BEHAVIORAL INDICES OF COGNITIVE PROCESSING IN CHILDREN

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DEDICATION

This thesis is dedicated to my husband, Michael. I can do anything if I have you.
ABSTRACT OF THE THESIS

Behavioral Indices of Cognitive Processing in Children
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For students, problem-solving is a critical aspect of the learning process. The cognitive processes involved in problem-solving, for example those that allow for planning, organization and execution of goal-directed behaviors are thought to be managed by Executive Function (EF). Previous studies on EF and problem-solving have mainly focused on how students internally represent a problem and the step-by-step processes a student uses to find a solution; however, such studies characterize cognition as an internal process. A more recent perspective on cognition suggests that it is not entirely an internal system, but rather a distributed system that involves the coordination of embodied information, environment and time. For example, studies of adults and older school-age children suggest that communicative behaviors (e.g., eye gaze and facial expression) reflect cognitive processes. However, such studies have mainly focused on older children and adults so it is unknown how nonverbal behaviors reflect cognitive processes in younger school-age children. Thus, the present study aimed to characterize how children use nonverbal behaviors (i.e., eye gaze and facial expression) in problem-solving contexts. Participants were 40 children (ages 3-4yrs and 7-8yrs) and 20 adults (ages 19-33). Two visuo-spatial tasks were utilized to investigate eye gaze patterns and facial expression production: Task (1) Mystery box—examined visual imagery skills and Task (2) Safari puzzle—examined spatial skills. The results suggest that eye gaze patterns vary according to development and the level of cognitive effort that is required to solve a problem. During low cognitive effort, younger children were more likely to make eye contact with the experimenter, while older children and adults showed similar gaze aversion patterns while thinking. However, with increased cognitive effort older children showed gaze patterns similar to younger children; whereas, eye gaze patterns in adults did not vary in these contexts. Furthermore, the data suggest that there are developmental trends in the production of facial expression. With increased cognitive effort, production of facial expressions in female participants increased with age; whereas, the production of facial expression in male participants remains steady over age. Moreover, these results suggest that display rules regarding facial expressions vary according to development and gender, such that female adults and children produced more positive facial expressions than male adults and children. Such findings confirm the role of social interaction in learning and have significant educational implications, particularly in classroom settings where teachers frequently depend on non-verbal cues to evaluate children’s attention and comprehension. The results also provide a foundation for future research in atypical populations.
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CHAPTER 1

INTRODUCTION

For students, problem-solving is a critical aspect of the learning process. The cognitive processes involved in problem solving (e.g., planning, organizing) are thought to be mediated by Executive Function control (EF). Previous studies on EF and problem-solving have mainly focused on children’s responses or answers as a window into their cognitive processes. However more recent perspectives on cognitive processing in adults and older children suggest that nonverbal behaviors (e.g., eye gaze and facial expression) used while problem-solving may also be reflective of cognitive processes (Whitehill, Bartlett, & Movellan, 2008). Such studies however have mainly focused on infants, older children and adults so it is unclear how nonverbal behaviors reflect cognitive processes in younger school-age children. By characterizing the development and use of nonverbal behaviors in problem-solving contexts we can better understand children’s problem-solving processes and also provide a foundation for future research with atypical populations.

COGNITIVE PROCESSING AND ITS ROLE IN PROBLEM-SOLVING

Problem-solving is the process “by which any goal-directed sequence of cognitive operations” is performed to solve a problem (Anderson, Greeno, Kline, & Neves, 1980; Jonassen, 2000). The cognitive processes that allow for successful planning, organization and execution of goal directed behavior are thought to be managed by Executive Function (EF) (Diamond, 2006; Zelazo, Muller, Frye, & Marcovitch, 2003). Studies on EF focus on three main cognitive processes: (1) Inhibition: the ability resist automatic responses to stimuli; (2) Working memory: the ability to hold multiple information in the mind and manipulate the information; and (3) Cognitive flexibility: the ability to take dual perspectives.

Previous research on EF and problem-solving has mainly focused on two aspects: (1) how a person represents a problem; and (2) the step-by-step processes a person uses to solve a problem. Problem representation is assumed to be an internal process and is defined as person’s internal understanding of the problem, the goal, and the necessary steps to solve the
problem (Novick & Bassok, 2005). For example, Novick and Hmelo (1994) were interested in how people internally represent word problems and if their representation affects how they problem-solve. In their study, college students were asked to show how they interpreted word problems. For example,

Two train stations are fifty miles apart. At 2 p.m. one Saturday afternoon two trains start toward each other, one from each station. Just as the trains pull out of the stations, a bird springs into the air in front of the first train and flies ahead to the front of the second train. When the bird reaches the second train it turns back and flies toward the first train. The bird continues to do this until the trains meet. If both trains travel at the rate of twenty-five miles per hour and the bird flies at a hundred miles per hour, how many miles will the bird have flown before the trains meet?

Results suggest that the ability to see multiple representations of a problem affects how it is solved. For example, from the train and bird problem above, participants who focused only the distance that bird flew had a more difficult time solving the problem than participants who focused on the speed and distance of the trains to find the answer.

Other studies emphasized the importance of understanding a problem-solver’s behavior in finding step-by-step solutions. For example, when adults are given problems with multiple possible solutions, such as in word anagrams (e.g. the letters uspry) adults will use heuristics to find the correct answer, such as, considering letter pairs that commonly begin words with the given letters (the answer is syrup) (Novick & Sherman, 2004; Ronning, 1965). The overall results suggest that adults are capable of holding multiple bits of information in their minds and manipulating the information in order to find the correct answer. However, adult performance on such tasks may not be reflective of children’s performance on similar tasks. Studies of adults with frontal lobe damage suggest that EF is mediated by the prefrontal cortex, an area of the brain that does not fully develop until young adulthood (Jacobs & Anderson, 2002). Since the prefrontal cortex is the last brain region to fully develop, it is important to consider the effects development on executive function in children.

**Cognitive Development in Children**

Piaget viewed the development of cognition as dependent on the changing child and her environment. He hypothesized that development moves through four stages: (1) Sensorimotor ("thinking" by interacting with the world through the senses); (2)
Preoperational (use of symbols to represent sensorimotor information); (3) Concrete operational (reasoning becomes logical); and (4) Formal operational (capacity for abstract & systematic thinking) (Berk, 2007; Piaget, 1985). Of particular interest to the present study are the preoperational and concrete operational stages, which are thought to occur between the ages 2-7 years and 7-11 years, respectively.

Between ages 3-5 years, performance on inhibition and cognitive flexibility tasks improves dramatically (Diamond, 2006). By three-years of age, children are able to participate in symbolic play, and language is becoming a part of their communicative repertoire. However, one critical aspect that three year-olds lack in their thinking skills, as compared to older children in the concrete operational stage, is that older children are able to view a situation from multiple perspectives whereas three year-olds cannot. For example, a seven-year-old can understand that a person can be both a teacher and a father and a husband at the same time. As indicated from previous studies on adults, the ability to take multiple perspectives on a situation is an important cognitive ability in problem-solving. By school-age (5-11 years) children show marked improvements in working memory, cognitive flexibility and inhibition tasks. For example, a classic test of cognitive flexibility is the Wisconsin Card Sort Task (WCST) (Crone, Ridderinkhof, Worm, Somsen, & Molen, 2004; Diamond, 2006). The task requires participants to sort cards according to color, shape or number on the basis of feedback from the experimenter, and after a number of correct consecutive sorts, sorting rules are shifted without warning. Crone et al. (2004) compared typically developing children and adults performances on the WCST (ages 8-25). Participant’s errors were scored as either performance error (the participant could not sort according the correct criteria) or distraction error (the participant was unable to keep up with the current criteria). Results showed that by age 8, children’s performance was comparable to adults; however, in regards to distraction errors, adult-like performance was only seen in children 13 years and up. This suggests that for some aspects, school age children’s EF abilities are similar to adult problem-solving behaviors, but not all.

