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Exploring the association between self-regulation and foraging performance in children aged 4 to 7 years

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Þakkir

Ég vil þakka leiðbeinendum mínum, Árna Kristjánssyni og Steinunni Gestsdóttur fyrir faglega og góða leiðsögn. Jafnframt vil ég þakka samstarfsmanni mínum, Tómasi Kristjánssyni, fyrir farsælt samstarf við gagnasöfnun og verkefnaskrif. Þá fá stjórnendur og starfsfólk Leikskólans Björtuhlíðar og Háteigsskóla bestu þakkir fyrir þátttökuna og samstarfið. Að lokum vil ég þakka unnusta mínum, Ásgeiri Viðari Árnasyni, og dóttur minni, Freyju Rún Ásgeirsdóttur, fyrir endalausan skilning, þolinmæði og stuðning á meðan á gerð þessa verkefnis stóð.

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Abstract

A considerable overlap in the characteristics of visual attention and self-regulation, suggests that these two processes are somehow linked. A growing number of researchers have taken interest in human foraging behavior, but to date, there is no research on the development of foraging performance. A novel iPad task where participants are required to locate 40 target items from two categories, embedded within a field of distractors, has been used to demonstrate that human foraging behavior changes drastically when attentional load is increased. Here, 4:0-7:3 year old children's performance on the iPad task was observed and compared to their performance on the HTKS behavioral self-regulation task. It was hypothesized that as the children got older, their performance would become more similar to that of adults, and that a higher amount of self-regulation ability would add to that effect. The results show that as children get older, their performance improves with regard to trial completion and response times, and self-regulation has an added effect in that regard. "Run behavior", or the pattern of consecutive selection of the same type of target items, on the other hand, became more dissimilar to adult performance as the children aged. The results clearly demonstrate a connection between self-regulation and visual foraging task performance. A greater understanding of the development of visual foraging is needed in order to fully comprehend its connection to self-regulation.

Exploring the Association Between Self-regulation and Foraging Performance in Children Aged 4 to 7 Years

Self-Regulation

Self-regulation is a broad, multidimensional construct that has been researched in many different disciplines, such as cognitive (Posner & Rothbart 1998, 2000), temperamental (Willoughby, Kupersmidt, Voegler-Lee & Bryant, 2011), and developmental psychology (McClelland & Cameron, 2011; Suchodoletz et al., 2013). As such, this construct has been defined in various ways, such as the ability to guide behavior via numerous contingency rules, in addition to prolonged monitoring of one’s behavior, thoughts and feelings in any given situation (Kopp, 1982), the ability to control ones behavior, emotions and arousal (Willoughby et al., 2011) and the ability to control, change, and inhibit ones cognitions, actions, or feelings according to rules, motives, plans, and norms (Steinunn Gestsdóttir, 2012). Despite differences in terminology, researchers agree that self-regulation is a complex construct that regulates cognition, emotion and behavior (McClelland, Ponitz, Messersmith & Tominey, 2010). Self-regulation is a significant component of a person’s success in life, as it enables people to modify their behavior to navigate their social environment and reach their goals (McClelland & Cameron, 2011; Steinunn Gestsdóttir, 2012).

In childhood, self-regulation generally refers to the behavioral aspects of the construct, or the application of attentional flexibility, working memory and inhibitory control. Those are the abilities to focus on the task at hand while ignoring distractions, keeping information in mind and using it while working, and refraining from acting out from impulsion, respectively (McClelland & Cameron, 2011). These aspects of self-control stem from executive functions (EF; Suchodoletz et al., 2013). Self-regulation is contingent upon awareness of appropriate behavior and is therefore an important part of the socialization of children (Kopp, 1982). Children with strong behavioral self-regulation find it easier to adapt their behavior to social rules and are therefore more functional in every aspect of life, such as school performance, social competence and motivation (McClelland & Cameron, 2011; Suchodoletz et al., 2013).

The Development of Self-Regulation

Kopp (1982) has described the development of self-regulation as moving from outer sources of control, such as parental soothing, towards becoming increasingly internalized. As an example of emotional self-regulation, when children are born they need the help of their parents to calm down, but in a few months most have learned to self sooth, e.g., by sucking their thumb when they feel upset. All aspects of self-regulation undergo rapid development in the first year when children learn to comply with their caregiver's requests, which is a form of control over their own behavior. In their second and third year, the source of control moves even further from caregivers and towards internal factors, where children adopt and internalize societal standards, in addition to guiding and monitoring their own behavior in the attempt to reach their goals.

When children are about four years old, their inhibitory control grows more sophisticated, resulting in greater ability for self-regulation (Diamond, Carlson, & Beck, 2005; Diamond, Kirkham & Amso, 2002). Self-regulation in all domains grows during the preschool years, which is especially important to prepare children for formal school environment. Blair and Razza (2007) found that self-regulation, and especially inhibitory control were strongly related to academic ability in kindergarteners. Behavioral self-regulation predicts academic achievement beyond the effects of intelligence (Suchodoletz, Trommsdorff, Heikamp, Wieber & Gollwitzer, 2009; Suchodoletz et al., 2013), and various other background measures, such as family structure, gender, age, parental occupation and mother's education (Gestsdottir et al., 2014). The ability for behavioral self-regulation enables children to pay attention in class, adhere to classroom rules, and concentrate on their assignments while ignoring distractions. The children can therefore adapt to school context and make the most of their time in the classroom (Gestsdottir et al., 2014; Suchodoletz et al., 2009).

Visual Search and Feature Integration

Recent studies have been focusing on the connection between attentional control and self-regulation (Rueda et al., 2004, 2005), but the relationship with other, more basic, aspects of attention has not previously been studied. Given that there is a considerable overlap in the characteristics of visual attention and self-regulation, e.g. dual task interference (Kristjánsson & Nakayama, 2002) and inhibition (Rueda et al., 2005), it is probable that these two processes are somehow linked.

Visual search is typically studied with single target search tasks, where participants are required to find a predetermined target in a display of distractor sets of various sizes (see e.g., Bravo & Nakayama, 1992; Treisman & Gelade, 1980). When the target is defined by a single feature, such as a green disc amongst red discs, participants tend to respond quickly regardless of set size. Such targets are said to pop-out. On the other hand, when the target is defined by a conjunction of features, such as a green square embedded within a display of red squares and green discs, response times rise in accordance with the number of distractors (Treisman & Gelade, 1980).

The feature-integration theory of attention proposes that across the visual field, features such as color, shape, size and orientation, are processed automatically and in parallel. Focused attention is then required to bind these features together to form objects. Stimulus location is processed serially to ensure that the features of each object are combined correctly, forming a single item in the visual field. When a target is defined by a single feature, integration is not necessary and visual search is therefore automatic and parallel. That results in a quick and efficient search with flat search slopes, regardless of distractor set sizes. When targets are defined by a conjunction of features, focused attention is needed to bind the features together. Objects are therefore identified serially, search is effortful and response times are dependent on distractor set sizes (Treisman & Gelade, 1980).

The Development of Visual Attention

In recent years, researchers have been investigating the development of visual search efficiency. The general consensus is that young children find it difficult to search for conjunctively defined targets, but, although baseline search times are somewhat slower than for young adults, children's performance in feature search is quick and efficient regardless of distractor set sizes, producing similarly shallow response time (RT) slopes as adult participants (Donnelly et al., 2007; Merrill & Conners, 2013; Merrill & Lookadoo, 2004; Taylor, Chevalier & Lobaugh, 2003; Trick & Enns, 1998; Woods et al., 2013).

Studies of infant attention traditionally use looking time or a mobile paradigm (where the infants are trained to kick in order to move a mobile above them) to assess their capabilities (see e.g., Colombo, Ryther, Frick, & Gifford, 1995; Rovee-Collier, Hankins, & Bhatt, 1992). These paradigms do not take into account distractor set sizes, and performance is measured over the span of seconds or minutes, not milliseconds. It is therefore difficult to compare data on infant pop-out to visual search studies of older children and adults (Adler & Orprecio, 2006). Adler and Orprecio (2006) measured saccade latencies in three month old infants and adults in feature- and conjunction search tasks, to find out whether infants' pop-out of single features is comparable to older children's and adults'. They found that like adults, infants do exhibit pop-out over the span of milliseconds, regardless of distractor set sizes. Similarly, Gerhardstein and Rovee-Collier (2002) developed a visual search task with game-like features to assess 12 to 36 month old children's performance in feature and conjunction search. They found that search slopes in the feature search task were relatively flat, meeting the (25 ms/item) cutoff criteria for parallel search mechanisms, and concluded that the same process is involved in feature search from infancy to adulthood. None of the 12 month olds were able to finish the conjunction search task, and for the older toddlers, the search was slow and inefficient, with steep RT slopes. Taken together, these studies suggest that when it comes to single feature search, infants as young as three month old possess visual search mechanisms that function in the same way as older children and adults, while processing of conjunctions does not reach peak performance until later in life. In accordance with that, Taylor et al. (2003) used event related potentials (ERP) to confirm that the mechanisms for processing of conjunction features develops later than simple attentional effects, and is not yet fully matured by 12 years of age.

