

DEVELOPMENTAL DIFFERENCES
IN REPEATED VISUAL SEARCH
AS MODULATED
BY SIGNAL TO NOISE RATIO

by

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ABSTRACT

This dissertation studied developmental differences in the way simultaneous and sequential signal to noise ratios impact contextual cueing effects. Contextual cueing refers to a form of implicit associative learning of the target location and its context. Over repeated exposures, participants typically respond faster to repeated displays than to new displays that are not repeated. Previous studies have suggested that children and adults are differentially sensitive to noise (irrelevant distracters) in the displays. The current study incorporated two forms of signal to noise ratio (S/N): simultaneous S/N, defined as the ratio of predictive and unpredictable distracters within each display; and sequential S/N, defined as the ratio of repeated and new displays within each block. Three age groups participated in the study: 6-8 year old children, 10-12 year old children and college students. The results suggested that all three groups demonstrated significant and comparable contextual cueing effects across three S/N ratio conditions in the simultaneous condition. The analysis of search efficiency also suggested that all three groups demonstrated guided search. Therefore, no developmental difference was found in the simultaneous condition. The results in the sequential condition suggested that adults demonstrated significant contextual cueing effects across all three ratio conditions. Older children demonstrated significant contextual cueing effects in the high and medium conditions but only marginally significant learning in the low condition. By contrast, younger children only demonstrated significant learning in the high and medium conditions, but not in the low condition. Hence, there was a significant developmental difference in the sequential condition.

Explicit memory tests suggested no conscious awareness about the repetition for any age group in any condition.

The results suggested that adults have an intact ability to extract repeated information from the information stream, as long as it is at least 33% predictive. Contextual cueing is hence a relatively robust form of implicit learning. Children's intact learning in the simultaneous condition might have reflected their relatively mature selective attention mechanisms. Children's impairment in the sequential condition might be due to their immature working memory. The practical and methodological implications of this dissertation were also discussed.

DEDICATION

This dissertation is dedicated to my late maternal grandfather, for his love and inspiration.

LIST OF ABBREVIATIONS AND SYMBOLS

<i>a</i>	Cronbach's index of internal consistency
<i>df</i>	Degrees of freedom: number of values free to vary after certain restrictions have been placed on the data
<i>F</i>	Fisher's <i>F</i> ratio: A ration of two variances
<i>M</i>	Mean: the sum of a set of measurements divided by the number of measurements in the set
<i>p</i>	Probability associated with the occurrence under the null hypothesis of a value as extreme as or more extreme than the observed value
<i>r</i>	Pearson product-moment correlation
<i>t</i>	Computed value of <i>t</i> test
<	Less than
=	Equal to
RTs	Reaction times
<i>n</i>	Sample size for group
<i>SD</i>	Standard deviation
ANOVA	Analysis of variance
S/N	Signal to noise ratio
SRT	Serial reaction time task
ADHD	Attention deficit hyperactivity disorder
ASD	Autism spectrum disorder
ASRT	Alternating serial reaction time task
Min	Minimum

Max	Maximum
PoF	Percentage of facilitation
M.D.	Mean difference

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CHAPTER 1: INTRODUCTION

Our daily environment is seldom 100 percent predictable. For instance, your favorite teapot could be in the kitchen, in the living room or in the bedroom depending on where you had your last cup of tea. In a world of infinite information, we need to extract the relevant information and ignore the irrelevant information. This ability is often impacted by the ratio of relevant versus irrelevant information in the environment (signal to noise ratio or S/N). It is more difficult to acquire useful information when there is a lot of irrelevant information present, and when the useful information cannot be easily distinguished from the irrelevant information. One domain of information processing where signal to noise ratio may have a profound impact is the effect referred to as contextual cueing. More specifically, contextual cueing is a form of implicit learning where one can associate spatial locations with their consistent contexts. In the teapot example, it is easier to locate the teapot when it is always in the same environmental context (predictable signal) than when it is surrounded by an ever-changing environment of other kitchenware (unpredictable noise). S/N might even play a bigger role in the acquisition of spatial associations for children than adults. For instance, when asked to go to the kitchen to get the teapot, a younger child may benefit more if everything in the kitchen remains in the same locations rather than if some of the context has been changed. The aim of this dissertation is to study how children and adults implicitly acquire spatial layouts under different S/N in a contextual cueing paradigm.

Implicit learning

The concept of implicit learning was first proposed by Reber (1967). It refers to “the process whereby organisms acquire knowledge about the regularities of complex environments

without intending to do so and largely independently of conscious awareness of the nature of what was learned” (Litman & Reber, 2005). Therefore, by definition implicit learning refers to a form of learning that is acquired without conscious awareness. The lack of conscious involvement could happen during knowledge acquisition and/or the subsequent use of that knowledge. A wide range of information could be learned implicitly. As a domain-general phenomenon, implicit learning is even suggested to operate in complex problem solving processes. Participants may transfer the knowledge learned about one subject to another subject without being aware of the analogic reference between the two fields (Schunn & Dunbar, 1996).

One of the classic implicit learning paradigms is artificial grammar learning (e.g., Vokey & Brooks, 1992). In the basic task, participants are presented some strings of English letters. Unbeknownst to the participants, these letters follow a specific sequence and there are probabilistic rules governing how letters are allowed to follow each other. Typically, these rules are so complicated that they are difficult to articulate. Despite this, after exposure to letters that follow the artificial grammar, the participants are able to distinguish sequences that are grammatical from those that are not, above chance levels of performance. Moreover, in a post-test when asked to reproduce the grammar of the letters, participants failed to do so, thus indicating an implicit learning of the artificial grammar.

A later paradigm developed to measure implicit learning involves serial reaction time learning (SRT, Nissen & Bullemer, 1987), which is also a form of perceptual/motor learning. Participants typically make a motor response to a target appearing in one of several possible locations. In this paradigm, the sequence of these target locations remains the same throughout the experiment. Over time participants respond faster to the target locations in the repeated sequence relative to those in random sequences. Just as in the artificial grammar task,

participants cannot verbally express the regularities after the experiment. Implicit learning has also been studied in other domains such as language learning (e.g., Lichtman, 2013; Swisher, Restrepo, Plante, & Lowell, 1995), category learning (Knowlton, & Squire, 1993; Reed, Squire, Patalano, Smith, & Jonides, 1999), and production control tasks (Berry & Broadbent, 1988). Indeed, it is fairly common to identify implicit as well as explicit processes in diverse domains of cognition.

The distinction between implicit and explicit learning has received considerable support in the learning literature. Studies from brain damaged patients suggested different brain regions are responsible for these two learning and memory systems. For instance, the famous patient H.M damaged his hippocampus after a lobotomy procedure aiming to control for his epilepsy. Even though he could no longer form new memories and was unable to recall anything new, he could still acquire implicit procedural learning (Ashcraft & Radvansky, 2009). As cited by the Swiss psychologist Claparède (Baddeley, 1987), a doctor hid a needle in his hand and then shook hands with an amnesic patient. The next day when he tried to shake hands with the same patient, she refused. However, unable to justify why she did so, the patient reasoned that people might hide things in their hands. Subliminal presentation offers another approach to understanding explicit versus implicit learning. Subliminal stimuli refer to those stimuli that are presented below the threshold of conscious perception. For instance, a visual image could be flashed on the screen for as brief as several milliseconds and although people are unaware of the subliminal stimuli, their behaviors are inevitably impacted by them (e.g., Gibson, & Zielaskowski, 2013; Brooks, et al., 2012; Robles, Smith, Carver, & Wellens, 1987; Rahnev, Huang, & Lau, 2012).

The relationship between implicit and explicit learning is relatively complex. First, implicit and explicit knowledge can be acquired concurrently. In the SRT task, some participants

were explicitly told about and practiced a repeated 12-unit sequence of the stimuli (Willingham, & Goedert-Eschmann, 1999). They were encouraged to memorize the sequence to facilitate response. After learning the repeated sequence, a test phase composed of both the random sequences and the repeated sequence was given. The participants were then told that now the sequences were random and the trials were only to test their baseline reaction time. It was presumed that these participants would not consciously make an effort to employ their explicit knowledge to perform the sequences in the test phase. It thus tested the implicit learning outcome for the participants under explicit conditions. They demonstrated as much implicit sequence learning as other participants under the traditional implicit condition where they had no knowledge about the repeated sequences. This research indicates that when participants were explicitly acquiring knowledge, implicit learning could occur in parallel.

Alternatively, there may also be a continuum of consciousness, with explicit learning and implicit learning developing from each other. On one hand, explicit knowledge can be transformed into implicit knowledge through proceduralization. Riding bicycles is an example of implicit procedural behavior. When a child first learns to ride a bicycle, he has to remember how to control his body, keep the bicycle balanced and not fall off. As he eventually learns how to ride a bicycle, the knowledge acquired in the initial process through explicit learning becomes “proceduralized” and is stored as implicit knowledge. Therefore, after many years he would actually find it difficult to articulate how to ride a bicycle to others. In this case, implicit knowledge is no longer accessible to consciousness and cannot be expressed explicitly.

On the other hand, explicit knowledge can be derived from implicit knowledge through some sort of elaborative process. Mathews et al. (1989) tested a group of participants in an artificial grammar task four times, each time scheduled one week apart. Participants needed to

distinguish between the well-formed strings that obeyed the artificial grammar and the strings with a violation of the artificial grammar. They were also asked to explicate in written words the rules or the exemplars of the strings as much as possible. Transcripts of their responses were recorded and shown to new participants who did not have any prior learning experience with the task. At week one, participants could not communicate these rules. However, at week four they expressed the “underlying” rules so well that the new participants performed as if they had completed the task before. Therefore, this study suggests that implicit knowledge can be converted into explicit knowledge.

In summary, implicit learning, as contrasted with explicit learning, is characterized by a lack of involvement of conscious awareness during the learning process. As measured by different paradigms, implicit learning is typically acquired through repeated exposures to the to-be-learned information. Moreover, it is important to note that implicit learning can involve relatively complex environmental information, even though it is learned without any intention.

Implicit Learning and Development

Implicit learning has long been suggested to rely on brain regions, such as the basal ganglia and the cerebellum, that develop early in life. Implicit learning is thus thought to operate independent of age and most cognitive impairments (Reber, 1992; Don, Schellenberg, Reber, Digirolamo, & Wang, 2003). This is in contrast to explicit learning, which is highly correlated with age and intelligence. Children as young as six years old demonstrate significant implicit learning in standard SRT tasks and do not differ from older children and young adults (Meulemans, & Van der Linden 1998; see also Thomas, & Nelson, 2001; Reber, 1992; Amso & Davidow, 2012; Clohessy, Posner, & Rothbart, 2001; see also Saffran et al., 1997 for incidental learning of language). However, while younger and older children may not differ in implicit learning, they differ in the explicit learning of the SRT information. When given the instructions

that the sequence would be repeating, 10 year olds demonstrated more explicit awareness of the repeated sequence than did 7 year olds. In contrast, explicit knowledge did not differ between the younger and older children when they did not receive any prior instruction about the repetition of the SRT task (Thomas & Nelson, 2001; see also Russo, Nichelli, Gibertoni, & Cornia, 1995).

Within developmental psychology, implicit learning is also studied in terms of statistical learning. Saffran and colleagues (1996) have used statistical learning to refer to young children's ability to learn the statistical patterns during early language acquisition (e.g., statistical relationships between neighboring sounds, see Arciuli, & Simpson, 2012; Newport & Aslin, 2004; Saffran et al., 2008). Saffran and associates (1996) presented 8-month-old infants a continuous stream of nonsense spoken words and that contained no cues for word boundaries. After habituation, these infants could differentiate the words from non-words that were not presented in the familiarization phase. Hence, these infants distinguished word boundaries. They demonstrated an ability to learn syllable strings based on higher transitional probabilities between syllables that were within the words relative to those that were between words. This study demonstrated one of the most important pieces of evidence supporting the premise that even infants exhibit intact implicit learning ability (Litman, & Reber, 2005). Moreover, infants also demonstrate some rudimentary degree of learning of artificial grammar (see Marcus, Vijayan, Bandi, Rao, & Vishton, 1999; however, see also Sirois, Buckingham, & Shultz, 2000).

Implicit learning in general is independent of cognitive abilities. Testing of over 600 German participants between the ages of 11 and 32 years old (Mean=15.5 years, S.D.=1.79 years) (Gebauer, & Mackintosh, 2007) found that scores on the psychometric test of intelligence did not correlate with performances in the standard implicit learning tasks such as artificial grammar learning, the SRT and the product control tasks (Berry & Broadbent, 1984). People

with intellectual disabilities have also demonstrated intact implicit learning and impaired explicit learning mechanisms within artificial grammar learning (Atwell, Connors & Merrill, 2003; see also Maybery, Taylor, & O'Brien-Malone, 1995). Most research supports the position that implicit learning is relatively independent of general cognitive abilities (Reber, 1992; Don, Schellenberg, Reber, Digirolamo, & Wang, 2003, however, see Fletcher, Maybery, & Bennett, 2000).

However, in some conditions, developmental differences can still be found in implicit learning tasks. For example, in a modified SRT task, Thomas and colleagues (2004) increased the ambiguities of the implicit sequences. More specifically, within a repeated sequence a specific item could potentially predict two items (e.g., in “ABAC”, A predicts either B or C). This was in contrast to a classic SRT task where an item usually only predicts just one item (e.g., in “ABCD”, A only predicts B). In their modified task, children 7-11 years old showed a smaller magnitude and a slower rate of learning implicit sequential knowledge than adults. Therefore, age differences were found when the variability of the sequence increased and the sequence was less predictable overall. Thomas et al. (2004)’s research may have reflected the role that probabilistic versus deterministic sequences plays in the varying implicit learning results between children and adults.

Similar findings of developmental differences were also reported in the statistical learning literature. In a typical statistical learning task for adults (e.g., Saffran et al., 2008), participants were exposed to artificial language as a background distraction while doing another task. They were informed that they would be tested on the language later but they were not informed about the structure of the language. To construct the artificial grammar, in predictive sentences a nonsense word was always predicted by another nonsense word. Suppose that a

sentence was composed of 2 words designated as A and D. The rule governing the predictive sentence might be that if D existed, A would proceed. When D appeared it had to be preceded by A. However, A did not have to be followed by D. Hence, the examples for the grammatical sentences were AD and A whereas the example for the ungrammatical sentences was D. Therefore, D covaried with A, and the possibility of the existence of A under the condition that D existed was 100% (i.e., the conditional probability of $A|D$ was 1.0). After listening to a series of sentences spoken by a human voice, participants were able to discriminate between the novel sentences that obeyed the rule from those that violated the rule. In the learning phase there was also another sentence type that did not contain the predictive cues (unpredictive sentences). In an unpredictable sentence, although either A or D had to exist, A and D were independent of each other (i.e., the conditional probability of $A|D$ was .5). Therefore, the grammatical situations in a sentence would be A, D, AD. The ungrammatical sentences would be those that did not contain either A or D. In this condition the existence of A could not predict the existence of D and vice versa. Participants demonstrated a much smaller difference between the unpredictable sentences and their corresponding ungrammatical sentences relative to the difference between the predictive sentences and their corresponding ungrammatical sentences. This thus indicated that participants have implicitly learned the conditional statistical information in the predictive sentences, rather than in the unpredictable sentences. The learning of the predictive statistical relationships characterizes human language and may have been used in early language acquisition.

Statistical learning and artificial grammar learning are so similar that Perruchet and Pacton (2006) refer to them as one phenomenon that is studied using two approaches. In fact, they were even embedded within each other in one study (Hunt & Aslin, 2001). Both approaches

describe the general learning mechanisms of attending to and learning regularities in an incidental manner. Whereas implicit sequential learning can be achieved by memorizing the chunks or fragments of a particular sequence and by acquiring deterministic information (i.e., a fixed sequence), statistical learning requires learning of relatively more complex conditional probabilities (i.e., sequences contain probabilistic information) (Perruchet & Pacton, 2006). Therefore, compared with implicit sequential learning, statistical learning may require a higher degree of cognitive flexibility in extracting statistical regularities and a higher tolerance of unpredictability.

Developmental differences in learning predictability and variability may help to account for developmental differences in implicit learning. For instance, children 7 to 9 years old were able to demonstrate learning in the predictive sentences relative to the unpredictable sentences, thus demonstrating that they could distinguish pairs that had high conditional probabilities from those that did not. Nevertheless overall children learned fewer total predictive and unpredictable sentences than adults (Saffran et al., 2008). Developmental differences were also found when the stimuli in the statistical learning were visual images (e.g., abstract shapes) rather than auditory sounds (Saffran, 2002; Arciuli & Simpson, 2011; 2012; Fiser & Aslin, 2001; 2002). In an experiment by Arciuli and Simpson (2011), children were presented with unfamiliar cartoon characters. Every three unique cartoon characters formed a repeated sequence (i.e., repeated triplets) during the learning phase. The participants' task was to detect when two identical cartoon characters were presented. This would ensure that the learning of the repeated triplets, if any, was incidental to the task. In the test phase, participants were asked to distinguish the repeated triplets from the new triplets that never appeared in the learning phase. Children 5 to 12 years old performed above chance level. However, multiple linear regression analysis suggested

that performance increased with age. Hence, although children could learn conditional probabilities, this competence still undergoes a developmental improvement. Therefore, whether the to-be-learned regularities are presented in a probabilistic or deterministic manner may impact whether developmental differences or developmental similarities are observed in implicit learning tasks.

Implicit cognition plays a prominent role in many general theories of human development. Child development, in its essence, is the process of gaining new information and integrating information into a new form. This is also the goal of learning in general. For a long time, researchers in both human development and implicit learning domains have suggested that early behavioral competencies as seen in infants reflect an internal representation of the environmental structures. This internal representation is presumed to be implicit and perhaps innate in nature. Karmiloff-Smith (1992)'s theory suggests that infant and child development involves the gradual and progressive building of implicit knowledge and the subsequent transformation of that implicit knowledge into an explicit form. According to Karmiloff-Smith (1992), the first stage of development appears to be at an implicit level (Perruchet & Vinter, 1998), which resembles the sensorimotor system of knowledge (Mandler, 1988). The sensorimotor system is highly dependent upon procedural knowledge (e.g., reaching, locomotion) that does not require conscious awareness. Development continues as the implicit knowledge becomes explicit through redescription and abstraction. This transformation is achieved through an internal process that extracts and reorganizes information from implicit knowledge to make the information more general and thus applicable to other similar situations. In the final step of development, the explicit knowledge can be expressed verbally.

Evidence in support of the innate, implicit knowledge position (Karmiloff-Smith, 1992) is typically based on observations that infants appear “surprised” when viewing impossible physical events. For instance, some researchers support the notion that infants may have an understanding of basic physics knowledge such as object permanence. Very young children (e.g., 3-5 months old) looked longer at the impossible event of a board completely covering a box (so it looked like the box disappeared) than the possible event of a board being stopped by the edge of the box (Baillargeon, Spelke, & Wasserman, 1985). However, Perruchet and Vinter (1998) suggested rather than having the concept of object permanence, it could be because children simply looked longer at the more variable condition than those that were less variable (i.e., the impossible conditions were associated with a wider variety of actions of the board than the possible conditions). In general, it may not be necessary to invoke the concept of innate knowledge in order to explain children’s responses to regularities in the environment. Instead, implicit knowledge could simply be explained by children’s learned sensitivity to some characteristics of the environments such as novelty, frequency and variability. This sensitivity reflects mechanisms of implicit learning. Implicit learning reflects the progressive efforts towards a better mapping of the world’s deep structure through “intrinsically unconscious associative mechanisms”. Perruchet and Vinter (1998) proposed that the development of explicit knowledge is not through redescription of implicit knowledge; instead it is a reconstruction of the physical world through inferential problem-solving.