While previous EF studies have been important in understanding how adults and children generate solutions to problems, such studies characterize cognition as a uniquely internal process. In doing so, such research has assumed that the “human mind, is much like a computer, processing symbols” into meaningful units that a person can then use to solve a
problem (Newell, 1980). Accepting this view of the human mind ignores the social factors that make human cognition a distributed system. More recent perspectives on cognition proposes that cognition is extended into the social framework in which it occurs. (Clark, 2008; Hutchins, 2000).

While Vygotsky also viewed the development of cognition as dependent on the developing child and her environment, he saw development as the result of social interaction between the child and her social environment. In Vygotsky’s theory of social development, the child learns first on a social plane, specifically in the context of social interaction with adults or more experienced individuals, and then knowledge is internalized and becomes part of the child’s repertoire (Elbers, Maier, Hoekstra, & Hoogsteder, 1992; Vygotsky, 1978). One concept of Vygotsky’s theory of social development is the zone of proximal development. The notion is that when a child is not able to do a task on her own, the adult scaffolds the child’s learning. What a child can and cannot achieve with the help of an adult is indicative of her cognitive abilities (Wertsch, 1979). The difference between what the child can do independently and within a social context is the “Zone of Proximal Development”. As the child develops skills, learned from the adult, the adult decreases the amount of scaffolding until the child can perform the task independently. In this view, the child acquires necessary problem-solving behaviors through interaction with an adult and eventually internalizes the information. She can then use such skills in subsequent problem-solving contexts independently. For Vygotsky, interaction is critical in the development of cognition. A more recent elaboration of how cognition is more than an internal process comes from those supporting cognition as a distributed process that involves the coordination of embodied information, environment and time.

**DISTRIBUTED COGNITION**

According to the view of Hutchins (2000), cognition can be distributed in three ways: (1) across members of a group, (2) through the coordination of embodied information (e.g., sensory information) and the environment (e.g., tools), and (3) across time. For example, a student learning to solve a math problem may write the equation using pencil and paper. During this action, the student has a question about the equation and asks her teacher for clarification. She then continues to solve the equation after getting additional help. Previous
research on problem-solving would ignore the interaction that the student had with her teacher as well as her use of tools (pencil and paper). However, proponents of distributed cognition view the teacher-student interaction and the student’s use of tools as integral components of the cognitive processes used to solve the equation: they are extensions of the student’s cognition (Clark, 2008; Hutchins, 2000). Since a large part of distributed cognition emphasizes the interaction between embodied information and the environment, for our purposes, it is important to understand how this interaction might change with the child’s cognitive development.

**SOCIAL INTERACTION AND PROBLEM-SOLVING**

While previous research has focused on the role of children as individual problem-solvers, a few studies have highlighted the adult-child dyad as a problem-solving unit. Mosier and Rogoff (1994) studied early social interaction and problem solving behaviors in 64 mother-infant dyads (ages 6 months to 13 months). Mother-infant pairs were recorded during structured play (mothers followed a guided script) and unstructured playtime with familiar and novel toys. Results showed that during scripted play when mothers were not allowed to give their infants the toy, infants at 6 months started to use nonverbal behaviors such as eye gaze (e.g., looking at the toy), gestures (e.g., moving mother’s hand towards the toy) and positive facial expressions (e.g., smiles) to encourage their mother to give them a toy. The use of nonverbal behaviors to engage the mother in interaction dramatically increased from ages 6 months to 13 months. These results suggest that at an early age infants begin to be actively involved in interactions and problem solving contexts (Mosier & Rogoff, 1994). However, little is known about how school-age children use nonverbal behaviors to regulate social interactions.

A study by Wertsch, McNamee, McLane and Budwig (1980) observed problem-solving behaviors (specifically, the occurrence of self-regulation behaviors) during an adult-child dyad. Eighteen mother-child dyads (children were ages 2-4 years) were asked to participate in a mother-child interaction study. Each dyad was presented with pieces of a puzzle and a model to recreate. Mothers were instructed to assist their child if they needed help. Self-regulation was measured by the frequency of gazes that the child made to reference the model in order to correctly complete the puzzle, and other-regulation was
measured by frequency of the mother’s attempts (i.e., verbal instruction, pointing, or gazing at the correct puzzle piece) to help their child. Results showed that mothers of younger children were more likely to regulate their child’s behavior by directing their child’s gaze to the model than did mothers of older children. This suggests that behaviors, such as eye gaze, can play an important role in the interactional problem-solving process.

**COMMUNICATIVE CHANNELS**

During face-to-face interaction, the face and the body are crucial communicative tools for relaying a person’s affective or cognitive state (e.g., making eye contact with another person suggests that they have your attention). Previous research on communicative channels suggest that there are developmental differences in how each channel is used for communicating cognitive states and perceiving affective states. For the purpose of this study we are focusing on how children use eye gaze and facial expression while problem-solving.

**EYE GAZE**

Previous research has suggested that eye gaze can be an indicator of cognitive processing in adults and children (Doherty-Sneddon, Bruce, Bonner, Longbotham, & Doyle, 2002; Glenberg, Schroeder, & Robertson, 1998). During tasks that require high cognitive effort, such as answering a difficult question, studies have shown that adults and children may avert their gaze from the interlocutor’s face. While some may argue that the face itself requires high cognitive effort to process and would therefore prompt gaze aversion, Glenberg et al. (1998) found similar gaze aversion behaviors in adults when they were asked to recall answers to general knowledge questions and arithmetic problems presented on a computer screen. Overall results suggest that during the thinking process, gaze is averted from the stimuli (whether it be a person’s face or the external environment) to decrease cognitive load and increase concentration. These results prompted researchers to investigate how these eye gaze behaviors develop and if there are developmental differences in how gaze aversion is used in children.

Doherty-Sneddon et al. (2002) and Doherty-Sneddon and Phelps (2005, 2007) studied the development of gaze aversion in typically developing school-age children (ages 5 and 8 years old) during a verbal reasoning task (i.e., spelling, repeat word lists, define words) and a mental arithmetic task (i.e., addition, subtraction, multiplication) with varying levels of
difficulty. Both verbal and mental arithmetic questions were given to the child by an adult Experimenter and were controlled for age and education appropriateness. Results showed that 8 year-old children were more likely to avert their gaze from the Experimenter while thinking of their response and when giving their answer in both tasks than the 5 year-old children. Despite averting their gaze less frequently than the older children, as a group, the 5 year-olds were nonetheless more likely to avert their gaze while thinking of their response then when giving their answer. This suggests that gaze aversion may be used to indicate the occurrence of the thinking process in children as young as five years-old.

Moreover, gaze aversion studies also suggest that for certain tasks (such as visual-spatial or memory tasks) increased gaze aversion may correlate with accuracy in solving the problem (Doherty-Sneddon, Bonner, & Bruce, 2001; Glenberg et al., 1998). Doherty-Sneddon et al. (2001) investigated how gaze aversion facilitates cognitive processing in children. Twenty-eight 10 year-old children were individually read the description of geometric shapes by an adult Experimenter. While they were listening, the children were instructed to make continuous eye contact with the Experimenter, look at the floor, or close their eyes. After they were read the description of the geometric shape they were asked to physically identify the described shape from a set of geometric blocks. Results suggest that children’s accuracy was higher when they looked at the floor while listening than when they made continuous eye contact with the Experimenter. These findings further suggest that eye gaze may be an important behavior in cognitive processing, particularly the thinking process; however, we do not yet know how younger children use gaze behaviors.

