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DEVELOPMENTAL CHANGES IN THE CAPACITY TO PROCESS FACE INFORMATION

A Thesis in

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by

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Abstract

The ability to recognize a face is an ability that improves with age. There is evidence that these improvements in performance are quantitative rather than qualitative, and have been interpreted as an increase in processing capacity (Itier & Taylor, 2004). We report results from a set of experiments designed to apply a precise, theoretically-motivated measure of capacity (Townsend & Nozawa, 1995) to this developmental question. Experiment 1 addressed two important questions: (a) whether children could complete the large number of trials needed to effectively use these capacity measures and (b) whether greater variability of children's response times would prevent clear inferences from being made about changes in processing capacity. The results of Experiment 1 showed that children could complete the large number of trials needed to effectively use these measures of capacity and that interpretable inferences about changes in processing capacity could be made for children using these measures. There was also evidence of an age-related increase in the capacity to process redundant target dot stimuli with age. The purpose of Experiment 2 was to use these measures to test the hypothesis that there are age-related changes in the capacity to process face information, specifically changes in configural and featural information. The results of Experiment 2 provided support for this hypothesis. Taken together, this work suggests (a) precise measures of processing capacity are available to use in studies of children (b) a more precise and theoretically-driven account of age-related changes in the capacity to process face information was possible using these measures (c) a parallel can be drawn between the age-related increases in processing capacity in both experiments.

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dedicated to my grandparents

Chapter 1

Introduction

The human face is a dynamic, content-rich source of visual information. It is the basis for verbal and nonverbal communication and provides a wealth of data that humans use to guide their behavior during social interactions. Adults are generally quite good at processing face information. A unitary glance at a face can provide an adult with a vast amount of information about another person's identity, age, race, gender, and emotional state. Adults can use this information to perform a multitude of tasks including the recognition of familiar faces, the discrimination of changes within a face and and the discrimination of differences between faces. Children are generally not as proficient as adults at face recognition and the detection of changes in face information (for reviews, see Chung & Thomson, 1995; Taylor, Batty & Itier, 2004). However, they do show improvements in these skills with age, including age-related decreases in mean response times (Carey & Diamond, 1994; Mondloch, LeGrand & Maurer, 2002) and increases in mean accuracy (Carey & Diamond, 1994; Mondloch, LeGrand & Maurer, 2002) and mean d' scores (Flin, 1985; Itier & Taylor, 2004) on face recognition and detection tasks. At this level of analysis, these changes can be interpreted as age-related improvements in overall speed, accuracy and sensitivity in face recognition and discrimination abilities.

Researchers have focused a great deal of attention on understanding and explaining the mechanisms responsible for age-related improvements in performance on face recognition and perception tasks. One debate within the literature is whether children perform worse than adults on these tasks because they encode and rely on qualitatively distinct information from the face than adults or whether there is a quantitative change in the manner in which children encode and rely on the same information from the face as adults, but do so less efficiently. Itier and Taylor (2004) provided evidence of age-related improvements in speed, accuracy and sensitivity on a face recognition task and suggested that an age-related increase in the capacity or efficiency to process face information might be one factor that is responsible for these quantitative improvements in face recognition.

The goal of the present study was to test the hypothesis that there are age-related increases in the capacity to process face information. Processing capacity is a construct that is often poorly defined in the literature and the statistical tests that are used to test hypotheses regarding changes in processing capacity are rarely linked to theoretical definitions (Townsend & Wenger, 2004a,b; Wenger & Gibson, 2004). The current study used a formal, theoretical definition of processing capacity and tested the hypothesis that there are age-related improvements in the capacity to process face information using statistical tests that can be linked to this theoretical definition. Processing capacity was defined as the way the perceptual system performs across changes in workload and changes in capacity were tested at the level of the hazard function of the response time distribution (Townsend & Ashby, 1978; Townsend & Nozawa, 1995; Townsend & Wenger, 2004a; Wenger & Townsend, 2000; Wenger & Gibson, 2004). This measure of processing capacity has been used in previous studies of face perception with adults to test for changes in processing capacity that occur at the level of configural and non-configural face information (Ingvalson & Wenger, 2005; Wenger & Townsend, 2006).

1.1 Development of Face Processing: Theoretical Accounts

1.1.1 Evidence for a Qualitative Change

The Switch In Processing Mode Hypothesis

Carey and Diamond (1977) offered one of the earliest theoretical explanations for developmental differences in face recognition abilities. They suggested that children encode face information in a qualitatively distinct manner than adults. This suggestion was based on the assumption that humans can represent face information in two distinct ways: (a) as a piecemeal representation or (b) as a configuration.

The assumption that humans can encode face information either as a piecemeal representation or as a configuration can be traced to work by Yin (1969, 1970). Yin (1970) tested the ability of typical adults and adults with right posterior brain damage to recognize face and non-face stimuli in upright and inverted orientations. Typical adults showed an inverse relationship between a high accuracy to recognize upright faces and a low accuracy to recognize the same faces when they were inverted. Patients with brain damage were 2 to 10% less accurate at recognizing upright faces than the control group and showed no effects of inversion. All participants failed to show an inversion effect for non-face objects.

Based on these results, Yin (1970) concluded that brain-damaged patients did not show an inversion effect and had similar patterns in performance for faces and non-face objects because they represented faces in the same manner as non-face objects. More specifically, Yin (1970) suggested that humans had the ability to encode face information in two independent ways: (a) as a piecemeal representation or (b) as a configuration. He argued that patients with damage to the right hemisphere were encoding face information similarly to objects, as a piecemeal representation, because encoding information as a configural representation required an intact right hemisphere while piecemeal encoding did not. Following this line of thinking, he concluded that encoding face information as a featural representation subsequently led to a decrease in the ability of the brain damaged-patients to accurately recognize upright faces.

Carey and Diamond (1977) agreed with Yin's (1970) suggestion that face information could be encoded as a piecemeal representation or as a configuration and used this conceptual framework to test and interpret the ability of 6, 8, and 10 year old children to recognize upright and inverted faces and houses. They reported that by age 10, children were more accurate at recognizing upright than inverted faces compared to children under the age of 10, who performed equally well in both conditions. The equivalent accuracies across the upright and inverted conditions for younger children was a pattern similar to those reported by Yin (1970) for patients with right posterior lesions. Carey and Diamond (1977) thus concluded that children under the age of 10 were encoding and relying solely on a piecemeal representation. They referred to this as the "switch in processing mode" hypothesis.

The switch in processing mode hypothesis suggests that children under the age of 10 encode and rely on featural information (e.g. the size or shape of the eyes, nose or lips) for the recognition of upright faces. After the age of 10, children are proposed to transition from encoding faces as a piecemeal representation (featural information) to encoding and relying on the spatial relationships or the relative distance between the isolated features (configural information). Diamond and Carey (1977) provided evidence in support of their hypothesis by showing that children under the age of 10 were more susceptible to errors in recognition when unfamiliar faces wore disguises (e.g., hats, sunglasses). They concluded this was further evidence that children under the age of 10 encoded faces based on their features rather than their configurations and as a result, these added "features" of the face were encoded as part of the piecemeal representation interfering with recognition.

The Expertise Hypothesis

More recent reports of infants processing configural face information (Cohen & Cashon, 2001) and face inversion effects in 4-months-olds (Turati, Simion, Milani & Umilt, 2002) have been cited as evidence against the switch in processing mode hypothesis. The argument against this hypothesis is that children under the age of 10 should not be responsive to changes in configural face information if they are only encoding and relying on featural information. The fact that young infants showed evidence of encoding and responding to configural face information led to the suggestion that children, like adults, can represent face information as a configuration.

An alternative account for these improvements was proposed by Diamond and Carey (1986) in the form of the expertise hypothesis, which argues that the inversion effect is a marker of expertise that increases in magnitude as a person becomes an expert at a specific type of stimulus (face or non-face). This theory proposes that both featural and configural information are available simultaneously, but a person encodes a stimulus more in terms of its configuration than as a piecemeal representation with increasing experience. Several researchers have reported an increased inversion effect for children on face recognition and discrimination tasks with age (Carey, 1992; Carey & Diamond, 1994; Mondloch, LeGrand & Maurer, 2002; Schwarzer, 2000), documenting an increase in the inversion effect for children on face recognition and perception tasks with age. These results suggest that as children grow older, they encode and rely more on the configuration of the stimulus, which leads to improvements in their performance on recognition tasks.

1.1.2 Evidence for a Quantitative Change

Contrary to predictions based on the expertise theory, Flin (1985) and Itier and Taylor (2004) each documented a steady improvement in face recognition performance with age for both upright and inverted faces using accuracy, reaction time and d' scores. Based on these results, Itier and Taylor (2004) suggested a quantitative account for the development of face processing. Unlike the switch in processing mode hypothesis, this account proposes that children process faces in the same manner as adults, but do so less efficiently. This account challenges the expertise hypothesis by suggesting that children do not become more reliant on configural information with age, but show a steady improvement in their use of configural information becoming more efficient at using this information as they get older. Itier and Taylor (2004) reasoned that their pattern of results and the pattern of results in the study by Flin (1985) provided data supporting this explanation because measures of d' showed a gradual increase in the sensitivity to recognize upright and inverted faces with age.

Itier and Taylor (2004) conjectured that the steady improvements in face recognition with age could be due to an age-related increase in the capacity to process face information. More specifically, they suggested that an increased efficiency to process face information with age. They linked this increase in efficiency to the maturation of attentional and memory processes rather than an increased reliance on configural cues as predicted by the expertise hypothesis. At least one other study (Diamond & Carey, 1977) has suggested that age-related improvements in face recognition might be the result of a developmental increase in the capacity to process face information.

1.2 Testing for Age-Related Changes in Processing Capacity

Although it has been suggested age-related improvements in performance on face recognition and perception tasks might be the result of an increase in capacity, no one has directly tested this hypothesis. One reason is that definitions of processing capacity are often vague and statistical tests used to test hypotheses of changes in capacity are rarely linked to logically-precise theoretical definitions. The present study provided a test of the hypothesis that there are age-related increases in the capacity to process face information using logically-precise definitions and theoretically-motivated statistical measures. Processing capacity was precisely defined as the instantaneous intensity of processing and the cumulative amount of work the perceptual system is capable of completing across variations in workload. It was represented at the statistical level of the hazard and integrated hazard functions of the response time (RT) distribution (Townsend & Ashby, 1978; Townsend & Nozawa, 1995; Townsend & Wenger, 2004a; Wenger & Townsend, 2000). At the level of the hazard function, support for the hypothesis would be evident as a reliable increase in the ordering of the hazard functions for two independent changes in configural and featural face information relative to two simultaneous changes in configural and featural information. At the level of the integrated hazard function, evidence in support of the hypothesis would be reflected by an increase in the ratio of cumulative hazard functions for simultaneous and independent changes in face information. The increasing ratio would indicate a greater efficiency to process simultaneous changes in face information with age.

Both experiments in the present study used a redundant targets design in order to measure changes in processing capacity. Perceptual load is varied between the conditions (within subjects) in terms of the number of target stimuli that are present on any trial, and processing capacity can be measured with respect to this variation in workload. The redundant targets design provides the necessary variations in workload within observers for processing capacity to be measured in a manner directly motivated by the theoretical definition.

