

Development of feature and conjunction foraging

Role of working memory, self-regulation and age

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Foraging behavior has traditionally been studied in animals, either in the laboratory or in the wild. Studies have shown that when animals and humans have two or more target categories to select from and the categories are distinct and easily discriminable from the environment and non target stimuli, then animals and humans will select from the two target categories at random, or rather, they pick the target closest to their focus of attention, regardless of which target category it belongs. If, on the other hand, the target categories are ambiguous or hard to detect, then predators and humans will select from the same target category exclusively until it is exhausted before selecting a target from the other target categories. This repeated selection of a target in the same category is called a run. By manipulating the difficulty of a foraging task using human observers Kristjánsson et al. (2014) observed similar patterns of long runs for a difficult conjunction foraging task but surprisingly, if the task was an easy feature foraging task observers tended to switch randomly between target types. The authors speculated whether this is due to attentional load or other factors. In this experiment we examine the role of working memory in this process as several models and experiments have shown the importance of working memory in visual search performance. The participants were children between the age of 4 and 7 years old. The results showed that run pattern for the childrens differ significantly from that of the adults and that working memory, as measured in this experiment did not affect the run behaviour. An interesting finding is that the older the children in this study were, the further away their pattern was from the adult pattern. Possible explanations, implications and direction of further research are discussed.

Visual search

History

Throughout our lives we are constantly scanning the visual scene for a target stimulus or even more likely many potential targets. These searches vary from mapping our environment, seeing where the door is, where the toy on the floor is located and so forth. Other times we may search for specific objects, our keys, specific person at a party or the ripest apples at the supermarket. Over the last several decades large amount of focus and research has gone into visual search (Bruce & Tsotsos, 2009). Over the decades several different aspects of visual search have been studied, from fundamental questions on object perception, priming, foraging behaviour and serial dependencies (e.g. Treisman & Gelade, 1980; Kristjánsson & Campana, 2010; Kamil & Bond, 2006; Fischer & Whitney, 2014). As each subfield advances there is a tendency to become more and more specific within each field. The methodologies change and evolve but generally within the specific subfield, and understandably so, as each subfield addresses a specific nature. But integrating and learning from each field, using methodologies across fields offers invaluable opportunities to advance our knowledge, not just within each subfield but towards understanding visual perception as a whole.

Feature and conjunction search

An early finding was a qualitative difference between feature search and conjunction search. Well documented is the difference in search slopes depending on the set-sizes which have traditionally been created by different number of distractors (Wolfe, 1998). In feature search, where the target stimulus is defined by a single feature or dimension, for example a red square amongst green squares, the number of distractors do not seem to matter. The search times remain the same. It is as if the target pops-out

from amongst the distractors (Wang, Cavanagh & Green, 1994). In conjunction search on the other hand, where the target stimulus is defined by a conjunction or relation between two or more features, for example a red square amongst green squares and red circles, search times increase as the number of distractors increases. How much it increases and how steep the search-slope is depends on the nature of stimuli, their presentation, response methods and the participants (Thompson & Massaro, 1989). This difference is by many thought to represent a difference in search strategy or more specifically the difference between parallel search, where all, or at least many, stimuli are processed simultaneously and serial search, where each stimuli is processed separately, one at a time (Wolfe, 2003). How steep the search slope is, is then used to infer the time it takes to process each individual stimulus (Thompson & Massaro, 1989).

Parallel search is fast and efficient while serial search is time consuming and inefficient, however it seems that from a very early age we are able to perform feature search in parallel while the ability to perform conjunction search with the slower, more inefficient serial processing only develops later (Merrill & Connors, 2013). It may seem like a contradiction that early on we have the necessary skills for a more efficient way of visual processing but have to learn at an older age to perform the other, more inefficient way of visual processing. However, this could be because of the nature of the two tasks. In conjunction search the target stimulus is defined by more than one feature or dimension, this means that not only do you have to find the two features defining the target, but you must also bind those feature together. How we manage to intergrate different dimensions into a perceptual whole has been called the “binding problem” (Treisman, 1996). So it is possible that it is not the search strategy per se that children are unable to utilize at a young age, but rather that difficulty in binding together different dimensions is the reason for their inability to perform conjunction search tasks. Another

possible explanation, not exclusive of the other, is that conjunction search requires more attentional load to perform, a load that young children cannot yet handle.

Foraging

Another line of investigation that ties into the attentional load explanation is the study of foraging behaviour. Originally studied with animals, these studies have expanded into human behaviour and one of the premise of those studies has been that increasing target complexity increases the attentional load of each target and results in the consecutive selection of homogenous targets, which means that animals and humans will, when targets are complex or hard to discriminate, repeatedly select one type of target even when another type of target is easily available closer to the focus of attention (e.g. Kristjánsson, Jóhannesson & Thornton, 2014; Bond, 1984). This can be contrasted with the situation where the target types are easily discriminable or simple. In that case, humans and animals will change between the target types depending on availability and how close they are to the focus of attention (Kristjánsson et al., 2014; Dukas, 2002). We refer to the repeated selection of targets from the same target category as runs.

Kristjánsson et al. (2014) had observers forage on an iPad, with 20 stimuli each from four stimulus categories, two of which being the target categories and two of which being distractors. In the feature foraging condition, the target categories were defined by colour only, while in the conjunction foraging condition the target categories were defined by colour and shape. They found that in general, observers seemed to be able to switch repeatedly between different target types during feature foraging, that is, they frequently switched between the two target categories. That was not the case in the conjunction foraging condition where most observers selected targets from the same

target category repeatedly until that category was exhausted, resulting in a pattern of two long runs.

Methodology

In most studies of visual search similar methodology has been used where observers must determine whether a single target is present or not among numerous distractors (Wolfe, 1998). A target is typically present on 50% of trials. Many researchers have employed this method and found numerous innovative angles and modifications to grow our understanding of attention and other cognitive processes such as priming (e.g. Maljkovic & Nakayama, 1994; Kristjánsson, Wang & Nakayama, 2002). Using the same methodology has its strengths as comparison between studies is easier and knowledge can be built up, on a strong foundation. However, real life visual search tasks are usually not as simple as the typical visual search task would imply. Using only one methodology severely restricts the inferences that can be made and hampers the progression towards scientific understanding of visual search.

In studies of visual foraging researchers have employed a more diverse range of methodologies and some merging of those fields seems logical. Foraging is in a sense an applied form of visual search. Foraging involves searching through the visual scene for targets, be they beads, grain, berries or prey. It is somewhat surprising that the innovative experimental methodologies of foraging studies have not been applied to traditional visual search experiments to a larger extent.

Roles of attention and working memory

Most models of visual search revolve around attention, whether it is needed for a particular and how it may facilitate and/or inhibit our ability to find a visual target (e.g.

Wolfe, 1994). Lavie (1995) showed that some attention is required so that a stimulus can be processed. Other researchers have reached similar conclusions, all emphasizing the importance of attention in perception (e.g. Rock, Linnett, Grant & Mack, 1992; Rensink, O'Regan & Clark, 1997; but see Treisman, 1985). Manipulating attention to see its effect on visual search is problematic as researchers do not agree on a clear definition of attention and because this normally involves trying to load the attention so that participants cannot deploy their full attention to a given task, but these loading tasks could be interfering in other ways (Kane, Poole, Tuholski & Engle, 2006). One of the mechanisms strongly linked with visual search and attention is working memory. Soto, Heinke, Humphreys & Blanco (2005) showed that working memory influences visual search of targets that were difficult to discriminate and later, Soto, Humphreys & Heinke (2006) found the same effect for pop-out targets. Soto and many other research groups have used visual working memory, which is necessary when understanding the workings of visual search and the role visual working memory plays. However making the connection to attentional load becomes problematic as visual working memory tasks do not only affect attention but other mechanisms as well, such as priming. If working memory load itself increases attentional load similar results should be found when working memory is loaded in other modalities. This is exactly what Soto & Humphreys (2007) found when they examined the effects of verbal working memory on visual search. Working memory thus seems to play an important role in visual search and one of the reasons for this experiment was to find if the development of working memory influences the development of the ability to perform visual conjunction search.