Trick and Enns (1998) found that compared to young adults, children are more susceptible to interference by distractors in conjunction search; even a single distractor had a considerable effect on their performance. They contribute this difficulty with conjunction search at an early age to the development of two processes; feature binding and voluntary movement of visual attention. That is, young children find it difficult to repeatedly move and re-engage their attention from item to item, and since feature binding requires serial identification, search becomes inefficient. In contrast with other studies on children's performance in visual tasks (see e.g., Donnelly et al., 2007; Gerhardstein & Rovee-Collier, 2002; Trick & Enns, 1998), both Hommel, Li and Li (2004) and Lobaugh, Cole and Rovet (1998) did not find different search slopes in conjunction search for children and adults. Lobaugh et al. (1998) explain these findings with speed-accuracy trade-off, because young children are much less accurate than older children and adults in the conjunction search task (see also Woods et al., 2013).

Children's performance in conjunction search improves significantly when they are between six and seven years old (Hommel et al., 2004; Lobaugh et al. 1998; Merrill & Lookadoo, 2004). Due to cognitive development, attentional top-down control is getting more sophisticated around the age of six years, meaning that serial search becomes more effective. For example, when there are two types of distractors in conjunction search, seven year olds are able to restrict search to a subset of the stimulus array, albeit not as effectively as young adults (Merrill & Lookadoo, 2004), but six year olds tend to get distracted in the presence of irrelevant distractors (Merrill & Conners, 2013). Meanwhile, there is practically no change in performance in the stimulus-based feature search task (Hommel et al., 2004).

Executive Functions and Attention

Studies using functional magnetic resonance imaging (fMRI) suggest that the brain's attentional circuits regulate activity in the entire brain, and therefore most or all of our thoughts and behavior (Rueda, Posner & Rothbart, 2004, 2005). Posner and Rothbart (1998, 2000) suggest that attention systems, such as the superior parietal lobe and temporal parietal junction, have a part in regulating cognition, and that they underlie the development of self-regulation; attention controls the sensory input to the brain via these mechanisms, and what we register will then influence our behavior. It is reasonable to assume that in order to carry out goal-oriented actions, which are defining features of self-regulation, it is necessary to be aware of ones surroundings, orient attention appropriately, and choose what to attend to. As such, the abilities measured with visual attention tasks may contribute to the more general ability of self-regulation.

Scholars studying visual search have also been interested in the relationship between self-regulation and attention. Woods et al. (2013) posit that children's difficulty with conjunction search may be traced to underdeveloped executive functions. They claim that mental planning and flexibility, working memory, and inhibition play a big role in conjunction search, making it possible to guide spatial attention, remembering where one has searched before, and preventing return to said locations. The limitations of young children's organization skills can be traced directly to lack of executive processing ability, which in return, hampers their performance in conjunction search. These limitations do not affect feature search performance which is reliant on more primitive processing mechanisms. In their study, Woods et al. (2013) measured children's organizational ability in visual search tasks, and found that as this ability develops, conjunction search performance improves. They suggest that improved performance in conjunction search reflects the maturation of executive processes contingent upon the development of the dorsolateral prefrontal cortex. Feature search performance is not affected because it is reliant upon development of other areas in the brain, such as the visual cortex. This conclusion is in accordance with Merrill and Conners' (2013) observation that young children find it difficult to search for a singleton target in the presence of heterogeneous distractors, concluding that they are lacking in the ability to maintain focus and ignore distractors (see also Merrill & Lookadoo, 2004).

Dempster (1992) posits that inhibition mechanisms play a major role in intellectual development. When children become able to inhibit irrelevant stimuli and responses, they become more efficient at various tasks in life. In his review, he links age related performance differences in various tasks to the development of the frontal lobes and the maturation of inhibitory processes. Hommel et al. (2004) reviewed the inhibitory account in the context of visual search. They found it plausible that inhibitory control, in addition to processing speed, contributes to increased efficiency in conjunction search with development, assuming that inhibiting distractors is more problematic in conjunction than feature search. Search times for children can be up to three times longer than that of adults in the simplest of tasks, such as looking among two objects for an item defined by one feature. But when search slopes on these simple tasks are taken in to account, performance is indiscriminable from adult performance. This can be explained by children's slower information processing, but there is a substantial increase in RTs between one and two item feature search for children, indicating their inability to ignore the distractor. This finding suggests a lack of maturation of inhibitory mechanisms.

Foraging

Traditional visual search paradigms consist of one target embedded within a field of distractors. Visual search in real life is usually much more complex than that, and therefore a growing number of researchers has taken interest in human foraging behavior; that is, how people attend to multiple targets across the visual field (Cain, Vul, Clark & Mitroff, 2012; Kalff, Hills & Wiener, 2010; Klein & MacInnes, 1999; Kristjánsson, Jóhannesson & Thornton, 2014; Wolfe, 2013). These types of studies have a long tradition in animal research, and focus on what kinds of behaviors lead to optimal foraging, i.e., how animals can maximize their energy intake with as little effort as possible, and whether predators forage optimally. Common research material is movement lengths and patch leaving behavior (for an overview, see Pyke, Pulliam & Charnov, 1977). These studies suggest that when food is easily found, predators randomly switch between different types of food items, but when food is difficult to detect, limited attentional capacities cause them to focus on a single type of food and ignoring other, equally available items (Dukas, 2002). In addition to actual movement in the environment, animals also search their memory and attend to external information to find patches where food is more likely to be abound (Todd, Hills, and Robbins, 2012). Switching between target categories has thus been described as a form of patch leaving which is analogous to foraging behavior in physical space (Hills, Jones & Todd, 2012).

Studies using computerized visual search tasks have found that human foraging behavior resembles that of animals, whereby they adapt their search strategy to the distribution of target items in the environment to optimize hit rate (see e.g., Cain et al., 2012; Kalff et al., 2010; Wolfe, 2013). Kristjánsson et al. (2014) have developed a new iPad task (the iDot foraging task) in order to gain insight into how humans forage for targets from different categories. The display consist of 80 items randomly distributed across the iPad screen. The participant is required to find and tap on two types of target items as quickly as possible without touching any of the two types of distractors. In the feature condition, the targets and distractors are defined by a single dimension (color). In the conjunction condition, the targets are defined by both color and shape. The conjunction manipulation is used to increase attentional load, and has the same effect on foraging behavior as using targets that are difficult to locate, e.g. due to camouflage or poor visibility. In their study, Kristjánsson et al. (2014) found that the foraging pattern was very different between conditions. In the feature condition, participants switched between target categories at random, tapping whichever target was the closest to the one that had just been cancelled, signifying that search was easy and switches effortless. In the conjunction condition, on the other hand, most participants cancelled one target category exhaustively before switching to the other category. So increasing search difficulty, dramatically changes foraging behavior, in much the same way as it does for animals (Dukas, 2002). These results imply that participants are able to hold two features in mind simultaneously and switch between them effortlessly, but when attentional load is high, switching between target categories becomes too difficult for most participants.

The Current Study

The current study has two goals; the first is observing children's performance on the iDot visual foraging task, and the second is comparing foraging performance with their behavioral self-regulation ability.

The development of visual foraging performance has not been previously studied. In the current study, it was decided to observe the performance of children aged between 4:0 and 7:3 years old, because previous studies of visual search development suggest that between six and seven years of age, children develop the ability to perform conjunction search (Hommel et al., 2004; Lobaugh et al. 1998; Merrill & Lookadoo, 2004). It is believed that with increasing age, foraging will require less effort, and performance will therefore become more efficient; the youngest children should be able to complete the feature foraging tasks, but not necessarily the conjunction ones. The oldest children, on the other hand, should be able to complete all of the iDot tasks. Their performance should be influenced by their increased attentional and information processing abilities, and should therefore be more similar to that of adults, who switch between target categories in the feature foraging task at random, with the majority of trials consisting of between 11 and 18 switches between target categories, but usually search each category exhaustively before making a switch in the conjunction task (Kristjánsson et al., 2014). Thus, it is hypothesized that as children get older, they will be better able to complete the conjunction foraging task. They will also find it easier to keep two item categories in mind, with number of switches becoming closer to random in the feature foraging task. RTs should also be smaller for older than for younger children, due to developing information processing abilities (Hommel et al., 2004; Merrill & Lookadoo, 2004), in addition to maturation of the ability to move and re-engage their attention (Trick & Enns, 1998).