1.2.1 Measures of Processing Capacity

The present study used two measures of processing capacity to test the hypothesis that there are age-related increases in the capacity to process face information. The first measure is the capacity coefficient, originally developed by Townsend and Nozawa (1995). The capacity coefficient makes use of the integrated hazard function and is a measure of the cumulative amount of work a system can perform up to a particular point in time. Specifically, the capacity coefficient contrasts the cumulative amount of work that can be done when two targets are presented at the same time to the cumulative amount of work that can be done when those two targets are presented separately. If the targets are changes in featural and configural information (as is the case in Experiment 2), and if we let $H_F(t), H_C(t)$, and $H_{FC}(t)$ be the cumulative hazard functions for the two single-target conditions and the double target condition (respectively), then the capacity coefficient can be written as:

$$C\left(t\right) = \frac{H_{FC}\left(t\right)}{H_F\left(t\right) + H_C\left(t\right)} \tag{1.1}$$

The baseline for the capacity coefficient is what is obtained if one assumes that the two targets are processed independently, in parallel, and with no interdependencies in rates of processing (see Townsend & Nozawa, 1995; Townsend & Wenger, 2004a,b, for details). In that case, the cumulative amount of work that can be accomplished when two targets—the featural and configural changes—are present together is equal to the sum of the work that can be accomplished when each of the changes is presented separately. Consequently, $H_{FC}(t) = H_F(t) + H_C(t)$ and so $C(t) = 1$. and indicates unlimited capacity processing. With this as the baseline, we can consider the two other possibilities.

First, if the cumulative amount of work that can be done when there are both featural and configural changes is greater than the cumulative amount of work that can be done in the single-target conditions, when the two types of changes are presented alone, the numerator will be larger than the denominator and the capacity coefficient will be greater than 1. This means that observers were able to accomplish more processing when the configural and featural changes were presented simultaneously relative to when they were presented separately. This finding maps on to an inference of super capacity processing. Second, if the simultaneous presence of both featural and configural changes reduces the amount of processing that observers can complete, relative to when the two changes are presented separately, the numerator of Equation 1.1 will be less than the denominator and the capacity coefficient will be less than 1. This finding maps on to an inference of limited processing capacity.

The capacity coefficient has been formally related to two other measures that can be used as complementary evidence for making inferences regarding unlimited, limited, and super-capacity (Townsend & Nozawa, 1995). These measures are expressed at the level of the survivor function (i.e. $S(t)$) rather than at the level of the cumulative hazard function. The first is what is known in psychology as the Miller (1982) inequality:

$$S_{FC}(t) - S_F(t) - S_C(t) + 1 \geq 0. \tag{1.2}$$

Violations of this inequality (i.e., values less than 0) indicate extreme super-capacity processing and would be consistent with values of $C(t)$ that are above 1. The second source of converging evidence is the Grice (Grice, Canham & Boroughs, 1984a; Grice, Canham & Gwynne, 1984b) inequality:

$$\min\left[S_F(t), S_C(t)\right] - S_{FC}(t) \geq 0. \tag{1.3}$$

Violations of this inequality (i.e., values less than 0) indicate mild to moderate limited capacity processing and would be consistent with values of C(t) that are less than 1.

If the hypothesis is true and there is a developmental increase in the capacity to process face information with age, there should be an increase in the values of $C(t)$ with age (e.g.

an increase from values of $C(t) < 1$ to values of $C(t) \geq 1$ indicating a shift from limited to unlimited or super-capacity processing). Values of $C(t)$ equal or decreasing with age would not be consistent with the hypothesis. In addition, if violations of the Miller and Grice inequalities are present, violations of the Grice inequality should decrease with age while violations of the Miller inequality should increase with age indicating a shift from limited capacity processing toward unlimited to super-capacity processing. An increase in the violations of the Grice inequality with age and a decrease of violations of the Miller inequality with age would not be consistent with the hypothesis.

1.2.2 Relative Differences in Capacity

An alternative and complementary method of assessing changes in processing capacity is by characterizing performance at the level of the hazard function across levels of load. Although the parametric estimation of hazard functions can be extremely difficult (see, e.g., Luce, 1986; Van Zandt, 2000, 2002), there is a semi-parametric method known as the Cox proportional hazards model (Cox, 1972) that allows for robust estimation of differences in hazard functions (see Wenger & Gibson, 2004). The Cox proportional hazards model is a regression model for survival data and assesses changes in capacity at the level of the hazard function rather than at the level of the integrated (cumulative) hazard function as does the capacity coefficient. One of the advantages of using this regression model is that it is considered semi-parametric: it estimates the effect of varying experimental factors without making any assumptions about the shape of the underlying hazard function. The general form of the Cox proportional hazards model is:

$$h_i = \lambda_0\,(t)\exp\left(\beta_1 x_{i1} + ... + \beta_k x_{ik}\right) \tag{1.4}$$

In this equation $\lambda_0\,(t)$ represents the baseline hazard function, which can be the hazard function for any experimental variable as long as the covariates all have values of 0. In this example factor i at time t is the product of the unspecified baseline hazard function $\lambda_0\,(t)$ and a linear function of a set of k exponentiated covariates.

The present study used the Cox proportional hazards model to test the effect of processing load. Assume that target trials are changes in configural and featural face information (as in Experiment 2). This model tests the effect of single-targets (a change in configural or featural information) on processing relative to the effect of double targets (changes in both types of information). In order to test the effect of load on processing, two instantaneous hazard functions are calculated: one for single-targets $(h_F\,(t) + h_C\,(t))$ and another for double-targets $(h_{FC}\,(t))$. A ratio of these hazard functions is taken in order to estimate the effect of perceptual load when it is increased from single-target changes to double-target changes in face information and can be represented as:

$$\frac{h_{FC}(t)}{h_F(t) + h_C(t)} = \exp[\beta_1(x_{FC1} - (x_{F1} + x_{C1})] \quad (1.5)$$

It is important to note that when the ratio of two hazards is taken following this model, the baseline hazard cancels out. This means that the individual hazard functions should be strictly parallel or at a constant ratio to each other over time. Following the example above, if any of the estimated values for β are reliably different from 0, it indicates a reliable ordering of the hazard functions for the associated independent variable. More specifically, if the perceptual load in the example above produces a reliable ordering on the hazard functions for the single and double-target conditions where $h_{FC}(t) > (h_F(t) + h_C(t))$. This can be interpreted as an increase in the capacity to process changes in face information as the perceptual load increased. In sum, the capacity coefficient (Equation 1.1), the Miller (Equation 1.2) and Grice (Equation 1.3) inequalities allow us to draw qualitative inferences regarding any changes in capacity as a function of age, and the Cox model allows us to quantify the relative magnitude of changes in capacity as a function of age.

1.2.3 Summary of Hypotheses and Related Predictions

Previous studies have reported improvements in face recognition with age characterized by decreases in mean reaction time and increases in accuracy, and d' scores. Researchers have suggested these improvements may be the result of an increase in the capacity to process face information with age (e.g. Carey & Diamond, 1977; Itier & Taylor, 2004). The goal of the present study was to test this hypothesis using a theoretically-motivated definition of capacity and statistical tools specifically relevant to that definition.

If there is an age-related increase in the capacity to process face information, there should be evidence of it reflected by the measures of processing capacity used in this study: $C(t)$, the Miller and Grice inequalities and the Cox proportional hazards model. First, values of the capacity coefficient should increase with age (e.g., shift away from a limited capacity to process changes in configural and featural face information toward an unlimited or super-capacity processing). If present, violations of the Grice inequality should decrease with age indicating a shift away from mild to moderately limited capacity, while violations of the Miller inequality should increase with age indicating a shift toward unlimited to super-capacity processing. Finally, values of β for the Cox proportional hazards model should reliably increase with age indicating improved efficiency to process face information with age.

Chapter 2

Experiment 1

2.1 Purpose

The goal of this study was to use theoretically-motivated measures of processing capacity to test the hypothesis that there are changes in the capacity to process face information with age. These measures of processing capacity have only been used in studies with adults. Two major factors were of concern in terms of using these measures with children: (a) The approach that was used requires a large number of trials per observer per stimulus condition. This is because it is necessary to estimate the entire response time distribution for each observer for each stimulus condition. (b) It is quite possible that children are more variable in their responses than adults and this greater variability might produce data that are not interpretable using the proposed measures (e.g., distributional overlap due to large variances within each stimulus condition).

The first experiment was designed as a redundant targets task similar to the one reported by Townsend and Nozawa (1995) with both children and adults as observers. The data provided by this design would allow us to assess the tractability of the approach in the simplest possible way, with a direct comparison to published results (Townsend & Nozawa, 1995).

2.2 Methods

2.2.1 Participants

Four adults and seven children participated in this experiment. The adults were three females (ages 20, 20, and 21) and one male (age 28). The children were recruited via a local internet advertisement. Of the seven children that participated, four were males (ages 5, 9, 10, and 12) and three were females (ages 5, 6, 13). All participants had normal to corrected-to-normal vision and unencumbered use of both hands. None of the participants had ever been diagnosed with a language, hearing, visual, neurological, developmental or psychiatric disorders. They were checked for impairments in color perception using the Ishihara colorblindness test. Participants were paid $8 per hour for their participation.

Children were also given the opportunity to select a small gift from a prize box.

2.2.2 Materials

There were four types of target stimuli: one dot presented .5 ° to the left of fixation, one dot presented .5 ° to the right of fixation, and two dots presented .5 ° to the left or right of fixation and no dots. The size of each dot was .2 °. The luminance of each dot was 7.1 cd/m^2. The dots were presented against a 50% gray background (RGB value 149), (see Figure 2.1).

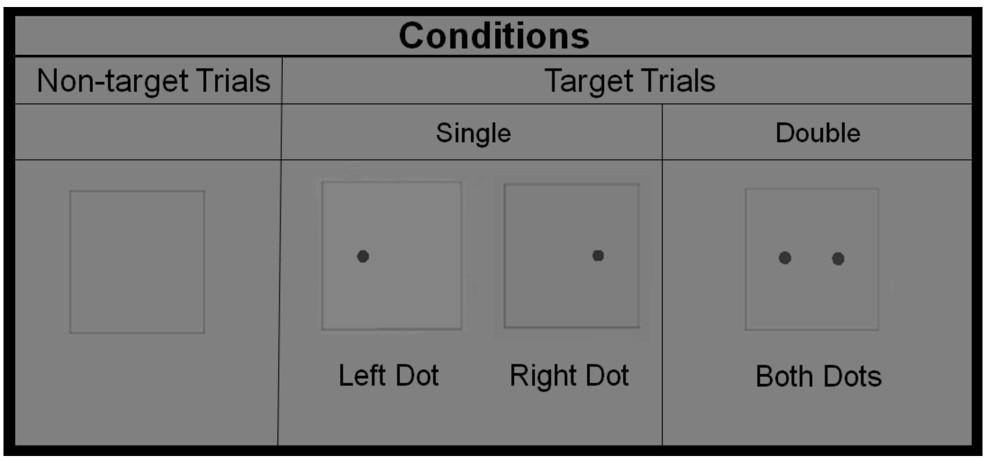

Figure 2.1: Experiment 1: Four Types of Stimulus Displays

2.2.3 Design and Procedure

The experiment was conducted as a 2 (left dot: present or absent) × 2 (right dot: present or absent) factorial design. Participants completed 1 to 2 sessions and a minimum of 840 and a maximum of 1680 trials with the number varying due to scheduling conflicts. Sessions were scheduled within two weeks of each other. Each session lasted approximately 60 minutes. Adult participants began each session with five minutes of dark adaptation. The door to the testing room was kept partially open during testing sessions with children so they could be monitored during the task. Although children were not adapted to the dark by conventional standards (i.e. in a dark room with the door closed), the door was closed 3/4 of the way, the lights were turned off in the testing room and the laboratory during sessions, and the shades were drawn greatly minimizing their exposure to light. Participants were seated at a viewing distance of approximately 76 cm from the computer monitor. Adults used a chin rest to maintain head position; children were not required to use a chin rest.