Development of visual search

There has been a longstanding debate concerning whether we perceive objects as parts or dimensions on one hand and as a whole on the other hand, do we perceive a red square as a whole which we can then break down into its constituent parts, red, square, the size and brightness etc., or do we perceive those dimensions first, the colour red, the square shape and then bind them together in order to perceive the red square as an object (Smith, 1989). There has been some agreement that answers to those questions depend on the level of processing, the task and particular stimulus parts (Kemler-Nelson, 1989; Navon, 1977; Treisman, 1987). In classification studies it has been found that children under the age of 6 years old tend to classify objects based on their overall similarity (e.g. Kemler, 1983; Ward, 1980), while children older than 6 years tend to classify objects by their similarity on one dimension (e.g. Vygotsky, 1962; Inhelder & Piaget, 1964; Denney, 1972). Earlier this was thought to reflect a qualitative difference, that classification by dimensions was a separate skill from classification by overall similarity (e.g. Shepp, Burns, & McDonough, 1980; Kemler, 1983). However, Smith (1989) argues that there is a quantitative shift from overall similarity to classification by dimensions, her results (and others) seem to support that the ability to assign weights to certain dimensions develops with age. In the beginning all dimensions are equally weighted and hence classification is based on overall similarity. As the ability to give each dimension different weight in the classification process it becomes possible to classify by dimensions where, when it is advantageous one dimension can be given a 100% weight and the other dimensions ignored. When these findings are taken together, there seems to be a developmental trend that goes from overall similarity to dimensional identity (Smith, 1989). If that is the case, one would predict that at the developmental stage before dimensional identity is used by children, that they would have a hard time

completing conjunction search or foraging tasks, since they do not use dimensions or features to categorize it should be hard for them to separate stimuli that consist of the same features but are separated by the relations between the feature, resulting in high overall similarity.

Autism and visual search

The literature on visual search in children and conjunction search in children in particular has recently been heavily skewed towards research on children with autism or autism spectrum disorder (ASD). Several researchers have shown that children with ASD perform better at conjunction search tasks than their non-ASD peers (e.g. Plaisted, O'Riordan & Baron-Cohen, 1998; Iarocci & Armstrong, 2014; Kaldy, Kraper, Carter & Blaser, 2011) with some limitations though (e.g. Hessels, Hooge, Snijders & Kemner, 2014). This finding is exciting, and shows that studying visual search in children can lead to practical and clinical understanding of disorders. But we are far from complete understanding of the basic processes in the development of visual search in children and must continue to push the field and our understanding forward.

Conjunction search and children

Smith's model of perceptual classification is important for visual search since, as explained before, conjunction search cannot be performed until features can be integrated into one object. Based on Smith's model one might expect the ability to perform conjunction search to emerge around the age of 6. Since that is when classification by dimension emerges. Before that age, the overall similarity between targets and distractors in conjunction conditions is likely to make categorization and therefore visual search and foraging difficult. Also, as the model proposes a quantitative shift, rather than qualitative jump, one might expect some variability in performance

around the age of 6. The correlation should not be all-or-none, that either the children can do it 100% or not at all but a gradual emergence.

Attention

What is attention?

Attention is a constant theme in the visual research literature, as in many cases visual search has been used as a model of the function of visual attention. Yet, no single definition of attention is commonly agreed upon. In part, the ambiguity regarding a definition stems from the fact that researchers and scholars disagree how attention works, and thus different models with different definitions exist. Also, since the word attention is commonly used in day-to-day language, the non-scientific meaning and understanding of the word often seems to confound the matter. Two dictionary definitions of attention are: 1. Notice taken of someone or something; the regarding of someone or something as interesting or important.

2. The action of dealing with or taking special care of someone or something.

Although different definitions exist in psychology most psychologists would probably agree that in regards to visual search two parts of those definitions are the most important. From the first definition attention reflects that notice is taken of something important. This is important since many definitions emphasize the role of attention as filtering out non-important stimuli and selecting those that are important at a given time. The second definition emphasizes the active role of attention, that attention is an act of engaging with something. That is another, although more debatable function of attention, dealing with and processing those stimuli that it deems important. Some researchers have claimed that in order to process a stimulus it has to be attended (Lavie, 1995) although others have found evidence for some level of pre-attentive processing

(Treisman, 1985). Attention is therefore integral part of visual search, where you filter out irrelevant stimuli, distractors, in order to find and process an important stimulus or stimuli, the target. It is not surprising then, that most models and theories on visual search use attention as an explaining factor or an actor in those models.

Different models of attention

A dominant type of attentional models and theories were for a long time the so called “spotlight theories” in which attention is likened to a spotlight, normally linked with eye movements and the part of the visual scene that falls on the fovea (Cave & Bichot, 1999). Where part of the visual scene is “highlighted”, perceived in details and can be processed while the rest of the visual scene is “darker”, less detailed and thus not available for processing (Posner, Snyder & Davidson, 1980). Similar theories that fall under spotlight theories are zoom lens theories where attention is likened to a lens on a camera where we zoom in on important stimuli in order to see them more clearly and be able to process them (Eriksen & Yeh, 1985; Eriksen & St. James, 1986). These models are very detailed and many specific experimental predictions have been derived and tested from them with mixed results.

One of the most fundamental assumption of these models is that selection is location based, that is, that attention selects stimuli from the location where the spotlight is shining or where the camera lens is zoomed in on. Location definitely has a special role in visual selection as the work of Posner et al. (1980) and Downing (1988) shows. There is however mounting evidence that selection is not purely location based but also object based (e.g. Kahneman, Treisman & Gibbs, 1992; Baylis & Driver, 1993; Chen, 1998). Another prediction from the spotlight models that has been tested experimentally is the prediction that if attention operates as a spotlight, two separate locations or objects

cannot be attended to at the same time (Cave & Bichot, 1999). Some early experiments seemed to support this prediction (e.g. Posner et al., 1980; Eriksen & Yeh, 1985; Heinze et al., 1994) but other researchers found conflicting results, but most of which could be explained away by the spotlight models (e.g. Castiello & Umiltá, 1992). Bichot, Cave and Pashler (1999) designed an ingenious method of testing the split attention question that could not be explained away and their results showed, convincingly, that attention can be split. In their paper they report on a series of six experiments, in the first one a series of eight frames, each with two numbers appeared (total of 16 numbers), the numbers were either green or red and the task was to name the highest red digit that appeared after all 8 frames has been presented. In half of the trials the red digits appeared simultaneously, that is, two red digits in the same frame, in the other condition one digit was always red and the other one was green. If attention can only be deployed to one spatial location the simultaneous short presentation of the digits separated in space should be much more difficult, yet, they found no difference. In the second experiment they added distractor digits in the space between the two target locations, this should make it impossible to attend to the two target locations as a whole, or if doing so, more distractors should make the simultaneous condition even more difficult, but again, no difference was found. They then proceeded to rule out alternative explanations, for example by using spatial probes and measuring the effect of the number of distractors between two target locations. All their results point towards the ability to split attention to two spatially separated locations without attending to the space between those locations. This breaks two fundamental premises of the spotlight theories and has led to the development of more complex models and theories such as neural network models (e.g. Fukushima, 1987; Reynolds & Heeger, 2009), connectionist models (e.g. Phaf, Van der Heijden & Hudson, 1990) and integrationist models (e.g.

Logan, 2002). These newer models are in general more complex and also more specific. Instead of trying to capture and explain attention as a whole, which can be argued is impossible, since a definition and the scope of the concept itself is not agreed upon, these newer theories explain a specific part or task of attention and the role attention plays in different mechanisms and tasks.

Attention and working memory

One of those specific theories of attention is the Engle and Kane (2004) two-factor theory of cognitive-control, which seeks to explain executive attention and working memory capacity. A lot of evidence supports the notion that attention and working memory are intertwined, for example with regard to interference resistance. A correlation has been shown between effective interference resistance in working memory tasks and effective attention control (e.g., Anderson, 2003; Dempster, 1992). And although most researchers have studied visual working memory when studying attentional control in visual search, Soto and Humphreys (2007) showed that verbal working memory influences visual search, indicating a deeper interplay between attention and working memory.

Working memory

What is working memory?

According to Baddeley and Hitch (1974) who popularized the term working memory in their memory model, working memory is “a system that provides temporary storage and manipulation of the information necessary for such complex cognitive tasks as language comprehension, learning and reasoning” (Baddeley, 1992). Given the previous discussion on attention, and the necessity of attention to process stimuli, it is

not surprising that attention and working memory are linked as the definition of working memory also emphasizes the role of manipulation of information. It is logical that without paying attention to stimuli, there is no information to store and manipulate in working memory, and conversely, without any working memory capacity, no matter how much attention you pay to stimuli if they are not stored and manipulated, the information will be lost.