**FACIAL EXPRESSION**

Previous literature on facial expression has mainly focused on children and adult’s perception of faces (e.g., emotion recognition). Findings from these studies suggest that facial expression recognition follows a protracted development (Bruce & Young, 1998; Taylor, Batty, & Itier, 2004). However, there are few studies that have addressed facial expression production in children or adults. The studies that do exist suggest that facial expressions produced during problem-solving tasks may reflect cognitive processing. For example, Whitehill et al. (2008) investigated the correlation between facial expression and learning. Results suggests that facial expression can be used to indicate how well a student
understands a lecture (Whitehill et al., 2008). Whitehill et al. (2008) had college students view a video clip made up of a series of mini lectures on different subjects. The students were asked to watch the video carefully as they would be asked to answer questions later. Students’ facial expressions were recorded while they watched the video and later correlated with their answers about each lecture topic. Results show that certain facial muscle movements, such as a brow furrow and narrowing of the eye opening, correlated with how well a student was understanding the lecture and if the lecture needed to be repeated or slowed down. Similarly, Michel and Smith (2007) also found that a person’s facial expression can influence their perception of a problem. In their study, college students were asked to either furrow their brows, or make a facial movement with no associated emotion while they solved a task. The results showed that students who were asked to furrow their brows perceived the task to be more difficult than students who did not furrow their brows. Such results suggest that facial expressions may play a role in cognitive processing in students, as well serve as an important communicative channel from student to teacher.

There is also a large body of research that has focused on cultural display rules and gender differences in the production of emotional facial expressions. Cultural display rules are defined as what a particular culture deems as acceptable or unacceptable in the expression of emotion (Ekman & Friesen, 1969, Matsumoto, Kasri, & Kook, 1999; Safdar et al., 2009). Previous studies on display rules indicate that there are both cultural differences as well as gender differences in conventions for expressing emotion. Safdar et al. (2009) investigated display rules cross-culturally in Canadians, US Americans and Japanese men and women. Participants took part in the Display Rule Assessment Inventory (DRAI) that required participants to rate appropriateness of displaying certain emotions in different situations. With respect to gender differences, they found that across cultures men were more likely to express emotions of anger, contempt, and disgust than women; whereas, women were more likely to express emotions of sadness, fear, and happiness than men. While previous studies have highlighted cultural display rules in adults, few studies have addressed the development of display rules. The present study addresses the development of emotional facial expression display rules in American children. Understanding the development of display rules is particularly important for teachers who work with a diverse student body.
**Gender Differences and Spatial Problem-Solving**

Spatial abilities are important for success in learning math (Hegarty & Kozhevnikov, 1999). For example, the ability to visually see patterns, mental rotations, and relations between variables require spatial skills. However, it is widely acknowledged that there are gender differences in spatial ability. Previous studies on adult spatial processing strongly suggest that there are gender differences in spatial abilities (Duff & Hampson, 2001; McGivern et al., 1997). For example, studies show a bias in men toward processing movement (mediated by the dorsal cortical stream) and a bias in women for processing objects (mediated by the ventral cortical stream). These findings imply that cognitive sex differences reflect a bias in the development of the dorsal and ventral cortical streams and that perhaps there are two different perceptual styles that underlie learning (Handa and McGivern; 2002; McGivern et al., 2010). For example, a processing bias toward objects and their associated characteristics is linked to an iterative, logical style of analysis, whereas a bias toward spatial processing can be associated with a more dynamic, global style. A few studies have investigated the development of gender biases in spatial processing abilities but results are inconsistent (Linn & Peterson, 1985). So it is unclear when such biases develop. Understanding the development of sex differences in spatial abilities have important educational implications, such that teaching strategies may be enhanced by tailoring approaches to individual differences in perceptual processing.

**Hypotheses**

Recent studies of cognitive processing in adults that have emphasized a distributed cognition approach suggest that nonverbal behaviors (e.g., facial expression) used while problem-solving maybe reflective of cognitive processes (Whitehill et al., 2008). In addition, results from a few studies that have addressed cognitive processing in older children from a distributed cognition perspective suggests that there are developmental differences in how nonverbal behaviors reflect cognitive processing in children (Doherty-Sneddon et al., 2002, 2005, 2008; Perner, Stummer, Sprung, & Doherty, 2002). However, these studies have mainly focused on older children and adults, so it is unclear if communicative behaviors also reflect cognitive processing in younger children in a similar way. The present study aimed to characterize the use and development of school-age children’s nonverbal behaviors in two
different problem-solving contexts: one task will emphasize visual imagery skills and the second task will emphasize spatial abilities. As previously stated the overall question of the present study is: Do nonverbal behaviors reflect cognitive processing in young school-age children? In efforts to answer the overall question, the following sub questions will be addressed:

**Question 1:** When do we see the emergence of adult gaze patterns? Are there developmental differences?

**Question 2:** If children produce facial expressions during the problem-solving contexts, how often do children produce facial expressions while thinking? If facial expressions are produced, what types of facial expression do children use (i.e., positive, negative, other)?

**Question 3:** How do boys and girls differ in performance on spatial problems?

Based on previous research that have characterized older children and adult’s nonverbal behaviors in problem solving contexts the following hypotheses are proposed:

1. Based on previous studies regarding cognitive load and eye gaze patterns in adults and older school-age children, we expect to see developmental differences in eye gaze patterns in younger school-age children that reflect differences in cognitive development.

2. In accordance with previous studies regarding display rules for facial expression production in adults we expect to see gender differences in the production of types of facial expression because previous studies indicate that women are more likely to display positive facial expressions than men.

3. We expect to see gender differences in performance on the spatial tasks because previous literature indicates that males and females rely on different cortical pathways in regards to spatial processing.
CHAPTER 2

METHOD

This chapter discusses the method used in this study, including participants, tasks, and procedures.

PARTICIPANTS

Subjects were 40 typically developing children (TD) ages 3 to 4 yrs (N = 20; 10 females; 10 males) and ages 7 to 8 years (N = 20; 10 females; 10 males) and college-age adults ages 19 to 36 years (N = 20; 10 females; 10 males). All data used for the present study were archival data collected by Dr. Judy Reilly of the Developmental Laboratory for Language and Cognition; they were collected via digital videotape with audio. Subjects were recruited from San Diego State University and from local preschool and elementary schools.

TASKS

Two tasks were utilized to characterize behavioral indices of cognitive processing in children and adults.

Task 1: Mystery Box Object

The first task was a novel problem-solving game, which required visual imagery. Participants were asked to play a protagonist in a story that the Experimenter narrated during which participants placed their hands inside a wooden box to obstruct the view of their hands. During the story, the Experimenter hands the participant five different objects (square block, triangle block, cylinder block, toy dinosaur, and toy duck) (Figure 1). The participants were asked to identify the objects using only haptic perception. There were no time constraints on the amount of time each participant took to think about the objects name. Participants were not corrected if they gave an incorrect answer.
Task 2 Safari Rush Hour

The second task was a series of three puzzles from the game, Safari Rush Hour that emphasized spatial abilities and with each new puzzle the level of difficulty increased (i.e., easy, medium, hard) (Figure 2). Participants were presented with a puzzle board that had marked grids, puzzle pieces and a marked end goal. Participants were told that they are the “Jeep puzzle piece and their goal is to go back to camp”. Each level of difficulty has a different configuration of puzzle pieces and a different amount of puzzle pieces. In order to solve the puzzle, participants must strategically move puzzle pieces to free their jeep piece. There is a seven-minute time limit for all three puzzles.

PROCEDURES

Nonverbal behaviors were annotated into the Eudico Linguistic Annotator (ELAN) (Brugman & Russel, 2004; Crasborn & Sloetjes, 2008), a video interface. ELAN allows for the coding of behavioral data across multiple channels (e.g., eye gaze and facial expression) and across time (millisecond). Speech was transcribed using the Child Language Data
Exchange System (CHILDES) (MacWhinney & Snow, 1991) transcription system and was also annotated into ELAN.

During each task the participant and Experimenter engaged in an interaction. To better understand the role of nonverbal behaviors that occurred during the interaction, the most meaningful functional components of the interaction were identified and labeled as:

1. Input: participant receives instructions, an object or when the puzzle is placed in front of them.
2. Latency/Response: time in which the participant is solving the problem (thinking stage).
3. Answer: participant gives an answer.
4. Turn surrender: participant’s observed behavior after completing an answer or puzzle.

Nonverbal behavior was coded in each task as follows:

**Eye Gaze**

Eye contact categories (yes = makes eye contact with Experimenter; no = no eye contact with Experimenter). Confirmation of eye contact with Experimenter was determined from two camera angles. Gaze behaviors were coded during the Input, Latency/Response, Answer, and Turn Surrender phases. Normalized frequency of eye contact and no eye contact will be calculated per phase.