After dark adaptation, participants completed a practice block of 16 trials. Stimulus images were presented on a computer monitor measuring 45 cm on the diagonal at a resolution of 1024 × 768 pixels. After the practice trials were complete, participants were presented with five blocks of 168 trials. Trial frequencies were set to negate contingency benefits for the double-target conditions (Mordkoff & Yantis, 1991) within each block. Participants were told they could take a break from the experiment at any point in time. Each trial was self-initiated and began with the word "READY" on the screen. When the participant was ready to begin a trial, they pressed a button on the keyboard. A fixation cross was presented with a random fore-period and a uniform distribution ranging from 600 to 800 ms. The offset of the fixation cross was followed by a 100 ms presentation of one of the four possible test stimuli. Participants responded to the presence of 1 or 2 dots by pressing the space bar on a keyboard with the index finger of their dominant hand and made no response on trials when they were presented with no dots.

The stimulus image was followed by a blank mid-gray screen for 1150 ms. Feedback images indicating the status of the participant's response (correct, incorrect, no response) were presented for 900 ms after the offset of the blank screen. In order to make the experimental task more engaging for the children, a story was presented to participants. The story asked the participants to help free captured cartoons from a jail cell that they had been placed in by a maniacal cartoon monkey. They were told that the monkey wanted to make the cartoons his servants and that each time they made a correct response, a cartoon would be freed from the jail cell. Feedback stimuli for correct answers consisted of 162 randomly presented cartoon images depicting a cartoon being freed from the jail with the word "Great Job!" written above it and "(name of cartoon) is free!" written below it (see Figure 2.2). There was a single feedback image for all incorrect trials: a frowning cartoon face with the word "Incorrect" written above it. Adults were presented with the same feedback stimuli and story, but were told that the primary purpose of the story and the images was to entertain children.

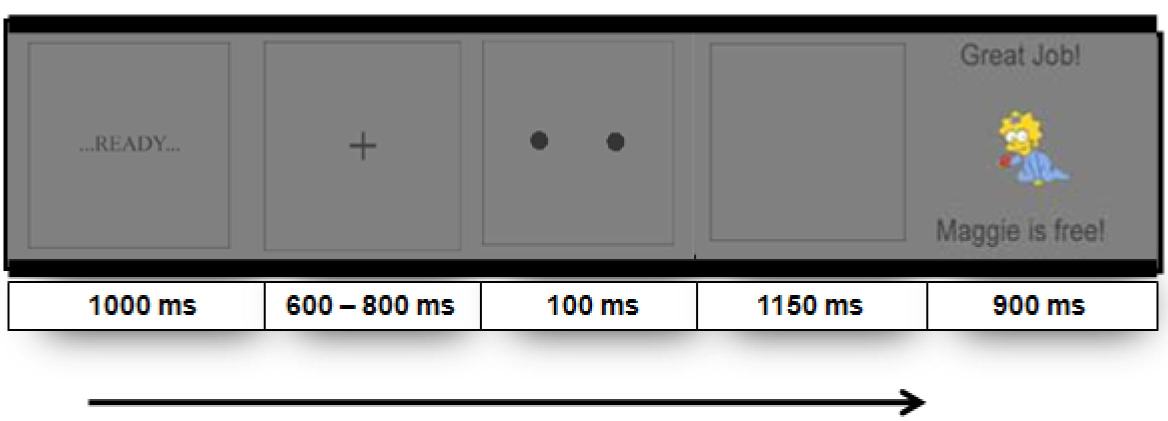

Figure 2.2: Experiment 1: Example of the Events on a Redundant Target Test Trial

2.3 Results

Only trials that elicited a correct response in the target conditions (i.e. the one or two dot conditions) were included in the analyses of the response times. Error rates in all cases were less than 3% for adults and 18% for children. In addition, responses with latencies of less than 100 ms and greater than 1300 ms (reflecting anticipatory responses or lapses in attention) were discarded prior to analyses. The alpha level used for all analyses was $< .05$.

2.3.1 Mean Response Times

Mean response times were analyzed using two-tailed, paired t-tests to test for differences in processing speed between the single-target dot and the redundant target dot conditions (see Table 2.1). The purpose of this analysis was to test the effect of perceptual load on the speed of processing. Six of the seven children and all four adults were faster when they responded to two dots (i.e. the redundant target) than when they responded to a single dot on the left or the right (see Figure 2.3). These redundancy gains were reliable for three adults, two children (ages 5 and 6), and approached reliability for one child (age 13). There was a general decrease in mean reaction times with age on single and double-target trials. In sum, these results suggest an increase in speed when participants processed redundant target dot information relative to single-target dot information. There was a decrease in mean response time with age for both single and redundant targets indicating a general, age-related decrease in processing speed for both single and double-targets. A decrease in mean response time on single-target trials is depicted in Figure 2.3 as a shift from the right of the graph to the left and a decrease in mean response time on double-target trials is depicted as a shift from the top of the graph to the bottom.

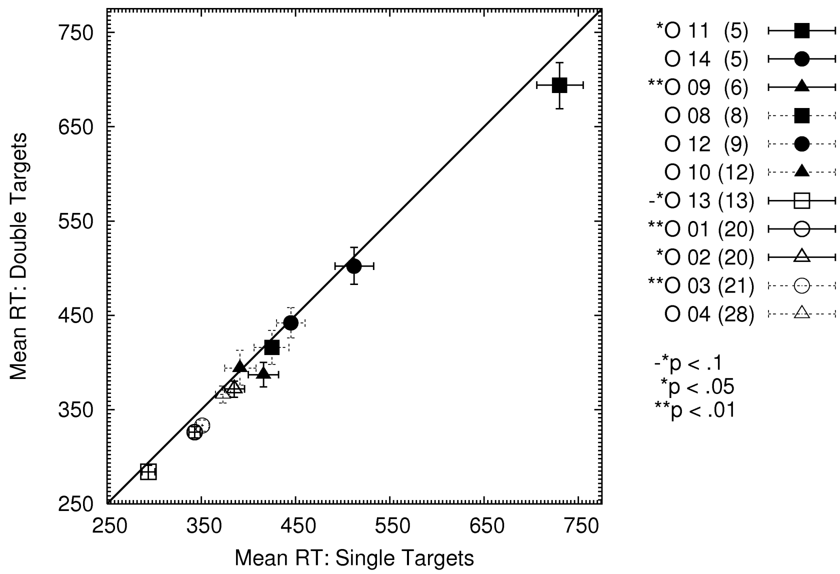

Figure 2.3: Experiment 1: Mean Response Times for Single and Double Targets by Observer/Age. Values below and to the right of the diagonal indicate faster responses on double-target trials and values above the diagonal indicate faster responses on single-target trials. The error bars represent the 95% confidence limits on the means. Observers are listed in the legend with their age in parentheses.

2.3.2 Survivor Functions

Figures 2.4-2.6 present the survivor functions for the single-target left dot, single-target right dot and double-target dot conditions. Each panel corresponds to these functions for a single observer. The more a survivor function is shifted to the right the slower the response times in the distribution for that specific condition. The purpose of plotting the survivor functions was to assess whether observers showed evidence of processing single-targets and redundant targets at different speeds at the level of the entire response time distribution. For example, if observers in this experiment processed single-target stimuli more slowly than double-target stimuli, the survivor functions for the single-target dot conditions would be located above and to the right of the survivor function for the redundant target condition. This is known as an ordering on the survivor functions. The KS_{sd} symbol in each panel represents the Kolmogrov-Smirnov test for orderings on the survivor functions. The purpose of this test was to check whether there was a reliable ordering on the response time distributions for single and double-target conditions. The reliability of this test is noted to the right of the test statistic and can be interpreted using the key at the right side of each panel.

Three of the four adults and three of the seven children showed a reliable ordering on

Table 2.1: Experiment 1: Summary of t-tests on Mean Response Times (in ms) for Single-Target and Double-Target Dot Conditions along with Redundancy Gains (in ms).

Observer	Age	Single	Double	Redundancy Gain	SE	t
4	28	374	367	7	6	1.13
3	21	352	334	18	5	3.88**
1	20	344	327	17	4	3.88**
2	20	386	372	14	7	1.97*
13	13	294	284	10	5	1.87-*
10	12	392	395	-3	13	-0.23
12	9	445	442	3	11	0.28
8	8	425	417	8	13	0.64
9	6	420	388	32	11	2.93**
11	5	731	694	36	18	2.06*
14	5	513	503	10	14	0.72

[0] $- * p < .1$ $*p < .05$ $* * p < .01$ $* * *p < .001$

the response time distributions where the distribution of responses for the double-targets was faster than the distribution of the responses on single-targets. These results indicate that many of the adults and a few of the children were processing redundant targets faster than single-targets at the level of the entire response time distribution. Observers showing a reliable ordering on the survivor functions showed a reliable ordering at the level of the mean with the exception of adult observer 04, who showed a reliable ordering on the survivor functions only.