Working memory capacity (WMC)

The most traditional method of studying WMC is with a reading span task, it has been shown to strongly predict performance in various complex cognitive operations such as language comprehension, learning and reasoning (Daneman & Merikle, 1996; Conway, Kane & Engle, 2003). Some have pointed out that this connection is not surprising and even a priori knowledge as a reading span task tests not only WMC but several other cognitive abilities such as reading skill, storage capacity, memory decay, mental resources or activation, processing efficiency or speed, mnemonic strategies, inhibitory control of memory interference, a limited structural capacity for focused attention or mental binding or any combination of these factors (Kane, Poole, Tuholski, Engle, 2006). This cannot explain away the correlation between WMC and other cognitive factors and several experiments have shown that controlling for these possible confounds or changing the WMC tasks still reveals strong correlations between WMC and learning, reasoning and language comprehension (for a summary of the supporting evidence see, Engle & Kane, 2004). Kane et al. (2006) argue and support with several experiments that the relation between WMC and those other cognitive factors are attentional in nature. They argue that WMC predicts other cognitive abilities so well because “they reflect, in part, the controlled, attentional, and domain-general ability to

maintain or recover access to stimulus or goal representations outside of conscious focus” (Kane et al. 2006). A major argument for an attentional component in the variance in cognitive tasks explained by WMC is that short term memory (STM) tasks do not explain nearly as much of the variance as does WMC and when both WMC and STM tasks are used, WMC tasks continue to predict cognitive performance even after controlling for performance on the STM tasks which can be seen as controlling for the nonattentional storage variance (Bayliss, Jarrold, Gunn & Baddeley, 2003). This relationship becomes especially clear when using an extreme-group-design where the top quartile performers on WMC tasks are compared to the bottom quartile performers (e.g. Bunting, 2006).

Current experiment

Ipad foraging study

Kristjánsson et al. (2014) used innovative methodology to study foraging behaviour in humans. They used an *iPad* with 80 stimuli, from four stimuli categories, two of which the target groups and two of which distractor groups. This is important for several reasons. One, this offers a new perspective on visual search tasks, using a methodology more akin to foraging studies. Second, this brings understanding from decades of visual search research to foraging studies by offering a new way of studying selection behaviour. While most previous studies used visual ambiguity to create categorical selection behaviour, Kristjánsson et al. (2014) used feature vs conjunction foraging in order to increase the attentional load and in vein with the discussion above on WMC load. Their results showed that during feature foraging participants randomly switch between the two target categories while during conjunction foraging, participants repeatedly select stimuli from the same category. Kristjánsson et al. (2014) speculate

whether this behaviour is due to the fact that participants can hold two features simultaneously in their working memory (although they do not specifically use the term working memory), while most participants cannot keep four features and the relation between them in their working memory simultaneously. They and several other researchers have found that a small portion of participants show different selection behaviour than most other participant. In this case, they did not show categorized selection behaviour in the conjunction condition. That could indicate that those participant are able to keep the four features and the relations in their working memory which suggests that there may be individual differences in working memory capacity.

Importance of children in visual search research

The results of Kristjánsson et al. (2014) are very clear, all participants use many short runs in feature foraging condition and very few trials are fewer than ten runs. In conjunction foraging condition over half of the trials are only two runs and most of the trials over two runs are contributed by few participants, so called super foragers. This is in line with results from animal foraging studies with the interesting addition of feature vs conjunction foraging. If this is a general tendency found in the animal kingdom it begs the question if it is a primary innate ability or if it depends on the development of some cognitive factors. One way to start understanding this pattern is to study children, asking such questions as when does this pattern emerge, is the emergence sudden, indicating a possible qualitative shift, or is the emergence gradual, indicating a quantitative shift. As argued before, we expect a gradual emergence and if that is the case, it raises the question whether that emergence follows the development of other cognitive mechanisms, such as working memory. These questions will not be answered by a single experiment, but in order to start our journey towards answering them, the

methodology of Kristjánsson et al. (2014) was used with children around the age that conjunction foraging capabilities would likely be emerging as per the models and research previously discussed.

Hypothesis

The first prediction is that the feature foraging condition will on average be performed with more runs than the conjunction foraging across all ages. Second, that the older the children are, the larger the number of runs in the feature foraging condition will be. Third, that an increased score on a working memory capacity measurement will be correlated with more runs in the feature foraging condition even when age is controlled for. Finally, that the number of completed conjunction foraging trials will be positively correlated with working memory capacity measurement.

Methods

Participants

42 kindergarten students and 24 first graders, aged from 4 to 7 years (33 females; $M = 68$ months, $SD = 11,9$ months) participated in this study. All had normal or corrected to normal vision according to teachers and them self, parental consent was obtained in addition to 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. Participants received a small prize (a balloon or a sticker) for participating in the experiment.

Equipment

The stimuli were displayed on an iPad 2 with screen dimensions 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 a bit more). 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 of the trials. 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.

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.

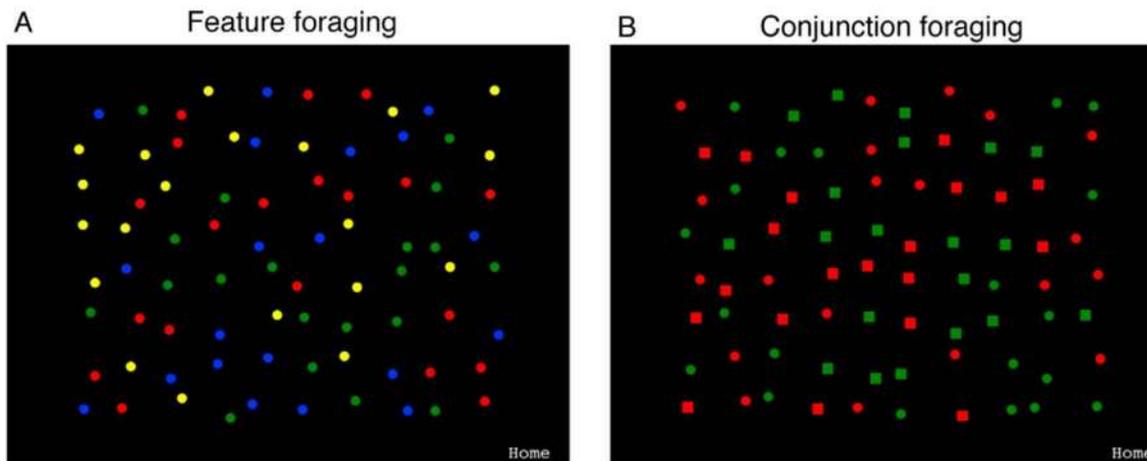


Figure 1. Examples of trials. Panel A shows the feature condition, where the task is to tap all red and green circles while ignoring blue and yellow (or vice versa). Panel B, shows the conjunction condition where the task is to tap all the red squares and the green circles (or vice versa).

Procedure

The experiments were run in a quiet room with normal illumination in the kindergarten and the primary school. The participants' task was to tap all targets as quickly as possible using the index finger of their right hand. A printed 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 attempted to complete nine trials, one training trial followed by two trials of each task in counterbalanced order. One trial refers to a completed sequence where all 40 targets were tapped.

Self-regulation task

The Head-Toes-Knees-Shoulders task (HTKS) is a direct measure self-regulation task. It measures a broad aspect of self-regulation, including working memory, attention and inhibition (Cameron Ponitz et al., 2008; Cameron Ponitz, McClelland, Matthews & Morrison, 2009). Scores on the HTKS have shown reliability and validity in recent studies (e.g., von Suchodoletz et al., 2012; Cameron Ponitz et al., 2008; Cameron Ponitz

et al., 2009; Wanless et al., 2011). 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 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. The Icelandic version used in this experiment has been translated back-translated from the original version and has been used in studies of self-regulation in Iceland (e.g. Birgisdóttir, Gestsdóttir & Thorsdóttir, 2015; Gestsdóttir et al., 2014).

Working memory task

The subtest Sentences from WPPSI-R^{IS} was used to assess working memory. The subtest requires the child to repeat increasingly long and complicated sentences after the examiner. It is used to assess verbal working memory. After the examiner reads a sentence, the child repeats it and the examiner counts the errors in the sentence that the child produces, compared to the original sentence. Errors can be skipping a word, adding words, adding or skipping endings of words and mixing the order of the words. The test consists of 12 sentences, starting with two word sentences and ending in 17 word sentence. Each sentence has a maximum score, that varies from one to five, depending on the complexity of the sentence, for the shortest sentences one error will give zero

points but in the last sentence points are given unless five or more errors are made.

Scoring is from 0-37.

Results

Descriptive statistic by age and by working memory are shown in tables 1 and 2 respectively.

Table 1. Descriptive statistics by age.