**Facial Expression**

Facial expressions were coded during the response phases using the Facial Action Coding System (FACS) (Ekman & Friesen, 1978), a taxonomy based on individual facial muscle movements in the adult face. The upper and lower parts of the face were coded separately to account for muscle movements in the lower face influencing muscles in the upper face and vice versa. Facial muscle movements will be coded for *onset* (when a muscle starts to contract) and *apex* (the highest intensity the muscle movement). After facial expressions were FACS coded, they were then given a valence label (positive, negative, or other facial expression). These valence labels corresponded to specific emotions based on FACS code combinations created my Ekman, Friesen, & Hagar (2002, p. 174).
Measuring Participants’ Performance on Safari Task

To characterize participants’ performance on the Safari task the following measures were scored:

1. Latency to start: time between input (seeing the puzzle for the first time) and touching the first piece.
2. Latency to move: the time between touching a puzzle piece and moving it.
3. Number of Moves: the number of moves it took to solve the puzzle. A move is defined as a linear movement of the puzzle in one direction or until the movement of the puzzle piece stops.
4. Duration: the time it took to complete a puzzle.
5. Errors: moves that violate the rules of the game.
CHAPTER 3

RESULTS

For reliability, a second coder coded 20% of the videos and inter-rater reliability for eye gaze was 96.6% and inter-rater reliability for facial expression was 85%.

Nonverbal behaviors (eye gaze and facial expression) were used to characterize behavioral indices of cognitive problem-solving in typically developing children and their performance on two visual-spatial tasks: (1) mystery box – an imagery task and (2) safari – a spatial task. Frequency and duration of eye gaze and frequency of facial expression were measured across all four interaction phases (input, latency/response, answer, and turn surrender) for both tasks. In the mystery box, to account for possible differences in complexity among the five objects (e.g., the duck has a more complex shape than the square block) and gender biases (e.g., boys might have had more exposure to the dinosaur toy than the girls), objects where grouped according to their similarities (i.e., the square block, triangle block and cylinder block where grouped together; whereas the dinosaur and the duck toy were analyzed separately). In the safari task, to account for the level of difficulty for each puzzle, the easier puzzles (puzzle 1 and 2) were analyzed together and the harder puzzle (puzzle 3) was analyzed separately. Moreover, to account for individual difference in participants’ performance, only participants who successfully completed puzzle 1 and 2 but failed to complete puzzle 3 were included in the analysis. Subjects included in the safari task were 37 typically developing children (TD) ages 3 to 4 yrs (N = 18; 8 females; 10 males) and ages 7 to 8 years (N = 19; 10 females; 9 males) and college-age adults ages 19 to 36 years (N = 12; 7 females; 5 males). For both tasks only significant findings are reported.

RESULTS FOR EYE GAZE

This section will address results for eye gaze in the mystery box task and safari task.

Task 1: Mystery Box

A 3x2x3 (Group x Gender x Object) Mixed-Model Repeated-Measures Analysis of Variance (ANOVA) with repeated measures over the last factor was conducted for frequency
and duration of eye contact for the square block, triangle block and cylinder block across the four interaction-phases: input, latency, answer and turn surrender. Tables 1 through 4 represent the means and standard deviations for these variables (see Appendix). Within group differences were addressed with Paired-Sample $t$ tests and between group differences were addressed with post-hoc comparisons using Bonferroni with a correction at $\alpha = .016$. A 3 x 2 (Group x Gender) Univariate Analysis of Variance (UNIANOVA) was conducted for both the frequency and duration of eye contact across each of the four interaction-phases for the dinosaur and duck toy separately.

**BLOCKS: EYE CONTACT DURING INPUT**

There was a significant main effect for age group, $F(2, 54) = 14.409, p < .001, \eta^2 = 0.327$. A higher proportion of younger children made eye contact with the Experimenter during input than older children or adults. Post-hoc comparisons between the age groups indicate that the younger children ($M = 0.333, 95\% \text{ CI } [0.244, 0.423], p = .003$) were more likely to make eye contact with the Experimenter during the input phase than the older ($M = 0.177, 95\% \text{ CI } [.027, .206]$, and adults ($M = 2.429 \text{ E-17}, 95\% \text{ CI } [-.089, .089]$ (see Figure 3).

*Figure 3. Proportion of participants who made eye contact with the Experimenter during the input phase across objects. With lower cognitive effort, a higher proportion of younger children made more eye contact than older children and adults. However, with increased cognitive effort, a higher proportion of younger and older children than adults made eye contact with the Experimenter.*
A significant interaction between age and gender was evident, \( F(2, 54) = 3.404, \ p = .041, \ \eta^2 = .077 \). Follow-up paired \( t \)-tests indicate that young males made more eye contact during the input phase than young females \( t(58) = 2.28, \ p = .028, \ \alpha = .05 \) (see Figure 4).

![Mystery box: Eye contact during latency](image)

**Figure 4. Average proportion of eye contact duration over latency duration across objects. Overall across objects, younger and older children made more eye contact than adults.**

**BLOCKS: EYE CONTACT DURING LATENCY**

There was a significant main effect for block during the latency phase \( F(2, 54) = 3.717, \ p = 0.27, \ \eta^2 = 0.061 \). Follow-up tests between the latencies for the three blocks indicate that overall rate of eye contact duration during the latency for the square block (\( M = .222, \ 95\% \ CI [.142, .302], \ p = .037 \), was significantly different from the latency for the triangle block (\( M = .108, \ 95\% \ CI [.048, .169] \). There was also a significant main effect for age group, \( F(2, 54) = 13.578, \ p <.001, \ \eta^2 = .328 \). Post-hoc comparisons between the three age groups indicate that younger children (\( M = .339, \ 95\% \ CI [.249, .428], \ p<.001, \ \alpha = .016 \)) made more eye contact during the latency phases for the blocks than the older children (\( M = .127, \ 95\% \ CI [.038, .216] \) and adults (\( M = .016, \ 95\% \ CI [-.073, .105] \) (see Figure 4).

**BLOCKS: EYE CONTACT DURING ANSWER**

There was a main effect for age group, \( F(2, 54) = 21.814, \ p < .001, \ \eta^2 = .442 \). Bonferroni post-hoc comparisons between the three groups indicate that younger children (\( M = .633, \ 95\% \ CI [.511, .756], \ p<.001, \ \alpha = .016 \)) and older children (\( M = .531, \ 95\% \ CI \)
[.408, .653], p < .001) made more eye contact while answering than adults (M = .095, 95% CI [-.027, .218] (see Figure 5).

![Figure 5. Average proportion of eye contact duration over the answer. Overall across objects, younger and older children made more eye contact while answering than adults.](image)

**BLOCKS: EYE CONTACT DURING TURN SURRENDER**

There was a significant main effect for age group, F(2, 54) = 33.119, p < .001, η² = 0.523. A post-hoc comparison between age groups indicate that a higher proportion of younger children (M = .833, 95% CI [.713, .954], p < .001, and older children (M = .867, 95% CI [.746, .987], p < .001) were more likely to make eye contact during the turn surrender phase than adults (M = .250, 95% CI [.129, .371] (see Figure 6).

**DINOSAUR: EYE CONTACT DURING LATENCY**

There was a significant main effect for age, F(2, 54) = 7.522, p = .001, η² = .216. Post-hoc pairwise comparisons between the three groups indicate that younger children (M = .342, 95% CI [.223, .461], p = .001, α = .016) made more eye contact during the latency period than adults (M = .019, 95% CI [-.101, .138] (see Figure 4).
Figure 6. Proportion of participants who made eye contact during turn surrender. Overall, across all five objects, a higher proportion of younger and older children made eye contact than adults.

**Dinosaur: Eye Contact during Answer**

There was a significant main effect for age, $F(2, 54) = 11.861, p < .001, \eta^2 = 0.293$. Post-hoc comparison between the age groups indicate that younger children ($M = .567, 95\% \text{ CI } [.416, .718], p < .001, \alpha = .016$) and older children ($M = .493, 95\% \text{ CI } [.416, .718], p < .001, \alpha = .016$) made more eye contact during the dinosaur answer phase than adults ($M = .085, 95\% \text{ CI } [-.066, .236]$ (see Figure 5).