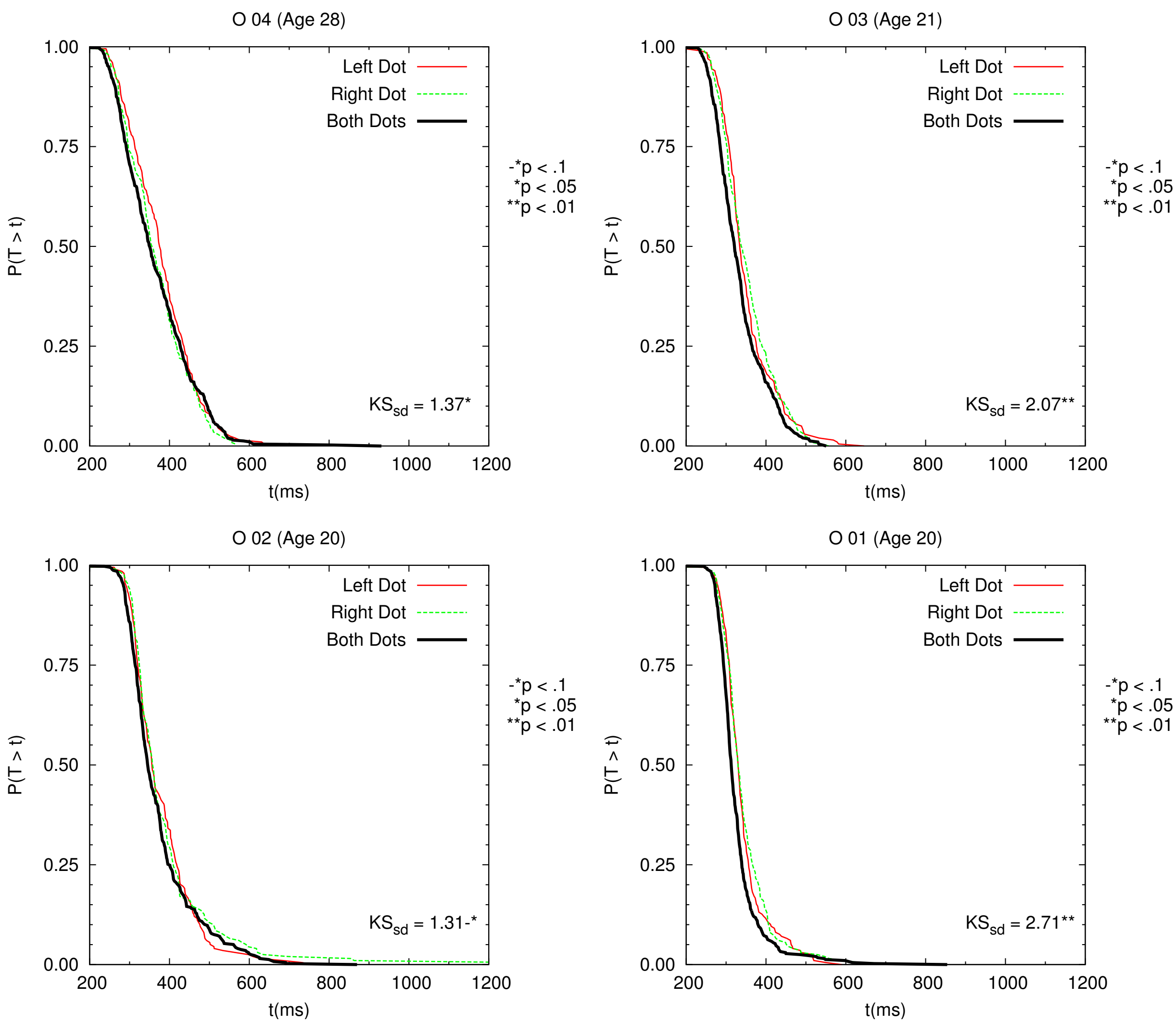

Figure 2.4: Experiment 1: Adults: Survivor Functions and Kolmogrov-Smirnov tests for Reliable Orderings on Single and Double-Target Trials

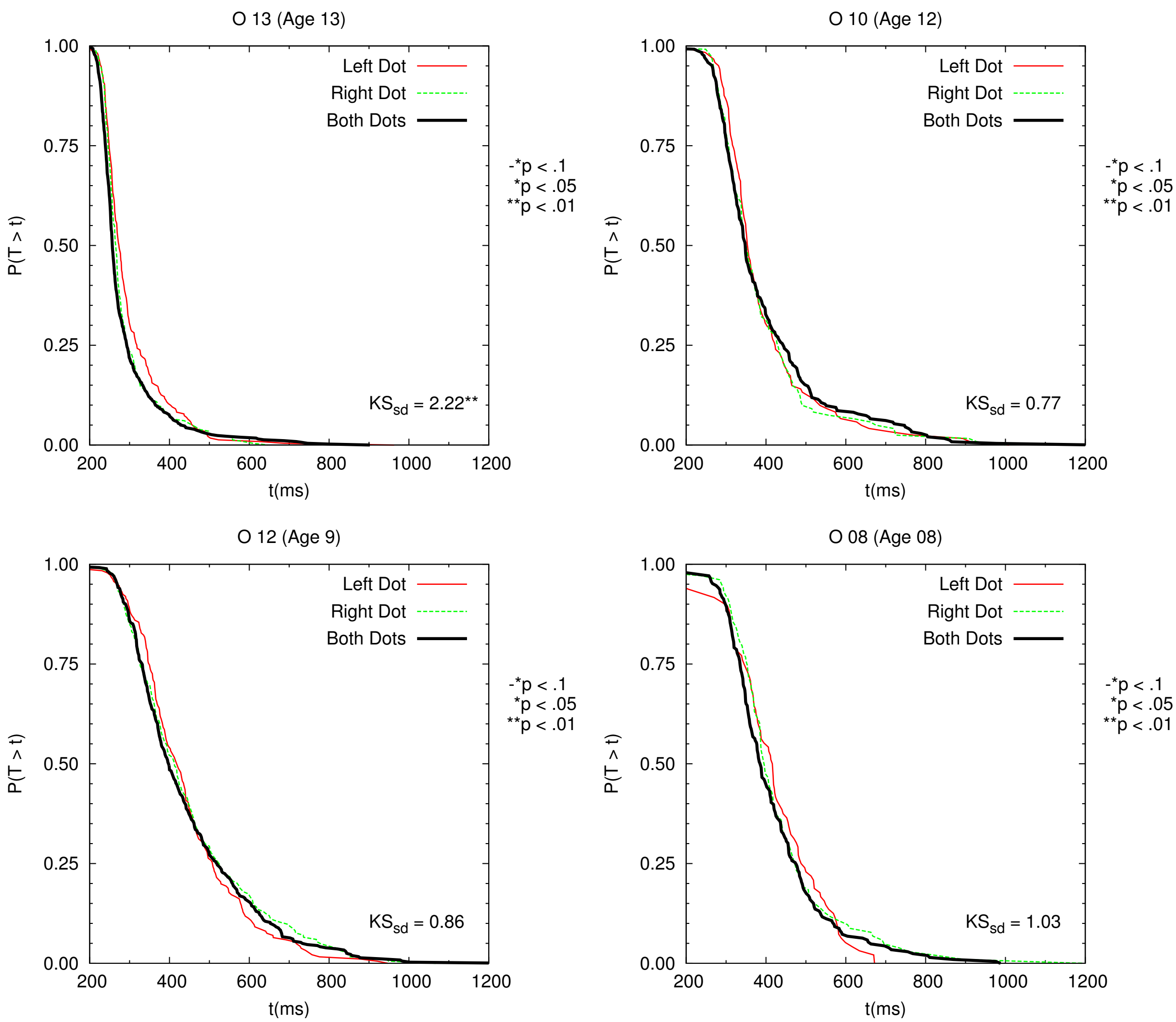

Figure 2.5: Experiment 1: Children (1 of 2): Survivor Functions and Kolmogrov-Smirnov tests for Reliable Orderings on Single and Double-Target Trials

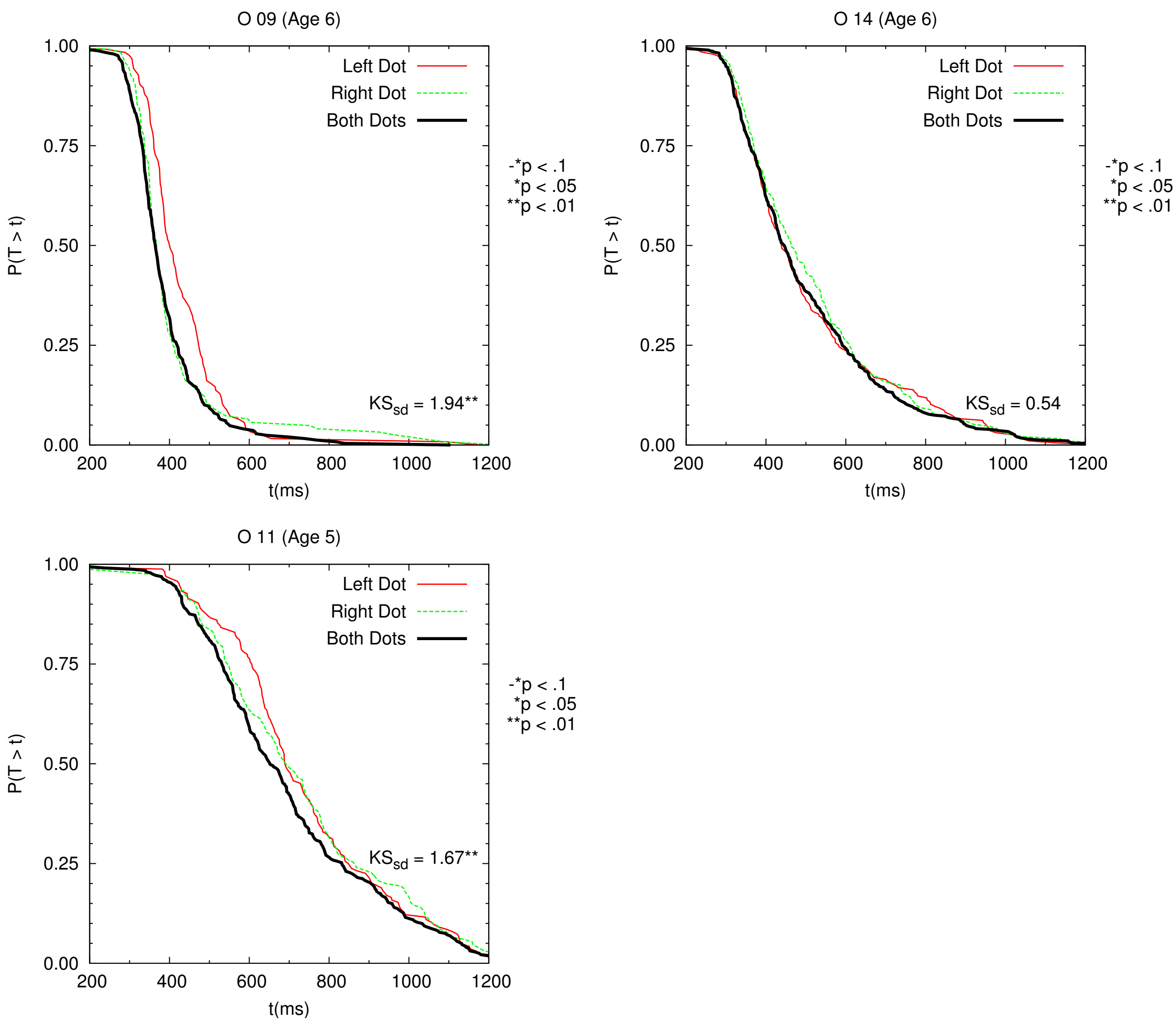

Figure 2.6: Experiment 1: Children (2 of 2): Survivor Functions and Kolmogrov-Smirnov tests for Reliable Orderings on Single and Double-Target Trials

2.3.3 Capacity

Four measures were used to make inferences about changes in processing capacity. They were the capacity coefficient, the Miller and Grice Inequalities, and the value of the hazard ratio of the Cox proportional hazards model. The purpose of analyzing these four sources of evidence in this experiment was to test whether there were age-related changes in the capacity to process simple target stimuli (i.e. 1 or 2 dots). Evidence supporting an age-related increase in processing capacity would be: (a) an increase in the values of the capacity coefficient with age, possibly accompanied by corresponding shifts in violations of the Miller or Grice inequalities and (b) an increase in the values of the hazard ratios obtained by the Cox proportional hazards model.

Capacity Coefficients, Miller and Grice Inequalities

Figures 2.7-2.9 plot the values of $C(t)$ (Equation 1.1) for the adult and child participants. Each panel contains the capacity coefficient for one participant. The left axis of each panel represents the range of values of $C(t)$, which is represented by a thick dark line in each panel. Values of $C(t)$ for three of the four adults were greater than or equal to 1 for the shortest response times (approximately 250 - 300 ms) on the response time distribution and fell below 1 after this point in time. The oldest child tested (age 13) showed a pattern similar to adults where values of $C(t)$ were greater than or equal to 1 for reaction times between 210 and 230 ms falling below 1 after that point in time. The remaining six children and one of the four adults all had $C(t)$ values below 1 at each point of the response time distribution. In sum, the values of the capacity coefficients showed a general increase with age at the shortest response times. This is evidence of an age-related increase in the efficiency to process redundant target stimuli with age ranging from a limited capacity to process redundant target dots in childhood toward an unlimited to super-capacity to process redundant targets in adulthood.