Studying implicit learning has the potential to shed light on which theoretical explanation best describes how human development transitions from tacit, procedural knowledge to explicit understanding. In summary, it may be that very young children and infants are able to implicitly learn regularities in the environment with a larger capacity and at a faster speed than previously

expected (Litman & Reber, 2005, also see Saffran et al., 1996). The notion of innate knowledge may be less important than suggested by early theories. Studying implicit learning mechanisms in general and in children more specifically may provide the basis for the reinterpretation of the basic, universal progress of human development.

Contextual Cueing

Contextual cueing refers to a form of attentional guidance where individuals are drawn to the location of a target object that has been consistently associated with the locations of the non-target objects in the visual environment. The spatial associative learning that results in contextual cueing is presumed to be implicit. Chun and Jiang (1998) were the first to report on this phenomenon. In their initial study, participants were shown displays containing a target (the letter T rotated 90 degrees) and several distracters (the letter L rotated 90 degrees). They were required to identify which direction the target T was pointing. Unbeknownst to the participants, some of the spatial configurations of the distracters were consistently associated with the target location across trials and thus always predicted the location of the target (the repeated or predictive condition). In contrast, some configurations of the distracters were random from trial to trial and did not predict the target location (the new or unpredictable condition). After several exposures, response times were much faster in the repeated than the new conditions. Tests conducted after the experiments indicated that the participants could not distinguish between the repeated and the new configurations (i.e., using recognition tests, see Chun & Jiang, 1998; Chun & Phelps, 1999). They also could not make correct predictions of the target locations in the repeated displays when the targets were replaced by other distracters or were missing (i.e., using generation tests, see Chun & Jiang, 2003; Jiménez, & Vázquez, 2011; Yang, 2012). These results provide support for the proposition that contextual cueing is implicit in nature.

Jiang and Chun (2001) also reported that for contextual cueing effects to accrue it is not necessary for all the distracters to predict the target. They presented half of the distracter Ls in the same color as the target T (e.g., red), which were called the attended distracters, and half in a different color (e.g., green), which were called the ignored distracters. Participants were told explicitly to search for the target in a specific color (e.g., red). They displayed significant contextual cueing effects when both the attended and ignored distracters predicted the target location (both-repeated condition), when only the attended distracters predicted the target location and the ignored distracters did not (attended-repeated condition), and when only the ignored distracters predicted the target and the attended distracters did not (ignored-repeated condition). Jiang and Chun then made the task more difficult in order to reduce the attention allocated to the ignored distracters, and to increase the attention allocated to the attended ones. In contrast to the earlier easy condition, the contextual cueing in the ignored-repeated condition disappeared, although robust contextual cueing still existed in the attended-repeated condition. In the both-repeated and attended-repeated conditions the contextual cueing effects were of similar magnitude. This indicated that the presence of random, ignored distracters did not interfere with learning for young adults.

In addition, participants can also learn the sequential regularities of a visual information stream and exhibit contextual cueing effects based on temporal information (Olson & Chun, 2001). Olson and Chun (2001) presented participants a sequence of letters and asked them to respond to a target letter when it appeared. Unknown to the participants, the inter-trial time intervals of the predictive sequences were repeated (e.g., the second letter appeared 50 ms after the first one; the next letter appeared 1350 ms later), whereas the inter-trial intervals of the new sequences were random. Results suggested that response times to the target were faster in the

repeated than in the new sequences. Apparently, participants learned the rhythm of the repeated sequences. In addition to inter-trial intervals, participants could also learn the identities of the letters in the sequence (e.g., ACFE). In their third experiment, the repeated sequence was composed of a series of displays composed of two shapes (a rotated L and a cross). The two shapes varied their locations within each display. However, the order of these unique displays was maintained and repeated. Participants showed faster reaction times in the repeated sequence of displays. Hence, participants can also learn the temporal or sequential information of the visual stimuli.

Many perceptual factors impact contextual cueing. For example, Olson and Chun (2002) suggested that physical proximity was one factor that influenced contextual cueing and that simply learning half of the whole configuration (e.g., left side or right side) was enough for contextual cueing to occur (see also Jiang & Wagner, 2004). Furthermore, Brady and Chun (2007) used a mathematical model to illustrate that as few as two distracters that were close enough to the target could elicit contextual cueing. Other researchers showed other factors that affect contextual cueing such as object identity (Endo & Takeda, 2004), good continuation (Fuggetta et al., 2007), spatial arrangement of color (Huang, 2006), and semantic properties of distracters (Goujon, Didierjean, & Mareche, 2007). Contextual cueing is the product of a robust learning and can be elicited by a variety of visual characteristics that have predictive power on the location of the target.

Contextual cueing could be seen as learning probabilities of different forms of visual information. The image that appears more often (i.e., repeated/predictive displays) is responded to faster than the image that appears less often (i.e., new/unpredictive displays). Contextual cueing is about learning the repeated spatial configurations. Similar to other implicit learning

tasks such as SRT, contextual cueing is also acquired through incidental and repeated exposures to the regularities. On the other hand, contextual cueing is also a unique form of implicit learning. Although both the basal ganglia and the medial temporal lobe are involved in other implicit learning mechanisms (e.g., Kolb, & Whishaw, 2009; Rauch et al., 1997; Kim et al., 2004; van Asselen & Castelo-Branco., 2009; Schendan, Tinaz, Maher, & Stern, 2013; Rieckmann, Fischer, & Bäckman, 2010), evidence suggests that the medial temporal lobe, particularly the hippocampus and parahippocampus, is involved in the acquisition of contextual cueing effects (Chun & Phelps, 1999; Negash et al., 2007; Geyer, Baumgartner, Müller, & Pollmann., 2002; Greene, Gross, Elsinger, & Rao, 2007). Contextual cueing is different from implicit sequential learning which reflects sensitivity to co-occurrence/co-dependency of the adjacent items. Instead, in contextual cueing, participants are learning how frequently the target location appears with a particular configuration of the distracters (Barnes et al., 2010; Jiménez, & Vázquez, 2011). Contextual cuing is also distinct in that as a form of associative learning, it requires participants to associate the target location with the spatial context. Learning does not appear to occur when associations between a target location and distracter locations do not exist or cannot be established. For instance, researchers failed to find contextual learning effects when the target of a repeated display moved around or was absent. In both situations, associative learning cannot be established because the layouts of the distracters cannot be paired with the target (Chun & Jiang, 1998; Kunar & Wolfe, 2011).

Just like many other implicit learning tasks (e.g., Dulany, Carlson, & Deway, 1984; Perruchet & Amorim, 1992), some theorists have questioned whether contextual cueing effects are learned without consciousness. For instance, Smyth and Shanks (2008) evaluated the implicit nature of contextual cueing. They increased the number of repeated and new displays in the

explicit generation post-test in order to increase the power and the reliability of the test. Participants' accuracy was significantly higher in the repeated (30.6%) displays than in the new (26.1%) displays. However, Jiménez, and Vázquez (2011) failed to replicate Smyth and Shanks's results even though they also increased the number of the repeated trials in the post-test. Additionally, Smyth and Shanks (2008) found that even the configurations for which participants only generated chance-level correct responses still resulted in successful contextual cueing. Furthermore, participants whose explicit tests were at chance level also demonstrated significant contextual cueing effects. The proposition that contextual cueing may be implicit is also supported by research on the effects of different strategies. When participants were given instructions to actively search in the displays, which thus encouraged them to engage in an explicit strategy, contextual cueing was not found. Rather, instructions to passively search the displays and allow the target to "pop out" actually facilitated the acquisition of contextual cueing (Lleras & Von Mühlénen, 2004; see also Chun & Jiang, 2003). Taken together, the majority of the research seems to indicate that even if consciousness is involved in contextual cueing, its influence is minimal.

There are two major theories regarding the underlying mechanisms of contextual cueing. Chun and Jiang (1998) originally used the Guided Search Model (Wolfe, Cave, & Franzel, 1990) to explain contextual cueing effects. They implemented the concept of context maps, which hold memory representations of the visual context. The more often a particular location is repeated, the higher weight/priority that location is going to be given in the context map. As a result, a potential target location that is associated with a particular repeated global context will be given a higher priority in searching. Attention is efficiently deployed to the target location once the repeated display is recognized. Another theory is that contextual cueing is driven by a facilitated

response selection process, rather than attentional guidance (Kunar, Flusberg, Horowitz, & Wolfe, 2007). One responds to the target faster once it is found. For instance, a sense of familiarity with a context can lead to greater confidence that the target has been found. This sense of familiarity results in overall faster responses without any attentional guidance. In addition to being more confident, participants may also reduce double-checking of a particular object and lower response threshold in repeated displays relative to new displays.

Evidence from eye movements (e.g., Brockmole & Henderson, 2006a) provides partial support for both theories. Peterson and Kramer (2001) found that in the repeated displays the first eye fixation fell straight to the target only a small percentage of the time. This was far from perfect attentional guidance. Nonetheless, there were typically fewer fixations needed to locate the target in the repeated displays compared to the new displays. Moreover, each distracter was recognized and discarded faster before fixing on the target (van Asselen, Sampaio, Pina, & Castelo-Branco, 2011). In addition to eye movement research, neuroimaging research and behavioral research have also shown that both attentional guidance and response selection processes contribute to the implicit learning of contextual cueing (e.g., Schankin & Schubö, 2009, 2010; Olson, Chun, & Allison, 2001; Johnson, Woodman, Braun, & Luck, 2007; Kunar, Flusberg, Horowitz, & Wolfe, 2007; Kunar, Flusberg, & Wolfe, 2008).

Contextual Cueing and Development

As a form of implicit spatial learning, contextual cueing has important ecological importance. One may not be able to recall the exact spatial layouts of a familiar environment but it is much easier to find things in familiar surroundings than in strange surroundings. It appears that we know more than we can explicitly remember. We can use that knowledge to make our lives in familiar settings more efficient. This skill is also important for children. In fact, it is likely a greater problem for young children than for adults when one is unable to recognize

his/her environment as familiar and is forced to wander around in search of a specific location. The extant research regarding whether children benefit from contextual cueing is mixed.

Vaidya and her colleagues (2007) compared school-aged children (6 to 13 years old) with college students using the original paradigm of Chun and Jiang (1998). Unlike adults, children did not display any contextual cueing effects. In a second experiment, the researchers considered the possibility that the stimuli in the original paradigm might be so difficult that they might have impeded the expression of implicit learning in children. Therefore, they tested adults on a more difficult search task to see if increased task difficulty could disrupt adult participants' ability to exhibit contextual cueing. The researchers reasoned that if task difficulty impeded children from exhibiting contextual cueing, it should impact adults in a similar way. The adults still exhibited contextual cueing despite their slower baseline reaction times. Hence, the level of difficulty alone could not explain why children did not display contextual cueing. Vaidya et al. (2007) indicated that the lack of learning in children might be due to their relatively immature hippocampal development.

Using the classic stimuli of rotated Ts and Ls may have underestimated children's competence. Contrary to Vaidya et al. (2007), Dixon and his colleagues (2010) found intact contextual cueing in school-aged children (5-9 year olds). They suggested that the previous experiments had not been sufficiently engaging and interesting to children. Therefore, they designed an age-appropriate version of the contextual cueing task. Children were asked to touch a red cartoon fish (the target) embedded among a set of red and blue cartoon fish (the distracters). Therefore, in addition to using simplified stimuli, they had the children directly locate the target to focus their attention on the spatial relations among stimuli. This was in contrast to Vaidya et al.'s study in which participants identified the direction the target was

facing. Dixon and colleagues (2010) found that young children demonstrated significant contextual cueing. Moreover, this learning was still considered to be implicit because the children could not recognize the predictable displays in a recognition test.

Merrill et al. (2013) found similar results after implementing a different modification of the contextual cueing task. In their task, participants needed to locate the quadrant in which the cartoon character Jiminy Cricket was embedded among 15 other different cartoon characters. In addition, they presented only the repeated displays during the learning phase and then included the new displays in the final test phase. This was different from the previous approaches that presented both repeated and new displays throughout the experiment. Merrill et al. (2013) found that implicit learning was relatively stable across children as young as 6 years old, young adults and older adults over 60 years old (for identical procedures see also Travers et al., 2013). Yang's thesis (2012) further suggested the potential of young children. Specifically, child and adult participants were asked to search for a Mickey Mouse among four depictions of a different version of Mickey Mouse and four pictures of Jerry Mouse. Unknown to the participants, the four Mickey distracters predicted the location of the target Mickey while the Jerry distracters were random from trial to trial. The procedure was also similar to Merrill et al. (2013) in that the new displays were not presented until the test phase. Results suggested that children as young as 5-6 years old as well as 9-10 years old demonstrated significant contextual cueing effects. In addition, the magnitude of contextual cueing in two groups of children did not differ from college students. Additional research has indicated that even children with ADHD (attention deficit hyperactivity disorder) and ASD (autism spectrum disorder) displayed contextual cueing effects in the classic paradigm, when the stimuli of the classic Ts and Ls were made easier to distinguish (Barnes et al., 2008; 2010).

Signal to Noise Ratio

Signal to Noise Ratio (S/N) is an electrical engineering term that contrasts the relative strength of a desired signal to the irrelevant background noise. Essentially, the higher the ratio, the easier it is to perceive the signal, and the less disruptive the background noise is in allowing the signal to be processed. In psychology, S/N is typically used to refer more generally to the ratio of useful information to false information encountered during information processing. S/N has a prominent role in the formulation of classic signal detection theories in perception and psychophysics (Chaudhuri, 2010). By manipulating S/N, researchers study psychophysical parameters such as detection threshold and sensitivity.

In cognitive psychology, the term signal has been adapted to refer to any pertinent information and the term noise to refer to any uninformative stimulus that does not benefit learning. For instance, Jungé, Scholl, and Chun (2007) used the term “signal” to refer to the repeated displays and the term “noise” to refer to the new displays in a contextual cueing task (see also Couperus et al., 2011). Essentially, signal is considered the useful/relevant information of interest in perceptual processing, while noise is considered the irrelevant information that may be useless or even distracting. Hence, S/N reflects the balance of different types of information.

In visual search, S/N can be presented in two different ways: in a sequential presentation of information and in a simultaneous presentation of information. Sequential presentation of S/N reflects the ratio of signal to noise accumulated over a series of independently presented stimuli. For instance, over a stream of encountered events, the first event may be a signal and the next event could be a noise. The S/N accrues over stimulus events rather than being reflected in any single event. One example is the AX continuous performance task (Rosvold, Mirsky, Sarason, Bransome, & Beck 1956), in which participants view a continuous stream of letters. They respond to a target X if it is preceded by A whereas they withhold their response when A

succeeds other targets. One common manipulation in this task is the probability of the target over time, reflecting a variation in S/N (Bekker, Kenemans, & Verbaten, 2004; Elvevåg, Weinberger, Suter, & Goldberg, 2000). On the other hand, simultaneous presentation of S/N reflects the ratio of signal to noise within a single encounter. For instance, among stimuli that are seen all at once, one stimulus or a few stimuli can be informative signal and other stimuli could be uninformative noise. In traditional search tasks such as “Where’s Waldo”, signal would be Waldo whereas noise would be all other figures who are not Waldo.

It is not new to distinguish different cognitive processes on the basis of sequential versus simultaneous presentations of stimuli (Henek, & Miller, 1976; Logie, & Pearson, 1997; Cornoldi, Tressoldi, & Rigoni, 1999; Pazzaglia, & Cornoldi, 1999). There is a clear distinction between sequential- and simultaneous-spatial working memory components (Mammarella, Pazzaglia, & Cornoldi, 2008; Mammarella, et al., 2006). In a sequential spatial working memory task, participants first see a series of locations that are presented one at a time and then recall these locations according to their original temporal order (e.g., Corsi task). In a typical simultaneous spatial working memory task, participants are first shown a visual pattern where half of all the cells in a matrix are colored. They are then asked to recall the locations of these cells (i.e., pattern recall test). Mammarella and colleagues (2008) suggest that sequential and simultaneous tasks each account for some unique variance in visuospatial working memory among 3rd and 4th grade children (mean age=8.2 years old). A finding that further supports the dissociation between simultaneous and sequential processing is that children with learning disabilities may have either a sequential or simultaneous working memory impairment, but not necessarily both (Mammarella et al., 2006). In addition, children with Down syndrome are more impaired in simultaneous relative to sequential visuospatial working memory (Carretti, Lanfranchi, & Mammarella, 2013;

Lanfranchi, Carretti, Spanò, & Cornoldi, 2009). As a main focus of this dissertation, it also specifically distinguishes between simultaneous and sequential information processing. In the following sections, sequential and simultaneous presentations of S/N and their developmental relevance are addressed separately.

Sequential S/N

Sequential S/N refers to the ratio of relevant to irrelevant events that are experienced across time. Sequential S/N is most often seen in the study of probability learning. S/N could be conceptually and mathematically converted into the occurrence probability of the signal. For instance, if the S/N is 1:1, the probability of the signal is 50% and the probability of the noise is 50%. Strictly speaking, the concepts of S/N and probability have different underlying assumptions. For S/N, the definitions of signal and its dichotomous counterpart (i.e., noise) are often arbitrary and subjective. By contrast, probability could refer to any specific event without considering its psychological relevance and meaning. This specific event could be a signal, noise, or even one of two different signals. For succinctness, the two terms S/N and probability are used interchangeably in this dissertation. Nevertheless, it is necessary to note that probability is a more general term than S/N.

A person encounters numerous events every day, and actively seeks regularities and probabilities within each event. It can come in the form of the likelihood of rain or finding a parking place close to the office. Being sensitive to S/N or the probability of the informative events has important survival meanings. S/N also directly impacts how easily we acquire knowledge and skills. For instance, as you listen to an artist playing a piece of music, identifying a single wrong note is easier when the music is short compared with when it is relatively long.

Are children sensitive to the manipulation of sequential S/N? Although children in late childhood (around 9 and 10 years old) or even younger children (Schlottmann, 2001;

Denison, Trikutam, & Xu, 2014) can understand the concept of probability (e.g., Piaget & Inhelder, 1975; Nikiforidou & Pange, 2010), their ability to explicitly extract statistical probabilities still undergoes development. For instance, when asked to choose the symbol associated with the highest probability of gain rather than loss and when given probabilistic feedback, children (9-11 years old) need more trials than adolescents (13-14 years old) and adults to identify the better choice among the two. That is especially true when the better choice is associated with a relative small (65%) rather than large (85%) likelihood of gain (Hammerer, Li, Muller, & Lindenberger, 2011). In a similar probabilistic reinforcement learning paradigm, children 10-12 years old committed more errors than adults when the probability of the better choice was 80%. By contrast, they did not differ from adults when the probability of the better choice was 100% (deterministic) or 50% (completely random) (Eppinger, Mock, & Kray, 2009).

Children not only show a weakness in explicitly expressing probabilistic knowledge, they also perform poorer when the tasks are implicit in nature. More specifically, developmental differences emerge when the distinction between signal and noise is less obvious or when the task involves more complicated associative relations. Janacsek, Fiser, and Nemeth (2012) studied age differences in implicit probabilistic sequential learning. Different from the classic SRT task which typically presents deterministic sequences (which is predetermined and always the same, e.g., 14325), the researchers employed a modified version of the SRT task—the ASRT task (i.e., alternating serial reaction time task, see Howard & Howard, 1997) where a random number alternated with numbers in the sequence (e.g., 1R4R3R2R5R where R refers to a random number). As a byproduct of the way ASRT task was constructed, there were two types of sequences with different raw probabilities: high frequency triplets and low frequency triplets. Each high frequency triplet was presented five times more often than each low frequency triplet.

After practice, adult participants typically responded much faster to the high than the low frequency triplets (Howard & Howard, 1997; Song, Howard, & Howard, 2007), thus indicating sensitivity to raw probabilities of implicitly learned events. Compared with young adults (18-29 years old) and teenagers (14-17 years old) who did not differ from each other, the reaction time difference between sequences of high and low frequencies was much more pronounced in children between 4-12 years old (Janacsek et al., 2012).

