Visual Attention and the Dimensional Change Card Sort

Nicholas Minar*, Dr. Vladimir Sloutsky
Department of Psychology

The current study examines cognitive flexibility and the development of executive function in children ranging from 3-5 years of age. The importance of executive function is seen in situations that involve multi-tasking, learning new routines, and functioning in a noisy environment. Our task is a variation of Zelazo's Dimensional Change Card Sort (DCCS), where young children are given one set of rules for sorting picture cards, which is then followed by a rule switch. Traditionally, 3 year olds fail to abide by the new set of rules and perseverate by using old rules, while 4 year olds effectively follow the new set of rules. The goal of the study is to understand what causes these perseverations. There is no agreement as to what causes perseverations; we suggest they stem from inability to inhibit irrelevant information. We test this hypothesis by examining patterns of eye movements using Tobii eye tracking equipment while children are tested on a computerized version of the DCCS. This approach elucidates children's ability to strategically allocate attention while looking at stimuli. We expect that children 3-4 years of age are unable to restrain their gaze from irrelevant dimensions, resulting in low efficiency of visual attention. We also predict that 4-5 year olds, who normally pass the postswitch phase, will also be unable to keep their gaze from irrelevant dimensions. However, we predict 4-5 year olds relative engagement with irrelevant features will be lower than that of younger children, which may be enough to reduce perseverations in the postswitch phase. We found similar behavioral data on our computerized version of the DCCS task, with the average 3 year old perseverating during the postswitch phase while on average 4 year olds passed. We also found via looking time data that 3 year olds had difficulty efficiently allocating their gaze away from irrelevant information. We found those who failed a given phase of the DCCS could not focus their visual attention on relevant dimensions of the stimuli for as long as those who passed.

Introduction

The ability to focus one's attention is very important. For example, if an individual is trying to multitask while blocking out a distracting environment, the ability to focus on the problem at hand is essential. Focusing ones attention also plays an important role in such tasks as learning new routines and holding multiple items in working memory. One could image the day to day difficulties without the mental flexibility to focus on what is important vs what is not. Psychologists have attributed the ability to focus ones attention on a given item while in a noisy environment to what is called "executive function" (Zelazo, Muller, Frye, & Marcovitch, 2003). There are many different lines of thought arguing over a specific definition of executive function. For example, one approach sees executive function

as a higher order cognitive mechanism, a cognitive module that effects inhibition, working memory, and organizational strategies (Zelazo et al., 2003). A contrasting view sees executive function in terms of separable dimensions that are associated with goal-directed problem solving (Zelazo et al., 2003). This view argues that executive function is a psychological process and can be defined in terms of what it accomplishes. Executive function is important in the eyes of both approaches because it relates to higher order thinking (Zelazo et al., 2003). Both views hold executive function as being central to the regulation of working memory, inhibitory processes, cognitive flexibility, task switching, and selective attention. These definitions are accurate in describing what executive function does, but more importantly they provide measurable variables which can be tested (Zelazo et al., 2003).

Much has been done to study the development of executive function; mental inflexibility for example has been an important topic in developmental psychology since the 1940's when psychologists made problem solving a central topic of research. Classic studies that first examined mental inflexibility as summarized by Zelazo et al., (2003) were Dunker's 1945 functional fixedness studies as well as Luchins 1942 addition and subtraction tasks. Current research examines mental inflexibility by measuring a participant's action of perseveration. Perseveration is defined as the repeated production of an action or method of problem solving in the absence of appropriate situations (Zelazo et al., 2003). One way developmental researcher's measure perseveration is with the Dimensional Change Card Sort (DCCS). This is a variation of the Wisconsin Card Sort, which is administered to adults who have suffered frontal cortex brain damage to asses working memory and abstract reasoning ability (Wang, Kakigi, and Hoshiyama, 2001). The DCCS however is designed to test cognitive flexibility in young children, often 3-5 years of age. In this task children are shown two target cards which differ along two dimensions, for example one target card would be a red rowing boat and the other would be a blue rabbit; therefore each target card would differ in shape and color. Young children would then be asked to sort a test card, which would
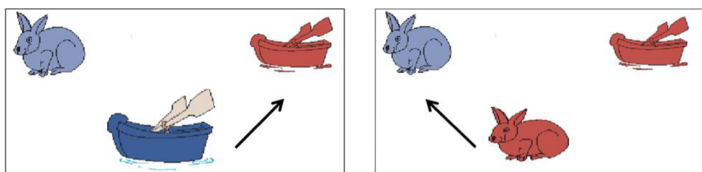

Fig 1 Preswitch phase of Zelazo's original DCCS task: Children are sorting by shape where two target cards are above a test card. Children are told to match the middle test card to the pile that matches in shape. In this "shape" game boats go with boats and rabbits go with rabbits.

match the target cards along one dimension (shape or color), into either one of the piles of target cards. An example of the first half, or preswitch phase, of Zelazo's original DCCS task can be seen below in figure 1 (Zelazo et al., 2003).