Similar effects should be observed for the children with the highest amount of self-regulation, beyond the age effects; better self-regulation skills should make it easier to attend to the task at hand, organize their foraging pattern, keep a larger amount of information in mind, and inhibit wrong responses, resulting in improved performance on the iDot visual foraging task.

Method

Participants

Participants were 42 kindergarten students and 24 first graders, aged from 49 to 86 months (33 females; M = 68.15 months, SD = 11.69 months). All had normal or corrected to normal vision according to both their teachers and themselves. An approval from the school administration was obtained, in addition to parental consent and verbal consent from each participant. All aspects of the experiment were reviewed and approved by the data protection authority and permission was granted by the Department of Education and Youth in the city of Reykjavik.

Measures

Foraging task. The iDot foraging task was used to measure the participants' foraging performance.

Equipment. The stimuli were displayed on an iPad 2 with a screen dimension of 20×15 cm and an effective resolution of 1024×768 pixels. The iPad was placed on a table in front of the participant in landscape mode, so that viewing distance was approximately 50 cm (this varied slightly as the younger children tended to move around while conducting the task). Stimulus presentation and response collection were carried out by a custom iPad application written in objective-C using Xcode and Cocos2d libraries.

Stimuli. In the feature-based foraging task, the targets were red and green disks and the distractors were yellow and blue disks for half of the trials while for the other half of the trials this was reversed. In the conjunction foraging task, the targets were red squares and green disks and the distractors were green squares and red disks for half of the trials and reversed for the other half. Each trial consisted of 40 target items and 40 distractors. There were 20 stimuli in each group, drawn on a black background (see Figure 1). The diameter of targets and distractors was 20 pixels, approximately 0.46° visual angle.

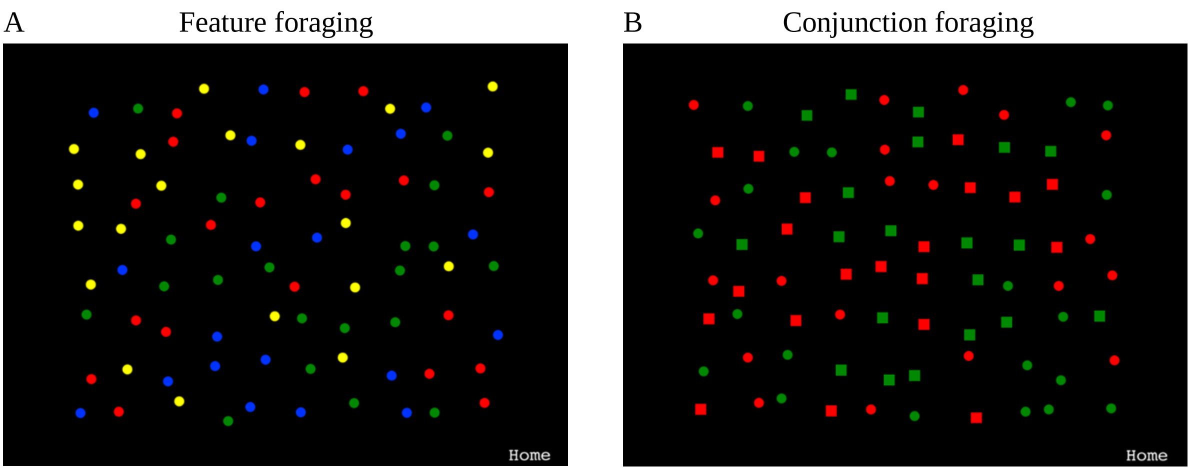

Figure 1. Example trials on the iDot task. The feature foraging task is shown in panel A, and the conjunction foraging task in panel B.

The items were randomly distributed across a non-visible 10×8 grid that was offset from the edge of the screen by 150×100 pixels. The whole viewing area therefore occupied 15×12 cm (approximately 17.1×13.7°). The exact position of individual items within the grid was jittered by adding a random horizontal and vertical offset to create a less uniform appearance. Gaps between rows and columns ensured that items never approached or occluded each other. The overall spatial layout and the location of targets and distractors was generated independently on every trial.

Data analysis. In line with the previous iDot foraging study (Kristjánsson et al., 2014), both RT and the number of runs in each trial were used as the dependent variables. The RT is the time between each tap on the target items and is measured in seconds. A run is defined as the consecutive tapping on the same type of target item, one or more times; preceded and followed by a tap on a different type of target or no tapping (Kristjánsson et al., 2014). The number of runs can thus be defined as how often a participant starts a new run in a single trial. In each trial, the minimum number of runs is two; where every single target of a specific type is cancelled before starting with the other item category. The maximum number of runs is 40; where there is a switch between item categories on every tap. When the switches between target categories are made randomly, the average number of runs should be around 20.

Behavioral self-regulation task. The Head-Toes-Knees-Shoulders task (HTKS) is a direct measure of self-regulation. It measures a broad aspect of self-regulation, including working memory, attention and inhibition (Ponitz et al., 2008; Ponitz, McClelland, Matthews, & Morrison, 2009). Scores on the HTKS have shown reliability and validity in recent studies (e.g., Gestsdóttir et al., 2014; Ponitz et al., 2008; Ponitz et al., 2009). The first ten items of the task include two types of commands (“touch your head” and “touch your toes”). The children are expected to do the opposite of what the examiner tells them to do. In the second part of the task, two new commands are added (“touch your shoulders” and “touch your knees”). In the third part the rules are reversed so now head is paired with knees and shoulders are paired with toes. Each part constitutes ten items that are given in a consistent order. Every part is preceded by a few rehearsal items. The items are scored with a 0 for an incorrect response, 1 for a self-corrected response (starting off responding incorrectly, but correcting oneself before the wrong body part is touched), and 2 for a correct response. Total scores on the HTKS range from 0 to 60, with higher scores indicating higher level of self-regulation. In each part of the test, administration is discontinued if the child is not able to answer at least five items correctly (either correct or self-corrected responses).

Procedure

The experiments were run in January and March, with the first graders having spent a little over a semester in a formal school setting. In both the kindergarten and the primary school, each session lasted about 20 minutes, and took place in a quiet room with normal illumination. The participants finished the foraging and HTKS tasks in a counterbalanced order. In the foraging task, participants were to tap all targets as quickly as possible using the index finger of their right hand. A printed out picture of the target stimuli was placed next to the iPad as to minimize the effect of remembering or forgetting the instruction for each round. The targets disappeared immediately following the tap. If participants tapped one of the distractors the trial ended, an error message was given, and a new trial started. Each participant participated in nine trials, one training trial followed by two trials of each task in a counterbalanced order. One trial refers to a completed sequence where all 40 targets were tapped. If the participants did not manage to complete a trial in five attempts, the examiner offered them to discontinue the task.

Results

The present study has two goals; 1) to observe how children perform in the iDot task, and how that performance varies with age and; 2) to examine the connection between self-regulation and iDot task performance. In order to gain a better insight into the data, descriptive statistics for each variable were calculated. Table 1 presents descriptive statistics for the dependent variables; the behavioral self-regulation and foraging performance measures.

Table 1

Descriptive statistics of behavioral self-regulation and foraging performance

Task	Mean	Std. deviation	% missing
HTKS	35.42	15.09	0
iDot – number of runs			
Feature foraging	10.09	9.16	4.5
Conjunction foraging	4.33	5.38	19.7
iDot - RTs			
Feature foraging	1.04	1.22	4.5
Conjunction foraging	1.22	1.95	19.7

Self-Regulation

As children grow older, their self-regulation skills mature. The HTKS task has shown to be a good measure of those emerging skills for children between three and seven years old (Ponitz et al., 2008). It was therefore expected that in line with previous research, HTKS scores would increase with age. Before comparing self-regulation with foraging performance, it was necessary to confirm that that was the case with the current sample. There was a positive correlation of 0.45 between HTKS scores and age (see Figure 2). A linear regression on the effects of age on HTKS scores was significant; *B* = 0.58, $t(64) = 3.99$, $p < 0.001$. This means that as children grow older, the more self-regulation they exhibit, as measured by the HTKS task.