It is hard to pinpoint the mechanisms responsible for differences between age groups in Janacsek et al. (2012). For instance, it is possible that compared with adults, children benefited more in implicit learning when the signal was of a higher probability. Hence, they would perform better than adults on the high frequency triplets with everything else being equal. On the other hand, it is also possible that children simply suffered more when the signal was of a lower probability. Hence, they performed much worse than adults on the low frequency triplets. Regardless of the different explanations, it is certain that the performance of children less than 12 years old is influenced more by variations in probability than are adults.

Simultaneous S/N

Simultaneous S/N refers to the ratio between relevant and irrelevant information within a single stimulus event. It emphasizes the ability to selectively attend to and learn the relevant information, and ignore the irrelevant information when they both appear at the same time. Suppose in a visual search task we look for a red target and define the signal as being in the same color as the target, the simultaneous S/N would be the ratio of the numbers of the red items versus other color items.

Are children sensitive to the manipulation of simultaneous S/N? When presented with both relevant and irrelevant information at the same time, children are more likely than adults to be distracted. Merrill and Connors (2013) demonstrated that the presence of an irrelevant

stimulus dimension would disrupt the normal pattern of a visual feature search in children more than adults (see also Merrill & Lookadoo, 2004). More specifically, participants needed to decide whether there was a circle among many squares. The researchers also varied the irrelevant dimension of color (stimuli were gray or black). Adults could successfully focus on the shape of the objects and demonstrated efficient search across all conditions (i.e., search rate did not change with the number of distracters in the search display). By contrast, the search performance of children was more impaired when the distracters were composed of two colors, rather than one. More specifically, 9 year olds were much less efficient than adults when the target was gray (the less attention grabbing of the two colors) if half of the distracter squares were gray and half of the distracter squares were black. The search performance of 6 year olds was less efficient than 9 year olds and adults when the distracters were of two colors. Moreover, they did poorer not only when the target was gray but also when the target was black. Hence, the presence of the irrelevant information associated with color, defined here as noise, impacted the performance of children more than adults and the performance of younger children more than older children.

Why Are Children Particularly Sensitive to Low S/N?

Based on the literature reviewed here, it is reasonable to conclude that it is more difficult for children relative to adults to acquire signal information when the S/N is low. Children are more influenced by varying the probabilities of implicitly learned events than are adults (e.g., Hämmerer, Li, Müller, & Lindenberger, 2011; Eppinger, Mock, & Kray, 2009; Janacsek, Fiser, & Nemeth, 2012). Additionally, children are more easily distracted by irrelevant noise (e.g., Merrill & Connors, 2013; Huang-Pollock, Maddox, & Karalunas, 2011). In this section, I consider the underlying mechanisms that might account for children's sensitivity to S/N. Two possibilities are children's limitations in cognitive processing resources and inefficiencies in inhibitory control.

One possible explanation for age-related learning differences under varying S/N conditions is that children have limited processing resources available to detect signal versus noise relative to adults. The resources theory (as reviewed by Bjorklund & Harnishfeger, 1990) focuses on children's limited short term memory capacity. Everyone has a finite amount of cognitive resources to perform a cognitive task. These resources can be divided for use among various components of short term memory. Typically, some of the resources are used for processing and some are used for storing information about our encounters in the world. With cognitive development, children acquire better strategic control over how they use their resources. In addition, with increased experience some cognitive processes can be completed with fewer processing resources. In the context of children's susceptibility to S/N, limited resource theory predicts that children generally have less cognitive capacity for extracting and processing useful information, especially when the S/N is low and there is relatively less profitable information. With more experience, better strategic control, and the gradual maturation of the information processing system, children's processing of S/N becomes more efficient.

There is another explanation why children are particularly susceptible to low S/N. Children may have difficulty making use of inhibition and selective attention mechanisms. More specifically, Bjorklund and Harnishfeger (1990) suggest that one major contributor to the cognitive development of children is increased competence of inhibiting irrelevant information from getting into working memory (see also Dempster, 1992). Studies on inhibition and selective attention consistently reveal that children are particularly vulnerable to distraction and cannot effectively inhibit attention towards irrelevant information. It is well known that selective visual attention improves with age in terms of focusing on the central task and ignoring the incidental stimulus features (Plude, Enns, & Brodeur, 1994; Huang-Pollock, Maddox, & Karalunas, 2011;

Lamm, Zelazo, & Lewis, 2006). Recently Lehman and colleagues (2010) conducted a national study on the development of visual attention with more than two thousand children between the ages of 5 and 17 years old. They used three attention tests that measured how well children could attend to relevant stimuli and inhibit competing stimuli. For instance, in one task children needed to name the font color of the word and ignore the word's meaning, which might or might not be consistent with the actual color of the word (i.e., a modified Stroop Task). In another task children needed to detect a particular digit with a particular font among many digits of various fonts. In a third task children needed to pick the same letters, ignoring whether they were capitalized or not (e.g., Aa but not AB). The researchers found a rather steady growth rate of attention development from the age of 5 to 15 years (see also Gomez-Perez & Ostrosky-Solis, 2006). On the other hand, there was evidence that the most pronounced changes in terms of selectively attending to relevant information and ignoring irrelevant information are between 6 and 11 years old (Tabibi & Pfeffer, 2007; Vakil, Blachstein, Sheinman, & Greenstein, 2009; Klenberg, Korkman, & Lahti-Nuutila, 2001; Chelune & Baer, 1986; Welsh, Pennington, & Groisser, 1991). In the context of S/N, based on these studies it is predicted that children would have more problems ignoring noise, especially when the noise is of a relatively high frequency. In addition, it is reasonable to expect the biggest changes to occur between 6 and 12 years old.

S/N in Contextual Cueing

S/N is an integral part of contextual cueing. Essentially in the contextual cueing task, participants learn that certain displays appear much more often (i.e., repeated displays) than others (i.e., new displays). However, it seems that for contextual cueing, the absolute number of repetitions is not the most decisive factor. Increasing exposures to the repeated displays did not necessarily improve learning since learning typically reaches its maximum after just 6 exposures of the same repeated display (Jiang & Chun, 2003). Instead, I am suggesting that it is the contrast

between the frequencies of repeated and new displays or the S/N that matters. Here the term “S/N” refers to the relative amount of predictive distracters or displays versus unpredictable distracters or displays that participants encounter in the contextual cueing task.

Sequential S/N. The difference between sequential and simultaneous S/N is also relevant to contextual cueing. Sequential S/N in contextual cueing refers to the differing amounts of repeated vs. new displays within each block of trials. In fact, a common practice in the study of contextual cueing is to present equal numbers of repeated and new displays within each block, which provides a measure of the gradual unfolding of contextual cueing effects over time. When half of the displays are repeated and half are new, S/N would be considered to be 50% (e.g., Chun & Jiang, 1998; Jiang & Chun, 2001). On the other hand, other researchers have presented only repeated displays in the learning phase without any new displays, after which presenting both repeated and new displays in the test phase (e.g., Rausei, Makovski, & Jiang, 2007). In this condition the S/N in the learning phase would be considered to be 100%. To my knowledge, no studies have directly compared these two different procedures to evaluate how S/N impacts contextual cueing.

On the other hand, one study is tangential to the current discussion. Jungé, Scholl, and Chun (2007) found that the presentation order of signal and noise impacts whether or not contextual cueing is observed in adults. Specifically, one group of participants received a few blocks of the signal displays (repeated displays) first and then a few blocks of the noise displays (new displays) without an overt break between the two types of displays. A second group of participants received the same amount of the repeated and new displays with the presentation order reversed (i.e., they viewed the new displays first and the repeated displays second). When tested later with both the repeated and the new displays in the same block, the first group of

participants demonstrated significant contextual cueing while the latter group did not. Therefore, in contextual cueing, the initial experience may decide whether the mindset for implicit learning is established. Finding no regularities at the beginning may have impeded subsequent learning. Although Jungé, Scholl, and Chun (2007) did not directly answer the question as to how S/N impacts contextual cueing, their research suggests that these two phenomena may be related.

Previous research from our lab also suggests that sequential S/N impacts contextual cueing. Specifically, we created a contextual cueing task modified after Jiang and Chun (2001) in which participants needed to look for a target Mickey among four other Mickey distracters and four distracters of Jerry Mouse. In the repeated displays, only the Mickey distracters predicted the target while the Jerry distracters did not. Participants could not pre-attentively discard the unpredictable distracters (Jerry). This was hence not like the stimuli in Jiang and Chun (2001) where participants could allocate all their attention to the predictive information. Using these types of displays in our lab, participants turned out to be more susceptible to varying S/N sequentially. Specifically, when both the repeated and new displays were presented within each block, adults demonstrated no learning after repeated exposure. By contrast, when the same repeated displays were presented alone without the new displays for the first few blocks, adults and even children showed significant learning in the test phase.

Sequential S/N may also moderate the learning and the expression of contextual cueing effects in children. One difference in procedures between studies that did and did not find significant contextual cueing in children is the S/N in the learning period. For example, Vaidya and colleagues (2007) intermixed the repeated and new displays within each block and they did not find significant contextual cueing effects in children. By comparison, Merrill et al. (2013) and Yang (2012) did not present the new displays until the test phase and they found contextual

cueing in children. It may be that young children's implicit learning was more easily disrupted than that of adults by the presence of noise during the acquisition phase. One aim of the current dissertation was to directly assess this possibility in children and adults while controlling other variables.

Simultaneous S/N. Simultaneous S/N in contextual cueing refers to the ratio of predictive distracters versus random distracters within each display. Jiang and Chun (2001)'s research on selective attention in contextual cueing could be interpreted as manipulating simultaneous S/N in the language of this dissertation. They found that adults demonstrate significant contextual cueing effects when only half of the distracters predict the location of the target, which is equivalent to a simultaneous S/N of 1:1. With respect to development, Couperus et al. (2011) modified Jiang and Chun's study (2001) and created three types of displays with the same total number of distracters yet different ratios of predictive versus unpredictable distracters. Specifically, in their 25:75 condition, there were 4 predictive, attended distracters (i.e., they predicted the target location and also shared the same color with the target), and 12 unpredictable, ignored distracters (i.e., they were random from trial to trial and also did not share the color with the target). In their 50:50 condition, there were 8 predictive and 8 unpredictable distracters in the displays. In their 75:25 condition, there were 12 predictive and 4 unpredictable distracters in the displays. Although adults demonstrated significant contextual cueing in both 75:25 and 50:50 conditions, they did not do so in the 25:75 condition. It appears that adults' acquisition of contextual cueing was subject to the manipulation of S/N. On the other hand, 10 year olds only showed significant contextual cueing in the highest S/N condition (75:25). Even when the researchers increased the number of the predictive distracters from 8 to 12 in their modified 50:50 condition, the 10 year olds still did not demonstrate any learning. Therefore, the low ratio

of predictive to unpredictable distracters in 50:50 condition, rather than the absolute number of predictive distracters, appears to have accounted for the lack of contextual cueing in children. Compared with adults, it is obvious that children are more vulnerable to the effect of lower S/N than adults in learning contextual regularities.

As defined, S/N is the ratio between signal information (relevant information) and noise information (irrelevant information). However, the concept of “information” reflects not only quantity, but also quality. In terms of visual search, S/N could be represented in terms of the level of complexity of signal and noise, in addition to the number of signal and noise objects. In Yang’s thesis (2012) on contextual cueing, participants were instructed to search for a target Mickey 1. In the distracter different condition, the two subsets of distracters were different from each other. One subset was another version of Mickey (Mickey 2) and the second subset was a version of Jerry Mouse. In the distracter similar condition, the Jerry Mouse distracters were replaced by a third version of Mickey Mouse (Mickey 3). Therefore, in the distracter similar condition both distracter subsets were similar to the target. Unknown to the participants, across both conditions the location of the distracter subset Mickey 2 was consistently paired with the location of the target Mickey 1 and thus predicted the location of the target. The location of stimuli from the other subset (either Jerry Mouse from the distracter different condition or Mickey 3 from the distracter similar condition) varied from trial to trial. In both conditions, the signal was the predictive subset and the noise was the unpredictable subset. Although there were equal numbers of distracters in the predictive subset and in the unpredictable subset across two conditions, the noise in the distracter similar condition was more disruptive and attracted more attention than the noise in the distracter different condition. Therefore, the amount of signal versus noise in the distracter similar condition might have been subjectively lower than that in

the distracter different condition. Although adults demonstrated contextual cueing in both conditions, 5-6 year olds exhibited intact contextual cueing effects only in the distracter different condition. Although the amount of signal to noise may not be the only explanation, it seems that the decrease of S/N might have contributed to the poorer performance of children 5-6 years old in this version of the contextual cueing task.

Statement of Problem

Based on the previous research on developmental differences in contextual cueing, the role of S/N in contextual cueing, and the possible developmental difference associated with the impact of S/N on information processing, this dissertation was designed to investigate the interaction between development, S/N, and contextual cueing. To be more specific, the major research question of this dissertation was how different manipulations of S/N impact the acquisition of contextual cueing in children and adults.

Research overview. Three age groups were tested: 6-8 year olds, 10-12 year olds, and young adults. Children between the ages of 6 and 12 years old are typically deemed school-aged children (e.g., Jacques, & Marcovitch, 2010). Children 6-12 years old experience many dramatic cognitive changes during this age range, some of which represent major developmental milestones (e.g., Berk, 2013; Jacques, Marcovitch, 2010). Pertinent to this dissertation, children 6-12 years old are within the age range where previous studies have found significant contextual cueing (e.g., Dixon et al., 2010; Barnes et al., 2008, 2010; Merrill et al., 2013; and Yang, 2012). However, it is also suggested that 6 year olds' contextual cueing may be less robust (e.g., Yang, 2012) and their inhibition and selective attention mechanisms are less mature than older children and adults (e.g., Merrill, & Connors, 2003; Lehman et al., 2010). Ten to twelve year olds, on the other hand, have demonstrated a better potential for successful learning under conditions of various S/N (e.g., Janacsek et al, 2012), which may result from increased information processing

capacity and more efficient inhibition and selective attention mechanisms (Tabibi & Pfeffer, 2007; Vakil et al., 2009; Klenberg et al., 2001). It was hypothesized that the development of the ability to efficiently detect signal among different S/Ns in contextual cueing tasks should be apparent in rudimentary form in the early stage of middle childhood. It should continue developing well into early adulthood. Therefore, selecting the early and late stages of middle childhood (i.e., 6-8 years old, 10-12 years old) would reflect major developmental changes in the mechanisms responsible for S/N and contextual cueing. Finally, a comparison group of young adults was selected to represent the optimal performance levels of participants in the contextual cueing tasks.

S/N was manipulated in two different ways: simultaneously and sequentially. Experiment 1 manipulated simultaneous S/N as defined by varying the ratios between predictive and unpredictable distracters within each display. I also took a different approach from the manipulations used by Couperus et al. (2011) and Jiang and Chun (2001). In Couperus et al. (2011) the perceptual contrast between the predictive and unpredictable subsets was so distinct (they were in different colors) that it might have permitted participants to preattentively discard and ignore the noise. Additionally, the ability to ignore the noise may also have varied across age groups. Therefore, to eliminate this potential confound, this dissertation made both the predictive and unpredictable subset physically look like each other and like the target. In this case, it was less likely that attention factors would interfere with the manipulation of S/N in terms of predictive and unpredictable distracters (for similar approaches, see also Rausei, Makovski, & Jiang, 2007; Yang, 2012). Experiment 2 manipulated sequential S/N as defined by varying the ratio between repeated and new displays within each block. In both S/N conditions (Experiments 1 and 2), three specific ratio conditions would be used (100%, 67% and 33% predictive).

Note that simultaneous and sequential S/Ns are not necessarily independent of each other; experiments can be constructed to vary both simultaneous and sequential S/Ns at the same time. However, to evaluate the interactions between two types of S/Ns it would require approximately three times the number of experimental trials in the current dissertation. It would in turn require children to complete an almost 2 hour long visual search task, which is unlikely to happen. Due to these reasons, the current dissertation assessed the effects of each independently.

Another factor to consider is that there are different ways to equate the three ratios within each experiment. More specifically, the three conditions in each experiment could have an equivalent amount of overall signal and noise (see Couperus, 2011); an equivalent amount of signal while varying the amount of noise; or an equivalent amount of noise while varying the amount of signal. In the proposed research, I manipulated S/N by presenting the same amount of signal in each condition with different amounts of noise. Therefore, in the simultaneous S/N manipulation (Experiment 1), the repeated displays had the same number of predictive distracters across the three ratio conditions. The only difference between the three ratio conditions was the different numbers of unpredictable distracters within each display. In the sequential S/N manipulation (Experiment 2), there were an equal number of repeated displays within each block for the three ratio conditions. The difference between the three ratio conditions was only the different numbers of new displays within each block. This approach should ensure that any difference associated with the different ratio conditions would be attributed to the manipulation of S/N, rather than a different absolute amount of signal.

To summarize, this dissertation was designed to address four core questions:

1. With equal amounts of predictive information, would S/N impact the acquisition of contextual cueing effects?

2. Would S/N affect contextual cueing differently for children and adults?
3. Would S/N impact the acquisition of contextual cueing effects differently in the simultaneous and sequential conditions?
4. If the answer to question 3 was yes, would simultaneous and sequential S/Ns impact contextual cueing differently for children and adults?

Predictions. Regarding the first two questions, there were four predictions.

Prediction 1. It was predicted that S/N would significantly impact contextual cueing acquisition. It was expected that the acquisition of contextual cuing effects would be the fastest in the highest S/N condition, and the slowest in the lowest S/N condition.

Prediction 2. Adults would exhibit larger contextual cueing effects than the older children who would in turn exhibit larger contextual cueing effects than the younger children.

Prediction 3. All age groups would demonstrate intact contextual cueing effects in at least the 100% S/N conditions.

Prediction 4. The influence of S/N in contextual cueing would interact with age. In other words, even though the younger and older children might demonstrate intact contextual cueing when the S/N was high, the children's performance would be more impaired than that of adults when the S/N was low. This is because children are likely to have greater problems extracting the signal/predictive information when the S/N is low.

Exploratory issue. This dissertation also tried to explore whether there would be a difference between the two methods of manipulating S/N. In general, regarding visual images, it seemed that we are more likely to extract regularities when all items are presented simultaneously compared with when they are presented in separate events (see Blablock, & Clegg, 2010; Saffran, 2002). Saffran (2002) constructed a statistical learning task using visual

stimuli. In this task, participants were exposed to probabilistic sequences of visual shapes that conform to a complex, rule-based finite grammar. When shapes were presented on the computer screen one by one, participants had difficulty distinguishing the sequences of those shapes that were grammatical from those that were not. However, when the same series of three or five shapes were presented at the same time on the screen, participants demonstrated better learning in the grammatical than ungrammatical conditions. This result contrasts with auditory statistical learning in which both children and adults can extract conditional probabilities from sequentially presented auditory stimuli. Also consistent with our daily experience, language is experienced one word at a time while the visual environment is usually seen all at once. More importantly, these studies suggest that the relative impacts of S/N may depend on the specific task conditions, whether the noise is introduced simultaneously with the target or over a period of time.

In contextual cueing, the simultaneous and sequential manipulations reflect two different ways that may make environmental regularities difficult to perceive. When S/N was manipulated sequentially, it was analogous to encountering multiple environments where the information was different in each environment. When S/N was manipulated simultaneously, it reflected situations in which some aspects of a single environment changed and some aspects remained the same across successive encounters. When S/N was high, the presentation mode might not matter. However, when S/N was rather low, there might be a difference between the two presentation modes in contextual cueing. It might be further amplified in children compared with adults. My results should provide data relevant to examining how different manipulations of S/N impact the acquisition of contextual cueing effects in different ways.