After 5 trails of sorting by shape children are told they will begin playing a different game, instead of playing the "shape game" they will now play the "color game". In this postswitch phase, the sorting rules have changed, now blue objects go with blue objects and red objects go with red objects, an example of this can be seen below in figure 2 (Zelazo et al., 2003).
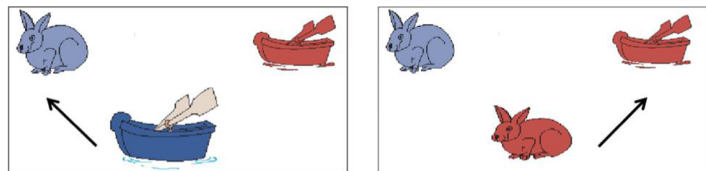

Fig 2 Postswitch phase of Zelazo's original DCCS task: Children are sorting by color where two target cards are above a test card. Children are told to match the middle test card to the pile that matches in color. In this "color" game blue objects go with blue objects and red objects go with red objects.

The postswitch phase again consists of 5 trials. In both preswitch and postswitch children are told the sorting rules on every trial. In the original study, measures were taken to counterbalance whether the "shape" or "color" game was played first (Zelazo et al., 2003). As stated earlier, this measures perseveration in young children. Traditionally, 3 year olds are unable to make the rule switch and match the postswitch cards by the novel sorting dimension. In contrast, Zelazo found 4 year olds are able to make the rule switch between sorting dimensions (Zelazo et al., 2003). The reason this task provides such an interesting problem is due to the fact that 3 year olds perseverated even when they are told the sorting rules on every trial. What is even more surprising is that when children are asked knowledge questions such as, "where do blue things go?" or "where do boats go?", they succeed (Morton and Munakata, 2002). What is it about the difference between 3 and 4 years of age that explains perseveration during postswitch card sorting on the DCCS?

A great deal of research has been done in attempts to elucidate Zelazo's findings on the original DCCS, including using many different variations of the task which have spawned numerous theories explaining the results (Zelazo et al., 2003). Complexity theories provide many possible explanations for why younger children perseverate on the DCCS task. The most prominent of these theories is Cognitive Complexity and Control Theory (CCC theory) and was developed by Zelazo (Zelazo et al., 2003). CCC theory emphasizes the importance of rule complexity and how a child's ability to comprehend these complexities grows

over time. According to this theory, changes in executive function are age-related and directly correspond to ones maximum mental complexity. CCC theory states that the degree to which a child can mentally represent multiple rules is a function of age (Zelazo et al., 2003). Zelazo illustrates this point by describing the network of rules much like a family tree, meaning as one gets older the more branches (or number of rules) can be held in mind. An example of this can be seen in figure 3.
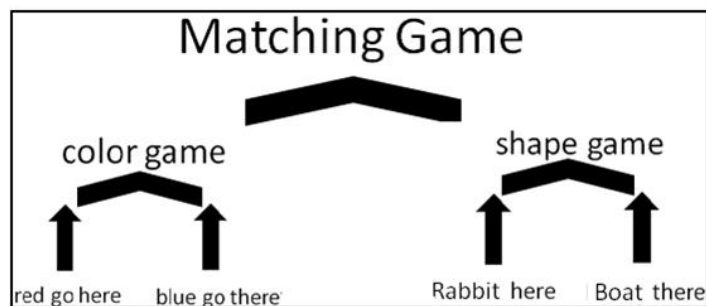

Fig 3

With this layout in mind, CCC theory focuses on embedded rules within a particular rule system. For example, the rules "if red go here, if blue go there" are embedded within the higher order rule pertaining to the "color game". CCC theory depicts how age-related changes occur and a particular level of complexity can be mentally represented. For example, children 3 years of age cannot switch between the higher order rules "color game" and "shape game", resulting in a weak degree of reasoning and control over their thinking and behavior; causing perseveration on the DCCS (Zelazo et al., 2003). In contrast, 4 year olds are able to switch between these rule branches because with age comes an increasing degree of maximum complexity, allowing greater cognitive flexibility and success on the DCCS.