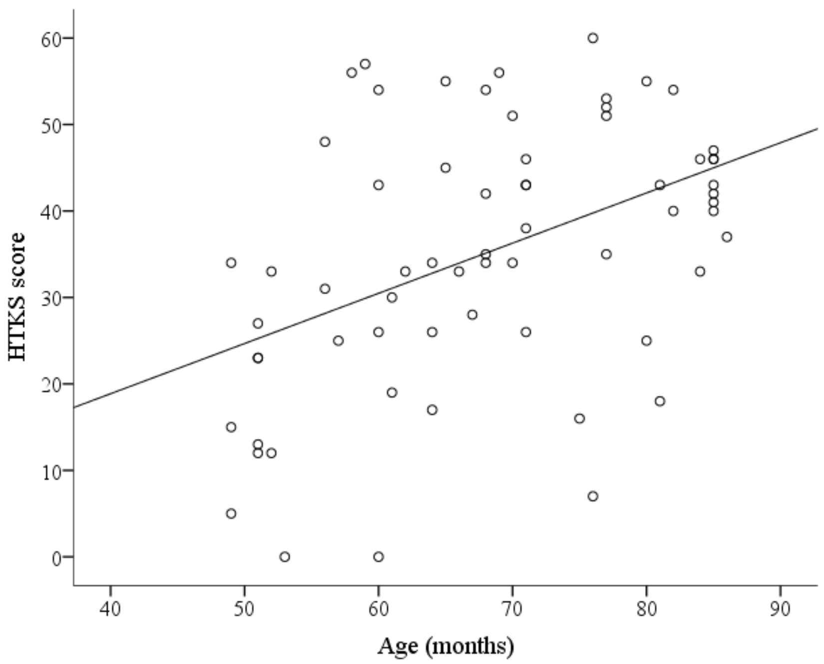

Figure 2. The correlation between HTKS score and age in months.

Foraging Performance

When studying the number of runs in the iDot foraging task one needs to consider that the quickest and most effective way of completing a trial is to cancel the target item closest to the imminently prior one. That is, tapping the target item currently closest to one's finger, regardless of said item's color. In order to do so, the participant needs to hold both item categories in mind at the same time. If the participant can do that, the number of runs for each trial should be random, and with repeated trials, aggregate around the mean of 20 runs. When attentional load is high, such as in the conjunction foraging task, the participant should not be able to hold both target categories in mind at the same time. In order to complete the trial without making an error, the best strategy should be to cancel one target category before the other, resulting in only two runs. With regard to the RTs, it was hypothesized that increased attentional load in the conjunction foraging task would lead to a slower response than in the feature foraging task.

As was expected, there was a difference of both the number of runs and RTs between the feature and conjunction foraging tasks, with a higher number of runs and lower RTs in the feature foraging paradigm. When looking at the number of runs, the mean difference between the feature and conjunction tasks was = 5.76 runs. A comparison of means showed a significant difference, $t(347) = 7.58$, $p < 0.001$. The mean difference of RTs between the two conditions was = -0.18 sec. A simple comparison of means showed a significant difference between the RTs in the feature and conjunction foraging tasks, $t(12652) = -3.71$, $p < 0.001$.

Comparing Self-Regulation and Foraging Performance

Number of runs. When looking at the number of runs in the iDot foraging task, it was expected that they would rise with increasing age, with the number of runs in each trial being closer to the mean of 20 than for younger children. The assumption was that with improved cognitive skills, children will find it easier to hold two features simultaneously in mind, and therefore switch more easily between the two types of target stimuli. It was hypothesized that the younger children were more likely to keep only a single target category in mind at a time. Therefore, their performance was expected to be characterized by long runs, with fewer switches between target categories each trial. On the same note, it was expected that a higher number of runs would go hand in hand with rising HTKS scores, beyond the effect of age, assuming it takes self-regulation to keep the two target items in mind and inhibit the wrong responses while focusing on the task.

There is a significant age effect on the number of runs in the feature foraging task, but the regression coefficient shows it is the opposite direction to what was expected, $B = -0.16$, $t(195) = -2.83$, $p = 0.005$. That means that as children grow older, the fewer switches they make between target categories each trial (see Figure 3). There was no age effect on the number of runs in the conjunction foraging task and no effect of HTKS in either condition (feature task: $p_{HTKS} = 0.12$; conjunction task: both *ps* > 0.60). The lack of connection between HTKS scores and runs should not come as a surprise, since the number of runs did not have the anticipated connection with age as was hypothesized. Therefore it seems that it is not a good measurement of visual foraging abilities in children.

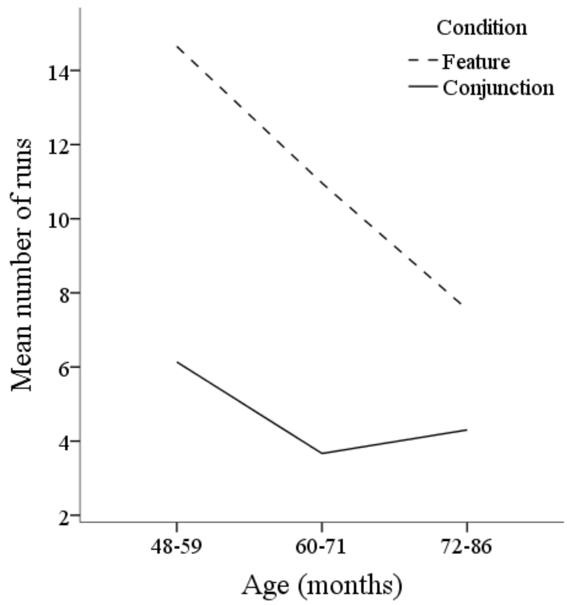

Figure 3. Average number of runs by each age group in both the feature and conjunction foraging tasks.

It could be that younger children find it easier than older children to keep two features in mind at the same time, and are therefore making more switches between target categories.

According to data on other foraging and visual search paradigms (Hills et al., 2012; Todd et al., 2012; Trick & Enns, 1998), in addition to what is known about general development, that seems a most unlikely interpretation. In order to gain a better understanding of these surprising results, the distribution of the number of runs for each age group and trial condition is shown in Figures 4-9 below. As can be seen from these figures, it was most common by far to trials to consist of only two runs, in both the feature and the conjunction foraging tasks. By noting the change of scales, it becomes evident that this pattern grows stronger as the children age. This is as was expected for the conjunction task, considering it is difficult to complete without exhaustively cancelling one category before the other. This pattern of responses in the feature foraging is surprising and will be addressed further in the discussion.

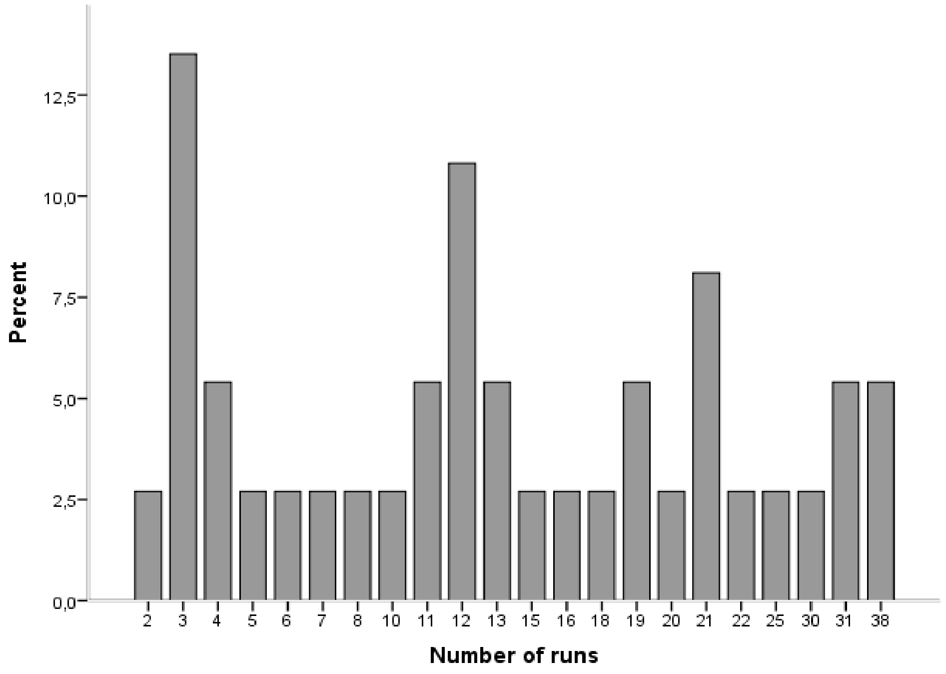

Figure 4. Number of runs in feature foraging for 48-59 month old children.