CHAPTER 2: EXPERIMENT 1 (SIMULTANEOUS)

Method

Participants

Three age groups were recruited: typically developing children 6-8 years old, children 10-12 years old, and college students. Child participants were recruited through afterschool programs, church groups, home school programs, and local ads. They were tested at the university, in the afterschool programs, or at their home, whichever was most convenient for the children and the parents. Each child participant was given a \$10 gift card at the end of the testing to compensate for his/her time and effort. Parental consent and child assent were obtained before testing. Young adults were students in Introductory Psychology classes and received course credit for participating. All recruitment and testing procedures followed the IRB guidelines of the university.

In Experiment 1, participants included 20 younger children (Age in years: $M = 7.59$, $S.D. = 0.97$; min: 6.00, max: 8.67; 11 boys, 9 girls), 20 older children (Age in years: $M = 11.13$, $S.D. = 0.80$; min: 10.17, max: 12.92; 11 boys, 9 girls) and 20 young adults (age range = 17 - 21; 7 males and 13 females). One additional younger child began the test but did not complete it.

Design

Experiment 1 was designed to evaluate age differences in the impact of simultaneous S/N on the acquisition of contextual cueing effects. The experiment was a Group (3: 6-8 years old, 10-12 years old, and adults) x Simultaneous Ratio (3: 100%, 67% and 33%) x Predictability (2: repeated vs. new) three-way ANOVA design.

Materials

Experimental materials were displays of animal silhouettes (dogs, cats, and birds). The task required participants to look for a specific depiction of a particular animal among other depictions of that animal and press keys on the computer keyboard to indicate which way the target animal silhouette was facing (i.e., left or right). There were three ratio conditions. In the 100% condition (see Appendix A), there were 8 identical distracter animals and one target animal that appeared in an invisible 5 x 5 matrix. Each animal silhouette could only occupy one cell of the matrix. In the 67% condition (see Appendix B), there was one subset of 8 distracters, one target, and another subset of 4 distracters in an invisible 5 x 5 matrix. In the 33% condition (see Appendix C), there was one subset of 8 distracters, one target, and another subset of 16 distracters in an invisible 8 x 6 matrix. In the repeated displays of all three ratio conditions, the 8-distracter-subset predicted the target and the other subset (0 distracters in 100% condition, 4-distracter-subset in 67% condition, and 16-distracters-subset in 33% condition) did not predict the target. In the new displays across all three conditions, none of the distracters predicted the target location and the distracters were random from trial to trial. Each animal silhouette across three ratio conditions was identical in size and thus occupied the same area on the retina. For each ratio condition, all the distracter and the target animal silhouettes belonged to the same animal category. Different animal silhouettes were used in the different ratio conditions. This was to keep children engaged in the search task and to prevent any possible interference across conditions. For instance, animal silhouettes might be different versions of dogs in the 100% condition; different versions of birds in the 67% condition; different versions of cats in the 33% condition. Additionally, the specific animal silhouettes used in each ratio condition were counterbalanced across participants within each age group such that each animal was presented an equal number of times in each ratio condition.

Four unique configurations of the predictive distracters were constructed and used for the repeated displays in each of the three ratio conditions. In a specific repeated display, the target faced left half of the time and right half of the time. The possible target locations were arranged in four quadrants across the four repeated configurations. There were also 16 new trials in each of the three ratio conditions. In the new displays all the distracters were random and did not predict the location of the target. The targets also faced left or right an equal number of times. Additionally, the targets in the new trials shared the same locations as those in the repeated trials. Therefore, any difference that was found between repeated and new trials would be due to learning the distracter layouts rather than learning the specific locations of the possible targets.

Procedure

The three ratio conditions were presented separately. For each of the three ratio conditions, there were 5 blocks of 12 repeated trials per block in a learning phase. Each repeated configuration was repeated three times in each block. After the learning phase, a test phase consisting of 16 repeated and 16 new trials was presented. All the trials within each block were randomized. All participants completed 276 trials in total with 92 trials in each ratio condition.

The experiment was programmed using Superlab 4.5.2 Software. Each trial started with a fixation cross in the center of the display that remained visible for 750 ms. The offset of the fixation cross was immediately followed by the stimulus display. The display remained visible until the participant made a response. The next trial began automatically 750 ms later. If participants made an error or did not respond within 10 seconds, a short beep was heard and an error was recorded. For each type of display (repeated and new) there were equal numbers of left and right responses within each block. Response times to identify the direction the target was facing were automatically recorded to the nearest ms.

All participants were tested individually. Prior to the start of each experimental condition the young adults were shown one sample display and provided general instructions. They were told to press “S” using the left hand if the target animal faced left and press “L” using the right hand if the target faced right. Speed and accuracy were emphasized. Particular efforts were made to engage the child participants with the search task. They were first told a cover story that a hunter was lost in the woods and three friends (a dog, a cat and a bird) were going to help him. However, there were many dogs, cats, and birds in the woods each time and the hunter had to find the right one. That one was identified as the target. The child was then shown a sample picture and told how to respond. Each experiment began when the experimenter was certain that the child understood how to respond and was ready. When the child completed a block of trials, there was a break and the child was told that he/she had helped the hunter complete one task. At the end of each ratio condition, a longer break was provided during which the experimenter engaged the child in conversation and encouraged a continued high level of performance in the task. Breaks lasted until participants said they wanted to continue. With breaks, the experiment lasted 30-45 minutes for the adults, 40-60 minutes for the older children, and 45-60 minutes for the younger children.

Explicit Memory Test

At the end of the experiment, participants were given an explicit memory test (see also Dixon et al., 2010). The participants were shown the repeated configurations that were used in the experiments with only the eight predictive distracters presented. All other locations were occupied by numbers and letters (see Figure 1). The participants were told that the target animal was now hiding in one of those places marked by numbers or letters. They were asked to indicate where they thought the target animal was by pressing the number or letter corresponding to that location.

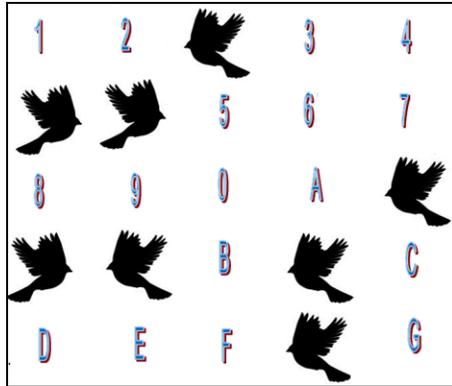


Figure 1. One example in the explicit memory test.

Results

Errors were rare, with no age group exhibiting error rates of more than 5%. Therefore, error rate was not subjected to further analysis. The primary dependent variable was response time to identifying which direction the target was facing. Mean response times (RTs) were calculated on correct responses for each type of display (i.e., repeated and new displays, if there were any) in each block of each ratio condition for each participant. These data were subjected to three primary analyses. First, RTs of the learning phase for repeated trials were analyzed as a measure of general learning performance. Second, RTs of the repeated vs new displays were compared in the test phase as a measure of contextual cueing. Third, RTs were converted to percentage of facilitation (PoF) for repeated relative to new displays in order to compare the benefit of contextual cueing across groups. These analyses were reported separately below.

RTs in the learning phase

I first conducted a 3 (group: younger children, older children, and adults) x 3 (ratio: 100%, 67%, 33%) x 5 (blocks) mixed ANOVA on RTs of repeated displays in the learning phase. The main effect of group was significant, $F(2, 57) = 21.28, p < .001, \eta^2_p = .427$, with adults (1839ms) and older children (2472ms) responding faster than younger children (3649ms), $p < .001$ (Bonferroni correction). The main effect of ratio was significant, $F(1.92, 109.60) = 149.23$ (Greenhouse-Geisser), $p < .001, \eta^2_p = .724$. RTs were slower in the 33% condition (3867ms) than the 67% condition (2432ms), which in turn were slower than the 100% condition (1661ms), all $p < .001$. In addition, the main effect of block was significant, $F(2.15, 122.45) = 29.36, p < .001, \eta^2_p = .340$ with faster RTs over blocks. There were three significant two-way interactions: ratio by group, $F(3.846, 109.60) = 9.61, p < .001, \eta^2_p = .252$; block by group, $F(4.30, 122.45) = 2.95, p = .020, \eta^2_p = .094$; and ratio by block, $F(3.55, 202.25) = 5.80, p < .001, \eta^2_p = .284$.

=.092. Finally, the three way interaction between ratio, block, and group was also significant, $F(7.10, 202.25) = 2.77, p = .009, \eta^2_p = .089$.

To analyze the three way interaction, I first looked at the effect of S/N by blocks in each group separately. For all three groups, the main effect of block was significant, indicating decreasing RTs with practice, $ps < .05$. The main effect of ratio was significant, indicating that RTs were slower in the 33% relative to 100% to 67% conditions, $ps < .05$. However, the interaction between block and ratio was only significant for the young children ($p = .036$), indicating that this group exhibited a larger decrease of RTs in the 33% relative to other two S/N conditions.

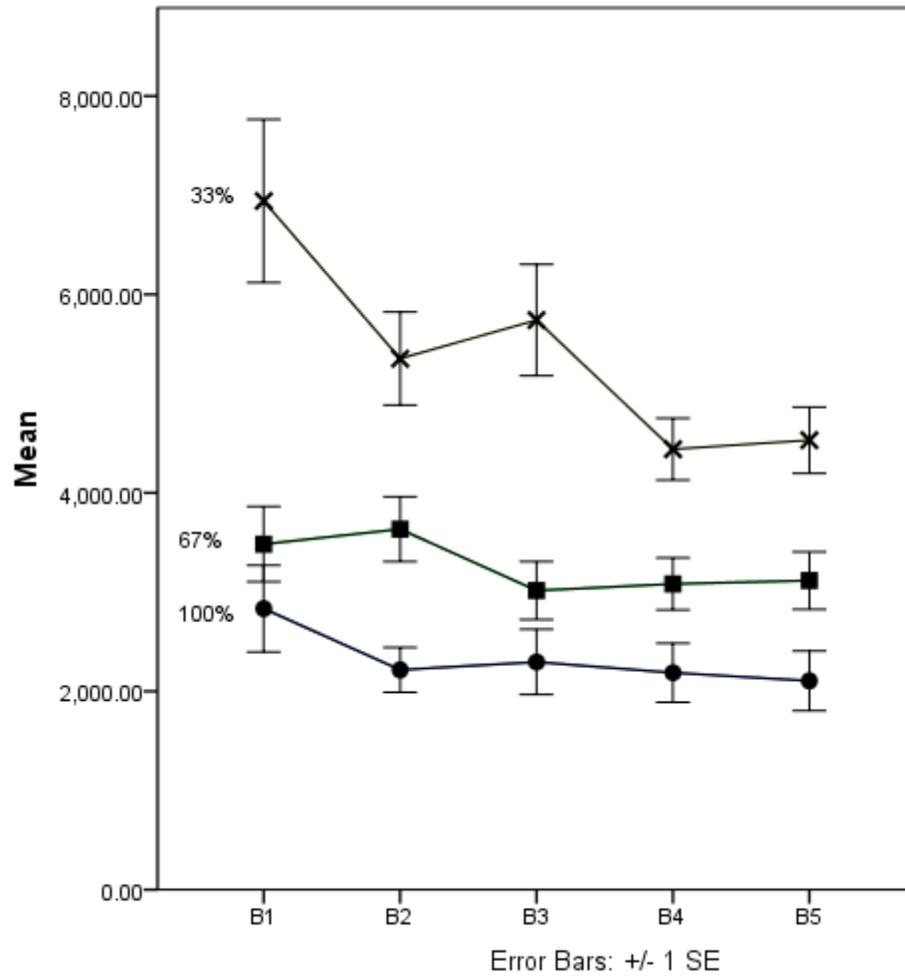


Figure 2. RTs in the learning phase across three ratio conditions for younger children in Experiment 1.

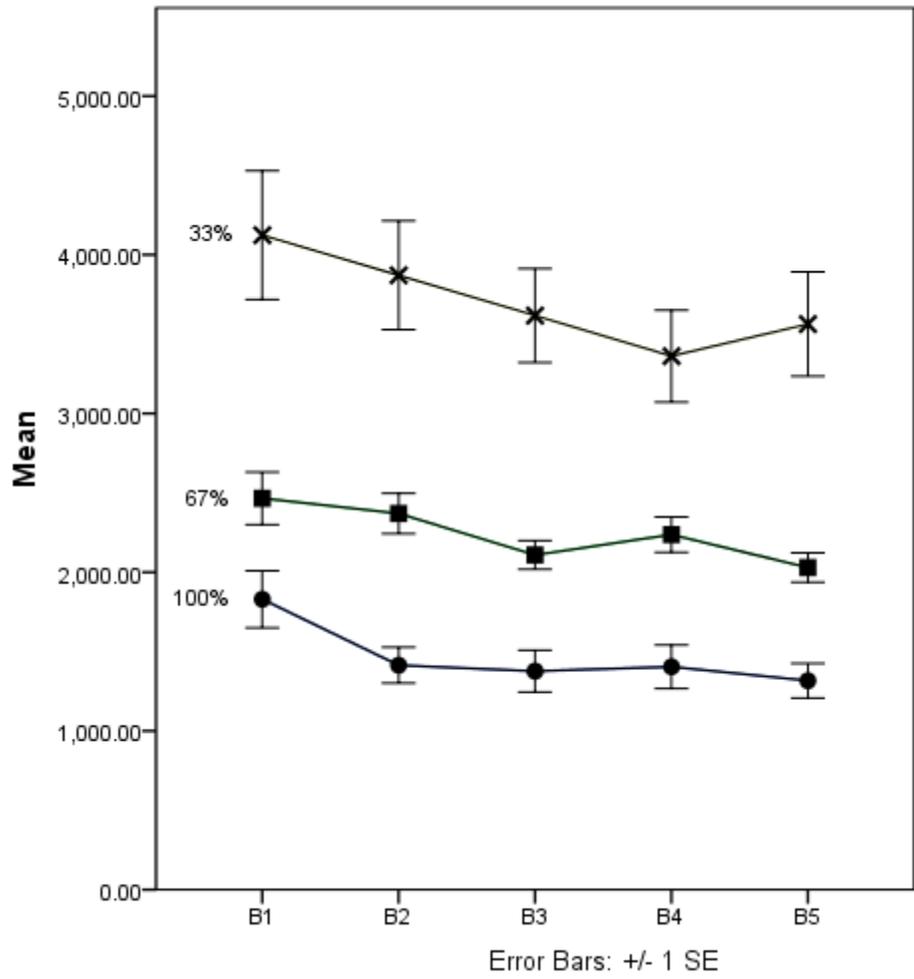


Figure 3. RTs in the learning phase across three ratio conditions for older children in Experiment

1.

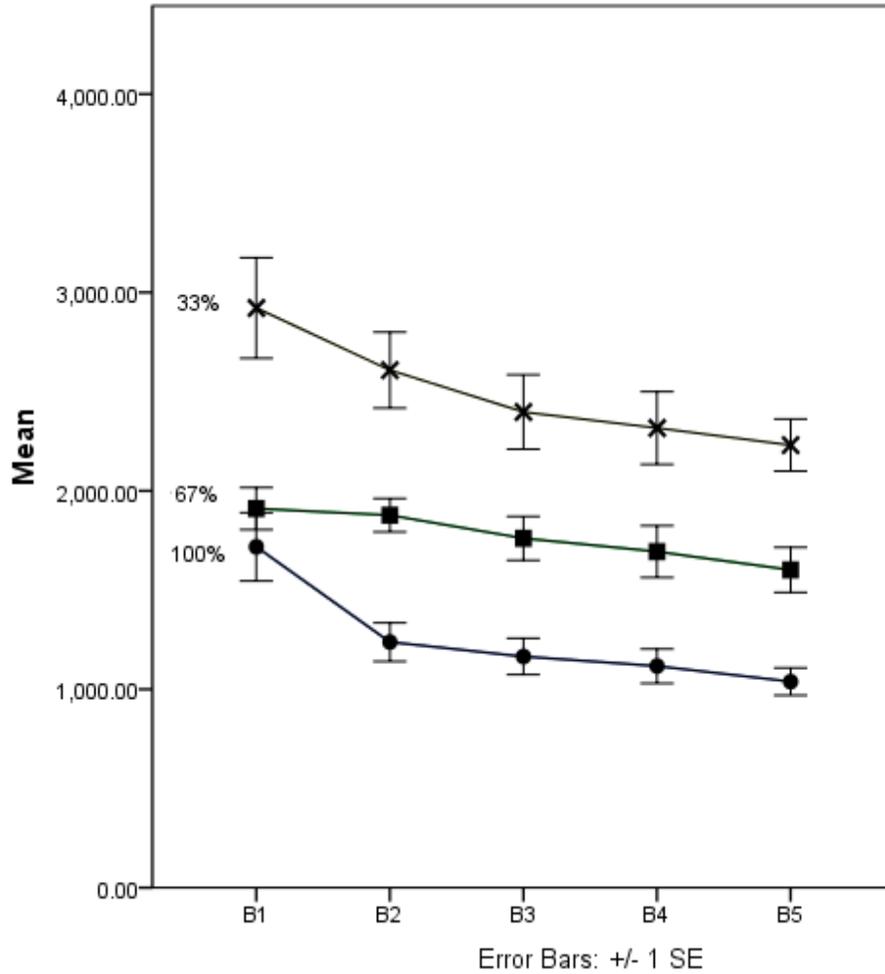


Figure 4. RTs in the learning phase across three ratio conditions for adults in Experiment 1.

Contextual cueing effects

I then conducted a 3 (group: younger children, older children, and adults) x 3 (ratio: 100%, 67%, 33%) x 2 (repetition: Repeated vs. New) mixed ANOVA on RTs of the repeated and new displays in the test phase. There was a significant main effect of group, $F(2, 57) = 25.79, p < .001, \eta_p^2 = .475$. Post hoc tests using Bonferroni correction suggested fastest RTs in adults (1643ms), followed by older children (2271ms), who in turn responded faster than younger children (3062ms), $ps < .05$. The main effect of ratio was significant, $F(1.61, 91.88)$

=145.03, $p < .001$, $\eta^2_p = .718$. RTs were faster in the 100% condition (1503ms) than the 67% condition (2192ms), which in turn was faster than 33% condition (3281ms), $ps < .05$. The main effect of repetition was also significant, $F(1, 57) = 86.36$, $p < .001$, $\eta^2_p = .602$; with faster RTs to the repeated displays (2171ms) than the new displays (2479ms). The interaction between ratio and group was significant, $F(3.22, 91.88) = 5.31$, $p = .002$, $\eta^2_p = .157$. All three groups showed faster RTs in the 100% condition than the 67% condition followed by the 33% condition. However, the RT difference was much bigger for the younger children than older children and adults. The interaction of ratio by repetition was also significant, $F(1.51, 86.14) = 6.50$, $p = .005$, $\eta^2_p = .102$. In all three ratio conditions, RTs were much faster in the repeated than the new condition. However, the difference was much bigger in the 33% condition (476 ms) than the 67% (298ms) and the 100% conditions (151ms). Analyses within each ratio condition for each age group further confirmed significant contextual cueing effects across all conditions. See Tables 1, 2, and 3.

Table 1

Mean RTs in test phase for adults in Experiment 1

	Repeated	New	Diff	Sig.(two tailed)
100%	1027 (321)	1188 (413)	161	<.001
67%	1426 (284)	1686 (546)	260	.002
33%	2073 (603)	2459 (860)	386	.005

Note: They were in ms (S.D. in parentheses). Diff=RTs of New displays-RTs of Repeated displays.

Table 2

Mean RTs in test phase for older children in Experiment 1

	Repeated	New	Diff	Sig.(two tailed)
100%	1334(550)	1472(545)	138	.001
67%	2042(384)	2268(453)	226	.019
33%	3012(950)	3497(1170)	485	.008

Note: They were in ms (S.D. in parentheses). Diff=RTs of New displays-RTs of Repeated displays.

Table 3

Mean RTs in test phase for younger children in Experiment 1

	Repeated	New	Diff	Sig. (two tailed)
100%	1922(1037)	2076(1062)	154	.001
67%	2660(732)	3069(882)	409	.003
33%	4044(1186)	4600(1470)	556	.004

Note: They were in ms (S.D. in parentheses). Diff=RTs of New displays-RTs of Repeated displays.