Another possible explanation for children's performance on the DCCS task is linked to their working memory and not the complexity or levels of embedded rules. Working memory in this context is referred to as, "simultaneous manipulation and maintenance of a representation"; so not only is working memory used for holding information in an individual's attention, but it also generates future courses of action with given information (Zelazo et al., 2003). Lesion studies examining patients who have had their prefrontal cortex damaged demonstrates short-term storage of information depends heavily on this area (Zelazo et al., 2003). Several theories have linked the development of executive function to the growth of short-term and working memory, which in turn is seen by the maturation of the prefrontal cortex (Zelazo et al., 2003). The most prominent of these memory accounts is proposed by Morton and Munakata (2002) who examined the role of the prefrontal cortex while assessing

active memory vs latent memory traces. A neural network approach was used to study how learning occurs in a computer model, which showed the strength of connections increases with experience (Morton & Munakata, 2002). Morton and Munakata concluded that even though knowledge of the sorting dimension was present in their neural models, the knowledge was insufficiently strong to overcome latent biases. In other words, the preswitch rule that had become a latent memory trace was still too strong to be overcome by the new active memory, or postswitch sorting rules. Since the prefrontal cortex is not as developed in 3 year olds, they lack the working memory strength to manipulate the active rule over the biases of the latent rule (Morton and Munakata, 2002). Morton and Munakata also concluded that latent memory traces are formed in the developed posterior cortex, which would explain why it is strong enough to overcome the active memory traces in the underdeveloped prefrontal cortex. According to this model, age-related changes in performance on the DCCS are the result of strengthening active memory and inhibitory control, which promotes success on the DCCS (Morton and Munakata, 2002).

Attentional inertia is also a prominent theory describing children's performance on the DCCS. Attentional inertia is related to a child's ability to mentally inhibit features of a given object and suppressing behavior (Kirkham, Cruess, & Diamond., 2003). Research suggest that inhibitory mechanisms develop in a parallel manner with the prefrontal cortex, which is involved in control over planning complex cognitive behaviors, moderating correct social behavior, decision making and personality expression (Zelazo et al., 2003). With relation to the DCCS, 3 year olds may be aware of the postswitch rules but cannot restrain the preswitch responses due to an immature inhibition mechanism (Zelazo et al., 2003). According to this model, it is not a problem for children to think of an object as both blue and also a boat, but rather they show great difficulty switching their cognition from thinking of that blue boat in terms only it's shape and matching it with the target red boat card (as in the "shape" game) (Kirkham et al., 2003). This theory holds that younger children clearly understand the postswitch rules, as shown by knowledge questions; they just cannot disengage from the previous mindset (Kirkham et al., 2003). Researchers believe if the second dimension were made more salient, meaning more obvious or tending to jump out to one's attention, the inhibition may be overcome by the new dimension, reducing perseveration (Kirkham et al., 2003). This theory challenges CCC theory with data that was found when testing adults. A computerized version of the DCCS task was given to adults, who were very accurate but showed a slowed reaction time when sorting by dimension 2 compared to dimension 1 (Kirkham et al., 2003). According

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to CCC theory, adults should be equally fast on each trial because they are fully developed and can hold more than enough embedded rules for the task. These findings are consistent with inertia theories because even though adults successfully disentangle dimension 1 from dimension 2, the effort of inhibition is seen as the cost of slower reaction time (Kirkham et al., 2003).

Redescription theories also give a possible account for the growth of executive function. This set of theories is based on the idea that young children have a difficult time on the DCCS task due to a lack of understanding perspectives (Zelazo et al., 2003). Redescription accounts hold that children lack the concepts to form two different and simultaneous perspectives of the same stimuli, as is needed to complete the DCCS (Zelazo et al., 2003). For example, in the preswitch phase the red rabbit card is described as the "red one" while later in the postswitch phase it is described as a "rabbit". Redescription theories hold that younger children fail to understand how two labels can be applied to the same object, a problem that is solved later in development (Zelazo et al., 2003). As previously stated, knowledge questions have been used to access whether or not children understand the rules, which they do. Redescription theories state that only some 3 year olds understand a single stimulus can contain 2 dimensions (color and shape) but that this understanding happens for a majority of children at 4 years of age (Zelazo et al., 2003). These theories state that around the age of 4, children begin to understand the concept of perspectives and realize the view of a single stimulus can change between multiple dimensions, thus producing success on the DCCS (Zelazo et al., 2003).

The last prominent line of thought about young children's performance on the DCCS is the development of an inhibition mechanism. This view holds that children who perseverate on the second half of the task do so because of a lack inhibitory control, or a mechanism that actually suppresses behavior (Zelazo et al., 2003). Inhibition ability parallels the growth of the prefrontal cortex, which in terms of the DCCS develops around the age of 4 (Zelazo et al., 2003). One way to think of this account is as a lack of response control, or children fail to suppress overlearned responses (in this case the preswitch rules) despite being told new rules (postswitch rules) (Zelazo et al., 2003). Summarized by Zelazo (2003), Carlson and Moses suggest children who fail the DCCS do so because of an action schema they have acquired during the preswitch phase. These children fail according to Carlson and Moses because they cannot inhibit this action schema during the postswitch phase (Zelazo et al., 2003). This account is similar to the previously discussed theory of attentional inertia, but differs due to the fact that the idea of perspectives is not what is being developed.

Inhibition mechanism theories stress the development of a child's ability to physically control their response, regardless of whether or not the stimulus is seen from two differing viewpoints (Kirkham et al., 2003).