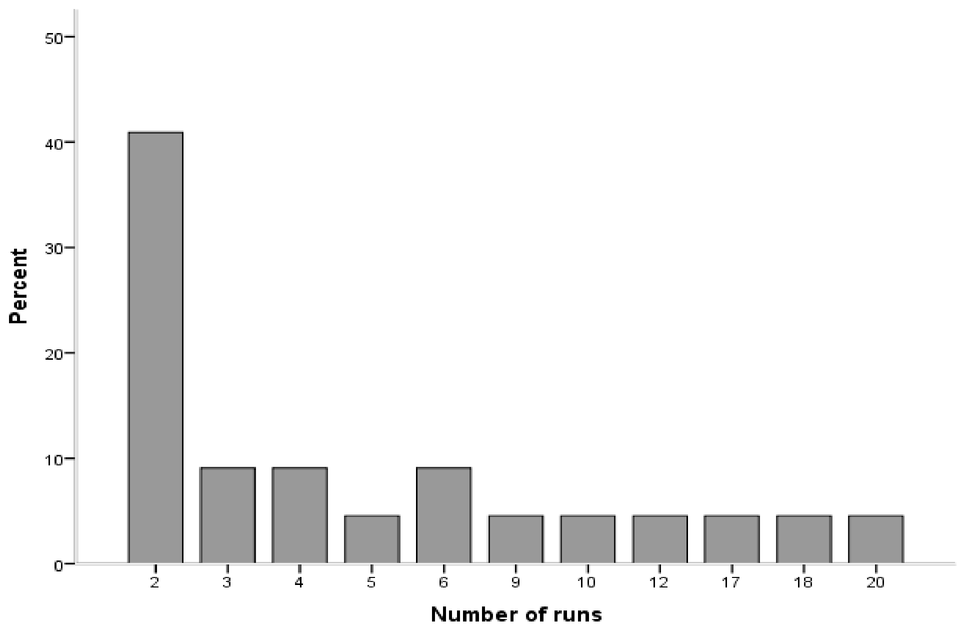

Figure 5. Number of runs in conjunction foraging for 48-59 month old children.

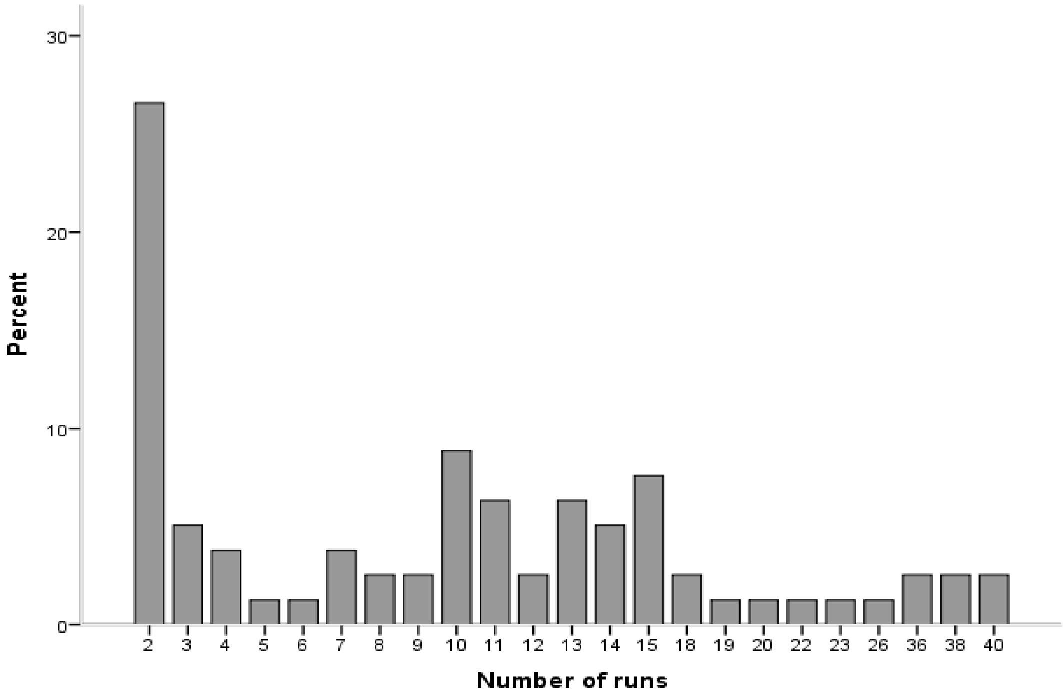

Figure 6. Number of runs in feature foraging for 60-71 month old children.

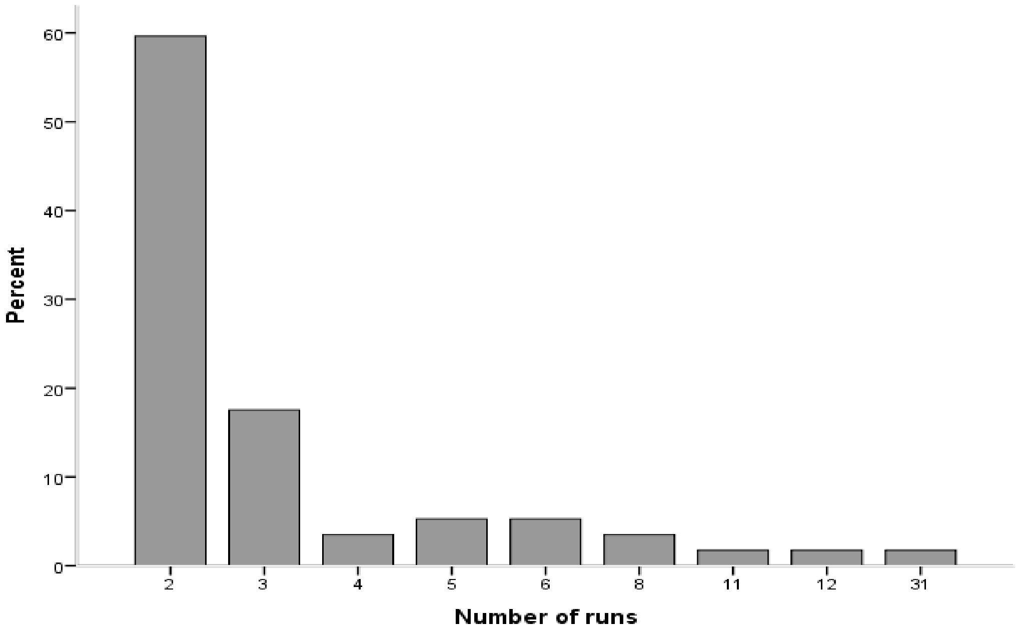

Figure 7. Number of runs in conjunction foraging for 60-71 month old children.

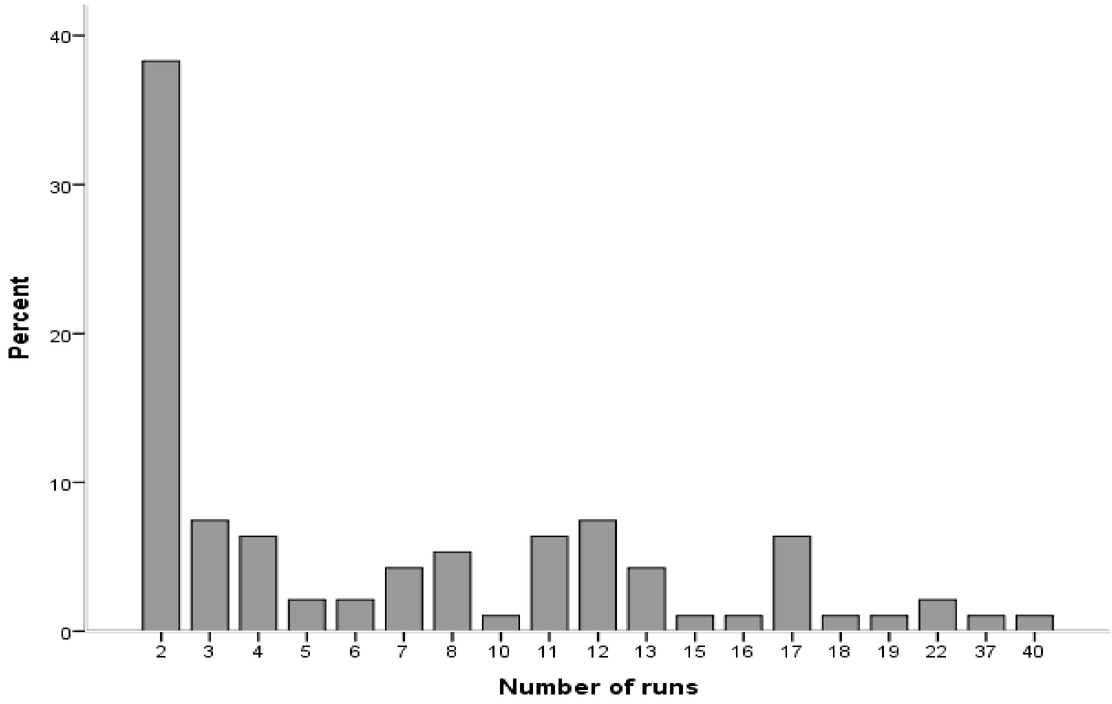

Figure 8. Number of runs in feature foraging for 72-86 month old children.