Percentage of Facilitation

To compare the relative magnitude of contextual cueing effects across three age groups within each ratio condition, a Percentage of Facilitation (PoF) effect was computed rather than simply comparing raw RT. When comparing different age groups, the approach of directly using raw RTs has been criticized for its failure to control for baseline processing speed difference (e.g., Pritchard & Neumann, 2009). Children typically respond slower than adults, reflecting their generally slower processing speed. A longer RT baseline of children would provide more room for improvement and hence a greater reduction in RTs relative to adults. To avoid those concerns, here I utilized PoF, rather than raw RTs, as a measure of contextual cueing to compare groups. Following the practice reported in Yang and Merrill (2014), raw RTs were converted into PoF using the following the formula:

$$\text{PoF} = (\text{RTs of New displays} - \text{RTs of Repeated Displays}) / \text{RTs of New displays}.$$

The comparison of PoF values for each group was used to determine whether the amount of facilitation attributable to contextual cueing was equivalent across the different age groups. I conducted a 3 (ratio: 100 %, 67% and 33%) x 3 (Group: younger children, older children and adults) mixed ANOVA on calculated PoF (see Table 4). None of the effects (group, ratio, and

group by ratio) was significant. Hence, all three groups demonstrated statistically similar magnitudes of contextual cueing in the three S/N conditions.

Table 4

Mean PoF of three groups in three ratio conditions of Experiment 1

	100%	67%	33%
younger children	.083(.097)	.115(.166)	.106(.149)
older children	.098(.108)	.084(.159)	.113(.186)
adults	.119(.101)	.124(.132)	.127(.188)

Note: S.D. in the parentheses.

Supplemental analysis

Because the participants took part in three conditions that varied in the number of items in the search displays, it was possible to calculate a regression equation relating RTs and display size for each individual. More specifically, for each individual, RTs of each type of display in each block were regressed on the three set sizes (8 for the 100% condition; 12 for the 67% condition; 24 for the 33% condition). Both intercept and slope values were computed for each individual and for each type of display combination. Commonly used in visual search research (e.g., Wolfe, 1998), a search slope denotes how search changes as a function of the number of search items, reflecting how long it takes to sequentially determine whether each item is the target. Intercept values reflect changes in processes that occur only once, such as perceptual processing and response selection. As an index of search efficiency, a smaller slope indicates a more efficient search per item than a larger slope. Participants can exhibit greater search efficiency by searching fewer items in the search display as in guided search (e.g., Wolfe, 1994). Alternatively, they may spend less time on each nontarget item in the display (e.g., Pashler, 1987). Kunar, Flusberg, Horowitz, and Wolfe (2007) used slopes to evaluate the deployment of attention in a contextual cueing task. Their rationale was that if attention could be directly guided towards the target, search efficiency, if not approaching zero, should at least be much faster in

the repeated displays than in the new displays. However, they did not find a reliable difference in search efficiency between repeated and new displays for young adults; nor did they find improved search efficiency for repeated displays over time. Instead, they found a smaller intercept for repeated than new displays over the last three epochs.

Using y-intercept and slope values calculated for the test phase enabled me to investigate whether contextual cueing effects were associated with changes in search efficiency for children and adults, and whether the magnitude of changes in search efficiency might differ for children and adults. Slope values were analyzed in a 3 (group: younger children, older children, and adults) x 2 (repetition: repeated vs. new) mixed ANOVA. The main effect of group was significant, $F(2, 57) = 11.355, p < .001, \eta^2_p = .285$. Both younger children (140 ms/item) and older children (110 ms/item) exhibited steeper slopes than adults (69ms), $ps < .05$ (Bonferroni correction). The two groups of children did not differ from each other. This is consistent with previous studies in top-down conjunction search and complicated feature search where slopes were steeper in younger children than adults (e.g., Donnelly et al., 2007; Trick, & Enns, 1998; Merrill & Connors, 2013; Merrill & Lookadoo, 2004). In addition, the main effect of repetition was also significant, $F(1, 57) = 9.36, p = .003, \eta^2_p = .141$. Search was more efficient in repeated displays (97ms/item) than in new displays (116 ms/item). The interaction term was not significant. In contrast to Kunar et al. (2007, 2008), I found increased search efficiency resulted from contextual cueing. Further, the magnitude of changes in search efficiency was not different for different age groups.

Y-intercept values were also analyzed in a 3 (group: younger children, older children, and adults) x 2 (repetition: repeated vs. new) mixed ANOVA. The main effect of group was marginally significant, $F(2, 57) = 2.53, p < .09$. However, no significant differences emerged

during tests of simple effects. Neither the main effect of repetition nor the group by repetition interaction approached significance. Hence, it appears that the contextual cueing effects exhibited by all three groups reflected primarily changes in search efficiency (attentional guidance) relative to, for example, response criterion changes or decision making time.

Explicit memory test

In the 100% and 67% conditions, there were 17 possible locations in each display and the chance performance was 1 out of 17 for each of the four explicit memory items (0.235 overall). In the 33% ratio condition, there were 40 possible locations and the chance performance was 1 out of 40 for each of the four items (.10 overall). Seven college participants, 20 older children and 18 younger children completed the post tests. Data were analyzed separately for each group. For the college students, one sample t-tests conducted for each ratio condition suggested that their explicit memory performance did not significantly differ from chance level (for 100%: $M=0$, $S.D.=0$, for 67%: $M=0.14$, $S.D.=0.377$; for 33% condition: $M=0.43$, $S.D.=0.786$; all available $ps>.05$ one tailed). Similar analyses for the older children indicated their recall was also not significantly higher than chance level (for 100%: $M=0.05$; $S.D.=0.223$; for 67%: $M=0.15$, $S.D.=0.366$; for 33% condition: $M=0.15$, $S.D.=0.489$; all $ps>.05$). Finally, analysis of the younger children's performance indicated their recall did not significantly differ from chance level (for 100%: $M=0.33$; $S.D.=0.594$; for 67%: $M=0.11$, $S.D.=0.323$; for 33% condition: $M=0$, $S.D.=0$; all available $ps>.05$). Therefore, I concluded that the performance of all participants was relatively implicit in nature.

CHAPTER 3: EXPERIMENT 2 (SEQUENTIAL)

Method

Participants

A new set of participants completed Experiment 2. There were again three age groups: 6-8 years old, 10-12 years old, and college students. Originally, 23 younger children (6-8 years old) and 23 older children (10-12 years old) were recruited. However, one child in the younger group did not complete the task due to boredom and fatigue. One child's data in the older group were not included because the participant made over 15% errors. The final sample included 22 younger children (Age in years: $M = 7.69$, $S.D. = 0.06$; min: 6.16, max: 8.92; 7 boys, 15 girls), 22 older children (Age in years: $M = 11.21$, $S.D. = 0.82$; min: 10.0, max: 12.42; 11 boys, 11 girls), and 22 college students (age range = 17 - 21; 15 females, 7 males). The recruitment procedures and compensation method were identical to Experiment 1.

Design

Experiment 2 was designed to evaluate age differences in the impact of sequential S/N on the acquisition of contextual cueing effects. The experiment was a 3 (group: 6- to 8-year-olds, 10- to-12 year-olds, and adults) x 3 (sequential ratio: 100%, 67%, and 33%) x 2 (predictability: repeated vs. new) three-way ANOVA design.

Materials

The basic materials of Experiment 2 were very similar to Experiment 1 except for the following. Across the three ratio conditions in Experiment 2, there were always 8 identical distracters and 1 target in each display. As in Experiment 1, two types of displays were constructed. To create the repeated displays, four unique configurations of the distracters were

constructed before the experiment. In the repeated displays, all the eight distracters predicted the unique target location. In the new displays, all the distracters were in random locations and did not predict the target location. Adults were presented with all four repeated displays in each ratio condition. To accommodate for children's longer time to complete the study and the impact of the repetitious nature of the search task on children, the total number of search displays was proportionally reduced for younger and older children. For each child participant and for each ratio condition, I randomly selected and presented three out of the four repeated displays. This reduction was done in a manner to ensure that across the three age groups, participants saw the same four repeated displays for each ratio condition and saw each repeated display the same number of times. Just as in Experiment 1, different animal silhouettes were used in the different ratio conditions.

Procedure

The procedure of Experiment 2 was very similar to Experiment 1 except the following. Across the three ratio conditions, there was a learning phase which consisted of 5 blocks of trials. However, the ratios of the repeated and new trials were different across the three conditions. More specifically, for adult participants, the 100% condition contained 12 repeated and 0 new trials per block; the 67% condition contained 12 repeated and 6 new trials per block; the 33% condition contained 12 repeated and 24 new trials per block. Each repeated configuration was presented three times in each block. After the learning phase, a test phase consisting of 16 repeated and 16 new trials was presented for each ratio condition. Adult participants completed 92 trials in the 100% condition, 122 trials in the 67% condition, and 212 trials in the 33% condition for a total of 426 trials. All the trials within each block were randomized. Note that the 100% conditions in Experiment 1 and Experiment 2 were identical.

For younger and older children, the learning phase of the 100% condition contained 9 repeated and 0 new trials per block; the 67% condition contained 9 repeated and 4 (odd block) or 5 (even block) new trials per block; the 33% condition contained 9 repeated and 18 new trials per block. Each repeated configuration was presented three times in each block, just as it was for adult participants. In the test phase of all three ratio conditions, there were 12 repeated and 12 new trials. Younger and older child participants completed 69 trials in the 100% condition, 91 trials in the 67% condition, and 159 trials in the 33% condition for a total of 319 trials. Participants again completed an explicit memory test at the end of Experiment 2. With breaks, the experiment lasted 30-45 minutes for the adults, 40-60 minutes for the older children, and 45-60 minutes for the younger children.

Results

Errors in the final sample (22 participants in each group) were extremely rare, with no age group exhibiting error rates of more than 5%. Therefore, error rate was not subjected to further analysis. Mean RTs were calculated on correct responses.

RTs in the Learning Phase

There were no new displays in the learning phase of the 100% condition and there were different numbers of new displays in the 67% and 33% condition. Hence, each ratio condition was analyzed separately. For the 100% ratio condition, I conducted a 3 (group: younger children, older children, and adults) x 5 (block) mixed MANOVA. The main effect of group was significant, $F(2, 63) = 17.25, p < .001, \eta_p^2 = .354$. Post hoc tests using Bonferroni correction suggested that adults and older children responded faster than younger children, $ps < .05$. The main effect of block was significant, Roy's $\theta = .906$ (Grice, & Iwasaki, 2007), $F(4, 60) = 13.59, p < .001, \eta_p^2 = .475$ with faster RTs found with increased practice. The interaction between block and group was not significant, Roy's $\theta = .098, F(4, 61) = 1.50$. Thus, all three age groups exhibited faster RTs over time, with younger children responding the slowest overall (see Figure 5).

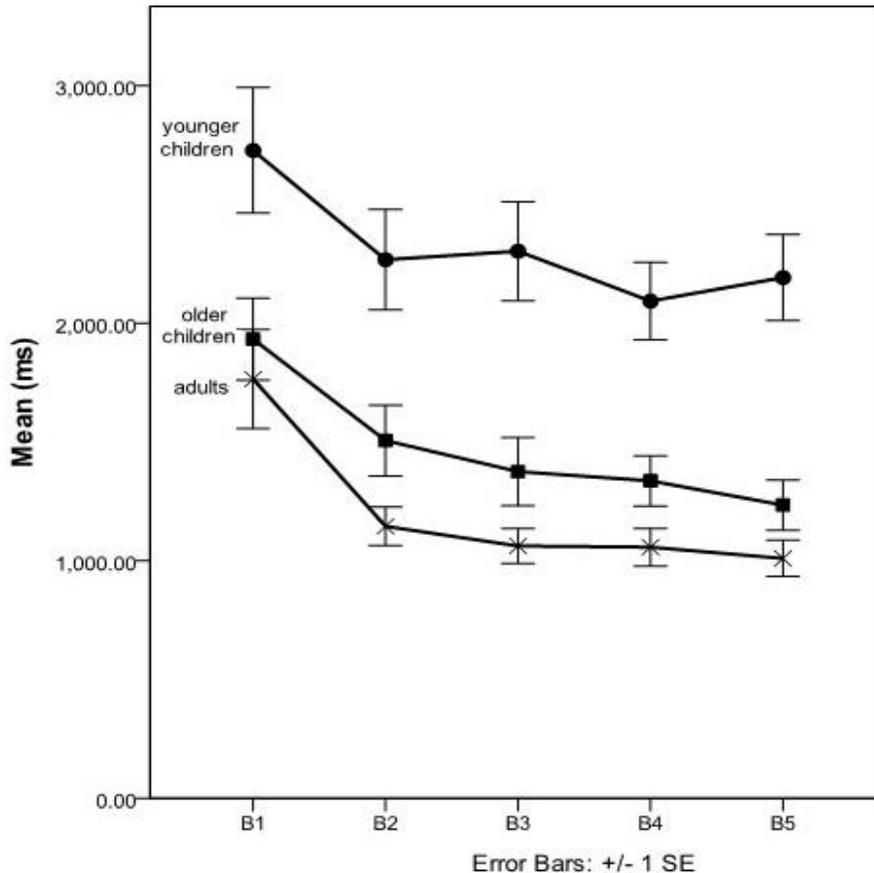


Figure 5. RTs of the repeated displays over five blocks of the learning phase in the 100% condition for three age groups in Experiment 2.

For the 67% ratio condition, there were both repeated and new displays in each block. Comparing the RTs between two conditions within each block could potentially identify when significant contextual cueing was first observed, if at all. Hence, despite the relatively few number of new displays (4 or 5) in each block for two groups of children, I conducted a 3 (group: younger children, older children, and adults) x 5 (block) x 2 (repetition: new vs. repeated) mixed MANOVA (See Figure 6). The main effect of group was significant, $F(2, 63) = 31.48, p < .001, \eta_p^2 = .500$; adults and older children responded much faster than younger children. The main effect of block was significant, Roy's $\theta = .936, F(4, 60) = 14.04, p < .001, \eta_p^2 = .484$, with faster RTs over time. The main effect of repetition was significant, Roy's $\theta = .247, F(1, 63) = 15.54,$

$p < .001$, $\eta_p^2 = .198$, with faster RTs to the repeated displays than the new displays. The interaction between block and repetition was also significant, Roy's $\theta = .322$, $F(4, 60) = 4.83$, $p = .002$, $\eta_p^2 = .243$, indicating that the difference between repeated and new displays varied across blocks. Post hoc tests using a Bonferroni adjustment suggested there were significant RT differences between the repeated and new displays in blocks 3 through 5 (p 's $< .05$), but not in blocks 1 and 2. The three-way interaction of block, repetition and group was not significant, Roy's $\theta = .111$, $F(4, 61) = 1.69$, nor were any other interactions significant. Taken together, these results indicate that significant contextual cueing effects were observed for all groups during the learning phase beginning at Block 3. In addition, there was no evidence that the rate at which contextual cueing developed was different for the three age groups. However, this latter conclusion is offered with some caution due to its reliance on accepting a null effect and the relatively small number of observations per block obtained for the children.

For the 33% ratio condition, the data were also analyzed using a 3 (group: younger children, older children, and adults) \times 5 (block) \times 2 (repetition: New vs. Repeated) mixed MANOVA (See Figure 7). The main effect of group was significant, $F(2, 63) = 25.60$, $p < .001$, $\eta_p^2 = .448$, with adults and older children responding faster than younger children. The main effect of block was significant, Roy's $\theta = .461$, $F(4, 60) = 16.91$, $p < .001$, $\eta_p^2 = .315$, with faster RTs over time. However, the main effect of repetition was not significant, Roy's $\theta = .060$, $F(1, 63) = 3.79$. The interaction was also not significant. Therefore, the data indicate that RTs decreased with practice and younger children responded more slowly, overall. However, overall contextual cueing effects did not reach significance during the learning phase in the 33% condition.

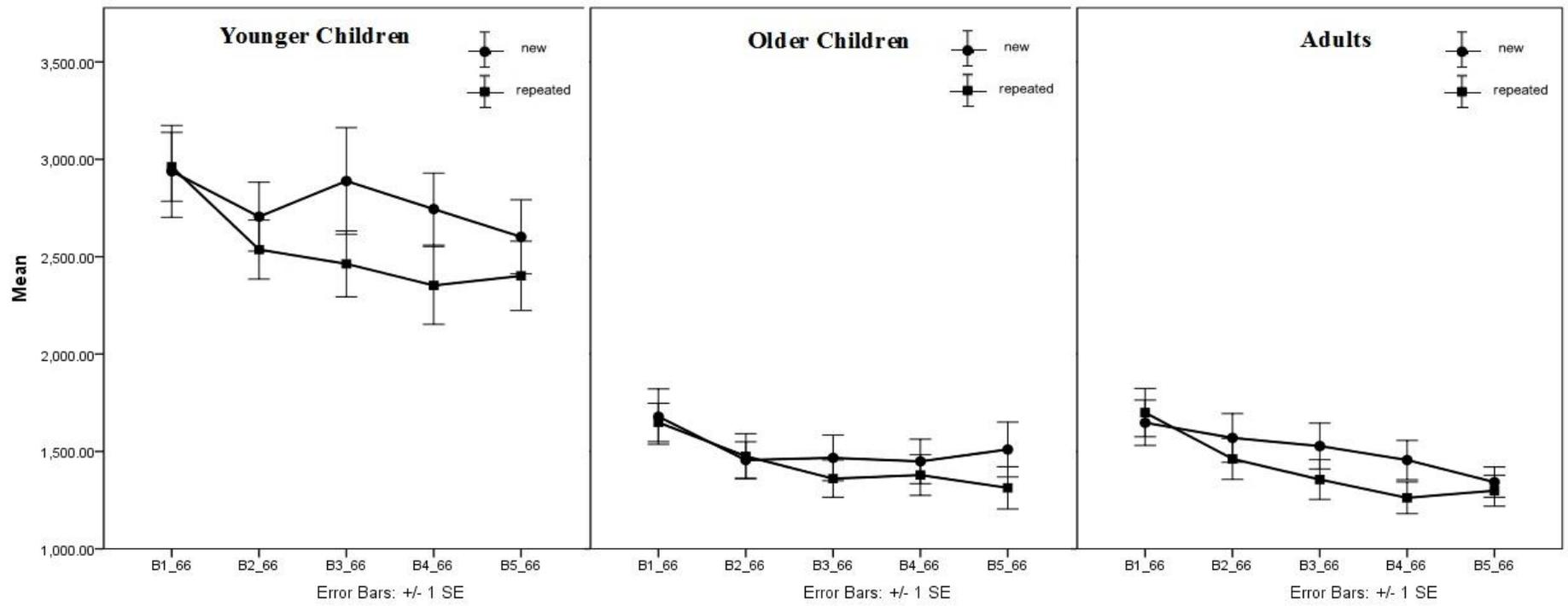


Figure 6. RTs of repeated and new displays in the learning phase of the 67% condition for three age groups in Experiment 2.