Age	N	MFT	MCT	RTF	RTC	MRF	MRC	WMC	SRS
48-59	17	2,18	1,29	1,69	1,84	14,65	6,14	18,13	27,53
60-71	25	3,16	2,28	1,11	1,25	10,96	3,67	20,12	35,64
72-86	24	3,92	3,46	0,74	1,03	7,55	4,3	19,75	40,79

Age is measured in months and corresponds to the age group of 4-5 years old, 5-6 years old and 6-7 years old, the extra two months added to the last group stem from the fact that data collection was delayed two months so that the oldest first graders tested were already 85 and 86 months old. N is for the number of participants, there are slightly fewer participants in the youngest age group due to availability of participants at the kindergarten. MFT stands for mean number of completed feature foraging trials and MCT stands for mean number of completed conjunction foraging trials. As can be seen from table 1, the average number of completed trials increases with age, both for feature and conjunction foraging. In each age group more feature foraging trials were completed than conjunction foraging trials, as is to be expected due to the more difficult nature of a conjunction foraging. It is interesting to note that there is no overlap between age groups, each group completes more conjunction trials than a younger group does of feature foraging.

RTF stands for the mean reaction time in the feature foraging condition in seconds. This was calculated by subtracting the time of each tap on a target stimulus from the previous tap, excluding the first tap in each trial. RTC stands for the mean reaction time in conjunction foraging condition in seconds, calculated the same way as RTF. Again we see that across age groups feature foraging and conjunction foraging differ, conjunction foraging being slower than feature foraging. As with the number of completed trials, there is no overlap between the reaction times between age groups and foraging conditions.

MRF stands for the mean number of runs in the feature foraging condition. MRC stands for the mean number of runs in the conjunction foraging condition. As table 1 shows, fewer runs are made in the conjunction foraging condition than in the feature foraging condition in all age groups. However, for this measurement there is overlap between age groups but not between conditions, that is, no matter the age group, conjunction foraging is on average completed with fewer runs than feature foraging. This is an indication that while for the other measurement covered so far, the age seems to separate performance, for the number of runs, it is the foraging condition that separates performance.

WMC stands for working memory capacity and was measured with the *Sentences* subtest of WPPSI-IS. SRS stands for self-regulation score and was measured with the Head, toes, knees and shoulders test. As table 1 shows, SRS scores increase with age but WMC scores do not. Only two points separate the highest and the lowest age group in WMC and the 5-6 year old age group outperforms the oldest age group, the standard deviation was between 4,8 and 5,8 so the difference between age groups is less than half a standard deviation and thus more reasonable not to assume any difference

between the age groups.

Table 2. Descriptive statistics by working memory capacity.

WMC	N	MA	MFT	MCT	RTF	RTC	MRF	MRC	SRS
1	11	61,55	1,72	1,09	1,47	1,21	12,79	4,5	16,45
2	26	69,34	3,42	2,76	1,07	1,34	8,79	5,27	36,85
3	18	72,44	3,61	2,58	0,84	1,01	10,15	2,67	41,94
4	10	65,7	3,5	3,2	0,99	1,27	10,2	4,69	41

Same abbreviations are used in table 2 as in table 1 with two exceptions. Firstly, working memory scores were grouped together, group 1 are participants with WMC score 14 and below, group 2 those with scores between 15 and 19, group 3 those with scores between 20-24 and group 4 for those with the score 25 and higher. Second, MA stands for mean age (in months). The mean age in the different WMC groups confirms what table 1 indicated that there is little or no relationship between age and WMC, at least as measured in this experiment.

Across foraging conditions similar patterns can be seen as in table 1. Participants, regardless of WMC complete more feature foraging trials than they do conjunction foraging trials. Reaction times are slower for conjunction foraging than for feature foraging with the exception of group one, those with the lowest WMC scores. Participants use higher run numbers during feature foraging than they in conjunction foraging. Unlike table 1 where there was no overlap between age groups in several comparisons, this is not the case for WMC groups, but it is of note that those participants with the worst WMC completed much fewer trials, both in feature and in conjunction foraging conditions. In both cases their mean number of completed trials is less than half of any other group. This group also has less than half the self-regulation score that any other group has. This indicates that as WMC was measured in this experiment, not much

differentiation can be found between those with scores of 15 and higher, but that those with a score under 15 are different from the rest of the participants.

To test the first hypothesis, that across all age groups, participants would use more runs in the feature foraging condition than in the conjunction foraging condition a T-test was conducted on number of runs by foraging condition. The T-test confirms what tables 1 and 2 suggested that there is a significant difference between the number of runs made in feature foraging condition and conjunction foraging condition, $t=7,11$ $p<,001$.

Table 1 already suggests that the second hypothesis, that the older the participants are, the higher number of runs they use in the feature foraging condition, is not supported. On the contrary, table 1 indicates that the older the participants are, the fewer runs in they use in the feature foraging condition. A One-way ANOVA with age as an independent variable and number of runs as the dependent variable supports that age affects the number of runs in the feature foraging condition. $F=9,225$ $p<,001$ telling us that there is a significant difference between some of the groups. Using the Bonferroni post-hoc correction for multiple comparisons shows that there is significant difference between age groups one and three ($p<,001$) and between age groups two and three ($p=,036$).

Hypothesis three is that an increased WMC score will be correlated with higher number of runs in the feature foraging condition. Table 2 does not show any such trend and a one-way ANOVA indicates that we cannot reject the null hypothesis, since there is no difference between any of the groups ($F=1,193$ $p=0,314$).

The last hypothesis is that the number of completed conjunction foraging trials will be positively correlated with the WMC score. A one-way ANOVA yields $F=3,877$ $p=,013$ confirms that there is a significant difference between some of the groups. Using

Bonferroni post-hoc correction for multiple comparisons shows that it is group one, those with the lowest WMC score that are different from the other groups. No significant differences were found between groups two, three and four. But group one differed significantly with 95% confidence from groups two ($p=,027$) and four ($p=,019$) and at 90% confidence from group three ($p=,089$).

Leaving further discussion on the hypothesis until the general discussion it is clear that most of the hypothesis were not supported. That is not to say that the experiment or results are all for nothing. Several interesting results were found during data processing that were not related to the original hypothesis. It is for example interesting to compare these results to the results found by Kristjánsson et al. (2014). Especially those concerning the number of runs in feature and conjunction foraging. Figure 2 shows the results from Kristjánsson et al. (2014), it is clear that most adult participants use only two runs in conjunction foraging while they use many more runs in feature foraging, peaking between 12 and 19 runs.

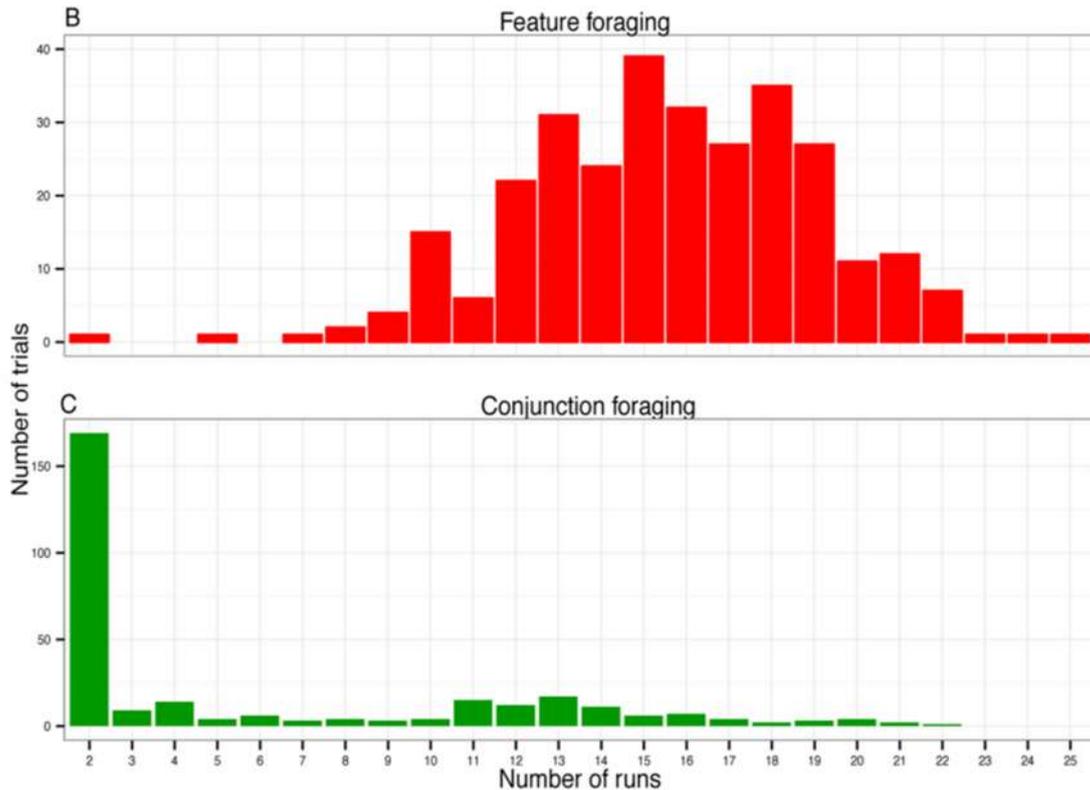


Figure 2. Two panels from a figure in Kristjánsson et al. (2014) showing the number of runs in feature and conjunction foraging.