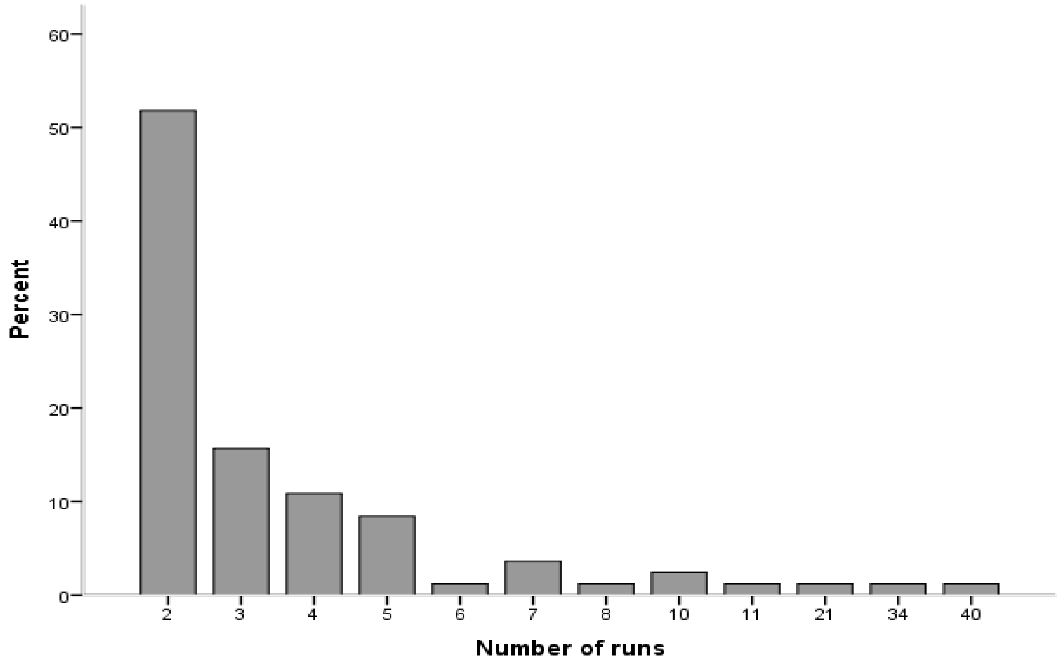

Figure 9. Number of runs in conjunction foraging for 72-86 month old children.

Response times. Since the RT distribution was very positively skewed, a natural logarithm was computed and used in all calculations. Due to improved information processing (see e.g., Hommel et al., 2004; Merrill & Lookadoo, 2004), and a greater ability to move and re-engage ones attention (Trick & Enns, 1998) as children get older, RTs were expected to decrease with increasing age.

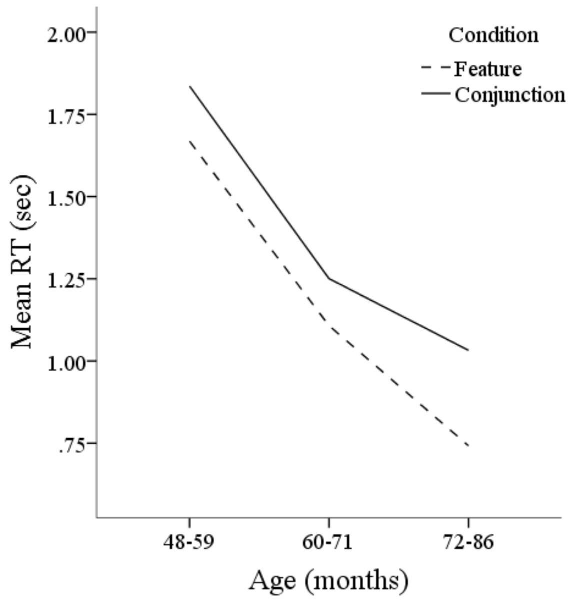

Figure 10. The main effects of age on RT in feature and conjunction foraging tasks.

Because higher HTKS scores indicate that the participant should find it easier to focus on the task and therefore get less distracted, they were expected to have a negative correlation with RT beyond the age effect. In both the feature and the conjunction foraging tasks, logRT decreased significantly as the participants got older (feature: $t(8108) = -35.69$, $p < 0.001$, conjunction: $t(6176) = -15.15$, $p < 0.001$; see Figure 10). As the HTKS score get higher, the logRT decreases in the feature foraging task, but there is not a significant effect in the conjunction foraging task (feature: $t(8108) = -8.16$, $p < 0.001$; conjunction: $t(6176) = -1.47$, $p = 0.141$).

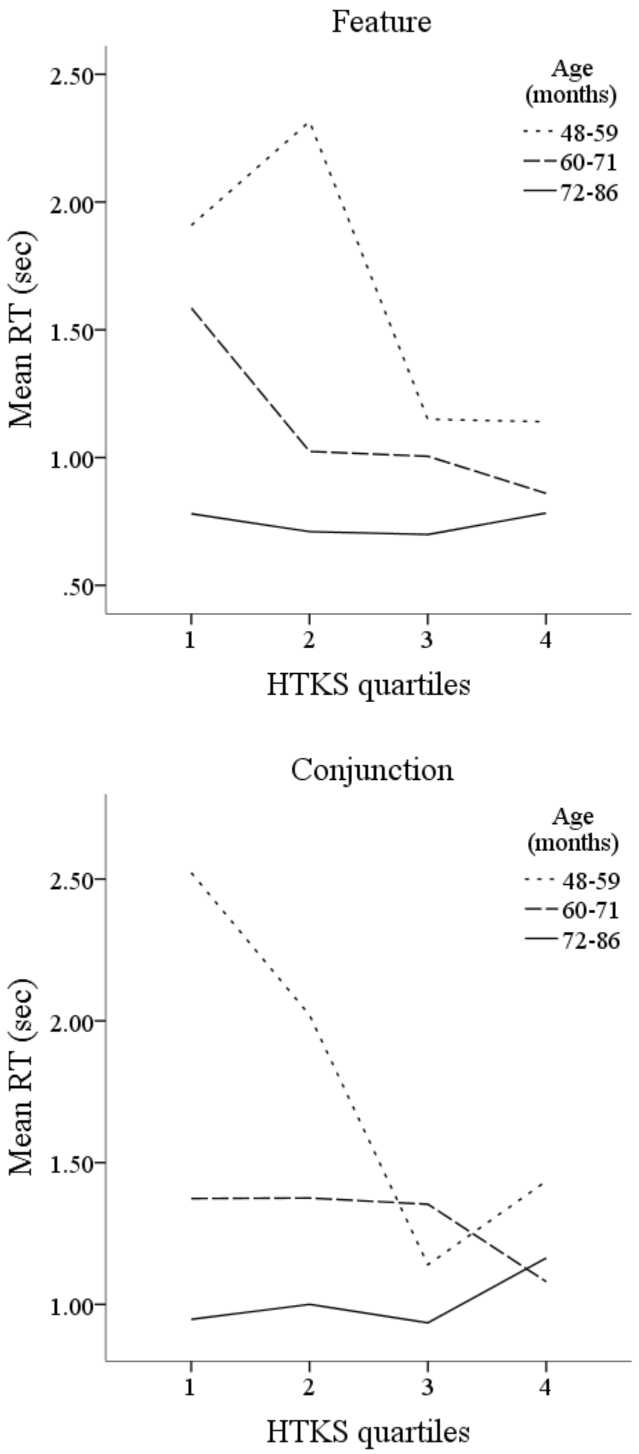

Figure 11. The effects of age and HTKS scores on RT in feature foraging (above) and conjunction foraging (below).