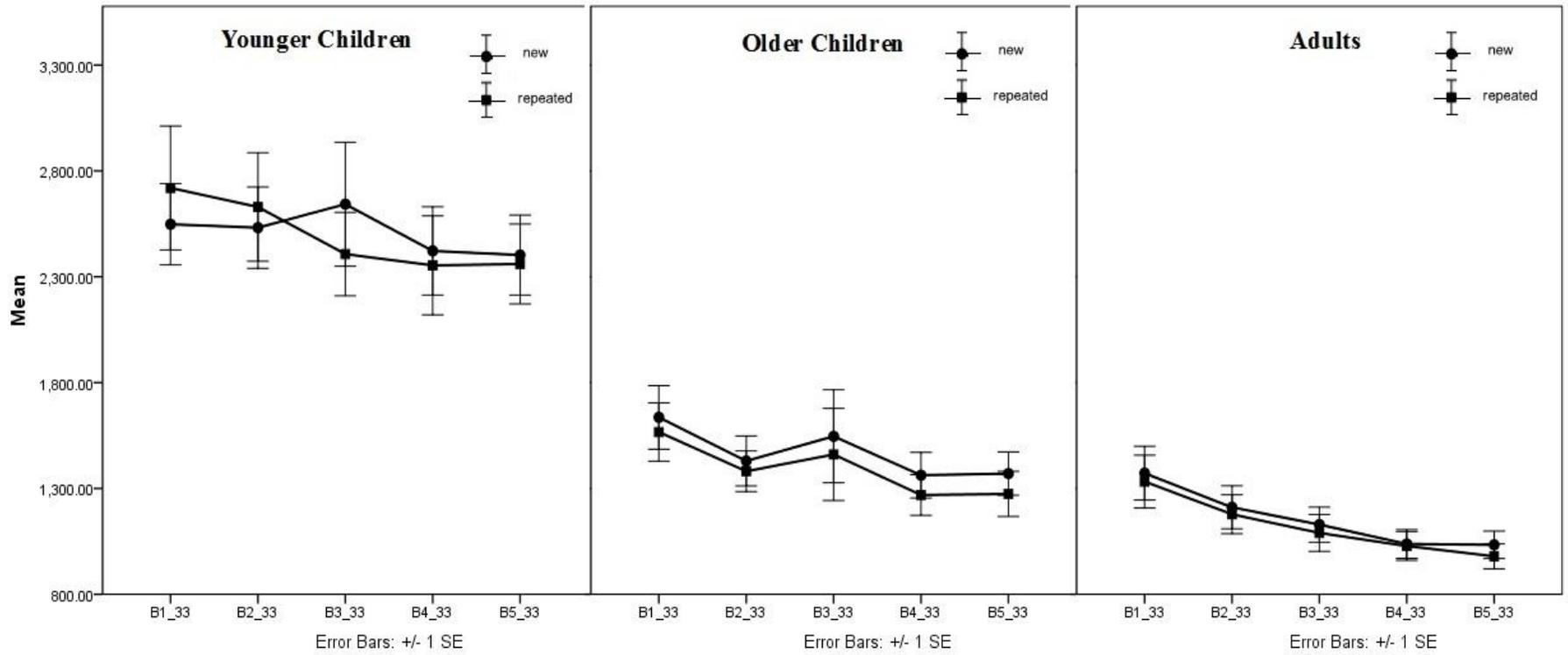


Figure 7. RTs of repeated and new displays in the learning phase of the 33% condition for three age groups in Experiment 2.

Contextual cueing effects

The analysis of contextual cueing effects was conducted on RTs in the test phase across all ratio conditions. A 3 (group: younger children, older children, and adults) x 3 (ratio: 100%, 67%, 33%) x 2 (repetition: new vs. repeated) mixed design MANOVA was conducted. The main effect of group was significant, $F(2,63)=57.99, p<.001, \eta_p^2=.648$, with adults (1104 ms) and older children (1299 ms) responding significantly faster than younger children (2208 ms). The main effect of ratio was significant, Roy's $\theta=.001, F(2, 62)=8.40, p=.001, \eta_p^2=.213$. Post hoc tests suggested significantly faster RTs in the 33% ratio condition (1409 ms) than the 67% ratio condition (1640 ms) and the 100% ratio condition (1562 ms), $ps<.05$. The main effect of repetition was significant, Roy's $\theta=.646, F(1, 63)=40.71, p<.001, \eta_p^2=.393$ with faster RTs in the repeated (1466 ms) than in the new condition (1608 ms). The interaction between ratio and repetition was significant, Roy's $\theta=.196, F(2, 62)=6.08, p=.004, \eta_p^2=.164$; post hoc tests suggested significant RT differences between repeated and new displays in 100% ratio condition (M.D.=177ms, $p<.001$) and in the 67% ratio condition (M.D.=226ms, $p<.001$) but not in the 33% ratio condition (M.D.=21ms). In addition, the predicted three-way interaction between ratio, repetition and group was significant, Roy's $\theta=.112, F(2, 63)=3.53, p=.035, \eta_p^2=.101$.

To evaluate the three-way interaction, I first compared contextual cueing effects across the three ratio conditions separately for each age group. This was to determine if S/N influenced the acquisition of contextual cueing for any of the age groups. The analyses were 3 (ratio: 100%, 67%, 33%) x 2 (repetition: new vs. repeated) MANOVAs. For the younger children, the main effect of ratio was not significant, Roy's $\theta=.235, p=.121$. However, the main effect of repetition was significant, Roy's $\theta=.363, F(1, 21)=7.62, p=.012, \eta_p^2=.266$. The interaction of ratio and repetition was also significant, Roy's $\theta=.369, F(2, 20)=3.70, p=.043, \eta_p^2=.270$. Post hoc tests revealed there were significant contextual cueing effects in the 100% and 67% conditions (See

Table 5), but not in the 33% ratio condition; in fact, the effect was in the wrong direction in the 33% condition, albeit not significant. Hence, younger children exhibited contextual cueing when the S/N was relatively high, but did not when it was low.

Table 5

Mean RTs in the test phase for younger children in Experiment 2

S/N ratio	New	Repeated	Mean difference	Sig (two tailed)
100%	2384(666)	2168(852)	216	.043*
67%	2465(706)	2128(553)	337	.001**
33%	2009(576)	2098(763)	-89	.422

NOTE: They were in ms (SD in the parentheses). mean RTs difference=RTs of new displays-RTs of repeated displays. **p< .01. * p<.05.

For the older children, only the main effect of repetition was significant, Roy's $\theta=1.53$, $F(1, 21) = 32.18$, $p < .001$, $\eta_p^2 = .605$. The main effect of ratio was not significant, Roy's $\theta = .091$, $p = .417$. However, the interaction between ratio and repetition was marginally significant, Roy's $\theta = .293$, $F(2, 20) = 2.93$, $p = .076$, $\eta_p^2 = .227$. As seen in the post hoc tests reported in Table 6, there were significant contextual cueing effects in the 100% and 67% conditions, but the effect was only marginally significant in the 33% condition, $p = .082$. It appears that contextual cueing effects in the 33% S/N condition were not as reliable as those observed in the 67% and 100% conditions for the older children.

Table 6

Mean RTs in the test phase for older children in Experiment 2

S/N ratio	New	Repeated	Mean difference	Sig (two tailed)
100%	1455(549)	1276(509)	181	.000**
67%	1426(491)	1230 (334)	196	.014*
33%	1240(419)	1169(406)	71	.082

NOTE: They were in ms (SD in the parentheses). mean RTs difference=RTs of new displays-RTs of repeated displays. **p< .01. * p<.05.

For the adults, the analysis revealed a significant main effect of repetition, Roy's $\theta=1.18$, $F(1, 21) = 24.69$, $p < .001$, $\eta_p^2 = .540$ with faster RTs for the repeated than for the new displays. There was also a significant main effect of ratio, Roy's $\theta=1.12$, $F(2, 20) = 11.17$, $p = .001$, $\eta_p^2 = .528$, with slower RTs in 67% condition than in the 100% and 33% conditions. The interaction between ratio and repetition was not significant, Roy's $\theta=.073$, $p = .497$. To further ensure that contextual cueing effects were obtained in each condition, I conducted post hoc tests and found significant contextual cueing in each condition as reported in Table 7. Hence, in contrast to the children, the adults demonstrated significant and statistically similar contextual cueing effects across all three ratio conditions.

Table 7

Mean RTs in the test phase for adults in Experiment 2

S/N ratio	New	Repeated	Mean difference	Sig (two tailed)
100%	1113 (406)	980(321)	133	.000**
67%	1369(520)	1224(396)	144	.013*
33%	1011(317)	929(245)	82	.011*

NOTE: They were in ms (SD in the parentheses). mean RTs difference=RTs of new displays-RTs of repeated displays. ** $p < .01$. * $p < .05$.

Percentage of Facilitation

After converting raw RTs into PoF following the procedure used in Experiment 1, a one way ANOVA comparing groups on PoF in the test phase was conducted separately for each ratio condition (see Table 8). For the 100% and 67% ratio conditions, the main effects of group were not significant, $F(2, 63) = .282$, and $F(2, 63) = .282$, respectively. However, for the 33% ratio condition, the main effect of group was marginally significant, $F(2, 63) = 3.07$, $p = .053$. Post hoc tests suggested that adults had significantly larger PoF than younger children, $p < .05$ while there was no difference between older children and adults, $p = .763$ and a marginally significant

difference between younger children and older children $p=.052$. Thus, the three age groups exhibited similar contextual cueing effects in the high and medium S/N conditions. However, group differences emerged when S/N was relatively low.

Table 8

Mean PoF in the test phase for all conditions in Experiment 2

Age group	100% ratio	67% ratio	33% ratio
younger children	.098 (.038)	.117 (.031)	-.043 (.046)
older children	.125 (.017)	.105 (.035)	.052 (.027)
adults	.105 (.020)	.083 (.029)	.066 (.023)

Note: S.E. in the parentheses

Explicit memory test

The explicit memory test was constructed in the same way as in Experiment 1. Fourteen college participants completed the post tests. One sample t-tests conducted for each ratio condition suggested that their explicit memory performance did not significantly differ from chance level (for 100%: $M=.231$; $S.D.=0.439$; for 67%: $M=0.615$, $S.D.=0.650$; for 33% condition: $M=0.539$, $S.D.=0.660$; all $ps>.05$ two tailed). For children, chance performance in this task was 1 out of 17 over the three explicit memory items (0.176 overall) in each ratio condition. Fourteen older children completed the post hoc tests. Their recall did not differ from chance level (for 100%: $M=0.00$; $S.D.=0.00$; for 67%: $M=0.077$, $S.D.=0.277$; for 33% condition: $M=0.154$, $S.D.=0.376$; all available $ps>.05$). Ten younger children completed the post hoc tests. Again, performance did not significantly differ from chance level (for 100%: $M=0.20$; $S.D.=0.421$; for 67%: $M=0.30$, $S.D.=0.483$; for 33% condition: $M=0.20$, $S.D.=0.421$; all $ps>.05$). These results suggested that participants did not exhibit conscious awareness of the target locations, thus indicating that their contextual learning was relatively implicit.

CHAPTER 4: CROSS EXPERIMENT COMPARISON

To explore whether the presentation mode (simultaneous versus sequential) had an impact on the developmental difference in contextual cueing as modulated by S/N, the PoF scores were subjected to a 3 (group: younger children, older children and adults) x 3 (ratio: 100%, 67%, 33%) x 2 (presentation: simultaneous vs. sequential) mixed MANOVA. The main effects of group and ratio were not significant, $F(2,120) = 1.032$; and Roy's $\theta = .034$, $F(2,119) = 2.00$, ns, separately. The main effect of presentation was significant, $F(1,120) = 3.95$, $p = .049$, $\eta_p^2 = .032$. Overall the PoF was larger in the simultaneous condition (.108) than in the sequential condition (.079). The interaction between ratio and presentation was significant, Roy's $\theta = .065$, $F(2,119) = 3.85$, $p = .024$, $\eta_p^2 = .061$. Post hoc tests using Bonferroni adjustments suggested a significant difference in the low S/N condition with higher PoF in the simultaneous condition (.115) than in the sequential condition (.025), $p = .003$. However, there were no differences between the two presentation modes in the high and medium conditions. No interactions involving Group were significant. To summarize, when the S/N was relatively low, the sequential presentation mode was more detrimental to the acquisition of contextual cueing than was the simultaneous presentation mode.

CHAPTER 5: DISCUSSION

The goal of this dissertation was to investigate the impact of S/N on the acquisition of implicit spatial learning in children and adults. In this research, signal referred to predictive and useful information while noise referred to unpredictable and irrelevant information. This dissertation also distinguished two types of S/N. The first type was simultaneous S/N where the noise was presented concurrently with the signal information. More specifically, participants completed three S/N conditions where the ratio of the unpredictable and predictive distracters within each display varied. The second type was sequential S/N where the noise was presented in separate displays than the signal information. More specifically, participants completed three S/N conditions where the ratio of the repeated and new displays within each block of trials varied. Three groups participated: younger children 6 to 8 years old, older children 10 to 12 years old and college students over 18 years old.

Simultaneous S/N

Experiment 1 evaluated the impact of simultaneous S/N on the acquisition of contextual cueing effects in children and adults. Across all three ratio conditions (high, medium, and low) of the simultaneous experiments, there were significant contextual cueing effects in each of the three age groups tested. Moreover, the magnitude of contextual cueing effects was similar across conditions and across age groups. Memory tests conducted after the experiment suggested that contextual cueing effects developed without participants' conscious awareness of the target locations in the repeated displays. Finally, all three groups demonstrated greater search efficiency for the repeated displays than the new displays, indicating more efficient attentional guidance by virtue of successful contextual cueing. Hence, the results not only indicate a robust contextual

learning mechanism resistant to the interference of simultaneous irrelevant distracters in general, but also attest to young children's capacity to implicitly learn environmental regularities in the presence of simultaneous noise.

The original hypothesis that children would not show significant learning in the lowest simultaneous S/N condition was not supported. In fact, the youngest children demonstrated successful contextual cueing in the 33% S/N condition as well as older children and adults. On the surface, this finding may seem inconsistent with previous results that used higher than 33% S/N and did not find significant learning in children. More specifically, in Couperus et al. (2011), 10 year old children did not acquire significant contextual cueing when the ratio of predictive blue distracters versus unpredictable red distracters was 25:75 (4 predictive vs. 12 unpredictable distracters) and when the ratio was 50:50 (8 predictive vs. 8 unpredictable distracters). These children only showed learning when the ratio was rather high such as 75:25 (12 predictive vs. 4 unpredictable). In Yang and Merrill (2014), children 6-7 years old did not show significant contextual cueing when the two subsets of distracters were similar and the ratio of the predictive and unpredictable distracters was 50:50 (4 predictive vs. 4 unpredictable distracters).

There were several methodological differences between the present research and both Yang and Merrill (2014) and Couperus et al. (2011). These differences may be able to explain why contextual cueing effects were observed here but not in previous research. With respect to Couperus et al., the most important change was that the current study did not intermix the repeated and new displays in the learning phase. The inclusion of new displays in which none of the distracters predicted the location of the target could be viewed as introducing additional noise into the procedure. Jungé et al. (2007) found that presenting a set of new displays prior to presenting repeated displays interfered with the acquisition of contextual cueing. It is not

difficult to imagine that intermixing new and repeated displays in the learning phase would slow learning for all participants and impact children to a greater degree than adults. In fact, intermixing repeated and new displays in Experiment 2 reduced or eliminated children's contextual cueing.

With respect to Yang and Merrill (2014), the absolute number of predictive stimuli might have made a difference. In that study, there were only 4 distracters that predicted the target. In this dissertation, there were 8 distracters that predicted the target. Perhaps there needs to be some critical mass of predictive distracters for contextual cueing to be observed. For instance, Song and Jiang (2005) found no contextual cueing in young adults when only 2 distracters, which were randomly selected from 11 identical distracters, predicted the target. In summary, even for high simultaneous S/N conditions, successful contextual cueing effects would still require sufficient numbers of predictive distracters.

On the other hand, however, when there are enough predictive distracters, would contextual cueing acquisition still be susceptible to simultaneous S/N? The answer is probably yes. Admittedly, across three S/N conditions, the magnitude of learning was comparable within each participant group. However, it is unknown how fast learning occurs. In other words, it is likely that the rate of contextual cueing might still be different when the simultaneous S/N varies. Hence, when the simultaneous S/N is too low, and when there are only a few exposure blocks, contextual cueing may not be observed in the test phase. Additionally, when there are more total predictive and unpredictable distracters, the predictive distracters would inevitably be more dispersed. In this case, distracters that are adjacent to the target relative to those that are more remote to the target would become more relevant for successful visual search (Olson & Chun, 2002). Therefore, it is likely that with a much lower simultaneous S/N, difference across S/N

conditions and/or across different age groups can still occur. It is a matter for future research to determine the interplay between the absolute amount of signal and the S/N in the acquisition of contextual cueing in children and adults.

On a positive side, the results of the current study suggested that both adults and children might exhibit contextual cueing under a wider range of conditions than previously thought. For instance, Hodsoll and Humphreys (2005) reported that adult participants were unable to exhibit contextual cueing effects when they were presented with 20 different English letters and instructed to look for letter Z or N. However, they did exhibit learning when the set size was reduced to 10 letters. The authors explained that when the set size was relatively large, the overall configurations might have seemed less variable between displays. This in turn made it more difficult for participants to recognize contextual regularities. They also suggested the possibility of participants employing a more active search strategy with larger displays, which can be detrimental to the acquisition of contextual cueing (Lleras & Von Mühlenen, 2004). The current dissertation suggested that participants were able to demonstrate significant contextual cueing even when there were 24 distracters and only 8 of the distracters were predictive. Furthermore, children as young as 6 to 8 years old exhibited significant contextual cueing. One possible explanation for the discrepancy is that in the current dissertation and different from Hodsoll and Humphreys (2005), not every distracter was unique. Instead, participants could group the distracters into subsets based on the physical similarities among the distracters. When the distracters were identical or composed of two subsets, contextual cueing has been common when the set size was as large as 16 (e.g., Chun & Jiang, 1998; Jiang & Chun, 2001). In addition, using animal silhouettes rather than English letters also might have been beneficial. It is likely that English letters required more detailed discrimination than animal silhouettes did. By using

easier-to-discriminate stimuli in this dissertation, it might be less demanding for attention to be allocated and to recognize contextual regularities, which hence produced contextual cueing.

Simultaneous S/N and Development

The most important developmental result of Experiment 1 was that young children and adults were fundamentally similar in implicit spatial associative learning in the presence of considerable noise presented simultaneously with the signal information. Even young children can extract the signal from the noise and exhibit contextual cueing effects under adverse conditions. Although it is always necessary to be extremely cautious when reaching conclusions based on a null finding, several facets of the data support this interpretation. First, each group exhibited significant learning effects for all three S/N conditions. Second, when converted to PoF, the relative magnitude of facilitation exhibited by each group in each condition was fundamentally the same. Third, the processes that support contextual cueing appear to be the same for the three age groups. Contextual cueing reflected changes in search efficiency in all three groups. Hence, it seems reasonable to conclude that young children are able to benefit from the potentially very important form of learning represented by contextual cueing effects over a wide range of conditions.

The observed similarities in contextual cueing effects between groups in the low S/N conditions have developmental implications. These observations imply that implicit selective attention processes are sufficiently mature to facilitate implicit learning in children ranging from 6-8 years old. Admittedly, selective attention continues to develop into early adolescence (e.g., Plude, Enns, & Brodeur, 1994; Huang-Pollock, Maddox, & Karalunas, 2011; Lamm, Zelazo, & Lewis, 2006). However, this dissertation suggests that children have developed the basic ability to extract simultaneously presented predictable information in the presence of unpredictable noise for contextual cueing effects. It may also be that implicit selective attention undergoes a

different developmental trajectory than explicit selective attention as tested in the previous studies. It may become mature earlier than does explicit selective attention.

On the other hand, these data are inconsistent with at least one model that has been proposed to account for age differences in contextual cueing. Darby, Burling and Yoshida (2014) proposed that contextual cueing was dependent upon overall search RTs in young children. More specifically, the researchers gave children 8-12 years old three types of contextual cueing stimuli. In the first condition, the target was a green horizontal bar that looked like a crayon (“sparse crayon”). The distracters were horizontal and vertical bars that were disconnected in the middle that looked like broken crayons. In the second condition, the target was patterned after the classic Chun and Jiang (1998), except the target and distracters were blue and the distracters L and the target T were more dissimilar. The third condition was very similar to the first condition except that the green bars now had texture and looked like real crayons with wrapped paper (“rich crayon”). Reaction times increased from the first to second to third condition. However, significant contextual cueing effects were only found in the second condition. The authors claimed that reaction times that were too fast or too slow might have hindered the development of contextual cueing in their child participants.