Comparison between those results and the results from this experiment can be seen in figures 3-8. Figures 3 and 4 show the number of runs for the youngest age group, 4-5 years old, in feature and conjunction foraging respectively. As we can see from figures 3 and 4, there is more variability in the number of runs in the feature foraging condition than in the conjunction foraging condition. Figure 4 resembles panel C from figure 2, high peak at two runs with much fewer trials above that. Figure 3 is different from panel B in figure 2 in several ways. The highest peak in figure 3 is at two runs and around third of the trials are completed in less than ten runs, adults however rarely used less than ten runs as we see in figure 2, panel B.

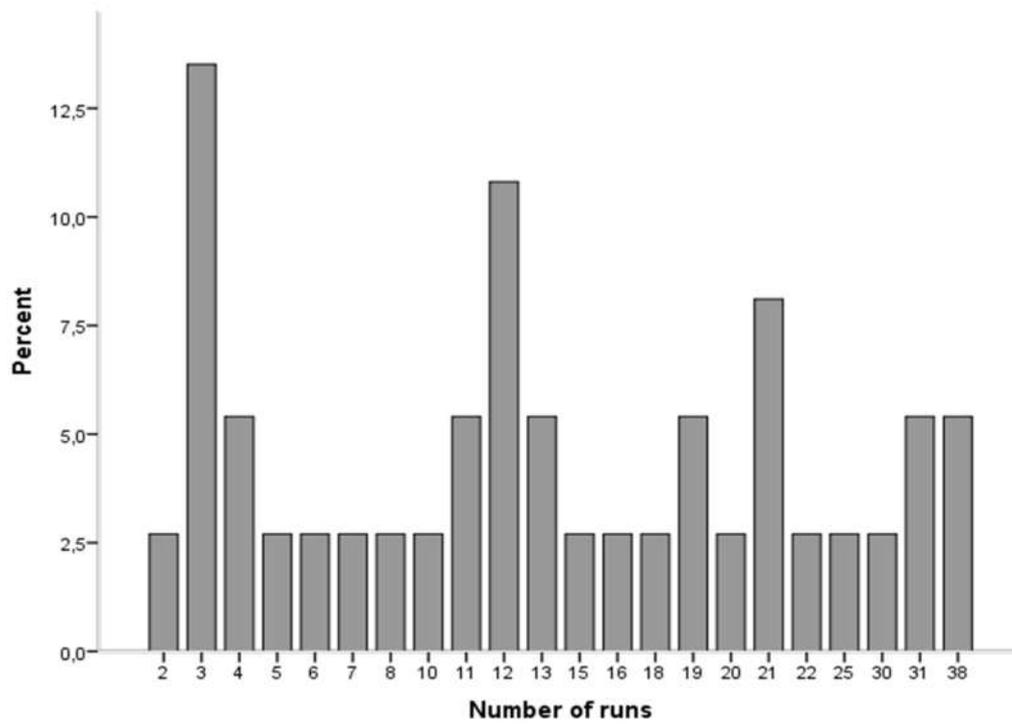


Figure 3. Number of runs in feature foraging for 48-59 months old children.

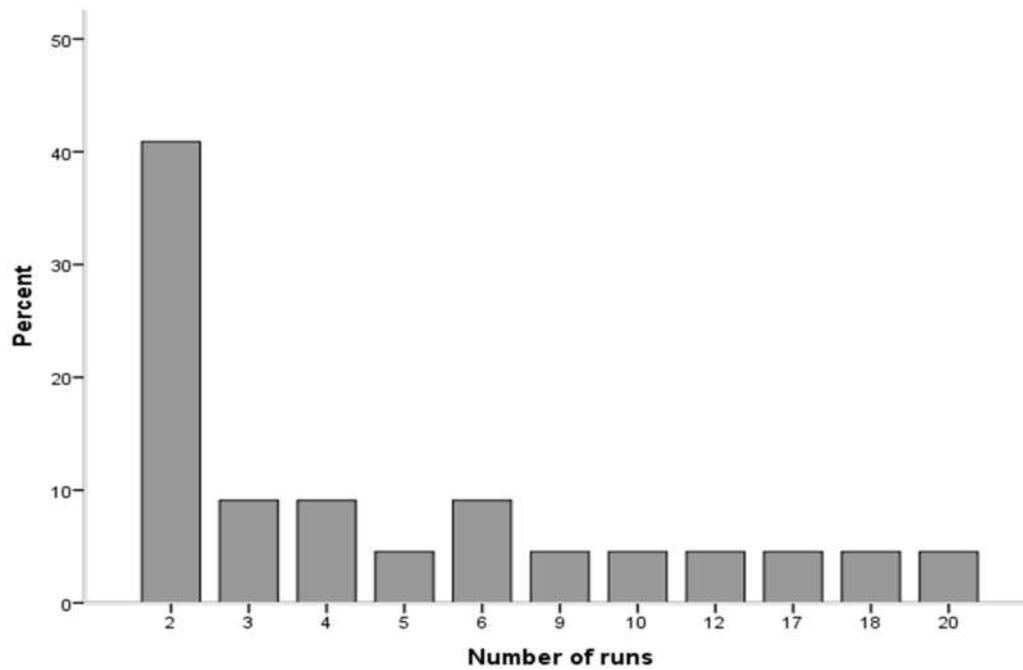


Figure 4. Number of runs in conjunction foraging for 48-59 months old children.

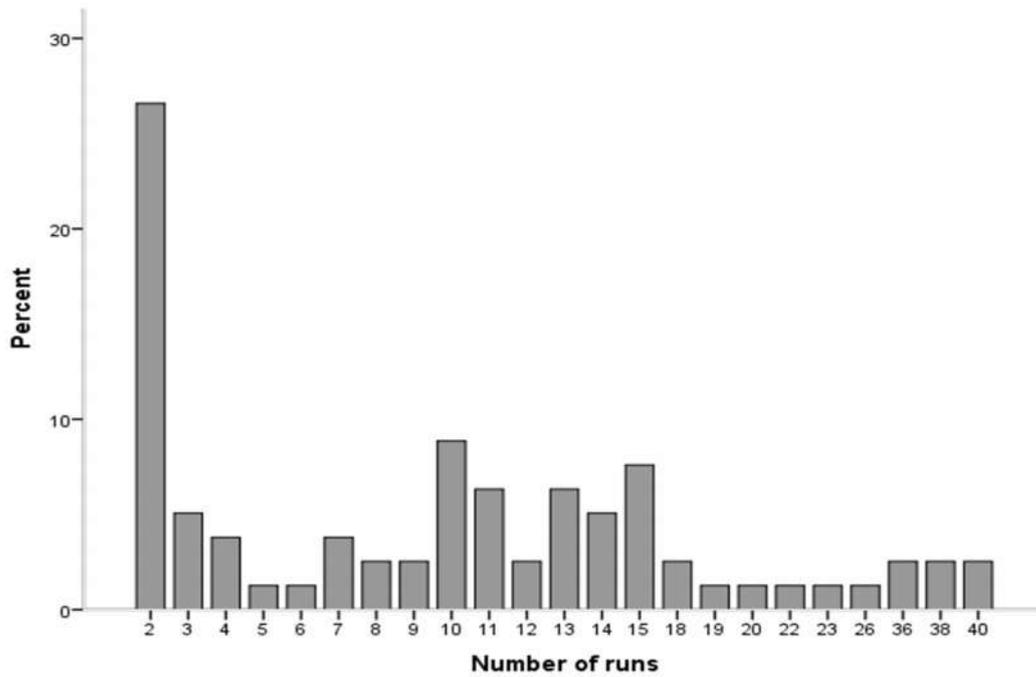


Figure 5. Number of runs in feature foraging for 60-71 months old children.