Figures 2.7-2.9 also plot values of the Miller (Equation 1.2) and Grice (Equation 1.3) inequalities. The Miller inequality is represented by a thin dark line while the Grice inequality is represented by a thin dashed line. A violation of either inequality would be indicated by a value less than 0. There were a small number of violations of the Miller inequality for three of the adults and the oldest child (age 13) in regions of the RT distribution where $C(t)$ was above 1, as would be expected by the $C(t)$ data (see Townsend & Nozawa, 1995; Townsend & Wenger, 2004a). These violations supported the inference of unlimited-capacity to super-capacity processing at points in the response time distribution where $C(t)$ was greater than 1. There were violations in the Grice inequality for two of the four adults and six of the seven children at regions of the RT distribution where $C(t)$ approached .50, which is consistent with an inference of mild to moderate limitations in processing capacity. In sum, the violations of the Miller and Grice inequalities provided supporting evidence for inferences made based on the capacity coefficient. These violations suggest an age-related increase in the capacity to process redundant target dot stimuli ranging from a mild to moderately limited capacity in childhood toward an unlimited or super capacity in adulthood.

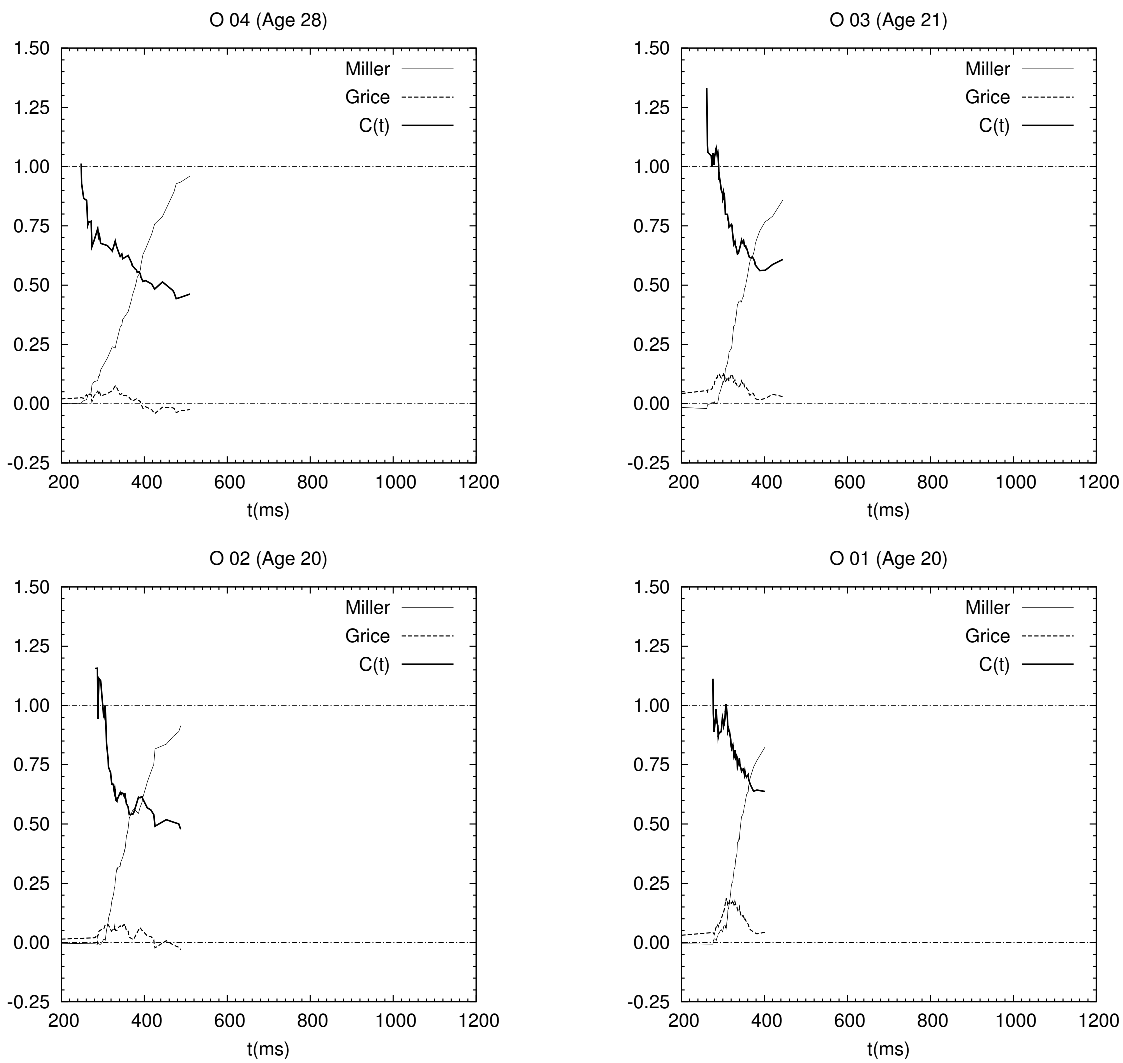

Figure 2.7: Experiment 1: Adults: Capacity Coefficients, Miller and Grice Inequalities. Lines are drawn at values of 1 and 0 on the Y axis. Values of $C(t) < 1$ indicate limited processing capacity, values of $C(t) = 1$ indicate unlimited processing capacity and values of $C(t) > 1$ indicate super-processing capacity. Values of the Grice inequality < 0 indicate limited processing capacity and values of the Miller inequality < 0 suggest extreme super processing capacity.

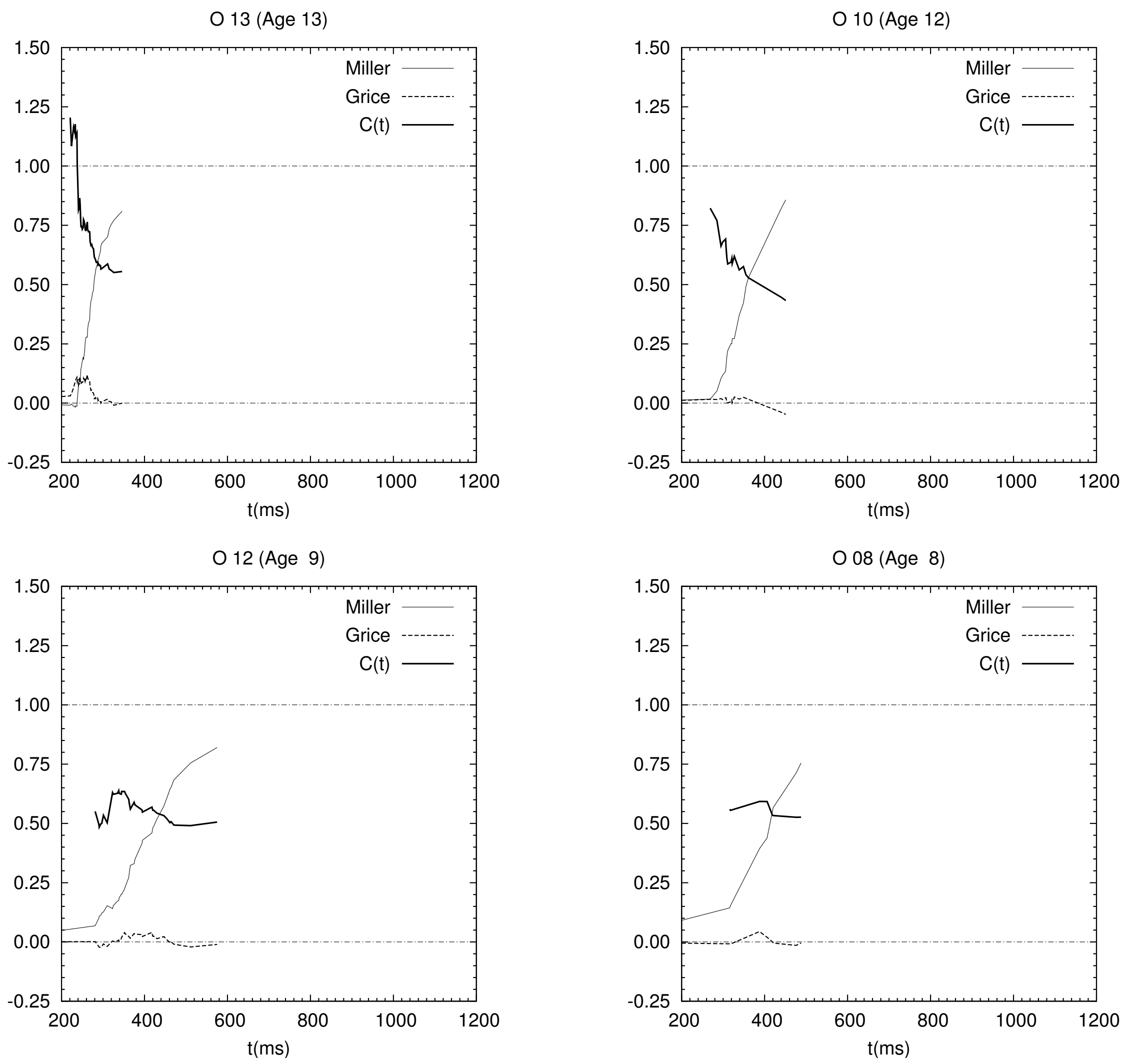

Figure 2.8: Experiment 1: Children (1 of 2): Capacity Coefficients, Miller and Grice Inequalities. Lines are drawn at values of 1 and 0 on the Y axis. Values of $C(t) < 1$ indicate limited processing capacity, values of $C(t) = 1$ indicate unlimited processing capacity and values of $C(t) > 1$ indicate super-processing capacity. Values of the Grice inequality < 0 indicate limited processing capacity and values of the Miller inequality < 0 suggest extreme super processing capacity

