both identities and locations were predictive. Our results also suggested a rare benefit of having small visual WM capacity in children, for whom difficulty in blocking out distracters can result in greater learning of distracter identities and, hence, in greater identity contextual cueing effects. Taken together, our results reflect the complexity, diversity, and dynamic nature of the development of the human implicit memory system (e.g., Schneider & Ornstein, 2015).

Acknowledgments

This research was partly supported by the Fundamental Research Funds for the Central Universities (16wkpy26) and the National Natural Science Foundation of China (31600898) awarded to Y.Y.

Appendix A

Flowchart depicting sequence of events within each trial in learning and test phases.



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