Our task is to examine where children, ages 3 and 4, are looking when presented with the DCCS task. We feel examining looking patterns will help shed light on the differences between those who pass the task and those that do not. By examining looking patterns we will not only shed light on what information children are using during this task, but also where an their visual attention is focused. We hypothesize that children who fail the DCCS will have trouble inhibiting their visual attention away from irrelevant features of the stimuli; or non-relevant sorting dimensions. We also hypothesize that 4 year olds will be able to allocate their gaze more efficiently than 3 year olds by attending to the relevant sorting dimensions in greater proportion. We believe, based on previous research, that situations of conflict create difficulty for children in the original DCCS, as the stimuli posses both sorting dimensions in the same physical space (Kirkham et al., 2003). We believe this will help elucidate why children pass knowledge questions pertaining to the sorting rules but fail behavioral responses under conditions of conflict. We will test these hypotheses with a modified version of the original DCCS. Our modified version will contain the same basic structure as the original in terms of rule sorting and instructions, but will differ by physically separating the matching dimensions. We will also add irrelevant information to the sorting stimuli, creating varying conditions of conflict. By creating conditions of conflict, inhibition of visual attention will be seen as children are forced to look away from irrelevant information and towards relevant sorting dimensions.

Methods

Overview

We administered two conditions of our modified DCCS task. Condition 1 consisted of a supportive condition phase in the preswitch and a conflict phase in the postswitch. Condition 2 consisted of the conflict phase in the preswitch and a supportive phase in the postswitch.

Task and Materials

As stated above, we added conflicting information and spatially separated our sorting dimensions. We chose to use two neutrally irrelevant stimuli that were rated by psychology 100 REP students as being saliently different (a bird and a table). We chose to place the sorting dimensions above and

below these irrelevant stimuli. Also, the irrelevant stimuli either created a supportive phase, where the irrelevant information in the test stimuli matched the irrelevant stimuli in the target cards or a conflict phase, where the irrelevant information in the test stimuli was in conflict with the irrelevant information in the target stimuli. We also extended our testing trials, preswitch and postswitch, to 20 trials per phase. We created more trials to increase the reliability of the Tobii Eye Tracker, our logic being 20 preswitch and 20 postswitch trials will provide more eye tracking data compared to only 5 preswitch and 5 postswitch trials. An example slide of our stimuli can be seen below in figures 4a and 4b.

Fig 4a Modified Version of the DCCS for Eye Tracker, Supportive phase: This is an example of the supportive phase, where children were asked to sort the circle above the irrelevant information according to color (blue circle with blue circle and red circle with red circle). This creates a condition that is supportive because the irrelevant information is also matching along with the sorting dimension (bird with bird and table with table).
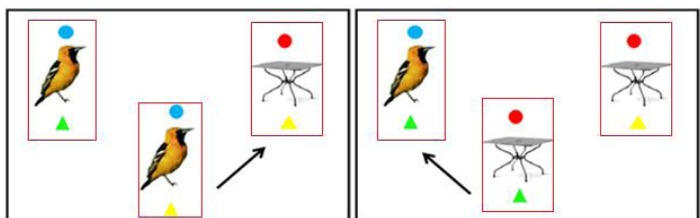
Fig 4b Modified Version of the DCCS for Eye Tracker, Conflict phase: This is an example of the conflict phase, where children are asked to sort the triangle below the irrelevant information according to color (green triangle with green triangle and yellow triangle with yellow triangle). This creates a condition of conflict because the irrelevant information does not match the sorting dimension (bird with table and table with bird).

Participants

A total of 73 children participated in this experiment. 38 children 3 years old (20 males, 18 females; M = 3.53 years of age, range = 3.05 - 3.99 years) and 35 children 4 years old (18 males, 17 females; M = 4.43 years of age, range = 4.06 - 4.89 years). Children were recruited from a database of signed permission slips sent out to local Columbus Ohio area preschools. On each permission slip parents indicated whether or not they would be willing to travel to the Ohio State Campus to participate in a short study. Informed consent was obtained from all parents of all children who took part in the study. Children were omitted either because of unwillingness to play the game or lack of sufficient eye tracking data (under 75% of trials). These conditions for omission usually occurred due to a child's inability sit still for a majority of the trials. A total of 12 children were omitted (9 three year olds and 3 four year olds) leaving a total of 29 useable 3 year olds and 32 useable 4 year olds (61 total).