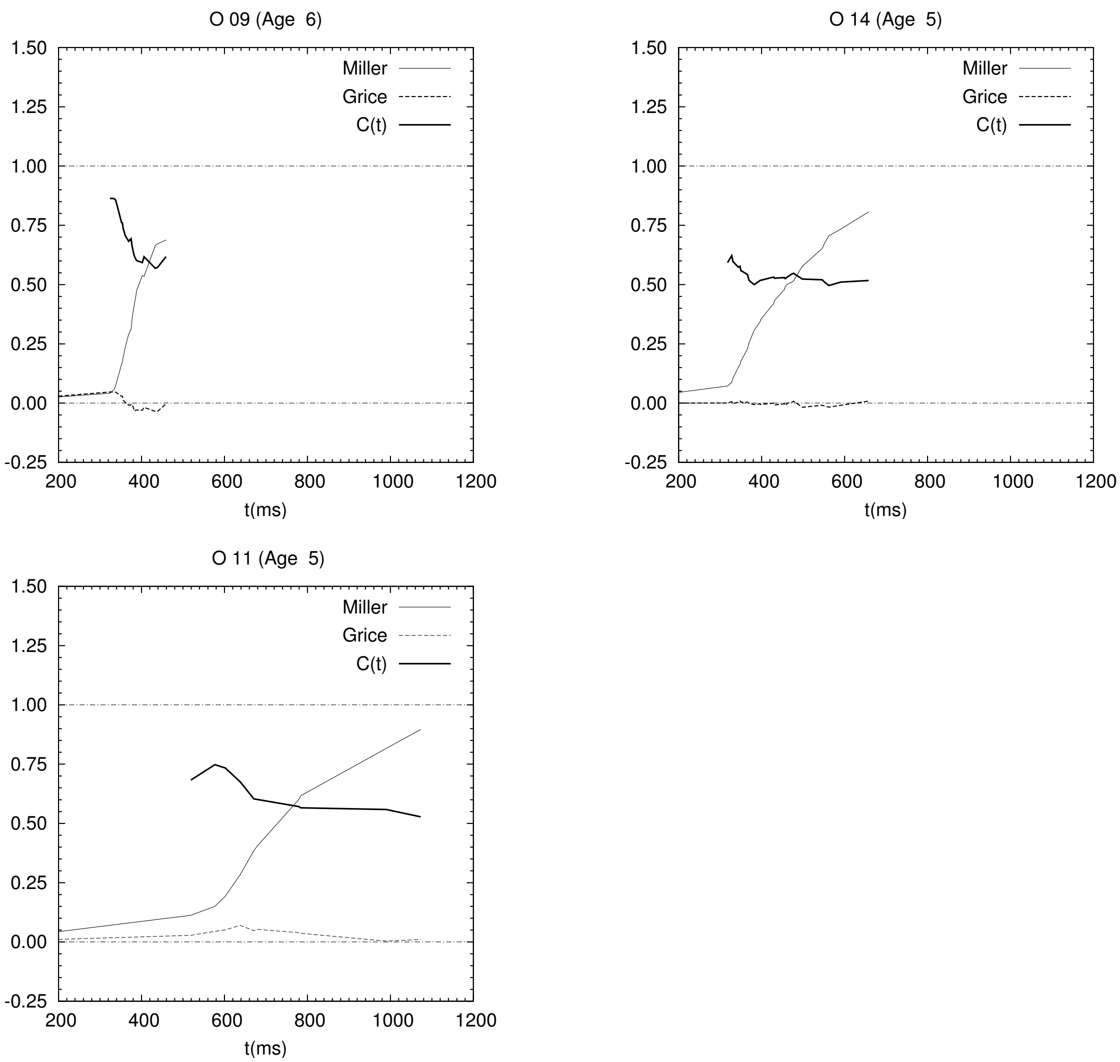

Figure 2.9: Experiment 1: Children (2 of 2): Capacity Coefficients, Miller and Grice Inequalities. Lines are drawn at values of 1 and 0 on the Y axis. Values of $C(t) < 1$ indicate limited processing capacity, values of $C(t) = 1$ indicate unlimited processing capacity and values of $C(t) > 1$ indicate super-processing capacity. Values of the Grice inequality < 0 indicate limited processing capacity and values of the Miller inequality < 0 suggest extreme super processing capacity

2.3.4 Cox Proportional Hazards Model

Hazard ratios were estimated using the Cox model and assessed for reliable changes in processing capacity when redundant target dots were processed relative to single-target dots (see Table 2.2). The purpose of estimating these ratios was to assess them for additional evidence of age-related changes in the capacity to process redundant target stimuli. Figure 2.10 shows a plot of the estimated hazard ratios by age followed by the transformation of these hazard ratios on the right where:

$$\text{Percent Increase in Capacity} = 1 - exp^{\hat{\beta}} \times 100 \tag{2.1}$$

The purpose of the right panel is to allow an easier interpretation of changes in processing capacity as the percent increase in processing capacity with age. Hazard ratios greater than 1 indicate greater efficiency processing redundant dot targets compared to processing single dot targets. The thin black line shows the regression fit measuring increases in processing capacity with age for all participants. The black dotted line shows the regression fit measuring these increases in processing capacity without observer 04 (age 28), who could be an outlier. Both of the regression lines show an increase in hazard ratios with age. This increase in the hazard ratios with age maps on to an inference of an increase in the capacity to process redundant target dot information with age.

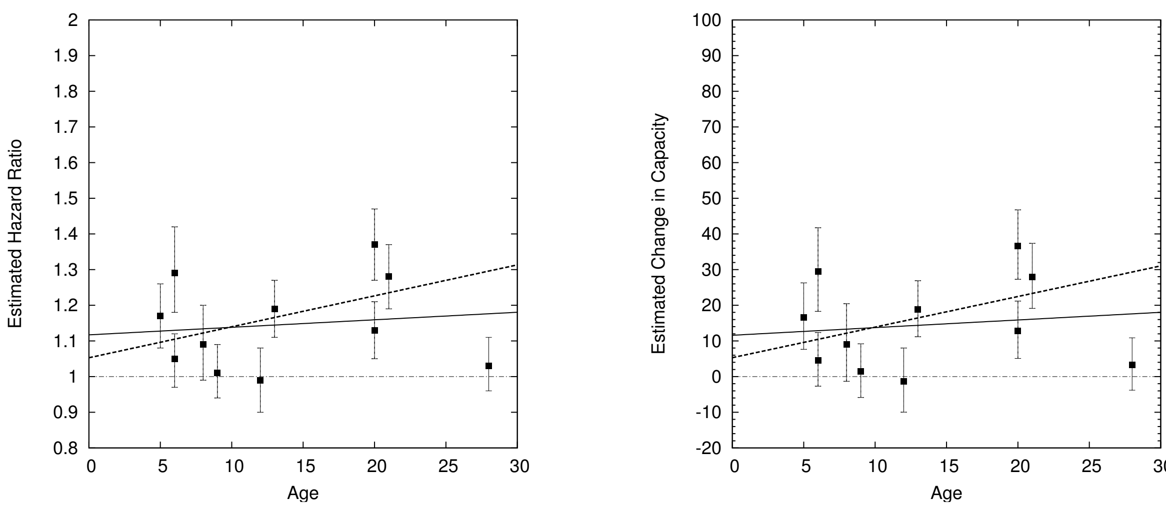

Figure 2.10: Experiment 1: Estimated Cox Model Hazard Ratios by Age. An increase in the ratios with age is evidence of an increase in the capacity to process double-target information relative to single-target information. The error bars represent the range of standard error from the mean. The thin black line shows the regression fit for all observers. The black dotted line shows the regression fit for all observers except one who might be an outlier.

Table 2.2: Experiment 1: Cox Proportional Hazards Model for Changes in Single and Double-Target Dots.

Observer	Age	$\hat{\beta}$	SE	χ^2	Hazard Ratio
O 4	28	0.032	0.071	0.21	1.033
O 3	21	0.246	0.071	11.96	1.279***
O 1	20	0.312	0.071	19.24	1.367***
O 2	20	0.121	0.071	2.89	1.128-*
O 13	13	0.172	0.066	6.79	1.188**
O 10	12	-0.014	0.091	0.02	0.986
O 12	9	0.014	0.074	0.04	1.014
O 8	8	0.086	0.100	0.75	1.090
O 9	6	0.259	0.090	8.17	1.295**
O 11	5	0.154	0.080	3.71	1.166-*
O 14	5	0.045	0.072	0.39	1.046

$^0 - * p < .1$ $\quad *p < .05$ $\quad * * p < .01$ $\quad * * *p < .001$

2.4 Discussion

The first aim of this experiment was to determine whether the measures of processing capacity could be used successfully with children. Two issues were of concern with regard to using these measures in studies of children. First, these measures of processing capacity require a large number of trials. The concern was that children might not be able to complete the number of trials required to make inferences about processing capacity using the proposed measures. All participants completed between 840 and 1680 trials, which was sufficient to calculate all of the measures. The data were also ordered sufficiently in all cases allowing interpretable results.

Second, there was concern that the greater variability in children's responses might have an impact on whether the converging sources of evidence for capacity would lead to interpretable data regarding capacity. Inferences regarding limited, unlimited and super capacity processing were consistent for both the adults and children across measures of processing capacity. Values of $C(t)$ greater than 1 were present for three of four adults and the oldest of the seven children (age 13) and corresponded to violations in the Miller inequality and no violations of the Grice inequality. These results were consistent with an inference of super processing capacity. Similarly, points in the response time distribution where values of $C(t)$ less than 1 corresponded to a handful of violations in the Grice inequality for both children and adults providing consistent evidence for limited capacity processing.

Finally, there was evidence from the regression analysis of hazard ratios and measures of the capacity coefficient suggesting a general increase in the capacity to process redundant target stimuli with age. Hazard ratios from the regression analysis showed a general increase with age. Measures of $C(t)$ also showed an age-related increase from limited processing where $C(t)$ was below 1 to unlimited to super capacity processing where $C(t)$ was equal to or greater than 1 at early points in time on the response time distribution. This finding will be discussed further in the general discussion section and becomes particularly interesting in relation to the results reported for Experiment 2.

Chapter 3

Experiment 2

3.1 Purpose

Previous studies have suggested that increases in performance on face perception and recognition tasks with age might be due in part to age-related increases in the capacity to process face information. The goal of Experiment 2 was to test this hypothesis using theoretically motivated measures of processing capacity. Studies of face perception in adults have used these measures to test differences in the capacity to process face information at the level of changes in configural and non-configural information (Ingvalson & Wenger, 2005). Age-related changes in the capacity to process face information were also tested at the level of changes in configural and featural face information in this study.

If the hypothesis is true and there are age-related increases in the capacity to process configural and featural information, a specific pattern of results should emerge on measures of processing capacity: (a) Values in the capacity coefficient should increase with age. An increase in values of $C(t)$ would imply an age-related shift away from a limited capacity to process changes in configural and featural face information toward unlimited or super capacity processing. (b) Violations of the Grice inequality should correspond to values of the capacity coefficient below 1 indicating limited capacity processing. (c) Violations of the Miller inequality should correspond to values of the capacity coefficient at or above 1 indicating unlimited to super capacity processing. (d) The hazard ratio should increase with age indicating a greater efficiency to process changes in configural and featural information simultaneously rather than independently.

3.2 Methods

3.2.1 Participants

Four adults and five children participated in this experiment. The adult participant group was comprised of one female (22 years old) and three males (ages 20, 21, and 21 years old). The children were recruited via a local internet advertisement. Of the five children that participated, one was male (age 11) and four were females (ages 6, 10, 12, and 15).

All participants had normal to corrected-to-normal vision and unencumbered use of both hands. None of the participants had ever been diagnosed with a language, hearing, visual, neurological, developmental or psychiatric disorders. They were checked for impairments in color perception using the Ishihara colorblindness test. Participants were paid $8 per hour for their participation. Children were also given the opportunity to select a small gift from a prize box. None of the children or adults participated in Experiment 1.

3.2.2 Materials

The set of face stimuli was comprised of pictures of four humans (two Caucasian males and two Caucasian females) that were in their early to mid-twenties. Individuals wore a surgical cap and scrubs in order to hide their hair and keep their clothing hidden. Images were cropped at the base of the neck and at the top of the image where the forehead met the hairline and the start of the surgical cap. All face images were presented against a 50% gray background (RGB value 149). Images were sized at 2.5 cm (v) $\times$ 2 cm (h). When viewed at a fixed distance of 76 cm, the images subtended 1.89° (vertically) and 1.51° (horizontally).

Four types of stimuli were created from each source image. An example of each of these four types of stimuli is presented in Figure 3.1. The first type of stimulus was a standard image created by taking the inner eyes of one of the models and pasting it into the contours of the eyelids of the images of other models. This procedure was used so that eye color was held constant across the face images and would not have an effect on the perception of the featural change, which was a change in the saturation of eye color. The edges of the inner eye were finely blurred in each face image so that the inner eye looked natural in all images. All standard images had irises of the eyes that were tinted blue (RGB value 0, 0, 255) at an opacity of 10%. The second type of stimulus image was created to represent a change in featural information only. These images had irises of the eyes that were tinted blue at an opacity of 100%. The third type of stimulus image created to represent a change in configural information only. Like the standard image, the irises of the eyes were tinted blue at an opacity of 10%. However, the eyes were crossed resulting in a change to the internal geometry of the face. The fourth type of stimulus was created to represent a change in both configural and featural information. These images had crossed eyes with the irises of the eyes tinted blue at an opacity of 100%.