**Dinosaur: Eye Contact during Turn Surrender**

There was a significant main effect for age, $F(2, 54) = 14.422, p < .001, \eta^2 = 0.341$). Post-hoc comparisons between the age groups indicate that a higher proportion of younger children ($M = .900, 95\% \text{ CI } [.724, 1.076], p < .001, \alpha = .016$) and older children ($M = .850, 95\% \text{ CI } [.674, 1.026], p < .001, \alpha = .016$) made eye contact during the dinosaur turn surrender phase than adults ($M = .300, 95\% \text{ CI } [.124, .476]$ (see Figure 6).

**Duck: Eye Contact during Latency**

There was a significant main effect for age, $F(2, 54) = 5.752, p = .005, \eta^2 = 0.173$. Post-hoc comparisons between groups indicate that younger children ($M = .289, 95\% \text{ CI } [.167, .412], p = .005, \alpha = .016$) made more eye contact during the latency than adults ($M = 4.68E-17, 95\% \text{ CI } [-.123, .123]$ (see Figure 4).
**DUCK: EYE CONTACT DURING ANSWER**

There is a significant main effect for age, $F(2, 54) = 8.475, p = .001, \eta^2 = 0.234$. Post-hoc comparisons between groups indicate that younger children ($M = .537, 95\% \text{ CI } [0.385, 0.689], p = .001, \alpha = .016$) made more eye contact during the answer phase than adults ($M = .109, 95\% \text{ CI } [-.043, .261]$ (see Figure 5).

**DUCK: EYE CONTACT DURING TURN SURRENDER**

There was a significant main effect for age, $F (2, 54) = 12.964, p < .001, \eta^2 = 0.302$. Post-hoc comparisons between groups indicate that a higher proportion of younger children ($M = .850, 95\% \text{ CI } [0.673, 1.207], p < .001, \alpha = .016$) and older children ($M = .850, 95\% \text{ CI } [0.673, 1.027], p <.001, \alpha = .016$) made eye contact during the duck turn surrender than adults ($M = .300, 95\% \text{ CI } [0.123, .477]$ (see Figure 6).

**Task 2: Safari**

A 3x2x2 (Group x Gender x Puzzle) Mixed-Model Repeated-Measures Analysis of Variance (ANOVA) with repeated measures over the last factor was conducted for frequency and duration of eye gaze for puzzle one and two across the three interaction-phases: input, response, and turn surrender. A 3 x 2 (Group x Gender) Univariate Analysis of Variance (UNIANOVA) was conducted for both the frequency and duration of eye contact across each of three interaction-phase for puzzle three. There were no significant differences for eye contact; all groups tended to look at the puzzle.

**Eye Gaze Results Summary**

While guessing at the block objects in the mystery box, across the input and latency phases, younger children significantly made more eye contact with the Experimenter than older children and adults. However, during the answer phase and turn surrender phase, a high proportion of younger and older children made more eye contact with the Experimenter; whereas adults did not make eye contact. Furthermore, when the complexity of the objects increased (i.e., the dinosaur and duck toy) younger and older children made more eye contact with the Experimenter than the adults across all phases. Also, adult eye gaze patterns did not change with complexity of objects.
In the safari task, all three age group showed similar gaze patterns across the input, response and turn surrender phases for the three puzzles (i.e., few participants’ made eye contact with the Experimenter). The participants’ gaze direction was mainly focused on the safari grid.

**RESULTS FOR FACIAL EXPRESSION PRODUCTION**

This section will address results for facial expression in the mystery box task and the safari task.

**Task 1: Mystery Box**

A 3x2x3 (Group x Gender x Object) Mixed-Model Repeated-Measures Analysis of Variance (ANOVA) with repeated measures over the last factor was conducted for frequency of facial expressions and for the type of facial expressions (i.e., positive, negative, and other) for the square block, triangle block and cylinder block across two interaction-phases: latency and answer. A 3 x 2 (Group x Gender) Univariate Analysis of Variance (UNIANOVA) was conducted for the frequency of facial expressions and for the type of facial expressions (i.e., positive, negative, and other) across two of the interaction-phase for the dinosaur and duck toy separately.

**BLOCKS: FREQUENCY OF FACIAL EXPRESSIONS DURING LATENCY**

For the total number of facial expression produced during the latency phase there was a significant main effect for age group, F(2, 54) = 6.526, p = .003, \(\eta^2 = 0.187\). Post-hoc comparisons indicate older children (M = 1.5, 95% CI [1.021, 1.979], p = .002, \(\alpha = .016\)) made more facial expressions than adults (M = .517, 95% CI [.038, .996] (see Figure 7).

**DINOSAUR: FREQUENCY OF FACIAL EXPRESSION DURING LATENCY**

For frequency of positive facial expressions there was a significant interaction between age group and gender, F(2, 54) = 4.976, p =.01, \(\eta^2 = 0.151\). Follow-up paired t-test analysis indicates that younger female children (M = 1.1, SD = 1.16) produced more positive facial expressions than younger male children (M=.20; \(SD = 1.19\)), t(38) = 2.15, p = .04 (see Figure 8).
Figure 7. Average frequency of facial expressions produced during the latency phase across all five objects. For all objects, older children produced more facial expressions than younger children and adults. However, the difference between older children and adults was only statistically significant for the less complex objects.

Figure 8. Average frequency of positive facial expressions during the latency phase for the dinosaur toy. Younger female participants significantly produced more positive facial expressions than younger male participants. Older male participants produced more positive facial expressions than older female participants; however, this difference was not significant.
**DUCK: FREQUENCY OF FACIAL EXPRESSIONS DURING THE LATENCY**

For the frequency of positive facial expressions produced, there was a significant main effect for age group, $F(2, 54) = 4.81, p = .012, \eta^2 = 0.150$. Post-hoc comparisons between groups indicate that older children ($M = 1.2, 95\% \text{ CI} [.863, 1.537], p = .014$) produced more positive facial expressions than younger children ($M = .5, 95\% \text{ CI} [.163, .837]$) (see Figure 9).

![Figure 9. Average frequency of positive facial expressions during the latency phase for the duck toy. Overall, older children produced more positive facial expressions than younger children.](image)

**DUCK: FREQUENCY OF FACIAL EXPRESSION DURING ANSWER:**

For the total frequency of facial expression produced, there is a significant main effect for gender, $F(1, 54)= 6.785, p = .012, \eta^2 = 0.103$. Overall, females ($M = 1.16, SD = .792$) produced more facial expressions than males ($M = .70, SD = .595$) (see Figure 10).

**Task 2: Safari**

A 3x2x2 (Group x Gender x Puzzle) Mixed-Model Repeated-Measures Analysis of Variance (ANOVA) with repeated measures over the last factor was conducted for the frequency of facial expressions and for the type of facial expressions (i.e., positive, negative,
and other) for puzzle one and two across the response phase. Tables 5 and 6 represents the means and standard deviations for these variables (see Appendix). A 3 x 2 (Group x Gender) Univariate Analysis of Variance (UNIANOVA) was conducted for the frequency of facial expressions and for the type of facial expressions (i.e., positive, negative, and other) across the response phase for puzzle three. Table 7 represents the means and standard deviations for these variables (see Appendix).

PUZZLE 1 AND 2: RESPONSE

See Tables 5 and 6 in the Appendix for means and standard deviations.

PUZZLE 3: RESPONSE

For the total frequency of facial expressions produced, there was a significant main effect for age group, \( F(2, 43) = 12.47, p < .001, \eta^2 = 0.156 \). Post-hoc comparisons between age groups indicate that adults (\( M = 12.42, 95\% \text{ CI } [8.41, 14.36], p = .001 \)) produced more facial expressions than younger children (\( M = 4.89, 95\% \text{ CI } [2.37, 7.18] \)) and older children (\( M = 7.32, \text{ SD } = 5.32 \)). Also, a strong significant main effect for gender of the participant was evident, \( F(1, 43) = 6.512, p = .014, \eta^2 = 0.083 \). Female participants (\( M = 9.24, \text{ SD } = 7.68 \)) produced more facial expressions than male participants (\( M = 6.04, \text{ SD } = 4.32 \)).