However, the current study does not support the proposition proposed by Darby et al. (2014). Instead, the current study is more consistent with the previous adult studies that reaction times per se should not impact the acquisition of contextual cueing. In Darby et al.’s study, the first condition was associated with about 1713 ms (average RTs of the repeated and the new displays). The second condition was 1950 ms and the third was 2289 ms. In this dissertation, significant contextual cueing was found in conditions where reaction times were as fast as 1300-1500 ms and as slow as 4000-5000 ms (i.e., for children 10-12 years old in the 100% S/N

condition and the 33% S/N condition separately). Instead, it is more likely that the specific stimuli, rather than the resulting RTs, impeded an otherwise intact contextual cueing process in children in Darby et al. (2014). In the current study, across three simultaneous ratio conditions, the complexity of the distracters did not change. However, in Darby et al. (2014), the complexity of distracters varied across conditions and the increased difficulty with perceptual discrimination might have been detrimental to contextual cueing. In addition, in Darby et al. (2014), repeated and new displays were also intermixed during the learning phase. As discussed later in the sequential condition, intermixing new displays lowers sequential S/N and, hence, reduces the magnitude or learning of contextual cueing. Previous research on adults has also increased RTs by increasing discrimination difficulty of the distracters. However, it did not necessarily impact contextual cueing. For instance, Rausei, Makovski and Jiang (2007) found the magnitude of contextual cueing was indistinguishable whether distracters were very similar and or only slightly similar to the target.

Taken together, the data indicate a fundamental similarity between children and adults exhibiting contextual cueing in the presence of simultaneous noise in repeated displays. Even so, there are some likely limits to this claim. In particular, it is reasonable to expect that the rate of acquisition of contextual cueing effects may be different for different age groups. New displays were not included during the learning phase because they would add additional noise. Hence, the simultaneous condition could only measure contextual cueing in the test phase after all participants had acquired contextual cueing. This procedure could have hidden possible differences in the rate of acquisition. Nevertheless, the basic similarities observed across the range of ages tested in this study indicate a robust mechanism of learning available to children at

a relatively young age that provides important tools for learning spatial regularities in the environment.

Sequential S/N

Experiment 2 evaluated how sequential S/N impacted contextual learning for children and adults. Sequential S/N was specifically defined as the ratio of repeated versus new displays presented during the exposure phase. Results suggested that sequential S/N impacted the performance of all three groups of participants. However, increased noise impaired the performance of children more than adults. When the learning phase contained only repeated displays resulting in 100% signal, all three age groups demonstrated significant contextual cueing effects. In fact, the three age groups exhibited roughly equivalent facilitation effects relative to their baseline RT. When the learning phase included 67% repeated displays (33% noise), again all three age groups demonstrated significant and comparable learning effects in the test phase. Moreover, as evidenced by the learning phase, the three age groups began to exhibit contextual cueing effects after approximately the same number of exposures to the repeated displays (after block 3). In contrast, when the learning phase included 33% repeated displays (67% noise), significant developmental differences were observed. While the adult participants demonstrated reliable contextual cueing and the older children demonstrated marginally significant facilitation in the test phase of the 33% condition, the younger children did not show any contextual cueing. However, the manipulation also impacted the adult participants. They did not exhibit significant cueing until the test phase of the 33% condition (after block 5). This was much later than was observed in the 67% condition. Thus, while it was clear that all three groups were susceptible to the manipulation of S/N, the greatest impact was on the youngest children who did not exhibit any significant learning in the lowest S/N condition.

The results of Experiment 2 have some basic implications for understanding the concept of contextual cueing in general. More specifically, the manipulation of sequential S/N impacts how fast learning takes place for those who are able to demonstrate successful contextual learning. Contextual learning was observed earlier in the medium than the low S/N conditions for adult participants. This reflected a need for increased exposures to the repeated displays before contextual cueing was acquired. This is consistent with and extends the observation of Jungé, Scholl and Jiang (2007), who found that presenting new displays first without any repeated displays interfered with contextual learning (see also Gebhart, Aslin, Newport, 2009).

Sequential S/N and Development

The results are particularly relevant to understanding possible developmental differences in acquiring contextual cueing effects. Young children seem to be at a greater disadvantage than older children and adults when noise is sequentially added to the information stream. Previous researchers have reached similar conclusions about other forms of implicit learning (e.g., Thomas et al., 2004; Janacsek et al., 2012; Saffran et al., 2008). For example, Thomas and colleagues (2004) increased ambiguities and employed probabilistic rather than deterministic sequences in their implicit sequential learning tasks. This seemed to be associated with a smaller magnitude and a slower rate of implicit sequential learning in children from 7 to 11 years old relative to adults (see also Meulemans et al., 1998). In another implicit sequential learning study (Janacsek et al., 2012), children 4 to 12 years old and adults showed faster RTs in sequential triplets of high frequency than low frequency. However, after a z-score transformation, those younger than 9 years old showed a much smaller magnitude of learning than young adults and children older than 9 years old. Taken together, these studies suggest that young children's implicit learning may be more easily disrupted than adults in the presence of sequentially presented noise.

One big difference between previous studies of probability learning and Experiment 2 is whether noise was intermixed with the-to-be learned sequence. In Experiment 2, the noise was independent of the to-be-learned information in the form of intervening trials. Intervening trials are often introduced as filler trials to prevent participants from developing conscious awareness of the research question (Chun & Jiang, 1998). For example, in a classic contextual cueing task, the ratio of repeated and new displays within each block is typically 50:50 (e.g., Chun & Jiang, 1998; Jiang & Chun, 2001). Introducing random trials into the learning procedure may help unveil developmental differences in learning in general and contextual cueing in particular. In fact, children may have been doubly disadvantaged in Couperus et al. (2011) because the researchers manipulated the number of predictable and unpredictable distracters within slides while intermixing repeated and new displays throughout their study.

One explanation for the age-related deficiencies observed in our younger children focuses on the role of working memory in the acquisition of contextual cueing. Despite being a form of implicit learning, contextual cueing is nevertheless dependent upon visuospatial working memory capacity. Working memory provides the repository where irrelevant information can be filtered out. It also extracts meaningful information before it is processed into long term memory (Baddeley & Hitch, 1974; Manginelli, Langer, Klose, & Pollmann, 2013). Working memory may also be involved in maintaining and retrieving the repeated spatial layouts (Manginelli, Baumgartner, & Pollmann, 2013). Under high working memory loads, contextual cueing effects can be significantly reduced or even eliminated (Travis et al., 2013; Annac et al., 2010). Children's relatively immature and limited working memory capacity undergoes significant development from 5 to 10 years of age (Riggs et al., 2006; Pickering, 2001). The suggestion here is that low working memory capacity may render children less able to match a repeated display

with repeated displays presented many trials ago. They are less able to maintain and recognize those displays as repeated, especially in the low S/N condition. Hence, younger children's limited working memory may impair information encoding and storage in contextual cueing.

Meanwhile, children's immature inhibition mechanisms may impede the retrieval process. There were more overall trials in the 33% than the 67% conditions. With more intervening new displays, the potential for a greater number of partially overlapping segments between new and repeated displays increases. The new displays would likely interfere with the memory retrieval of the previously seen displays more in the low than in the high and medium S/N conditions. Consistent with previous research, young children were less competent in interference control than older children and adults (e.g., Merrill, & Connors, 2013; Ikeda, Okuzumi, Kokubun, & Haishi, 2011). Younger children are more susceptible to interference from new displays that share commonality with the repeated displays than are older children and adults. Therefore, the interference effect from new displays might be more detrimental to young children than to older children and adults.

One may wonder whether learning would occur if younger children were provided more exposures to the repeated displays in the 33% condition. I postulate that extended exposure per se cannot guarantee the expression of learning. As found in the 67% sequential condition, the three age groups not only all demonstrated significant learning but also did so at a similar pace. That is, in comparison with adults, children did not learn contextual cueing any slower. Additionally, if the lack of learning in the low S/N condition is due to children's immature working memory as suggested earlier, then increased exposures still would not compensate for their limited working memory capacity. Future empirical research would have to be conducted to examine these different possibilities.

Simultaneous vs. Sequential S/N

The cross-experiment analysis suggested overall stronger contextual cueing effects in the simultaneous than the sequential conditions. Nevertheless, this difference was solely attributable to the lowest S/N conditions. Although all three participant groups demonstrated learning in the simultaneous 33% S/N condition, only adults demonstrated reliable contextual cueing in the sequential 33% S/N condition. Hence, it may be more detrimental to present noise as independent events (sequential) than in the same event with the signal (simultaneous), especially for children. The fact that sequential presentation led to a greater detriment in contextual cueing supports the suggestion that working memory may be responsible for the problems exhibited by the younger children. Working memory is needed more for keeping information active and identifying relevant stimuli across displays than within displays.

Distinguishing simultaneous and sequential information processing is important because they reflect the operations of different cognitive mechanisms. The manipulation of simultaneous S/N as in this dissertation probably reflects a high requirement of focused and selective attention. Once participants have distinguished between the predictive and unpredictable subsets, they can implicitly direct their attention to the target in the repeated displays. Even better, this predictive subset predicted the target location perfectly in every single display participants encountered (100% sequentially predictable). On the other hand, the manipulation of sequential S/N condition presents a higher processing demand for memory consolidation and maintenance. Learning repeated displays was more difficult because the repeated displays did not appear as often and were always interleaved with many new displays. Furthermore, even if the repeated displays could be learned, its benefit to visual search would be significantly reduced since only a small percentage of displays could be facilitated by contextual cueing. In this situation, contextual cueing might not be expressed in behavioral results (Jiang & Leung, 2005).

Because they likely rely on different cognitive mechanisms for learning to take place, the low S/N simultaneous and sequential conditions may also present different cognitive demands for children. The results indicated that for the simultaneous condition, children can selectively attend to the relevant information. By contrast, children have more problems in the sequential condition because of their limited working memory capacity. These different mechanisms also have different implications for promoting optimal performance in children. It is likely that performance in low sequential S/N condition may be difficult to improve with instructions or strategies because of its working memory demand. In contrast, in the simultaneous S/N condition, providing instructions to selectively attend to the predictive subset and hence increasing effective attentional allocation may further benefit the acquisition of contextual cueing in children. The current study suggested that in contextual cueing, at least for children, consistent repetitions of just a few locations embedded in an otherwise random space are much better than consistent repetition of the overall layout embedded in a series of random events.

Importance

This dissertation first attests to the robustness of contextual cueing effects. Previous studies have revealed that contextual cueing can be learned with just 4 or 5 exposures (Chun, 2000), remembered even one week after the initial learning (Chun & Jiang, 2003), associated with a very large capacity (Jiang, Song, & Rigas, 2005), found using real life scenes (Torralba, Oliva, Castelhana, & Henderson, 2006; Brockmole, & Henderson, 2006b), acquired via auditory presentation (Kawahara, 2007), and acquired temporally (Olson, & Chun, 2001). The current dissertation indicates that contextual cueing can be acquired even when only a small portion of a context predicts the target or when only a small percentage of the displays are repeated. In many of these conditions, even children as young as 6-7 years old exhibited contextual cueing.

This dissertation also indicates the importance of distinguishing between noise that is presented simultaneously with the signal and noise that is presented sequentially with the signal. Previous contextual cueing studies employed 50% or 100% sequential S/N without acknowledging its potential impact on the acquisition of contextual cueing (e.g., Chun & Jiang, 1998). Additionally, there was only one study that examined simultaneous S/N in children (i.e., Couperus et al., 2011), but that study confounded simultaneous with sequential S/N. The current dissertation systematically manipulated both simultaneous and sequential S/N. By looking at unpredictable information across time and space within the same study context, this dissertation clearly demonstrated that sequential and simultaneous presentation modes of S/N are not equivalent. They apparently have different effects on implicit spatial learning. Presenting noise across the same space as the signal is less detrimental to learning than spreading noise over time, especially for young children.

Implications

The current dissertation first addressed what can and cannot be learned by children by evaluating the potential and the limits of children in early and late childhood. The experimental materials were age-appropriate and engaging to children. Hence, I was able to gather data on the relative abilities of implicit spatial associative learning (i.e., contextual cueing) in children from 6 to 12 years old. Most importantly, the current dissertation identified mechanisms of development that were responsible for age-related changes in what children can and cannot learn implicitly. More specifically, I compared how the general ability to extract signal/useful information from noise/useless information developed with age in the domain of contextual cueing. I manipulated S/N in two different ways in order to identify mechanisms that are particularly immature in younger versus older children and adults. The simultaneous condition focused on selective attention issues and the sequential condition focused on working memory

issues. Age-related changes in the general ability of processing signal in the presence of noise are likely responsible for age-related performance improvements across several other domains (e.g., language, attention). Hence, understanding what variables influence age-related differences in this general ability may provide data valuable to understanding cognitive development in general.

The results of this dissertation have practical implications in real world learning. Overall, a sound ability to implicitly learn the layouts of environments would surely make daily visual search and navigation easier for both children and adults. A common scenario where contextual cueing takes place is that one finds things faster in a familiar than in a strange environment. A child is more likely to find his friend's house down the street if he is already familiar with the environment. In this dissertation, the sensitivity and robustness of children's competence in contextual cueing was further explored under different manipulations S/N. In real life, few things are 100% predictable. It is important that mechanisms that respond to environmental regularities operate in the presence of some ambiguity.

One important result observed in the simultaneous S/N condition was that participants exhibited significant contextual learning in the lowest S/N condition (33% signal). The results indicate that the mechanisms responsible for contextual cueing can tolerate considerable uncertainty that is presented simultaneously. Hence, the conditions in which contextual cueing can impact performance are likely to include many real world situations where at least some spatial regularities and some spatial irregularities are present. For example, contextual cueing has the potential to aid in determining which objects are useful as landmarks when navigating environments. At most navigational choice points, there are likely to be some objects that will always be there (e.g., lamp posts, mailboxes, trees) and some objects that are likely to move the next time they are encountered (e.g., parked cars, people, construction signs). Learning

environments in the absence of explicit attention and memory may be available to even young children across a wide range of situations where irrelevant information is presented alongside with the predictive information in the same scene.

There are also practical implications from the results of the sequential S/N conditions. A developmental difference in the ability to extract signal as a function of sequential S/N exposure suggests that children may need more exposures to static, relative to changing, environments, in order to have a better understanding of their spatial layouts. It implies that we should provide children more experience with well-constructed environments consisting of built-in and relevant spatial regularities, rather than many differing new environments. For instance, a toy store will be easier to navigate if merchandise is seldom rearranged or if the child is not taken to different stores (noise) in between visits to his favorite toy store. Parents should be aware that young children may be more likely to get lost or feel confused by the layout of the environment if they do not visit that place often enough. Compared with adults, younger children may have greater need for environmental regularities. Being exposed to more seemingly random environmental layouts is more likely to lead to a failure to acquire the spatial configurations for children than for adults. While it may not be possible to completely keep children from encountering environments that are not “learning friendly,” it is important to be aware of the potential problems that children, but not adults, have in these environments and it is crucial to know what to do about them.

Revealing children’s particular susceptibility to low sequential S/N also has methodological implications. First, the results imply that future studies that are interested in developmental differences in contextual cueing or other forms of learning, should be particularly careful when adopting adult methodologies. Some manipulations while seemingly innocuous for

adults, may introduce forms of irrelevant information into the information processing environment. Intermixing new displays with repeated displays has been a common practice in the adult literature. However, the results suggest that it may inadvertently increase the task difficulty for children and possibly other intellectually less mature groups as well (e.g., older adults, people with intellectual/developmental disabilities). As hypothesized earlier, this is likely an important difference between studies that did report contextual cueing effects in young children (e.g., Merrill et al, 2013) and those that did not (e.g., Vaidya et al., 2007). Future studies should further evaluate the potential interactions between simultaneous and sequential S/Ns in contextual cueing.

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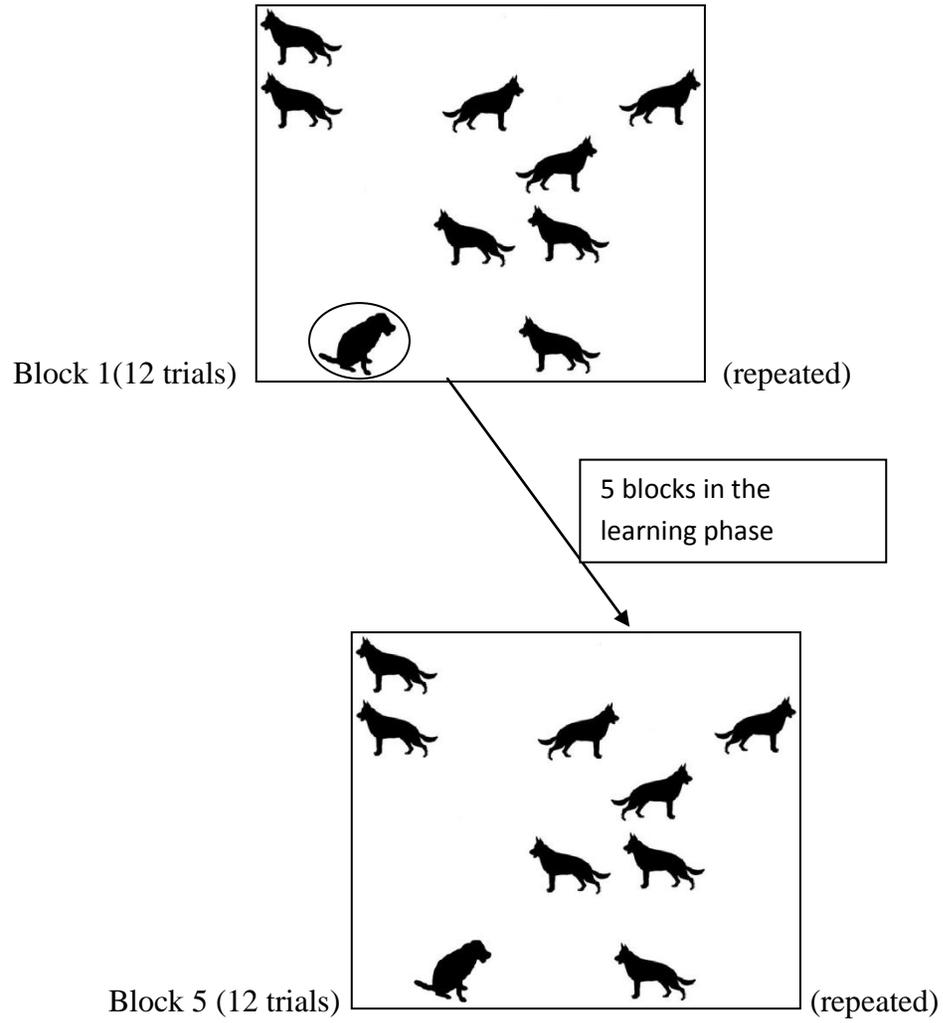
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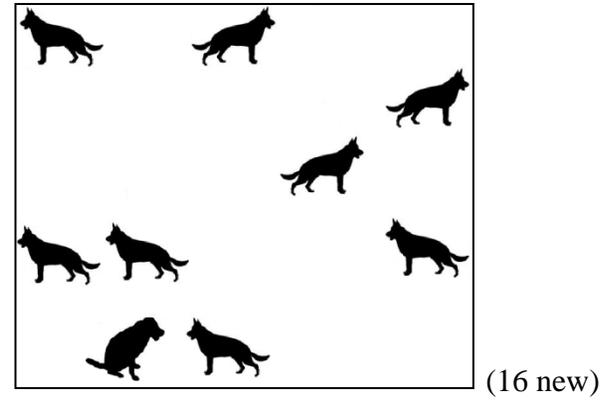
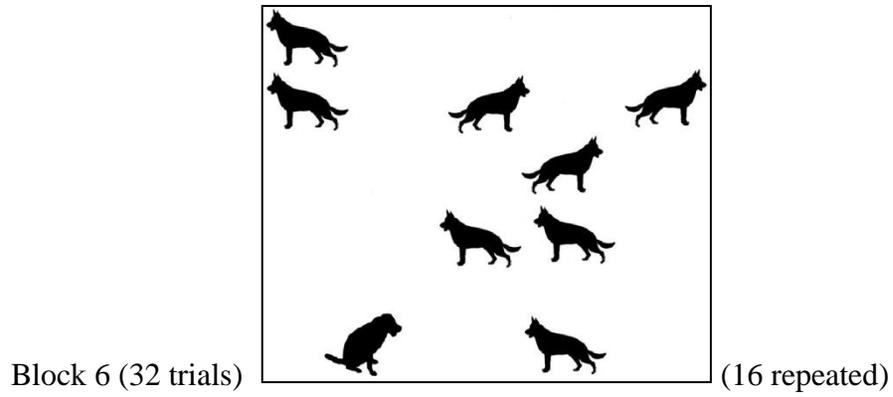
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Appendix A