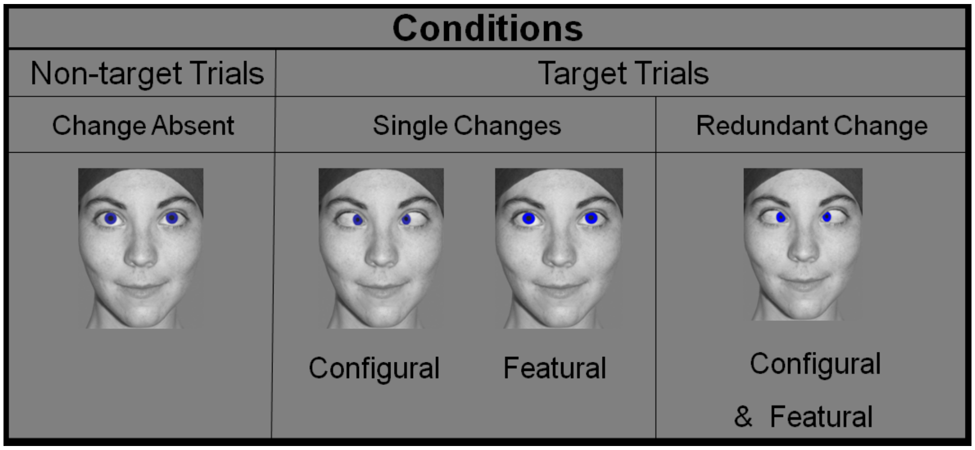

Figure 3.1: Experiment 2: Four Types of Stimulus Displays

3.2.3 Design and Procedure

The experiment was conducted as a 2 (featural change: present or absent) × 2 (configural change: present or absent) factorial design. Participants completed two or three sessions and completed a minimum of 1680 trials with variations due to problems in scheduling. Sessions were scheduled within two weeks of each other. Each session lasted approximately 90 min. Adult participants began each session with 5 minutes of dark adaptation. The door to the testing room was kept partially open during testing sessions with children so they could be monitored during the task. Although children were not adapted to the dark by conventional standards (i.e. in a dark room with the door closed), the door was closed 3/4 of the way, the lights were turned off in the testing room and the laboratory during sessions, and the shades were drawn greatly minimizing their exposure to light. Participants were seated at a viewing distance of approximately 76 cm from the computer monitor. Adults used a chin rest to maintain head position; children were not required to use a chin rest.

After dark adaptation, participants completed a practice block of 20 practice trials. Stimulus images were presented on a computer monitor with a 45 cm diagonal at a resolution of 1024 × 768 pixels. After the practice trials were complete, the participants were presented with 10 blocks of 96 trials. Trial frequencies were set to negate contingency benefits for the two-change conditions (Mordkoff & Yantis, 1991) within each block. Participants were told they could take a break from the experiment at any time point in time. Each trial was self-initiated and began with the word “READY” on the screen. When the participant was ready to begin a trial, they pressed a button on the keyboard and were presented with a standard (see description in paragraph above) face image for 1000 ms. A blank mid-gray screen was presented at a random interval with a uniform distribution between 500 and 700 ms. The test stimulus, a picture of a face with the same identity, but with a configural, featural, both a configural or featural or no change in face information was presented for

68 ms. The participants were instructed to indicate whether they perceived a change in the test stimulus by pressing a button using the index finger of their dominant hand or the same by pressing a button using the index finger of the non-dominant hand. The stimulus image was followed by a blank mid-gray screen for 1500 ms. Feedback images indicating the status of the participants response (correct, incorrect, no response) were for presented for 350 ms after the offset of the blank screen.

In order to make the experimental task more engaging for children, a story was presented to participants. They were told that at the end of each of the 10 blocks of trials they would be presented with a key to a pirates treasure. Once they earned 10 keys a pirates treasure would open and the experiment would be over. A key was presented to them after the end of each block of trials regardless of their performance. Feedback for a correct response was an image of a happy face with the word correct written above it, while only the word incorrect would appear on the screen when participants responded incorrectly. Adults were presented with the same feedback stimuli and story. However, they were told that the primary purpose of the story and the images was to entertain children.

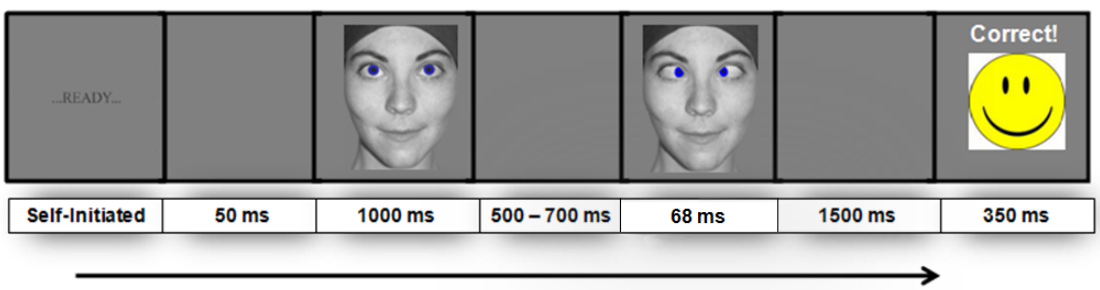

Figure 3.2: Experiment 2: Events on Each Experimental Trial

3.3 Results

Only trials on which observers responded correctly were included in the analyses. Error rates in all cases were less than 17%. Prior to analyses any latencies of less than 100 and greater than 1300 ms were discarded reflecting anticipatory responses or lapses of attention. The alpha level for all analyses was $< .05$.

3.3.1 Mean Response Times

Mean response times were analyzed using two-tailed, paired t-tests to test differences in overall processing speed between the single-target and redundant target conditions (see Table 3.1). Eight of the nine participants showed reliable redundancy gains. The remaining participant (age 11) showed redundancy gains that were marginally reliable ($p = .0657$).

These results suggest an increase in processing speed when participants processed redundant target changes in face information relative to single-target changes in face information. There was evidence of a general increase in processing speed for both single-target and redundant target conditions with age. A decrease in mean response time on single-target trials is depicted in Figure 3.3 as a shift from the right of the graph to the left and a decrease in mean response time on double-target trials is depicted as a shift from the top of the graph to the bottom.

Mean response times were also analyzed to test differences in overall processing speed between the single-target configural and single-target featural change conditions (see Table 3.2). Adult observers and one of the five children were reliably faster on single-target featural trials compared to single-target configural trials (see Figure 3.4). Two of the four children that were not reliably faster showed improvements in speed in the featural target condition that approached reliability ($p < .1$). The youngest participant (age 6) was faster on single-target configural trials at a level that approached reliability, while the second youngest participant (age 11) showed no reliable differences in mean reaction times for the two single-target conditions. These results suggest an increase in processing speed when participants processed single changes in featural face information relative to single changes in configural information. One participant (age 6) showed evidence of the opposite pattern where processing speed increased during the configural condition. In addition, there was also evidence of a general increase in processing speed for single configural and single featural targets with age. A decrease in mean response time on single configural target trials is depicted in Figure 3.4 as a shift from the right of the graph to the left and a decrease in mean response time on single featural target trials is depicted as a shift from the top of the graph to the bottom.

Overall, an analysis of the mean response times showed children and adults were faster to respond on redundant target trials compared to single target trials. Adult observers and one of the children were also reliably faster to respond to changes in featural face information compared to configural face information. There was a general decrease in mean reaction times with age for the single and redundant targets.

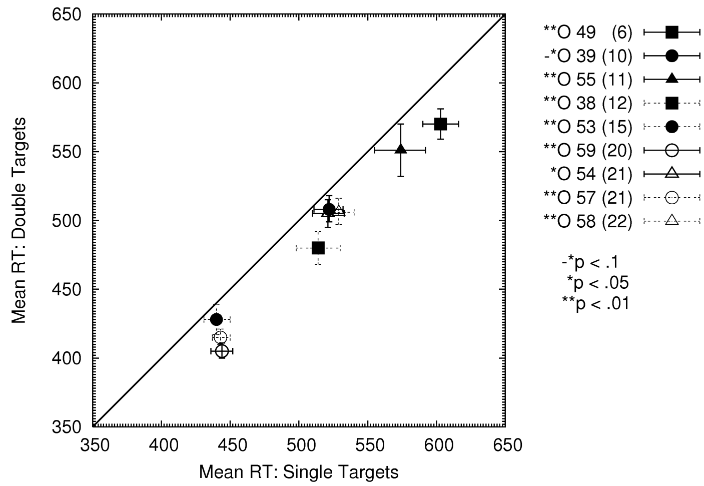

Figure 3.3: Experiment 2: Mean response Times for Single and Double Targets by Observer/Age. Values below and to the right of the diagonal indicate faster responses on double-target trials while values above the diagonal indicate faster responses on single-target trials. The error bars represent the 95% confidence limits on the means. Observers are listed in the legend with their age in parentheses.

Table 3.1: Experiment 2: Summary of t-tests on Mean Response Times (in ms) for Single-Target and Double-Target Configural and Featural Face Information along with Redundancy Gains (in ms).

Observer	Age	Single	Double	Redundancy Gain	SE	t
58	22	529	506	23	7	3.06**
54	21	521	505	16	8	2.13*
57	21	443	415	28	4	6.39***
59	20	444	405	39	5	7.78***
53	15	434	411	24	5	4.73***
38	12	495	460	36	6	5.72***
55	11	562	534	28	9	3.11**
39	10	522	508	13	7	1.84-*
49	6	603	570	33	8	3.87***

[0] $-*p < .1$ $*p < .05$ $**p < .01$ $***p < .001$

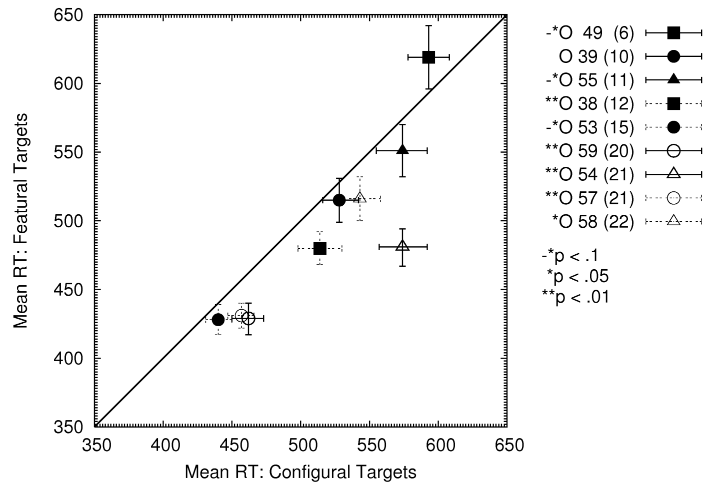

Figure 3.4: Experiment 2: Mean Response Times (in ms) for Configural and Featural Targets by Observer/Age and Redundancy Gains. Values below and to the right of the diagonal indicate faster responses on featural target trials and values above the diagonal indicate faster responses on configural target trials. The error bars represent the 95% confidence limits on the means. Observers are listed in the legend with their age in parentheses.