A significant interaction between age of the participant and gender was evident and qualified the main effects, \( F(2, 43) = 7.616, p = .001, \eta^2 = 0.196 \). Follow-up tests, indicate that
adult females (M = 17.57, SD = 8.26) produced more facial expressions than adult males (M = 5.2, SD = 2.28). Overall, production of facial expressions in female participants increased with age; whereas, production of facial expressions in male participants did not increase with age (see Figure 11).

![Figure 11. Average frequency of facial expression during the response phase for puzzle 3 across age groups and gender. Overall, production of facial expressions in female participants increased with age; whereas, production of facial expressions in male participants remains steady with age.](image)

For frequency of positive facial expressions there was a significant main effect for age of the participant, F(2, 43) = 12.477, p < .001, η² = .23. Post-hoc comparisons between age groups indicate that adults (M = 8.64, 95% CI [6.479, 0.75], p < .001) produced more positive facial expressions than younger children (M = 1.86, 95% CI [.13, 3.59]) and older children (M = 3.86, 95% CI [2.18, 5.53]). There was also a significant main effect for gender of the participant, F(1, 43) = 11.11, p < .001, η² = 0.10. Overall, female participants (M = 6.55, SD 6.70) produced more positive facial expressions than male participants (M = 2.8, SD = 2.39).

Further, there was a strong statistically significant interaction between age of the participant and gender of the participant, F(2, 43) = 13.99, p < .001, η² = 0.25. Follow-up paired t-tests indicate that adult females produced more positive facial expressions than adult
males, t(22) = 3.48, p <.004. Overall, for female participants production of positive facial expressions increased with age; whereas, for male participants, production of positive facial expressions did not increase with age (see Figure 12).

![Safari Puzzle 3: Frequency of positive facial expression during response](image)

**Figure 12.** Average frequency of positive facial expressions during the response phase for puzzle 3. Overall, production of positive facial expressions for female participants increased with age; whereas, production of positive facial expressions in male participants did not increase with age.

With respect to production of negative facial expressions, there was a statistically significant interaction between age and gender, F(2, 43) = 4.41, p = .018, \( \eta^2 = 0.17 \). Follow up paired \( t \)-tests indicate that older female children produced more negative facial expressions than older male children, \( t(36) = 2.03, p = .049 \), and adult females produced more facial negative facial expression than adult males, \( t(32) = 2.34, p = .029 \). In addition, for male participants production of negative facial expressions decreased with age (see Figure 13).

A follow-up paired \( t \)-test between production of positive facial expression and negative facial expressions for adult females indicated positive facial expressions were produced at a higher rate than negative facial expressions, \( t(12) = 4.64, p <.001 \).

**Facial Expressions Results Summary**

In the mystery box, during the less complex items, younger and older children did not differ in their production of facial expression. However, when the complexity of the objects
increased (i.e., the dinosaur and duck toy), older children produced more facial expressions than younger children. Moreover, female participants produced more facial expressions than male participants.

During the harder safari puzzle (puzzle 3), adults produced more facial expressions than younger and older children. Overall female participants produced more facial expressions than male participants. With respect to the production of positive and negative facial expressions, adult females produced more positive and negative facial expressions than adult males. Within the adult females, more positive facial expressions were produced than negative facial expressions.

**Results for Safari Performance Measures**

A 3x2x2 (Group x Gender x Puzzle) One-Way Repeated-Measures Analysis of Variance (ANOVA) with repeated measures over the last factor was conducted for response duration, the frequency of number of moves, errors, and latency to start, for puzzle one and two during the response phase. A separate 3 x 2 (Group x Gender) Univariate Analysis of Variance (UNIANOVA) was conducted for the frequency of number of moves, errors, and latency to start for puzzle three.
**PUZZLE 1 & 2: RESPONSE DURATION**

There was a significant main effect for response duration, $F(1, 43) = 30.809$, $p < .001$, $\eta^2 = 0.407$. Participants across age groups and gender, had longer response duration for puzzle two ($M = 55.87$, $SD = 42.99$) than puzzle one ($M = 18.23$, $SD = 14.61$) (see Figure 7).

**PUZZLE 3: RESPONSE DURATION**

There was a strong significant main effect for age, $F(2, 43) = 6.680$, $p = .003$, $\eta^2 = 0.542$. Post-hoc comparisons between the age groups indicate that adults ($M = 171.24$, 95% CI [66.07, 122.94], $p = .002$) had a longer response duration than younger children ($M = 93.89$, 95% CI [140.17, 207.92]). Paired $t$ tests comparing response 3 duration to response 2 duration indicate that overall, across age groups, participants spent more time on puzzle 3 than puzzle 2, $t(48) = -5.79$, $p < .001$ (see Figure 14).

![Safari: Response duration](image)

Figure 14. Average response duration time for puzzles 1 – 3. Overall, participants had longer response times for puzzle 3 than puzzle 1 and 2. Further, adults had longer duration times for puzzle 3 than younger and older children.
PUZZLE 3: MOVES

There was a significant main effect for age group $F(2, 43) = 5.953, p = .005, \eta^2 = 0.194$. Post-hoc comparisons indicate that adults ($M = 36.386, 95\% \text{ CI} [25.576, 47.196], p = .016$) made more moves than younger children ($M = 15.212, 95\% \text{ CI} [6.456, 23.969]$). There was also a significant main effect for sex, $(F(1, 43) = 4.071, p = .05, \eta^2 = 0.066$. Male participants ($M = 33.33, \text{SD} = 26.55$) made more moves than female participants ($M = 22.465, \text{SD} = 11.87$) (see Figure 15).

![Safari Puzzle 3: Number of moves](image)

Figure 15. Average number of moves made by each age group to complete puzzle 3. Overall, adults made more moves than younger children.

PUZZLE 3: NUMBER OF ERRORS

There was a significant main effect for age group, $F(2, 43) = 8.957 p = .001, \eta^2 = 0.288$. Post-hoc comparisons indicate that older children ($M = .644, 95\% \text{ CI} [-.071, 1.36], p = .005$) and adults ($M = .171, 95\% \text{ CI} [-.740, 1.083]$) made fewer errors than younger children ($M = 2.375, 95\% \text{ CI} [1.637, 3.113]$) (see Figure 16).

PUZZLE 3: LATENCY TO START

There was a significant main effect for age group, $F(2, 43) = 7.947, p = .001, \eta^2 = 0.259$. Post-hoc comparisons indicate that adults ($M = 5.023, 95\% \text{ CI} [3.872, 6.175]$),
Figure 16. Average number of errors made during puzzle 3. Overall, younger children made more errors than older children and adults.

\[ p = .002 \] took longer to start than older children (\( M = 2.409, 95\% \text{ CI} [1.506, 3.313] \)) and younger children (\( M = 2.410, 95\% \text{ CI} [1.477, 3.343] \)) (see Figure 17).