In order to examine the interactive effects of age and HTKS scores on RTs, the participants were divided into four HTKS groups, based on quartile performance; so the lowest 25% are in Group 1 and the highest 25% in Group 4. As can be seen from Figure 11, HTKS scores have a bigger effect on RT for four year olds than the older children, both in the feature and conjunction foraging tasks. In the feature foraging task, four year old children in the two groups with the lowest HTKS scores had considerably larger RTs than their peers with higher HTKS scores. Meanwhile, there is little to no effect of HTKS scores on the six year olds. The same pattern can be seen for the conjunction foraging task. A 3x4 ANOVA on age and HTKS scores was conducted for both the feature and conjunction foraging tasks. For both tasks, the interaction is significant, $F(6, 8099) = 42.55$, $p < 0.001$, and $F(5, 6168) = 14.0$, $p < 0.001$, respectively, indicating that while self-regulation has an effect on RTs for the younger children, it does not affect the oldest children's performance.

Completed trials. As can be seen in Table 1, out of the 66 participants, 4.5% were not able to complete even a single iDot trial, and were thus omitted from all of the previous analysis. In addition, 11 more participants were not able to finish any conjunction foraging trials, leaving 19.7% of the sample out of the analysis of the conjunction task performance. It is probable that those not able to complete the iDot tasks, were in fact the children that had the lowest amount of self-regulation. To be able to include these participants in the analysis, the children were split into two groups based on whether they had finished at least one conjunction foraging trial. An ANOVA with the ability to finish a conjunction trial as a factor and age as a covariant, shows that HTKS scores are different between these two groups, mean difference = 20.93, $F(1, 62) = 12.37$, $p = 0.001$. The age effects were not significant ($p = 0.11$; see Figure 12).

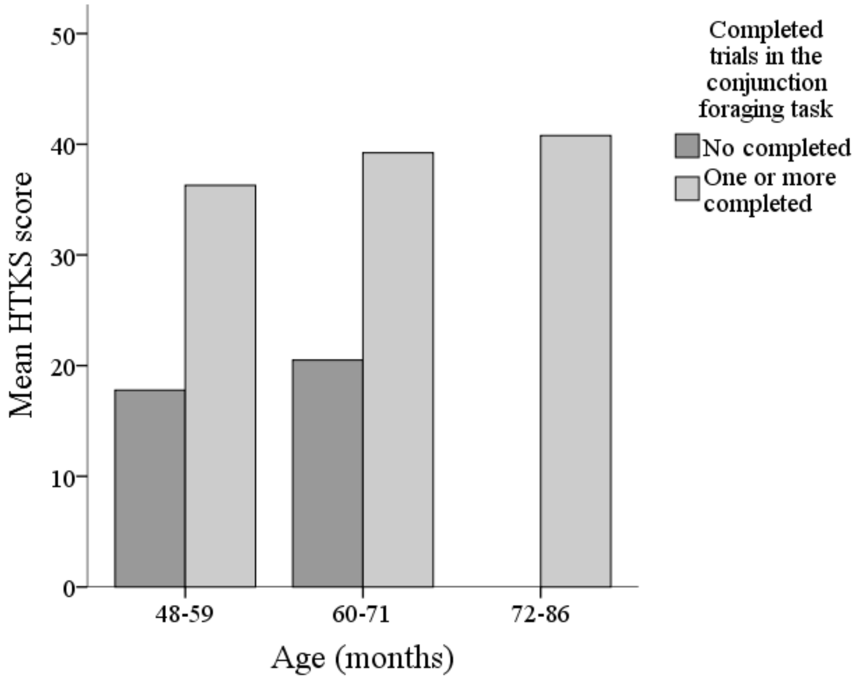

Figure 12. HTKS scores divided between conjunction foraging ability and age.

Figure 12 shows that those children who did not finish a single conjunction trial exhibit considerably lower self-regulation on the HTKS task than their peers. Also note that even though age effects were non-significant, in contrast with the younger children, every six year old was able to complete at least one conjunction foraging trial.

To explore further the effect of the ability to complete the task trials, each participant’s number of finished trials was calculated, for both the feature and conjunction foraging tasks. Since the participants were asked to complete four trials of each condition, the number of completed trials ranges from 0 to 4. Figure 13 shows the difference in HTKS scores divided by how many trials were completed in both the feature and conjunction foraging tasks. The mean difference between the participants that had not finished any feature foraging trials, and the ones that had finished all of them, was = 23.42. A 3x5 ANOVA on age and completed trials in feature foraging, shows a marginally significant difference of

HTKS scores between the amount of completed trials, $F(4, 55) = 2.44$, $p = 0.058$. There was no significant interaction and no added effect of age on HTKS scores (*p*s = 0.19 and 0.15, respectively).

A Bonferroni post hoc test shows that there is a significant difference in HTKS scores between those who did not finish any feature foraging trial and those who finished four trials, mean difference = 28.88, $p = 0.005$. The difference between those who finished one feature foraging task and those who finished four is trending towards significance, mean difference = 13.54, $p = 0.069$.

The mean difference in HTKS scores between the participants that had not finished any conjunction foraging trials, and the ones that had finished all of them was = 21.74. A 3x5 ANOVA on age and completed trials in conjunction foraging, shows a significant difference of HTKS scores between the amount of completed trials, $F(4, 54) = 4.00$, $p = 0.006$, but no significant interaction and no effect of age on HTKS scores (*ps* = 0.48 and 0.35, respectively).

A Bonferroni post hoc test on completed trials shows that there is a significant difference in HTKS scores between those who did not finish any conjunction foraging trial and those who finished two, three, and four trials, mean differences = 25.38, $p = 0.004$; = 23.05, $p < 0.001$; = 21.74, $p < 0.001$, respectively. The difference between those who did not complete a single conjunction foraging trial and those who finished one is trending towards significance, mean difference = 14.75, $p = 0.065$.

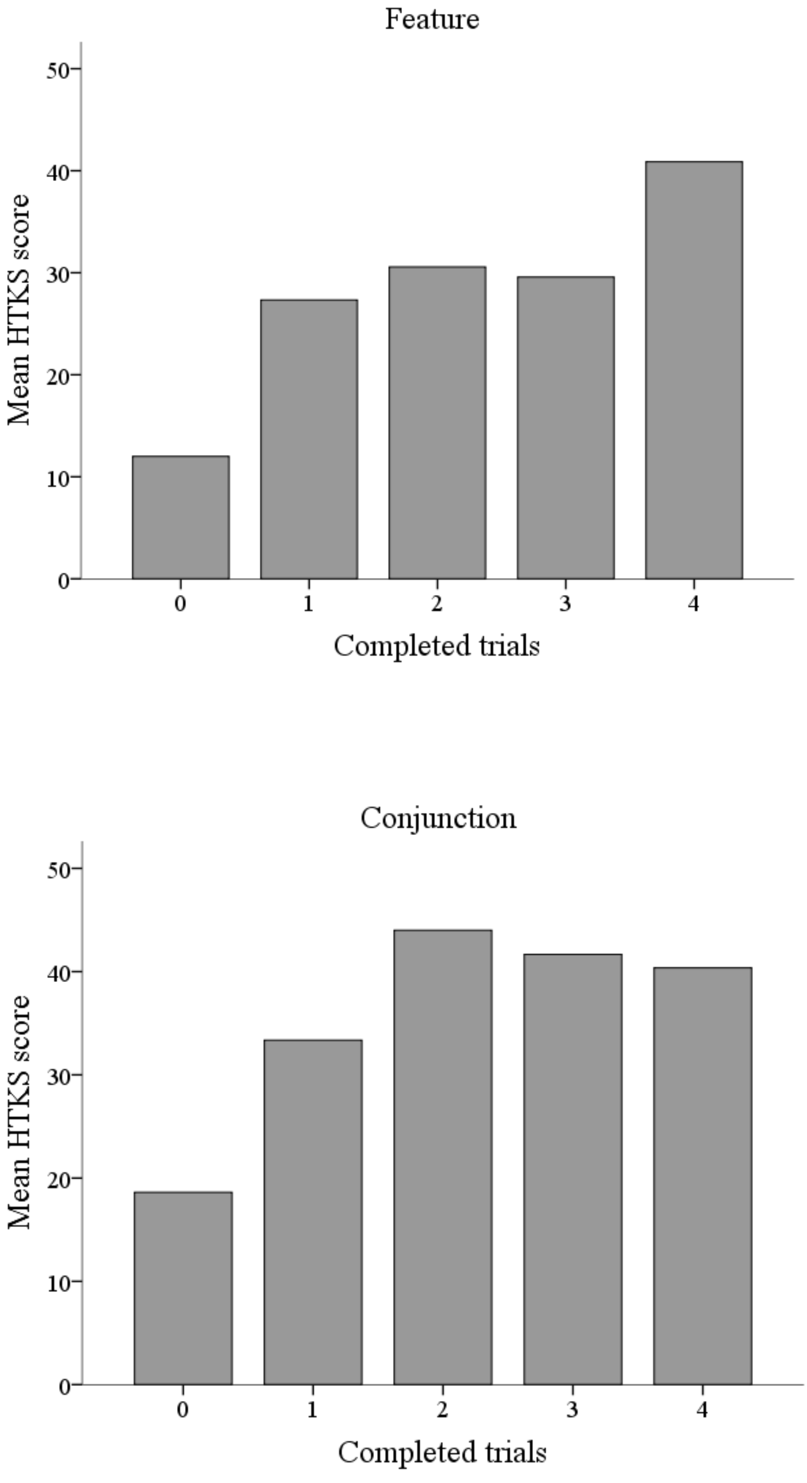

Figure 13. The difference in HTKS scores divided by the number of completed trials in the feature foraging task (above) and the conjunction foraging task (below).