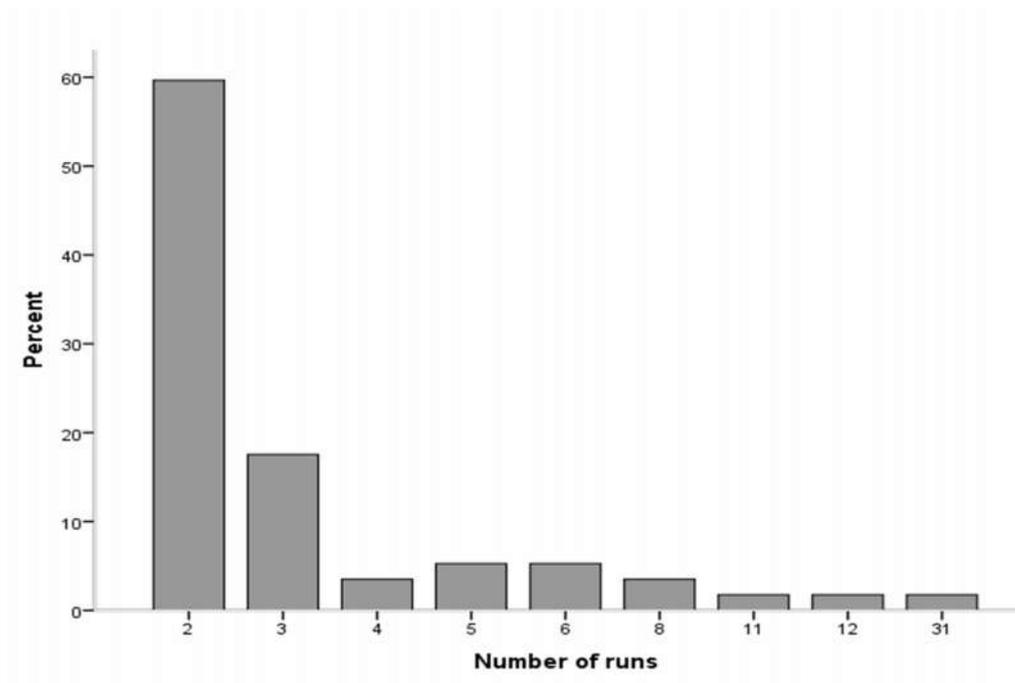


Figure 6. Number of runs in conjunction foraging for 60-71 months old children.

A similar pattern can be seen in figures 5 and 6 for the age group 5-6 years old and in figures 7 and 8 for the age group 6-7 years old. High peaks at two runs in both feature and conjunction foraging conditions, yet when looking at the percentages the

peak is more pronounced for the conjunction condition. But in all age groups, a far higher higher portion of trials in the feature foraging condition have two runs and a much higher portion of trials are less than ten runs than in the adult results from Kristjánsson et al. (2014).

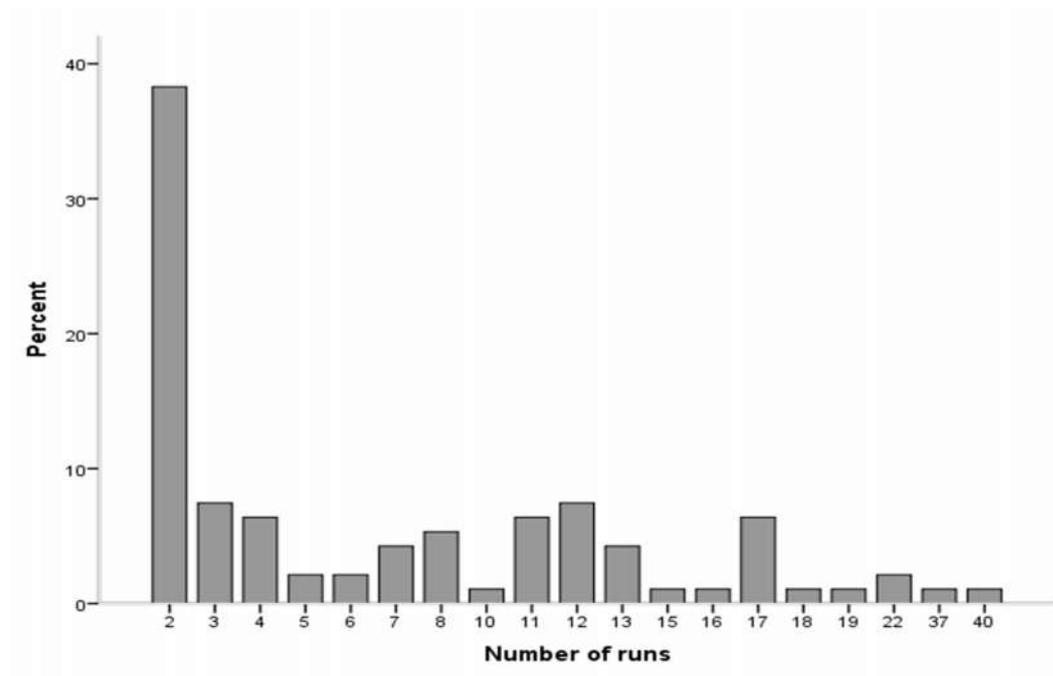


Figure 7. Number of runs in feature foraging for 72-83 months old children.

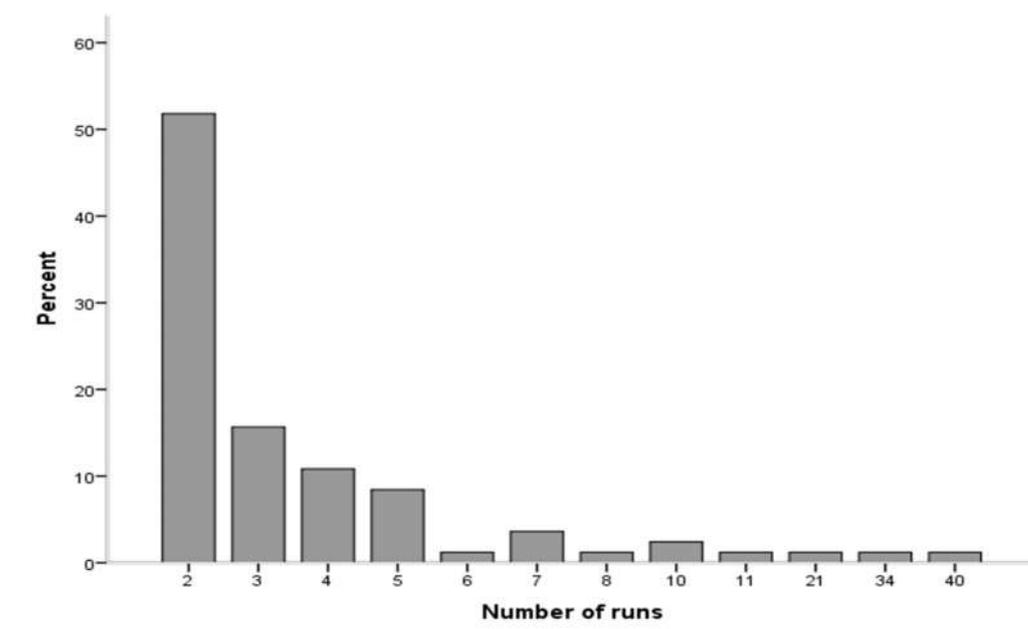


Figure 8. Number of runs in conjunction foraging for 72-83 months old children.

There is clearly a difference between the pattern of runs between children and adults, especially in feature foraging condition. Interestingly, even if the patterns look similar between age groups, looking at the percentages reveals interesting differences. In feature foraging, where adults rarely use two or three runs, four to five year olds use two to three run in 16% of the trials, five to six year olds in 32% of the trials and six to seven years old in 47% of the trials. Moving further and further away from the pattern found in adults with age.

An multivariate ANOVA model with age, WMC and SRS as independent variables and number of runs as the dependent variable for each foraging condition reveals that for feature foraging the model is significant $F=4,751$ $p<,001$ with significant main effects for all three independent variables (age: $F=2,202$ $p=,021$; WMC: $F=3,371$ $p=,037$; SRS: $F=7,499$ $p<,001$). No significant interaction was found. The adjusted R^2 is ,525 meaning that the model can explain around 53% of the variance in the number of runs used in feature foraging condition. For conjunction foraging the model is significant $F=5,769$ $p<,001$ but main effect is only significant for SRS $F=16,550$ $p<,001$. The adjusted R^2 is ,606 so the model explains 61% of the variance in the number of runs used in conjunction foraging.