**Safari Performance Results Summary**

Overall, during the easier safari puzzles, performance across age groups and gender did not differ. However, during the harder safari puzzle, adults made more moves and took longer to start the puzzle than older and younger children. Moreover, adults and older children made fewer errors (i.e., moves that violate rules) than younger children. Furthermore, male participants made more moves than female participants.
Figure 17. Average latency time to start (in seconds) response to puzzle 3. Overall, adults had a longer latency to start time than younger and older children.
CHAPTER 4

DISCUSSION, RECOMMENDATIONS, CONCLUSIONS

For students, problem-solving is a critical aspect of the learning process. Previous studies of cognitive processing have highlighted problem-solving strategies as a window into the student’s internal cognitive processes. However, more recent perspectives in cognitive processing suggest that nonverbal behaviors may also reflect internal cognitive processes such as thinking. Previous studies of adults and older school-age children suggest that eye gaze patterns and facial expressions may index the effects of high cognitive load as well as level of understanding (Whitehill et al., 2008). However, such studies have mainly focused on adults and older children so it is unclear whether nonverbal behaviors also reflect cognitive processing in younger school-age children. The present study aimed to characterize behavioral indices of cognitive problem-solving in pre-school and school age children by investigating nonverbal behaviors (i.e., eye gaze and facial expression) during two visual-spatial tasks. During both tasks, the participant and Experimenter were engaged in interaction. To better understand the role of nonverbal behaviors as they occurred during the interaction, functional components of the interaction were identified for both tasks: Mystery box) input, latency, answer and turn surrender; Safari) input, response, and turn surrender. Frequency and duration of eye gaze and facial expression were then measured during each interaction phase. Results suggest that eye gaze patterns vary according to development and the level of cognitive effort that is required to solve a problem. During low cognitive effort, younger children were more likely to make eye contact with the Experimenter, while older children and adults showed similar gaze aversion patterns while thinking. However, with increased cognitive effort older children showed gaze patterns similar to younger children; whereas, eye gaze patterns in adults did not vary with cognitive effort. However, with respect to production of facial expression, individual differences made it difficult to identify clear patterns. Nonetheless, a trend reflecting the emergence of display rules was evident and suggested that adult females produced more positive facial expressions than adult males and younger and older children.
We now turn to our original hypotheses:

**Hypothesis 1:** Based on previous studies regarding cognitive load and eye gaze patterns in adults and older school-age children, we expect to see developmental differences in eye gaze patterns reflecting differences in cognitive development.

Analyses confirmed this hypothesis during the mystery box task, as older children displayed similar gaze patterns to adults during the block objects; whereas, younger children made more eye contact with the Experimenter than older children and adults across all phases of the interaction. Interestingly with the dinosaur and duck toys, older children’s gaze patterns were more similar to younger children suggesting a reversion to earlier strategies; and adult gaze patterns did not change by stimulus.

**Hypothesis 2:** In accordance with previous studies regarding facial expression production in adults we expect to see gender differences in the production of facial expression, especially positive, because previous studies indicate that women are more likely to display positive facial expressions than men.

Analyses partially confirmed this hypothesis, as individual differences in production of facial expression made it difficult to observe patterns. However, during the harder Safari puzzle, adult females produced more facial expressions than younger and older children. Furthermore, female participants produced more positive facial expressions than male participants, and adult female participants also produced more negative facial expressions than adult male participants. However, within the adult female group, more positive facial expressions were produced than negative facial expressions. These results suggest a late development of gender biases in production of facial expressions.

**Hypothesis 3:** We expect to see gender differences in performance on the spatial tasks because previous literature indicates that males and females rely on different cortical pathways in regards to spatial processing.

Analyses did not confirm this hypothesis in either the mystery box or safari task. During the mystery box, across all five objects, there were no gender differences in latency duration time.

Within the Safari task, during the harder safari puzzle, adults had longer response times than younger children suggesting that adults took a longer time period to think about the problem. Adults also took longer to start the harder puzzle suggesting that they are taking the time to think ahead. Overall, adults and older children made fewer errors during the harder puzzle than younger children. With respect to gender differences, males overall made more puzzle piece moves than females.
**DISCUSSION**

Together, the results suggest that eye gaze patterns vary according to development and the level of cognitive effort that is required to solve a problem. For the less complex objects (i.e., the blocks) across all the interaction phases, younger children were more likely to make eye contact with the Experimenter, while older children and adults showed similar gaze aversion while thinking. However, when the complexity of the objects increased (i.e., the toy dinosaur and duck) older children showed gaze patterns similar to younger children (i.e., younger and older children made more eye contact with the Experimenter while thinking and answering); whereas, eye gaze patterns in adults did not vary across stimuli. With respect to older children and adults, the results are in line with previous research regarding gaze patterns and cognitive load: while thinking, older children and adults tend to avert their gaze (from the environment or from a person’s face) to decrease cognitive load and increase concentration (Doherty-Sneddon et al., 2002; Glenberg et al., 1998). However, few studies have investigated gaze patterns in younger children. Results from the present study suggest that eye gaze patterns in younger children may reflect social referencing, and their view that the Experimenter will help as well as a shift in cognitive development between younger and older children. Such findings are in line with a Vygotskyan view in which children are seeking support from the expert. In infants this has been labeled “social referencing.”

Social referencing is the process by which a person uses affective information from others around them (e.g., a smile from a parent) to formulate decisions for their own behavior (Bradshaw, Goldsmith, & Campos, 1987; Campos & Stenberg, 1981; Zarabatany & Lamb, 1985). Previous studies suggest that 1-year-old infants can use affective cues, such as positive and negative facial expressions from their caregivers, to determine their own behaviors. For example, in the visual cliff study investigated the role of emotional face recognition in babies and its role in regulating behavior (Bradshaw et al., 1987, Campos & Stenberg, 1981). Babies were placed on a mock cliff, which they needed to cross to get to their mothers. The baby’s mother was cued to smile as their baby approached the cliff, but were cued to display a negative facial expression as their baby reached the cliff. By 8 months-old, babies reliably looked at their mother and used her mother’s facial expressions as cues as to whether or not she should cross the cliff; however, younger babies were not able
to use their mother’s facial expression as a cue. This suggests that by 8 months babies are able to extract, at least negative and positive meaning from their mother’s facial expressions. Previous studies suggest that social referencing can also occur with adults other than the mother or care giver.

In a study by Bradshaw et al. (1984), 12-month old infants were placed in the same social referencing contexts as the previous visual cliff study mentioned above. However, in this instance there were two adults in the room (i.e., the mother and an unfamiliar adult to the infant). Both adults were cued to display specific facial expressions (either positive or negative). Results indicate that the infants were just as likely to use the unfamiliar adult in the room for social referencing as they did their mother. These results suggest that social referencing may occur with a broader adult category. However, studies of social referencing are limited to infants. Yet eye gaze results from the present study suggest that the children in the mystery box task are using the Experimenter as a social referent to determine their own behaviors or how they should answer. This suggests that younger children are more socially dependent in this task situation than the older children, and that social referencing occurs beyond infancy as would be predicted by Vygotsky: in the harder task, even the older children are solving the problem using the social context. Further, younger and older children’s use of the social context to solve the task supports the embodied view of distributed cognition (i.e., a person forms information based on external information received through sensory input).

Distributed cognition suggest that cognition is a coordination between embodied information and then environment (Clark, 2008; Hutchins, 2000). For example, in the infant social referencing studies mentioned above, the infant plays an active role in deciding whether she should cross the visual cliff. However, her decision to cross is not a uniquely internal process, but rather a coordination between her visual assessment of the cliff and the information she receives from her mother’s facial expression. Similarly, the younger and older children’s performance in the mystery box task is a coordination between sensory input (i.e. the information they receive from manipulating the objects in their hands) and the information they receive from directing their gaze towards the Experimenter. Making eye contact with the experimenter may give them information about their performance as well as signal for assistance from the Experimenter.
The difference between younger and older children’s use of eye gaze may also reflect a developmental shift from a child who is in the preoperational stage (i.e., younger children) to the concrete operational stage (i.e., older children). During the preoperational stage, children are able to form internal representations of their behaviors (e.g., touching the dinosaur toy and visualizing it); however, these representations are heavily dependent on the child’s physical interaction with their surroundings (Piaget, 1985). In the mystery box task, the quality of interaction with the objects was diminished because the children’s view of the objects was obstructed, requiring them to make internal representations of objects using only information they receive through haptic input. This suggests that while younger children were able to correctly guess the objects in the mystery box, it was not done without effort and that the younger children’s eye contact with the Experimenter was to elicit help. On the other hand, older children who are in the concrete operational stage have mental representations that are less dependent on their physical interaction with their surroundings. This suggests that older children did not need to elicit help from the Experimenter and therefore did not need to make eye contact at least with the easier and more common blocks. However, as the objects became more complex, they too looked at the Experimenter.