To conclude, even though the number of runs were in direct contradiction to what had been hypothesized, other factors point towards a connection between self-regulation and visual foraging ability. RTs decreased with increased age as was expected, in both the feature and the conjunction foraging tasks, as well as with higher HTKS scores for the feature foraging task. The HTKS scores were not connected to RT in the conjunction foraging task, which can be explained by increased attentional load and speed-accuracy trade-off (Lobaugh et al., 1998). That explanation is in accordance with the superior HTKS scores of the participants that completed the highest number of trials in the iDot task, because a high level of precision is required to be able to complete the task.

Discussion

Foraging Performance and Self-Regulation

The main dependent variable of the study, the number of runs, did not have the connection to self-regulation that had been expected, but in fact, the opposite. In a previous study on adult performance on the iDot task, run behavior in the feature foraging task was random, with the average number of runs being between 12 and 19, signifying that switching target categories was easy and effortless. Run behavior in the conjunction foraging task, on the other hand, mainly consisted of two runs per trial, meaning that participants exhaustively cancelled all targets from one item category before moving on to the second one (Kristjánsson et al., 2014). It had been hypothesized that with increasing age, foraging behavior would develop to becoming more similar to that of adults, and high self-regulation skills would add to that trend, with the average number of runs shifting closer towards 20 in the feature foraging task. It turned out that on the contrary, as the children got older, more trials consisted of only two runs, a pattern that has previously been interpreted as a difficulty with holding both target categories in mind at the same time (Kristjánsson et al., 2014). In addition, no connection was found between self-regulation and the number of runs. This surprising result might be explained by underdeveloped metacognition, which is an important aspect of self-regulation (Clerc, Miller, & Cosnefroy, 2014). Metacognition can be defined as the ability to monitor ones actions and performance, evaluate ones skills, and regulate behavior and learning accordingly (Clerc et al., 2014; Destan, Hembacher, Ghetti, & Roebers, 2014; Finn & Metcalfe, 2014). There has been little research on the metacognition of young children, and how these abilities emerge and develop, the reason being that children younger than seven years old are rarely able to complete the metacognitive tasks used in studies (Vo, Li, Kornell, Pouget, & Cantlon, 2014). Although recent evidence points towards that children as young as five (Vo et al., 2014), and even three years old (Destan et al., 2014) have developed rudimentary metacognition, children tend not to be very good at using their prior performance to adapt to the same tasks with repeated exposure, and tend to be overconfident in regard to their own performance (Finn & Metcalfe, 2014). In regard to the iDot performance, the oldest children may have developed the strategy to cancel every target item of one category before turning onto the next one, failing to realize that this might not be the most effective way of cancelling out all of the target items. Indeed, while conducting the iDot task, a number of participants vocalized their intent of completing one target category before the other. Aside from that, this seems a plausible assumption because almost 40% of the oldest children’s feature foraging trials consisted of only two runs, which is a considerably larger amount than that of the younger children, and accounts for the decreased number of runs associated with increasing age. This strategy is obviously helpful in the conjunction foraging task, and the children beginning with that task may have been likely to continue using it in the feature foraging task, not having the metacognitive skills to realize it was not having the same benefit for performance as in the previous task. This negative effect of strategy transfer between similar tasks has been documented in association with recall performance (Clerc et al., 2014).

Response Times and Speed-Accuracy Trade-Off

Due to developing information processing skills, it was hypothesized that RTs would decrease with increasing age. Self-regulation scores were also assumed to have a connection with RT, because greater self-regulation ability means less distractibility and greater organization skills, which should turn up faster responses. As was expected, the oldest children had the smallest RTs. In addition there was a negative correlation with self-regulation ability, beyond the effect of age, in the feature foraging task, but not the conjunction task. When taking a closer look at the data, it becomes clear that self-regulation does affect the RTs of the youngest participants, but not the older children, in both the feature and conjunction foraging tasks. It is plausible that speed-accuracy trade-off is the reason for this lack of correlation for all but the youngest participants. Speed-accuracy trade-off is in accordance with the fact that there was a significant relationship between self-regulation and the number of completed trials, both in the feature and conjunction foraging tasks. Completing a conjunction trial requires a substantial amount of concentration and accuracy, because making one mistake nullifies the trial and the participant will have to start from the beginning. Another way that self-regulation could be contributing to a higher number of completed trials is sustained attention. Many of the participants got frustrated with the iDot task and quit after a few rounds. Those who persevered and completed all eight trials were the children with the highest self-regulation skills.

Limitations and Future Directions

A limitation of the current study is that the iDot task was not adapted to being performed by young children. The number of items in the display should be variable, so that the youngest children will be able to complete the trials. That way more data will be collected for each participants and a better understanding of the abilities of the ones with the poorest performance will emerge. Another caveat was the size and distance of the items. Many children that intended to cancel a target item, missed and cancelled a distractor item instead, nullifying that trial and requiring them to start all over again. That lead to a considerable amount of frustration for some of the participants and resulted in fewer completed trials. In future studies, it would be advisable to make the display consist of larger items with more distance between them, in order to prevent this from happening.

In order to minimize distractions, it might be appropriate to follow in the footsteps of Gerhardstein and Rovee-Collier (2002) and make the items more interesting for the children by using a display of cartoon characters, animals or other non-abstract items. Since it can be problematic for young children to adhere to instructions of performing as quickly as possible, another attribute of Gerhardstein and Rovee-Collier's (2002) study could be integrated into the iDot task. In order to maximize speedy performance, when the target items were touched, an appealing "ta-da" sound was triggered, rewarding the toddlers and adding to the probability of them being eager to locate the next target.

It seems evident that there is a connection between self-regulation and visual foraging performance, but the nature of this connection is still unclear. Although the results of this study are interpreted in such a way that increased self-regulation abilities underlie a better performance on the iDot foraging task, it is important to note that this is a correlational study. It might as well be that visual search abilities are underlying for a better self-regulation performance, or that these abilities both rely on a third factor, e.g. executive functions, which are closely connected to both of these abilities.

To gain a better insight into which features of self-regulation are important when it comes to visual foraging, a number of studies comparing scores on various aspects of self-regulation with visual foraging performance need to be conducted. For example, it seems likely that inhibition plays a role in the limited amount of runs in the feature foraging tasks. In that paradigm, it probably requires at least some effort to pass over a target item that has been noticed, in order to complete the cancelling of the other target category. Attentional flexibility could be another interesting line of inquiry, it might be that the number of runs could rise with increased flexibility. On a similar note, increased attentional flexibility could lead to a change of foraging strategies if the current one is not efficient. The switching between strategies is also reliant upon the participant realizing that the current strategy is not working as well as anticipated. That requires metacognition, which would therefore be a useful ability to measure in relation to the iDot task.

The research on children's foraging performance is in its infancy, and before addressing any of these questions, a more comprehensive knowledge of children's performance on the iDot task is required. It is necessary to collect data from children of all ages to observe the differences in the number of runs, and when run behavior starts trending towards that of adults. When there is some knowledge of appropriate run behavior according to age, it is possible to start inquiring into what causes these age differences, and how self-regulation and metacognition come in to play. In the future, the iDot foraging task might become a good screening device to identify potential markers for dysfunctional attention. Furthermore, gaining a deeper insight into the development of visual attention in childhood can be informative for the development of theoretical accounts of visual attention, and can guide further research in this field of study.

Conclusion

Even though one of the main dependent variables did not turn out as was expected, the results clearly demonstrate a connection between self-regulation and visual foraging task performance. A greater understanding of the development of visual foraging is needed in order to fully comprehend its connection to self-regulation.

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