Procedures

Procedures common to all conditions: Each child was tested individually at the Cognitive Development Lab at Ohio State in a quiet room containing the Tobii eye tracking machine. Each testing session lasted approximately 10-12 minutes. Once the child was comfortable with the experimenter he/she was seated on a high chair approximately 60-70cm in front of the Tobii eye tracker, with his/her parent sitting about 5 feet away in a chair. Once the child was settled facing the eye tracking monitor, calibration would begin. The child would follow either a kitty cat or a red dot bouncing around the screen. Once all areas of the screen were reading good calibration the experiment would begin. Instructions would be on the screen, the experimenter would then pull up a chair and read the prompts to the child and explain the game. The experimenter would start by saying:
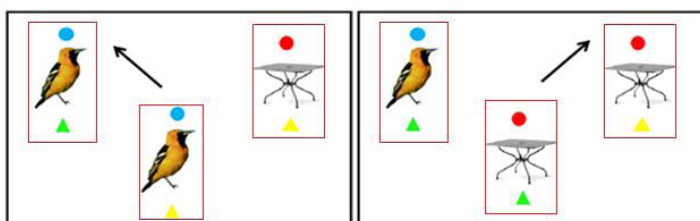
We're going to play a matching game now. We are going to start by either playing the circle (or triangle) game, the experimenter would be referencing an example screen and pointing out the circles or triangles. Participants would then be asked if they knew what either a circle or triangle is and the colors in the game. We are going to see three objects on screen, the experimenter would then point to three boxes around the three pairs of stimuli. Our job is to look at the one in the middle. If it has a blue circle above it, it goes here (the experimenter would point to the matching circle) but if it has a red circle above it, it goes here (the experimenter would point to the matching circle). Okay? Instructions were repeated if the child was confused. Before the first trail appeared a blank screen was presented and the experimenter would remind the child that they were playing either the circle game or the triangle game. The first trial would then appear and the experimenter would ask, "where does this one go?" The child would select and the experimenter would advance the trial as soon as possible to avoid extra looking data and then mark down whether the child indicated left or right.

During this time children were not given feedback on

their performance, but were reminded of the sorting rules between each trial. Special care was taken to ensure the experimenter never mentioned the irrelevant information (either the bird or the table). After repeating this procedure for the first 20 trials then the rule change would occur and the experimenter would say:

Okay, you're doing such a great job (regardless of performance) now the computer is going to change the rules on you. Now instead of playing the circle (or triangle) game, we are going to play the triangle (or circle) game. Again an example screen would be showing during this time and the experimenter would be pointing to the triangles (or circles). Now, instead of matching circles (or triangles) we are going to match triangles (or circles). If the triangle on the bottom is green, it goes here (experimenter would point to matching triangle, but if the triangle on the bottom is yellow it goes here (experimenter would point to matching triangle). Okay? Instructions were repeated if the child showed confusion. Before the first trial appeared a blank screen was presented and the experimenter would remind the child that they were playing either the triangle game or the circle game. The first trial would then appear and the experimenter would ask, "where does this one go?" The child would select and the experimenter would advance the trial as soon as possible to avoid extra looking data and then mark down whether the child indicated left or right.

As in the preswitch phase, children in the postswitch were not given feedback on their performace and were reminded of the sorting rules between each trial. Children were considered to have passed a given phase by scoring an 80% or higher (16 out of 20 trials correct). The experimenter recoded the child's responses on a separate sheet of paper after advancing each trail, accuracy was checked after the study was complete.

Results

As stated above, passing a given phase meant correctly answering 80% of the trials (16/20) or higher. We will first compare behavioral data for the Supportive-Conflict (supportive preswitch and conflict postswitch) condition and then the Conflict-Supportive (conflict preswitch and supportive postswitch) condition before discussing eye tracking data. Results partly replicate Zelazo's original findings, with 3 and 4 year olds passing the preswitch phase and 3 year olds on average performing under 80% on the postswitch phase. A graph can be seen below in figure 5

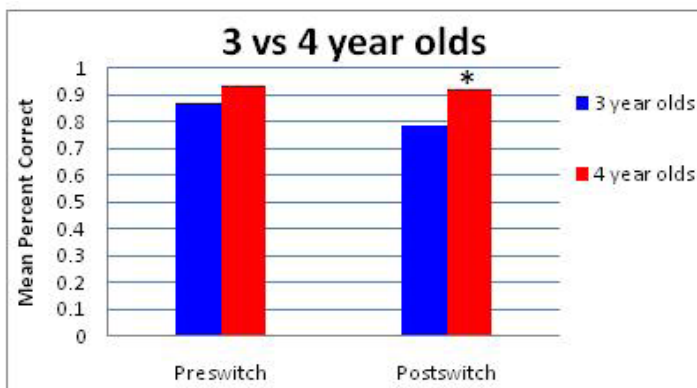showing mean percent correct for each age group by phase, regardless of supportive or conflict condition.

Fig 5 This figure shows mean percent correct by age group and phase. Results replicate Zelazo's original findings with 3 and 4 year olds passing the preswitch, but 3 year olds (on average) failing the postswitch.