In addition to developmental gaze patterns, the data suggests that display rules regarding facial expressions vary according to gender and development, such that female participants produced more positive facial expressions than male participants. In addition, production of positive facial expressions in female participants increased with age. Cultural display rules are defined as what a particular culture deems as acceptable or unacceptable in the expression of emotion (Ekman & Friesen, 1969, Matsumoto et al., 1999; Safdar et al., 2009). Previous studies on display rules indicate that there are both cultural differences as well as gender differences in conventions for expressing emotion. Safdar et al. (2009) investigated display rules cross-culturally in Canadians, US Americans and Japanese men and women. Participants took part in the Display Rule Assessment Inventory (DRAI) that required participants to rate appropriateness of displaying certain emotions in different situations. With respect to gender differences, they found that across cultures men were more likely to express emotions of anger, contempt, and disgust than women; whereas, women were more likely to express emotions of sadness, fear, and happiness than men. While previous studies have highlighted cultural display rules in adults, few studies have addressed
the development of display rules. The present study adds to the current literature in characterizing the developmental trend of display rule for positive facial expressions. Moreover, the results support another aspect of the distributed cognition theory, which suggests that particular patterns of behavior are spread throughout a community, in this case, the use of facial expressions in social contexts, particularly by female participants (Hutchins, 2000).

While results fall in line with previous studies on gender differences and display rules, they do not fall inline with previous studies on facial expression and problem-solving. Previous studies that have addressed correlations between facial expression and thinking have suggested that certain facial expressions (e.g., brow furring) correlate with how well a student perceives a lecture (Whitehill et al., 2008). The current study’s results may not reflect findings from previous studies because it addresses the social aspect of problem solving; whereas, previous studies have mainly focused on the student as an individual problem-solver. The present results add to the current literature on facial expression and problem solving by highlighting the role of facial expression during an interaction.

**RECOMMENDATIONS**

The present study indicates that nonverbal behaviors such as eye gaze are possible indices of cognitive processing in children in an interactional context similar to that of student and teacher. If eye gaze patterns are a reliable index of thinking, how could teachers use such nonverbal cues to help their students in their learning process? In a study by Doherty-Sneddon and Phelps (2005), teachers were paired with three elementary students and were recorded as they instructed the students to solve a task. Recordings were then coded for students’ eye gaze patterns and the teachers’ response to children’s gaze aversion. Results indicated that teachers did not use the students’ eye gaze patterns as indices of thinking; however, when teachers were asked how they would judge if a student was in the thinking process, teachers reliably indicated gaze aversion as an index of thinking. These results suggest further studies into how teachers might use eye gaze patterns in teaching contexts to better facilitate the learning process.

Nonverbal behaviors often co-occur during interaction. During face-to-face interaction, the face and the body serve as crucial tools for relaying affective and cognitive
information. Do other nonverbal behaviors such as gestures, also reflect cognitive processing in children? Cook, Mitchell and Goldin-Meadow (2008) investigated that role of gestures and learning in elementary school-age children. Children were divided into two groups: (1) they learned with gesture and (2) learned with speech only. Results indicate that children who were required to gestures along with the concept being taught were more likely to retain the material; whereas, students who were taught just using speech retained less material. These results indicate the nonverbal behaviors may also help with the learning process. A future study might look at how do different nonverbal behaviors such as eye gaze and facial are integrated during the learning process.

In considering how this study might be improved, one limitation is the lack of data on children’s behaviors in the absence of the Experimenter. Would children exhibit similar facial expressions without the presence of an Experimenter? Results from the Whitehill et al. (2008) study on facial expression and thinking suggests that certain facial expressions produced by an adult student, who watched video lectures with out the presence of an Experimenter, correlated with the student’s level of understanding the lecture material. Also, with respect to facial expressions, parental ratings of children’s temperament may help answer questions of individual differences.

**CONCLUSION**

To better understand the role of nonverbal behaviors as a reflection of cognitive processing in children, the present studied characterized eye gaze patterns and facial expression production in younger school-age children during problem-solving contexts. Two visual-spatial tasks were utilized to characterize eye gaze and facial expression patterns while children were thinking and answering. Results indicate that there are developmental eye gaze patterns that vary with age and level of task difficulty, which reflect the cognitive process of thinking. Furthermore, a late developmental and gender trend in facial expression production indicates that cultural display rules influence how males and females use facial expressions in problem-solving contexts. By characterizing the development and use of nonverbal behaviors in problem-solving contexts, we can better understand children’s problem-solving processes and their development, and how the social environment plays a role. In addition, these findings will provide a foundation for future research with atypical populations.
REFERENCES


APPENDIX

EYE CONTACT AND FACIAL EXPRESSION MEANS
Table 1. Mystery Box Input Phase: Proportion of Participants Who Make Eye Contact

<table>
<thead>
<tr>
<th>Object</th>
<th>Younger</th>
<th>Older</th>
<th>Adults</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
</tr>
<tr>
<td></td>
<td>M(SD)</td>
<td>M(SD)</td>
<td>M(SD)</td>
</tr>
<tr>
<td>Square</td>
<td>.60(.52)</td>
<td>.20(.42)</td>
<td>.10(.32)</td>
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<td>.40(.51)</td>
<td>.10(.32)</td>
<td>.10(.32)</td>
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<tr>
<td>Cylinder</td>
<td>.40(.52)</td>
<td>.30(.48)</td>
<td>.10(.32)</td>
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<tr>
<td>Dinosaur</td>
<td>.30(.48)</td>
<td>.10(.32)</td>
<td>.10(.32)</td>
</tr>
<tr>
<td>Duck</td>
<td>.30(.48)</td>
<td>.10(.32)</td>
<td>.20(.42)</td>
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Table 2. Mystery Box Latency Phase: Proportion of Eye Contact Duration

<table>
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<td>M(SD)</td>
<td>M(SD)</td>
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<td>Cylinder</td>
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<td>Dinosaur</td>
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<td>Duck</td>
<td>.34(.39)</td>
<td>.23(.37)</td>
<td>.12(.32)</td>
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### Table 3. Mystery Box Answer Phase: Proportion of Eye Contact Duration

<table>
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</tr>
<tr>
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<td>M(SD)</td>
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<td>.59(.48)</td>
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<td><strong>Duck</strong></td>
<td>.60(.38)</td>
<td>.44(.35)</td>
<td>.05(.17)</td>
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### Table 4. Mystery Box Turn Surrender: Proportion of Participants Who Make Eye Contact

<table>
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<td>M(SD)</td>
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<td><strong>Duck</strong></td>
<td>.80(.42)</td>
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### Table 5. Safari Puzzle 1 Average Frequency of Facial Expressions

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<th>Facial expression</th>
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<td>5.2(2.28)</td>
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<td>Negative</td>
<td>.40(.22)</td>
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<tr>
<td>Other</td>
<td>.52(.22)</td>
<td>.44(.24)</td>
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### Table 6. Safari Puzzle 2 Average Frequency of Facial Expressions

<table>
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<th>Facial expression</th>
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<tbody>
<tr>
<td>Facial expression</td>
<td>4.8(.95)</td>
<td>2.78(.72)</td>
<td>1.6(.93)</td>
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<td>Negative</td>
<td>1.8(.73)</td>
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<td>0(0)</td>
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<td>Other</td>
<td>.63(.27)</td>
<td>.33(.24)</td>
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Table 7. Safari Puzzle 3 Average Frequency of Facial Expressions

<table>
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<tr>
<td>Facial expression</td>
<td>5.8(4.59)</td>
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<td>6.78(5.12)</td>
<td>7.8(5.73)</td>
<td>5.2(2.28)</td>
<td>9.24(7.68)</td>
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<tr>
<td>Total Positive</td>
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<td>2.62(2.87)</td>
<td>5.11(4.64)</td>
<td>2.6(1.26)</td>
<td>2.8(2.38)</td>
<td>5.92(6.6)</td>
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<tr>
<td>Negative</td>
<td>3.1(3.72)</td>
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<td>.44(.88)</td>
<td>1.4(1.89)</td>
<td>1.2(1.79)</td>
<td>1.04(1.43)</td>
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