Given that SRS seems to explain some of the variance in the number of runs, a Pearson correlation was calculated between SRS, WMC and the number of runs in each foraging condition. Interestingly neither SRS nor WMC was significantly correlated with the number of runs in either foraging condition (highest Pearson correlation between SRS and number of runs in conjunction foraging ,062 $p=,431$). However, when looking at the top quartile of SRS, which had scores at or over 51, then working memory became highly correlated with the number of runs in feature foraging (Pearson correlation ,441 $p=,001$) but not in conjunction foraging (-,027 $p=,865$). In the bottom

quartile of SRS, scores at or under 33, no such correlation was found. In feature foraging where the high correlation was found in the top quartile of SRS the correlation was $-0,005$ $p=,970$.

Discussion

The results are interesting for many reasons, Kristjánsson et al. (2014) discuss the possibility that adult participants can hold two features in their working memory at the same time and hence can perform the feature foraging task in a more random manner, selecting the next target stimulus based on the distance from the focus of attention rather than the category of the previous target stimulus. While the four features and the relations between them (binding two and two together) appears to put too much load on working memory leading to a more efficient strategy of picking out all the targets from one target category before selecting from the other one, meaning that only two features and their relation is needed to be kept active in the working memory at a time. Based on those speculations which are in line with Kane et al. (2006) discussion on WMC and its role in visual search and the fact that Soto & Humphreys (2007) found effects of verbal working memory on visual search, it was predicted that higher age and verbal working memory would lead to more runs in the feature condition. With increase WMC it should be easier to hold the two features needed in the feature foraging condition, active in the working memory. Age was also predicted have a positive correlation with the number of runs in feature foraging condition. Self-regulation, memory and several other cognitive abilities are developing during these years and with an overall better developed cognitive abilities, the older children should find the feature foraging condition easier than the younger children and hence use the more economical random strategy.

The fact that working memory did not seem to affect the number of runs can be explained in several ways. For one, the measurement, the Sentences subtest of WPPSI-IS was not created for the purpose of assessing WMC per se, but rather is a part of a whole test, assessing general intelligence. Second, it is possible that the nature of the foraging task, using 80 stimuli on a small screen created such a demand on the working memory that the results represent a floor effect. However, this explanation, although a possible contributor to the null effect of working memory is not likely to be the sole culprit as there was a wide variety in the number of runs used and the fact that those with the highest working memory score did not differentiate from the other groups on the number of runs used.

The fact that, in this experiment, there was an opposite age effect, the older the children were, the fewer runs they used in feature foraging condition, is very interesting. It raises the question whether children need to develop cognitive skills in order to figure out and use the two run strategy and that in these early stages of cognitive development the increased age enables them to use the two run strategy. If that is the case, further studies are required to see at which age this trend turns around and at which age children start being able to hold both features active in their working memory and use the more efficient random strategy, like adults do.

It is also interesting that self-regulation explained the largest amount of variance in the number of runs in the conjunction foraging condition and was in fact the only significant variable there. Working memory is a part of self-regulation (SR) and one would expect certain amount of covariance between the two (von Suchodoletz et al., 2013). The fact that SR score but not WMC score explains a significant portion of the variance in the number of runs in the conjunction condition is interesting and calls for

further studies to find which parts of SR are contributing to this effect. SR has many different definitions but it is common to count working memory, memory, inhibition and attention as parts of SR. If working memory does not contribute to this effect a logical step would be to examine whether memory, inhibition or attention do.

The results, that the working memory of the top performers on the self-regulation task correlated highly with the number of runs in feature foraging, could indicate that children need a certain level of self-regulation before the effects of working memory can have an effect. This makes sense if we look at other abilities that self-regulation is thought to incorporate, like inhibition. If children are unable to inhibit them self from pressing a distractor stimulus, then no matter how many features or relation they can hold in their working memory, that ability will not translate into a better performance.

Several changes to the methodology should be considered for further studies. 80 stimuli on a small screen may be overwhelming for four year old children and many children give up, not because of the inability to complete the task but because it seems endless. Having so many stimuli on a small screen also creates a possible confound in fine muscle movement ability. The stimuli are often very close to each other and on many occasions the children tapped a different stimulus than the one they were aiming for. Also, the fact that a trial is only recorded upon completion of tapping all 40 target stimuli is unfortunate. Several children made errors during the last five target stimuli and the data from the 35-39 taps could give valuable information. Another change to consider for further experiments is the inter-trial period. Upon completing a trial, the next trial starts immediately after a brief presentation of a smiley face, after concentrating for around a minute, children were not ready to see the screen fill up again

and start all over. A longer interval or a tap activation for the next trial would be preferable.

Despite these methodological flaws, this experiment yielded some very interesting results, and the great difference between this methodology and the methodology of most visual search and developmental studies provides an exciting opportunity for innovation and hopefully to answer some of the many unanswered questions in both fields.

References

- Anderson, M. C. (2003). Rethinking interference theory: Executive control and the mechanisms of forgetting. *Journal of Memory and Language, 49*, 415–445.
- Baddeley, A. (1992). Working memory. *Science, 255*(5044), 556-559.
- Baddeley, A. D., & Hitch, G. (1974). Working memory. *Psychology of Learning and Motivation, 8*, 47-89.
- Baylis, G. C., & Driver, J. (1993). Visual attention and objects: Evidence for hierarchical coding of location. *Journal of Experimental Psychology: Human Perception & Performance, 19*, 451-470.
- Bayliss, D. M., Jarrold, C., Gunn, D. M., & Baddeley, A. D. (2003). The complexities of complex span: Explaining individual differences in working memory in children and adults. *Journal of Experimental Psychology: General, 132*, 71–92.
- Bichot, N. P., Cave, K. R., & Pashler, H. (1999). Visual selection mediated by location: Feature-based selection of noncontiguous locations. *Perception & Psychophysics, 61*, 403-423.
- Birgisdóttir, F., Gestsdóttir, S., & Thorsdóttir, F. (2015). The Role of Behavioral Self-Regulation in Learning to Read: A 2-Year Longitudinal Study of Icelandic Preschool Children. *Early Education and Development*, (ahead-of-print), 1-22.
- Bond, A. B. (1982). The bead game: Response strategies in free assortment. *Human Factors, 24*, 101–110.
- Bruce, N. D., & Tsotsos, J. K. (2009). Saliency, attention, and visual search: An information theoretic approach. *Journal of Vision, 9*(3):5, 1-24.

- Bunting, M. F. (2006). Proactive interference and item similarity in working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *32*, 183–196.
- Cameron Ponitz, C., McClelland, M. M., Jewkes, A. M., Connor, C. M., Farris, C. L., & Morrison, F. J. (2008). Touch your toes! Developing a direct measure of behavioral regulation in early childhood. *Early Childhood Research Quarterly*, *23*, 141–158.
- Cameron Ponitz, C., McClelland, M. M., Matthews, J. S., & Morrison, F. J. (2009). A structured observation of behavioral selfregulation and its contribution to kindergarten outcomes. *Developmental Psychology*, *45*, 605–619.
- Castiello, U., & Umiltà, C. (1992). Splitting focal attention. *Journal of Experimental Psychology: Human Perception and Performance*, *18*(3), 837-848.
- Cave, K. R., & Bichot, N. P. (1999). Visuospatial attention: Beyond a spotlight model. *Psychonomic Bulletin & Review*, *6*(2), 204-223.
- Chen, Z. (1998). Switching attention within and between objects: The role of subjective organization. *Canadian Journal of Experimental Psychology*, *52*, 7-16.
- Conway, A. R. A., Kane, M. J., & Engle, R. W. (2003). Working memory capacity and its relation to general intelligence. *Trends in Cognitive Sciences*, *7*, 547–552.
- Daneman, M., & Merikle, P. M. (1996). Working memory and language comprehension: A meta-analysis. *Psychonomic Bulletin & Review*, *3*, 422–433.
- Dempster, F. N. (1992). The rise and fall of the inhibitory mechanism: Toward a unified theory of cognitive development and aging. *Developmental Review*, *12*, 45–75.