Analysis of variance (ANOVA) was the statistical test used to access significance. The average difference in preswitch between age groups was not significant, however the postswitch differences were, with children under 4 years of age on average scoring under 80%. Even though the average percent correct for 3 year olds was under 80% (failing), only 31% truly perseverated on the postswitch phase of the task (9/29 children) this is still higher than the perseveration rate of 4 year olds, 9% or 3/32 children. This shows us that our version of the task was inherently easier than Zelazo's original. We will go into some possible explanations for why this could be in the discussion section of the paper. Children of all ages did better in the supportive phase, regardless of whether or not it came first (93% average supportive phase score vs 80% average conflict phase score). Conflict phases however presented difficulty for 3 year olds. It is worth noting that 47% of 3 year olds failed the conflict phase when it was presented first, compared to just 12.5% of 4 year olds. Right away this tells us 3 year olds have more difficulty behaviorally producing correct responses under conditions of conflict. We will examine looking data next to see if there is a significant difference between age and supportive or conflict phases.

To quantify looking data we first obtained an optimization score for each trial. This optimization score ranges from -1 to 1 and takes into account the relative number and size of the irrelevant information compared to the relevant information on the screen, equally penalizing a child for looking at irrelevant information and rewarding a child for looking at relevant information. A score of -1 meant the child was looking at nothing but irrelevant information (bird and table) on that trail and a score of 1 meant the child looked at nothing but relevant information (sorting dimension) on that

trial. This formula can be seen below in figure 6.

$$\frac{((T_r/(N_r * Area_r)) - (T_i / (N_i * Area_i)))}{((T_r + T_i) / ((N_i * Area_i) + N_r * Area_r))}$$

Fig 6: Tr = Total number of relevant stimuli on screen
    Nr * Area r = number of relevant stimuli on screen times
      their size in pixels
    Ti = Total number of irrelevant stimuli on screen
    Ni * Area i = number of irrelevant stimuli on screen times
      their size in pixels
    Ti = Total number of irrelevant stimuli on screen

With optimization scores obtained for each trial across children, we combined them to result in an average optimization score for each trial. For example, we have an average optimization score on trail 14 for both 3 and 4 year olds, allowing us to compare the age groups directly as the task progresses. A univariate one way ANOVA was used to compare optimization scores between groups. What we found was optimization scores differed significantly between supportive and conflict phase, regardless of age and which came first $F(1,118) = 23.86$, $p < .001$. A graph of this data can be seen below in figure 7 comparing the average optimization score for all children in either supportive or conflict phases.
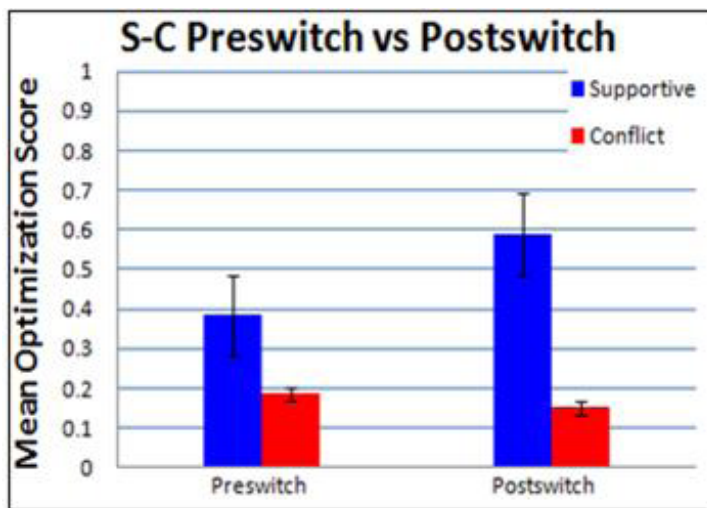

Fig 7 <u>Supportive-Conflict Preswitch vs Postswitch</u>: As the graph shows, there are significant differences in looking at relevant (closer to 1) vs irrelevant information (closer to 0) between supportive and conflict phases, regardless of which came first. It is also interesting to note that the supportive phase (blue bars) are identical trials, however children did better (regardless of age) when these trials came in the postswitch phase as opposed to the preswitch phase.

We also compared optimization scores within age groups. For example, did 3 year olds optimize their gaze to a higher degree in postswitch as opposed to preswitch? The answer is yes. 3 year olds showed higher optimization