Experiment 1 (Simultaneous) / Experiment 2 (Sequential) 100% S/N Condition



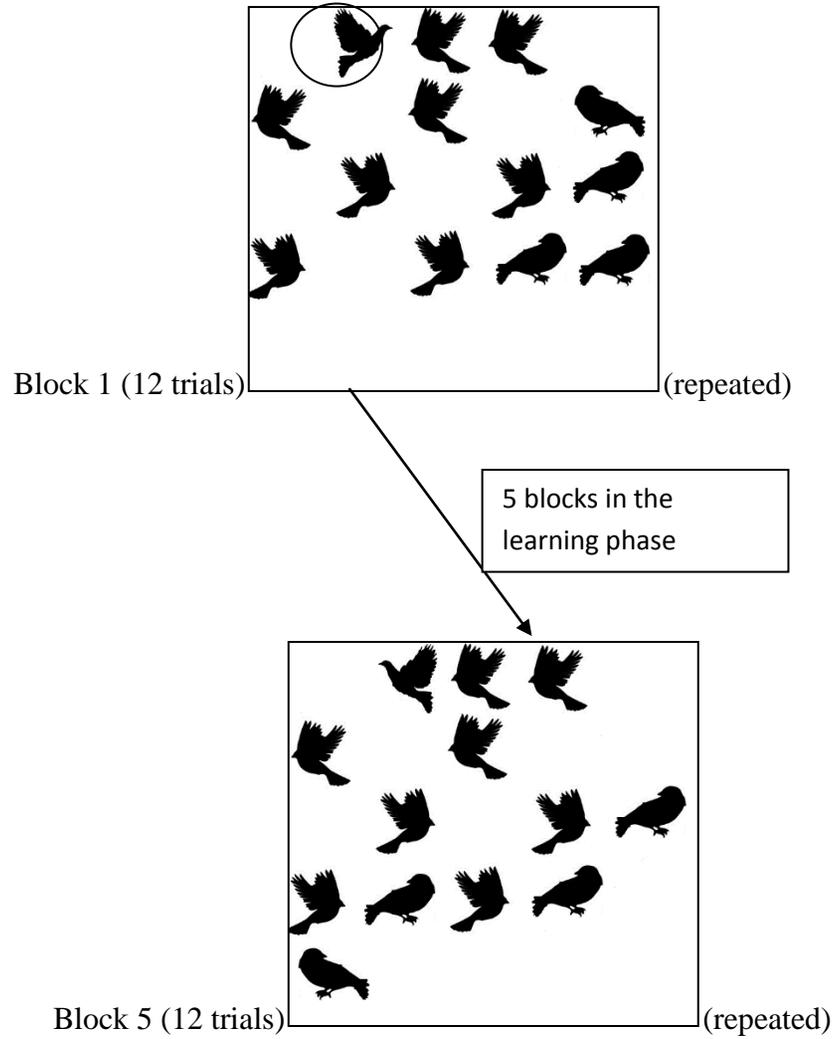
Blocks 1-5 are the learning phase
and Block 6 is the test phase



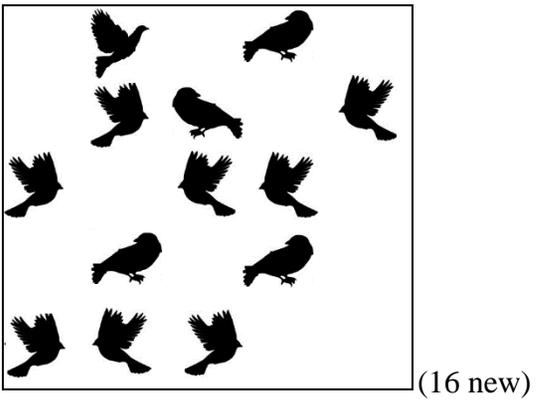
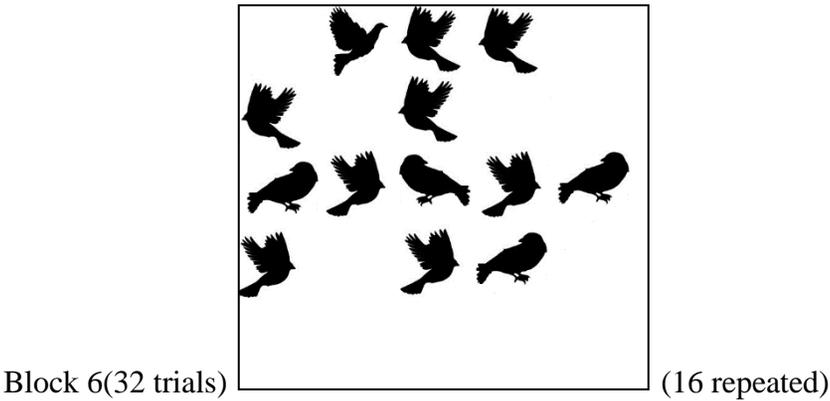
Note: the target was highlighted in a circle. However, in the actual test, the circle did not exist.

Appendix B

Experiment 1(Simultaneous) 67% S/N Condition



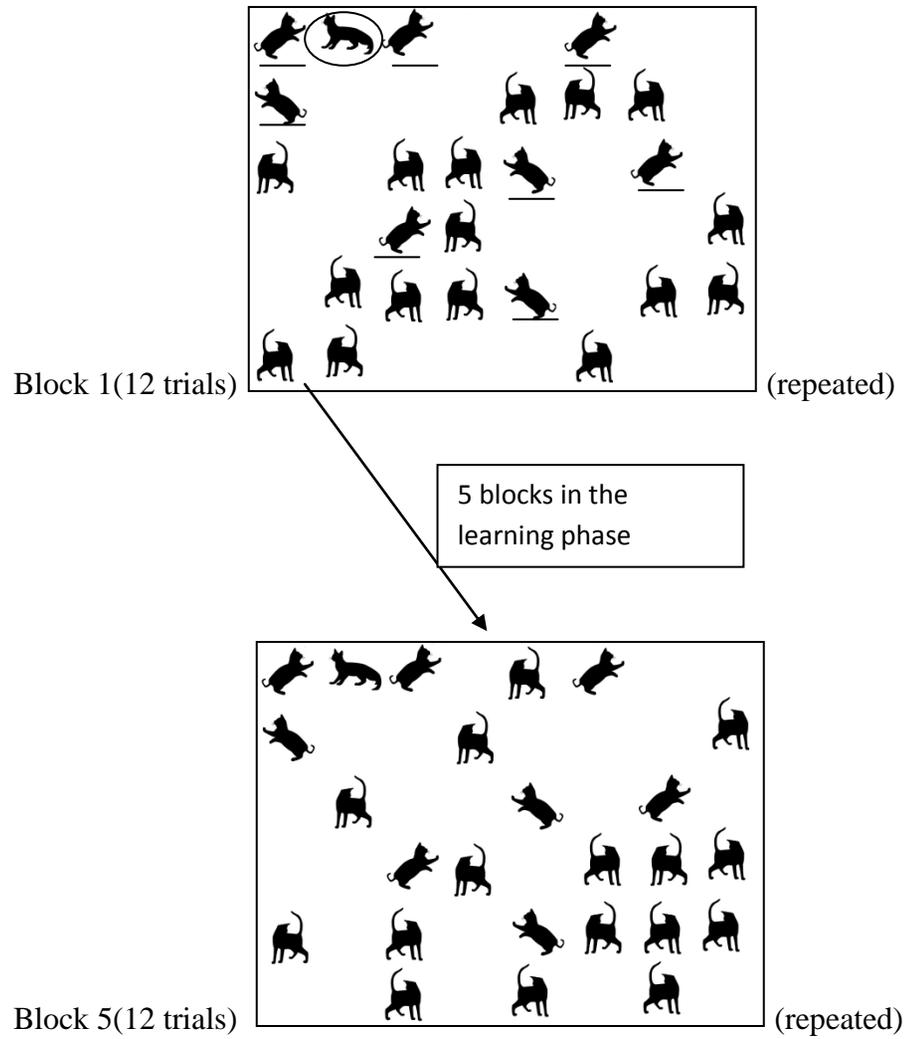
Blocks 1-5 are the learning phase
and Block 6 is the test phase



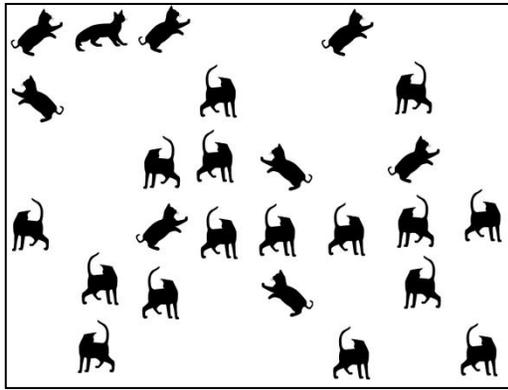
Note: In the repeated displays, only the 8 birds with both wings flying predicted the target bird, while the 4 birds who were not flying did not predict the target.

Appendix C

Experiment 1 (Simultaneous) 33% S/N Condition

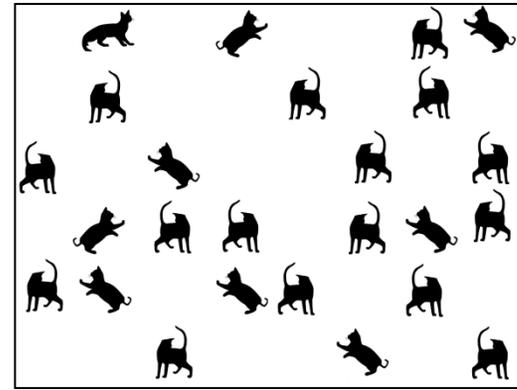


Blocks 1-5 are the learning phase
and Block 6 is the test phase



Block6 (32 trials)

(16 repeated)



(16 new)

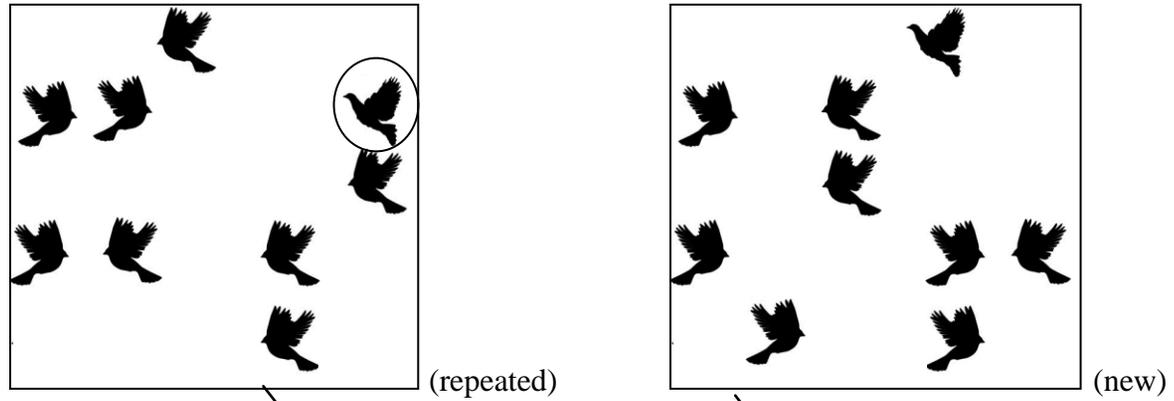
new)

Note: In the repeated displays, only the set of 8 cats predicted the target cat while the set of 16 cats did not. In the picture of Block 1, the repeated distracters were underscored to highlight their identities for readers. The target was circled. In the actual test, however, the circle and underscore lines did not exist.

Appendix D

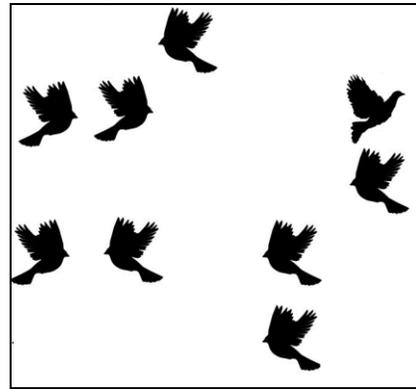
Experiment 2 (Sequential) 67% S/N Condition

Block 1 (18 trials: 12 repeated + 6 new)

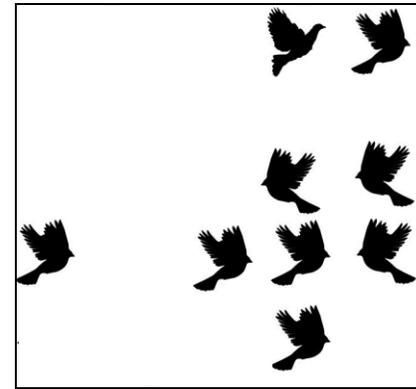


Block 5 (18 trials : 12 repeated + 6 new)

5 blocks in learning phase



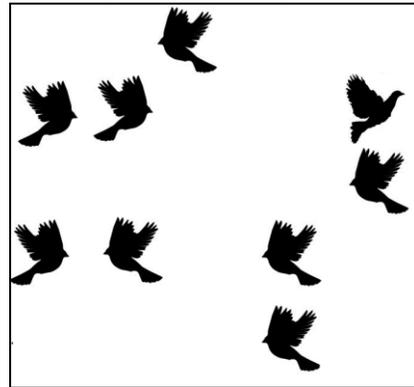
(repeated)



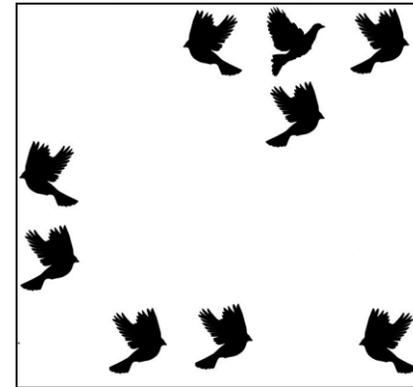
(new)

Blocks 1-5 are the learning phase
and Block 6 is the test phase

Block 6 (32 trials: 16 repeated + 16 new)



(repeated)

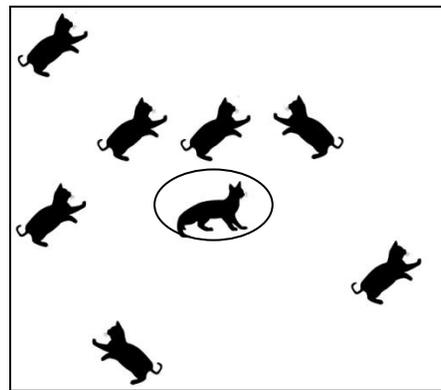


(new)

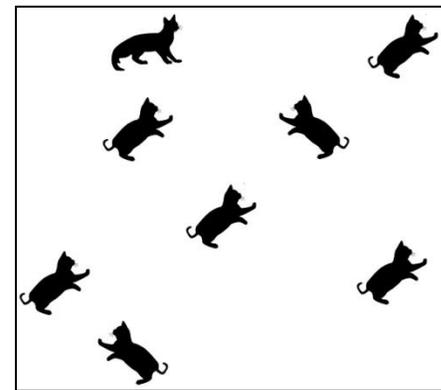
Appendix E

Experiment 2 (Sequential) 33% S/N Condition

Block 1 (36 trials: 12 repeated + 24 new)



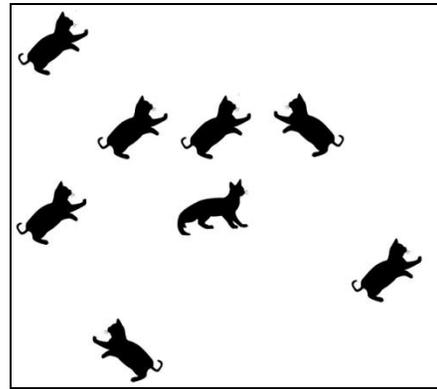
(repeated)



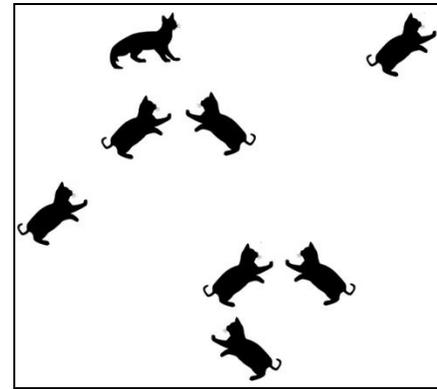
(new)

5 blocks in learning phase

Block 5 (36 trials : 12 repeated + 24 new)



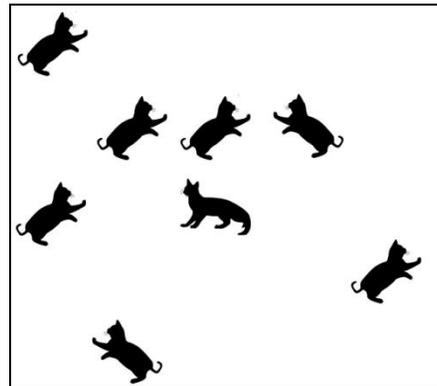
(repeated)



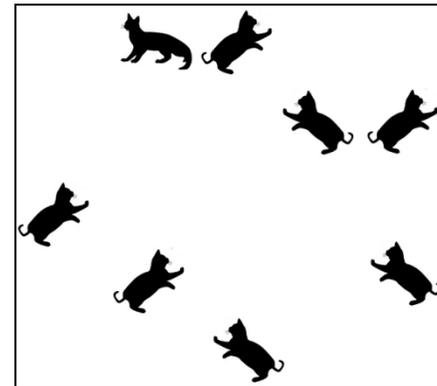
(new)

Blocks 1-5 are the learning phase
and Block 6 is the test phase

Block 6 (32 trials: 16 repeated + 16 new)



(repeated)



(new)

Appendix F

Institutional Review Board Approval

Office for Research
Institutional Review Board for the
Protection of Human Subjects



June 11, 2013

Ed Merrill, PhD
Dept of Psychology
College of Arts & Sciences
Box 870348

Re: IRB#: 13-OR-211 "Attention and Visual Search"

Dear Dr. Merrill:

The University of Alabama Institutional Review Board has granted approval for your proposed research.

Your application has been given expedited approval according to 45 CFR part 46. You have been granted the requested waiver. Approval has been given under expedited review category 7 as outlined below:

(7) Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies

Your application will expire on June 9, 2014. If your research will continue beyond this date, complete the relevant portions of the IRB Renewal Application. If you wish to modify the application, complete the Modification of an Approved Protocol Form. Changes in this study cannot be initiated without IRB approval, except when necessary to eliminate apparent immediate hazards to participants. When the study closes, complete the appropriate portions of the IRB Request for Study Closure Form.

Please use reproductions of the IRB approved stamped information sheets to obtain consent from your participants.

Should you need to submit any further correspondence regarding this proposal, please include the above application number.

Good luck with your research.