- Denney, N. W. (1972). A developmental study of free classification in children. *Child Development, 43*, 221-232.
- Downing, C. J. (1988). Expectancy and visual-spatial attention: Effects on perceptual quality. *Journal of Experimental Psychology: Human Perception & Performance, 14*, 188-202.
- Dukas, R. (2002). Behavioural and ecological consequences of limited attention. *Philosophical Transactions of the Royal Society B: Biological Sciences, 357*, 1539–1547.
- Engle, R. W., & Kane, M. J. (2004). Executive attention, working memory capacity, and a two-factor theory of cognitive control. *Psychology of Learning and Motivation, 44*, 145-200.
- Eriksen, C. W., & St. James, J. D. (1986). Visual attention within and around the field of focal attention: A zoom lens model. *Perception & Psychophysics, 40*, 225-240.
- Eriksen, C. W., & Yeh, Y.-Y. (1985). Allocation of attention in the visual field. *Journal of Experimental Psychology: Human Perception & Performance, 11*, 583-597.
- Fischer, J., & Whitney, D. (2014). Serial dependence in visual perception. *Nature Neuroscience, 17*, 738-743.
- Fukushima, K. (1987). Neural network model for selective attention in visual pattern recognition and associative recall. *Applied Optics, 26*(23), 4985-4992.
- Gestsdottir, S., von Suchodoletz, A., Wanless, S. B., Hubert, B., Guimard, P., Birgisdottir, F., Gunzenhauser, C., & McClelland, M. (2014). Early behavioral

- self-regulation, academic achievement, and gender: Longitudinal findings from France, Germany, and Iceland. *Applied Developmental Science*, 18(2), 90-109.
- Heinze, H.-J., Luck, S. J., Munte, T. E., Gös, A., Mangun, G. R., & Hillyard, S. A. (1994). Attention to adjacent and separate positions in space: An electrophysiological analysis. *Perception & Psychophysics*, 56, 42-52.
- Hessels, R. S., Hooge, I. T., Snijders, T. M., & Kemner, C. (2014). Is there a limit to the superiority of individuals with ASD in visual search? *Journal of Autism and Developmental Disorders*, 44(2), 443-451.
- Iarocci, G., & Armstrong, K. (2014). Age-Related Changes in Conjunction Visual Search in Children with and without ASD. *Autism Research*, 7(2), 229-236.
- Inhelder, B., & Piaget, J. (1964). *The early growth of logic in the child*. New York: Norton.
- Kahneman, D., Treisman, A., & Gibbs, B. J. (1992). The reviewing of object files: Object-specific integration of information. *Cognitive Psychology*, 24, 175-219.
- Kaldy, Z., Kraper, C., Carter, A. S., & Blaser, E. (2011). Toddlers with autism spectrum disorder are more successful at visual search than typically developing toddlers. *Developmental Science*, 14(5), 980-988.
- Kamil, A. C., & Bond, A. B. (2006). Selective attention, priming, and foraging behaviour. In T. R. Zentall & E. Wasserman (eds.), *Comparative cognition: experimental explorations of animal intelligence*. Oxford: Oxford University Press. pp. 106–126.

- Kane, M. J., Poole, B. J., Tuholski, S. W., & Engle, R. W. (2006). Working memory capacity and the top-down control of visual search: Exploring the boundaries of "executive attention". *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *32*(4), 749-777.
- Kemler, D. G. (1983). Exploring and reexploring issues of integrality, perceptual sensitivity, and dimensional salience. *Journal of Experimental Child Psychology*, *36*, 365-379.
- Kemler-Nelson, D. G. (1989). The nature and occurrence of holistic processing. In B. E. Shepp & S. Ballesteros (Eds.), *Object perception: Structure and process* (pp. 357-386). Hillsdale, NJ: Erlbaum.
- Kristjánsson, Á., & Campana, G. (2010). Where perception meets memory: A review of repetition priming in visual search tasks. *Attention, Perception, & Psychophysics*, *72*(1), 5-18.
- Kristjánsson, Á., Jóhannesson, Ó. I., & Thornton, I. M. (2014). Common attentional constraints in visual foraging. *PloS One*, *9*(6), e100752.
- Kristjánsson, Á., Wang, D., & Nakayama, K. (2002). The role of priming in conjunctive visual search. *Cognition*, *85*(1), 37-52.
- Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. *Journal of Experimental Psychology: Human Perception and Performance*, *21*(3), 451-468.
- Logan, G. D. (2002). An instance theory of attention and memory. *Psychological Review*, *109*(2), 376-400.

- Maljkovic, V., & Nakayama, K. (1994). Priming of pop-out: I. Role of features. *Memory & Cognition*, 22(6), 657-672.
- Merrill, E. C., & Conners, F. A. (2013). Age-related interference from irrelevant distracters in visual feature search among heterogeneous distracters. *Journal of Experimental Child Psychology*, 115(4), 640-654.
- Navon, D. (1977). Forest before trees: The precedence of global features in visual perception. *Cognitive Psychology*, 9, 353-363.
- Phaf, R. H., Van der Heijden, A. H. C., & Hudson, P. T. (1990). SLAM: A connectionist model for attention in visual selection tasks. *Cognitive Psychology*, 22(3), 273-341.
- Plaisted, K., O'Riordan, M., & Baron-Cohen, S. (1998). Enhanced visual search for a conjunction target in autism: A research note. *Journal of Child Psychology and Psychiatry*, 39(5), 777-783.
- Posner, M. I., Snyder, C. R. R., & Davidson, B. J. (1980). Attention and the detection of signals. *Journal of Experimental Psychology: General*, 109, 160-174.
- Rensink, R. A., O'Regan, J. K., & Clark, J. J. (1997). To see or not to see: the need for attention to perceive changes in scenes. *Psychological Science*, 8(5), 368-373.
- Reynolds, J. H., & Heeger, D. J. (2009). The normalization model of attention. *Neuron*, 61(2), 168-185.
- Rock, I., Linnett, C. M., Grant, P., & Mack, A. (1992). Perception without attention: results of a new method. *Cognitive Psychology*, 24, 502-534.

- Shepp, B. E., Burns, B., & McDonough, D. (1980). The relation of stimulus structure to perceptual and cognitive development: Further tests of a separability hypothesis. In J. Becker & F. Wilkening (Eds.), *The integration of information by children* (pp. 113-145). Hillsdale, NJ: Erlbaum.
- Smith, L. B. (1989). A model of perceptual classification in children and adults. *Psychological Review*, *96*(1), 125-144.
- Soto, D., & Humphreys, G. W. (2007). Automatic guidance of visual attention from verbal working memory. *Journal of Experimental Psychology: Human Perception and Performance*, *33*(3), 730-737.
- Soto, D., Heinke, D., Humphreys, G. W., & Blanco, M. J. (2005). Early, involuntary top-down guidance of attention from working memory. *Journal of Experimental Psychology: Human Perception and Performance*, *31*(2), 248-261.
- Soto, D., Humphreys, G. W., & Heinke, D. (2006). Working memory can guide pop-out search. *Vision Research*, *46*(6), 1010-1018.
- von Suchodoletz, A., Gestsdottir, S., Wanless, S. B., McClelland, M. M., Birgisdottir, F., Gunzenhauser, C., & Ragnarsdottir, H. (2013). Behavioral self-regulation and relations to emergent academic skills among children in Germany and Iceland. *Early Childhood Research Quarterly*, *28*(1), 62-73.
- Thompson, L. A., & Massaro, D. W. (1989). Before you see it, you see its parts: Evidence for feature encoding and integration in preschool children and adults. *Cognitive Psychology*, *21*(3), 334-362.

- Treisman, A. (1985). Preattentive processing in vision. *Computer Vision, Graphics, and Image Processing*, 31(2), 156-177.
- Treisman, A. (1987). Properties, parts and objects. In K. Boff, L. Kaufman, & J. Thomas (Eds.), *Handbook of perception and performance* (pp. 159-198). New York: Wiley.
- Treisman, A. (1996). The binding problem. *Current Opinion in Neurobiology*, 6(2), 171-178.
- Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology*, 12(1), 97-136.
- Vygotsky, L. S. (1962). *Thought and language*. Cambridge, MA: MIT Press.
- Wang, Q., Cavanagh, P., & Green, M. (1994). Familiarity and pop-out in visual search. *Perception & Psychophysics*, 56(5), 495-500.
- Wanless, S. B., McClelland, M. M., Acock, A. C., Cameron Ponitz, C., Son, S.-H., Lan, X., & Li, S. (2011). Measuring behavioral regulation in four societies. *Psychological Assessment*, 23, 364–378.
- Ward, T. B. (1980). Separable and integral responding by children and adults to the dimensions of length and density. *Child Development*, 51, 676-684.
- Wolfe, J. M. (1994). Guided search 2.0 a revised model of visual search. *Psychonomic Bulletin & Review*, 1(2), 202-238.
- Wolfe, J. M. (1998). What can 1 million trials tell us about visual search? *Psychological Science*, 9(1), 33-39.

Wolfe, J. M. (2003). Moving towards solutions to some enduring controversies in visual search. *Trends in Cognitive Sciences*, 7(2), 70-76.