of gaze (looking towards relevant information to a greater degree) in postswitch over preswitch $F(1, 54) = 6.15$, $p < 0.016$. Children 4 years of age showed a similar pattern but to a greater degree, meaning they obtained higher optimization scores in the postswitch phase, $F(1,60) = 24.20$, $p < 0.000$. Another finding was that 4 year olds obtained significantly higher optimization scores than 3 year olds in supportive phases $F(1,118) = 23.86$, $p < .001$. However, when comparing the two age groups in conflict phases, the results were flat. This is important to note since as previously discussed 3 year olds failed the conflict phase 47% of the time when it was presented first, compared to 4 year olds who only failed it 12.5% of the time, this will be examined further in the discussion section. A graph of these findings can be seen below in figure 8. This graph illustrates that 4 year olds out performed 3 year olds (by looking to relevant information more frequently) in supportive phases. However, both had trouble optimizing their gazes during conflict phases.
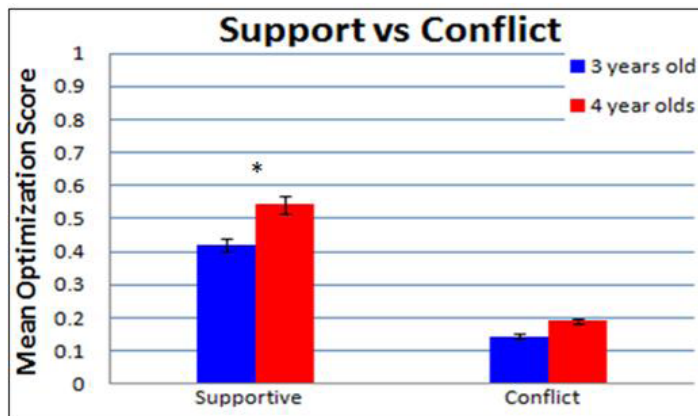

Fig 8 <u>Supportive-Conflict by age</u>: As the graph shows, there is a significant difference between looking patterns in the supportive phase, with 4 year olds looking at relevant information to a higher degree than 3 year olds. However, this difference is not seen by optimization scores in the conflict phase which is relatively flat.

Lastly, we compared optimization scores between those that failed and those that passed a given phase, regardless of whether or not it was supportive of conflicting. We first gathered optimization scores by trail for those who passed and averaged them together, repeating this for those who failed. Next, we smoothed the data by averaging every 3 trials together, making patterns apparent and the data less noisy. Significant differences were apparent $F(1,118) = 25.29$, $p < 0.000$. A graph of this data can be seen in figures 9.

Discussion

Behavioral Data: As previously stated, average percent correct for 3 year olds was below passing. Although, only roughly 30% of 3 year olds perseverated compared to 9% of
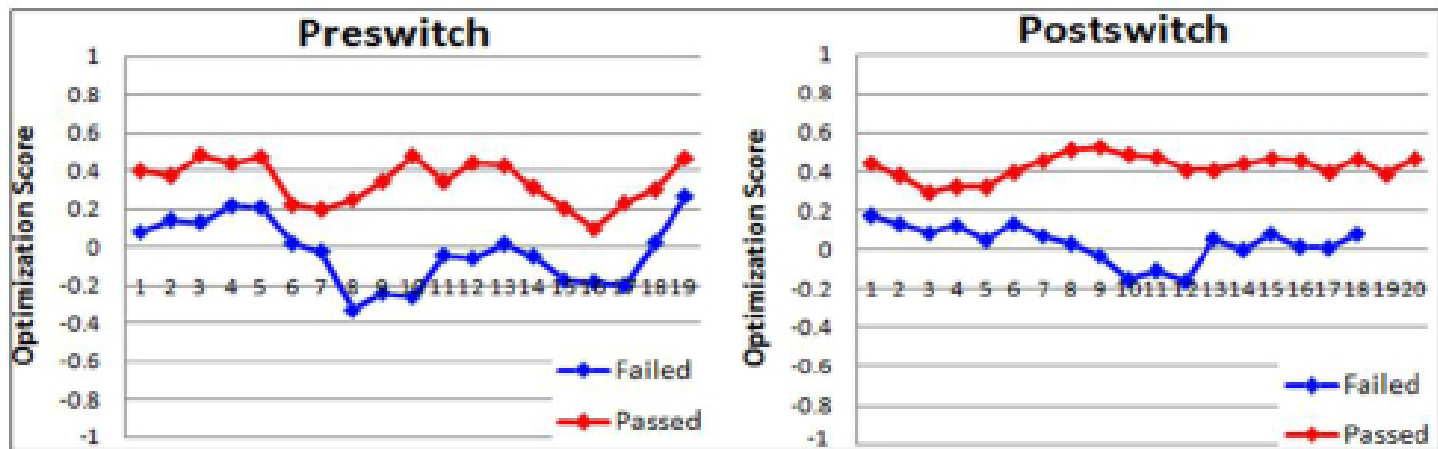
Fig 9 <u>Children who failed vs Children who passed</u>: It is apparent that those who failed (Blue) consistently had a lower optimization score than those who passed (Red). Showing even as time went on, those who failed consistently looked at irrelevant information over relevant information. This is regardless of supportive or conflict phases and age.

4 years olds, we feel the task imitates the original to DCCS to a great enough degree. We feel not as many children perseverated due to the fact that the sorting dimensions were spatially separated, which may have made the task inherently easier than the original, where sorting dimensions are located in the same stimuli. Also, one aspect that may have contributed to younger children not perseverating to as great a degree compared to the original is the number of trials. It could be that given 20 postswitch trials, young children heard the rules enough to prevent a proportion of them from perseverating. On average, children in the supportive phase did better (93% correct) than those in the conflict phase (80%). One particular interesting finding is that 47% of 3 year olds failed the conflict phase when it was presented first, even before any rule switch was made. These 47% then went on to perform much better in the postswitch supportive phase, despite the rule switch, which should hamper their performance. Optimization scores helped illuminate why this is.

Looking Data

Optimization scores help elucidate the findings by showing us how efficiently children were controlling their gaze towards what was relevant on each trial. By comparing looking data with behavioral data, children performed better in supportive phases across the board (93% correct on supportive vs 80% correct on conflict), the looking data supports this by showing significant differences in optimization between supportive and conflict phases. As seen by the graph in figure 7, children in the supportive condition were able to better control their gaze, and in turn their visual attention, to relevant dimensions of the sorting task. As predicted, children 4 years of age were better at optimizing their gaze towards relevant dimensions of the stimuli (figure 8). However, the looking data between the

two age groups is almost identical in the conflict phase, yet 3 year olds failed 47% of the time when presented first as opposed to 12.5% by 4 year olds. Looking data can offer a possible explanation to the discrepancies between optimized looking and performance on conflict phases. For example, 3 year olds had bad optimization during conflict phases, which was predictive of their failure. However, 4 year olds also had poor optimization, but it was not predictive of failure. One possible explanation could be that 4 year olds were able to overcome their visual attention to irrelevant stimuli and still select the correct answer, even though they were looking at the wrong parts of the stimuli. 3 year olds on the other hand were not able to overcome their visual attention and failed conflict phases at a much higher rate (47% vs 12.5%). We believe this suggests that under conditions of conflict, children have trouble inhibiting their attention away from irrelevant stimuli and towards the task at hand. These findings support Kirkham et al., (2003), who stated inhibition control is lacking in those who fail the DCCS. Since 4 year olds were better at controlling their behavioral responses, regardless of where they were looking, they succeeded to a much higher degree. On the other hand, because the supportive phase required less inhibition of irrelevant stimuli, as seen in figure 8, children of all ages did a much better job of efficiently allocating their gaze. Optimization scores, as seen in figure 9 were actually predictive of a child's performance. If the child was having difficulty (optimization scores under 0.2) we could accurately predict an unsuccessful attempt on our modified version of the DCCS. As predicted, children who failed our version of the DCCS had trouble inhibiting their visual attention away from irrelevant information on a given trial. This is very important, since we did not change the actual number of embedded rules or their structure, Zelazo's CCC theory cannot explain these findings. The number of rules and their complexity were consistent with Zelazo's original, the factor that predicted success was gaze control.

We however did not manipulate gaze patterns (training the child where to look) so we cannot say poor optimization caused failure, but it was predictive. Even though a child's understanding of complex rules develops with age, these results show that the number of embedded rules on the DCCS task may not be the only determining factor describing children's performance, visual attention must be taken into account. Looking data can provide no evidence either supporting or refuting redescription theories. However, active vs latent memory traces can be addressed. There is no way to tell with looking data alone whether or not the active memory was strong enough to overcome the latent memory trace, but we can speculate that at least for those who failed, working memory may not be strong enough to control their visual attention towards relevant dimensions of the sort task.

Conclusion

Children who failed our modified version of the DCCS were unable to effectively focus their visual attention to relevant sorting dimensions. Even though 3 year olds did not perseverate at the same high rate as Zelazo's original DCCS, they still perseverated more than 4 year olds. Also, 3 year olds obtained a lower correct performance average than 4 year olds. Poor looking time was predictive of failure, with those failing looking more at irrelevant information. Since we did not manipulate gaze via experimental methods we can only point out correlations. Conflicting information also played an important part, as nearly half of the 3 year olds failed preswitch when conflict was present before any rule switch was made. CCC theory cannot account for these results since the number of embedded rules was held constant. Inhibition accounts are supported by saying those who passed were able to control their gaze towards relevant sorting dimensions. More research is needed to establish if visual attention is actually why children fail the DCCS or merely a byproduct of something else.

Acknowledgements

ARTS & HUMANITIES

References

[1] Kirkham, N. Z., Cruess, L., & Diamond, A., (2003). Helping Children Apply their Knowledge to their Behavior on a Dimension-switching Task. *Developmental Science*, 6, (5), 449-476.

[2] Morton, B.J., & Munakata, Y., (2003). Active Versus Latent Representations: A Neural Network Model of Perseveration, Dissociation, and Declage. *Developmental Psychobiology*, 40, (3), 255-265.

[3] Wang, L., Kakigi, R., & Hoshiyama, M., (2001). Neural activities during Wisconsin Card Sorting Test — MEG observation. *Cognitive Brain Research*, 12, 19–31.

[4] Zelazo, P.D., Müller, U., Frye, D., & Marcovitch, S., (2003). The development of executive function: Cognitive complexity and control--revised. *Monographs of the Society for Research in Child Development,* 68, (3), 1-119.