3.3.2 Sensitivity

Itier and Taylor (2004) reported an age-related increase in observers' sensitivity to recognize faces using the signal detection theory measures of sensitivity (d'). Values of d' were calculated for Experiment 2 only in order to determine if similar evidence of an age-related increase in sensitivity could be found for changes in single-target configural, single-target featural and double-target configural and featural information. Measures of sensitivity were calculated for a same-different design following MacMillan and Creelman (1991, 2005). A hit was defined as a trial when two different faces were presented and the observer responded they were different. A false alarm was defined as a trial when the same face was presented twice on a trial and the observer responded that the two faces were different. The sensitivity measure (d') was calculated as:

$$d' = 2z\left(\frac{1}{2}\left\{1 + \left[2p(c)_{SD,IO} - 1\right]^{\frac{1}{2}}\right\}\right) \tag{3.1}$$

where

$$p(c) = \Phi\left\{\left[z(HR) - z(FA)\right]/2\right\} \tag{3.2}$$

Table 3.2: Experiment 2: Summary of t-tests on Mean Response Times (in ms) for Changes in Single-Target Configural and Featural Face Information along with Differences in Reaction Times (in ms).

Observer	Age	Configural	Featural	Difference	SE	t
58	22	543	516	27	11	2.42*
54	21	574	481	94	11	8.39***
57	21	457	431	26	7	3.87**
59	20	462	429	33	8	4.08***
53	15	440	428	12	7	1.70-*
38	12	514	480	34	10	3.44***
55	11	574	551	23	13	1.69-*
39	10	529	515	13	11	1.27
49	6	593	619	-26	13	-1.95-*

[0] $- * p < .1$ $*p < .05$ $* * p < .01$ $* * *p < .001$

Measures of response bias (c) were also calculated as:

$$c = \frac{-.5\left[z(HR) + z(FA)\right]}{z(HR) - z(FA)} \tag{3.3}$$

Figure 3.5 reports measures of d' for [a] all conditions, [b] the double target condition, [c] the single target configural condition, and the [d] single target featural condition. There was evidence of a general increase in sensitivity with age across all trial types. There was also evidence that participants were slightly biased during the single-target configural condition to say that the two face images were the same when they were different. Younger participants (ages 5 and 11) showed a similar bias when they responded on single-target featural trials, while all other participants showed little evidence of being biased on these trials. None of the participants showed evidence of bias on double-target trials. Overall, these results suggest a general increase in sensitivity to respond to independent and simultaneous changes in configural and featural information with age. Several participants showed a slight bias toward saying there was no change in face information when there was a single configural change in face information. Two children showed evidence of a similar response bias when there was a single change in featural information.

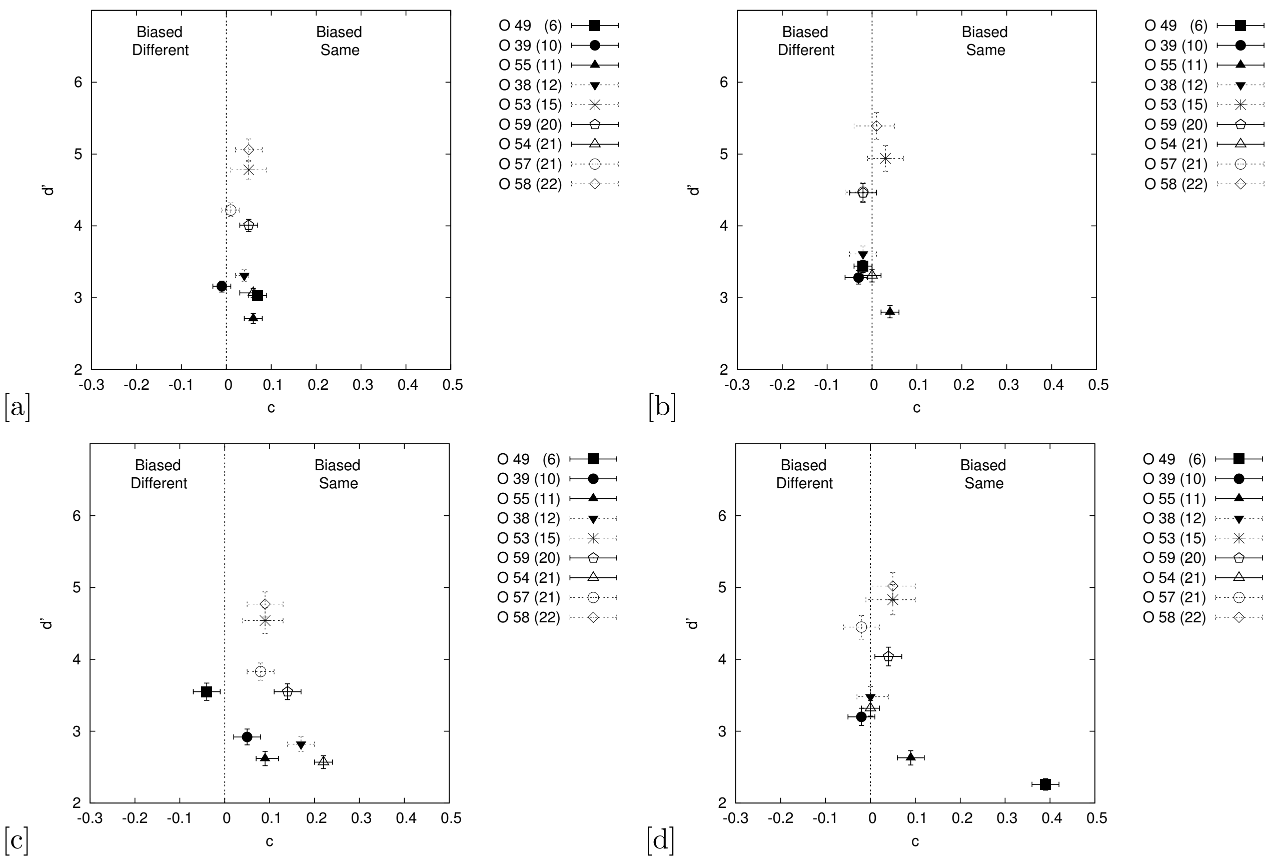

Figure 3.5: Experiment 2: Adults: Experiment 2: Sensitivity and Response Bias across Observers. Panel [a] reports values of sensitivity and response bias for all conditions, panel [b] reports values for the double target condition, panel [c] reports values for the single target configural condition, and panel [d] reports values for the single target featural condition. Values below and to the left of the line at 0 indicate a bias to say two faces were different when they were the same. Values to the right of the line at 0 indicate a bias to say two faces were the same when they were different. Observers are listed in the legend with their age in parentheses

3.3.3 Survivor Functions

Figures 3.6-3.8 present the survivor functions for the single-target configural, single-target featural and double-target configural and featural change condition. The purpose of plotting the survivor was to determine if participants showed evidence of processing single target changes in face information at a different speed than they processed redundant target face information at the level of the entire response time distribution. The KS_{sd} symbol in each panel represents the results of the Kolmogrov-Smirnov tests for orderings on the survivor functions for the single-target face versus the double-target trials. The reliability of this test is noted to the right of the test statistic and can be interpreted using the key at the right side of each panel. All participants showed a reliable ordering on the response time distributions where responses for the double target changes were faster than the responses for single-target face changes at the level of the RT distribution. The data at the level of the survivor function and the mean consistently suggested an increase in processing speed for double-target compared to single target changes in face information.

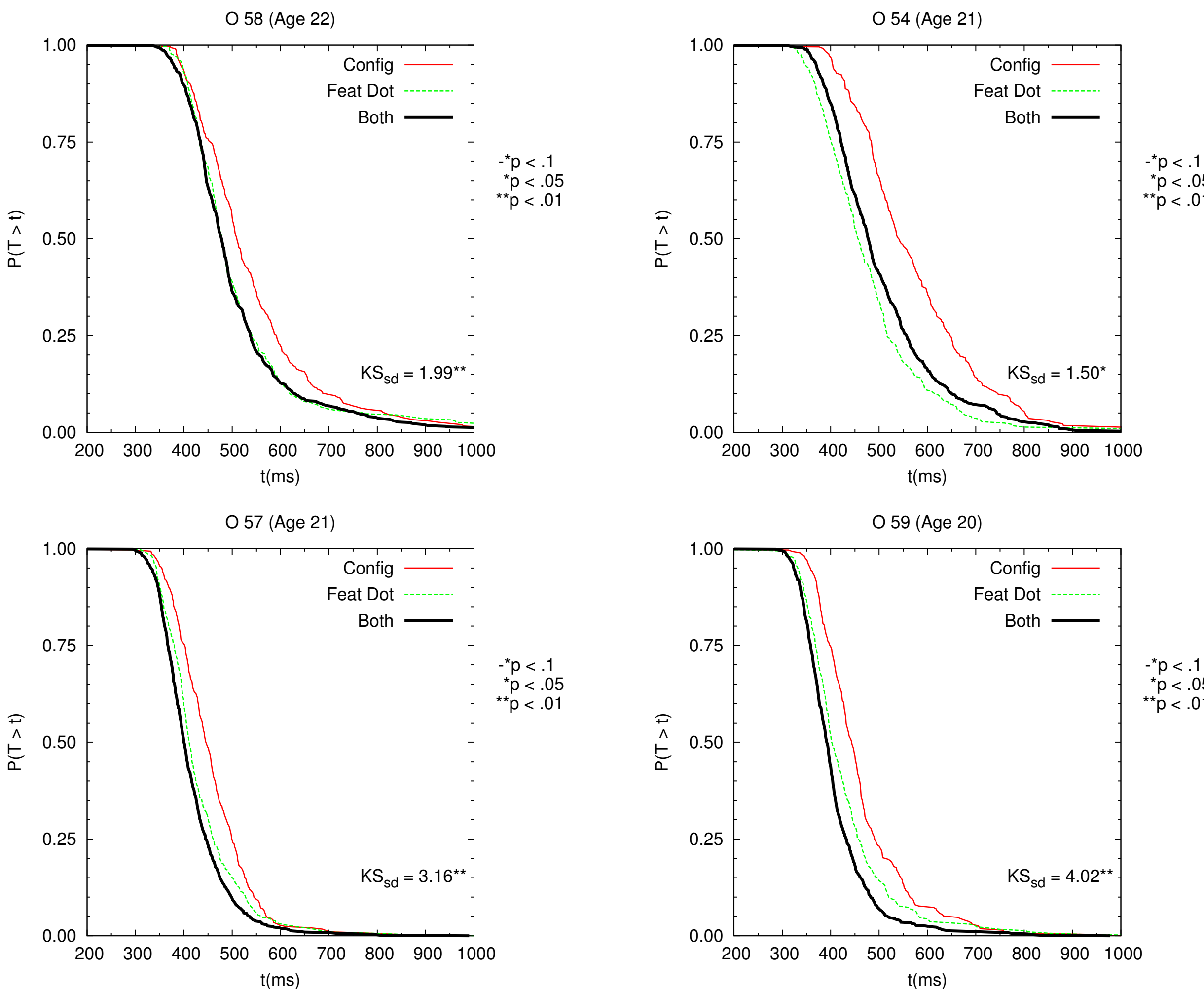

Figure 3.6: Experiment 2: Adults: Survivor Functions and Kolmogrov-Smirnov tests for Reliable Orderings on Single and Double-Target Trials

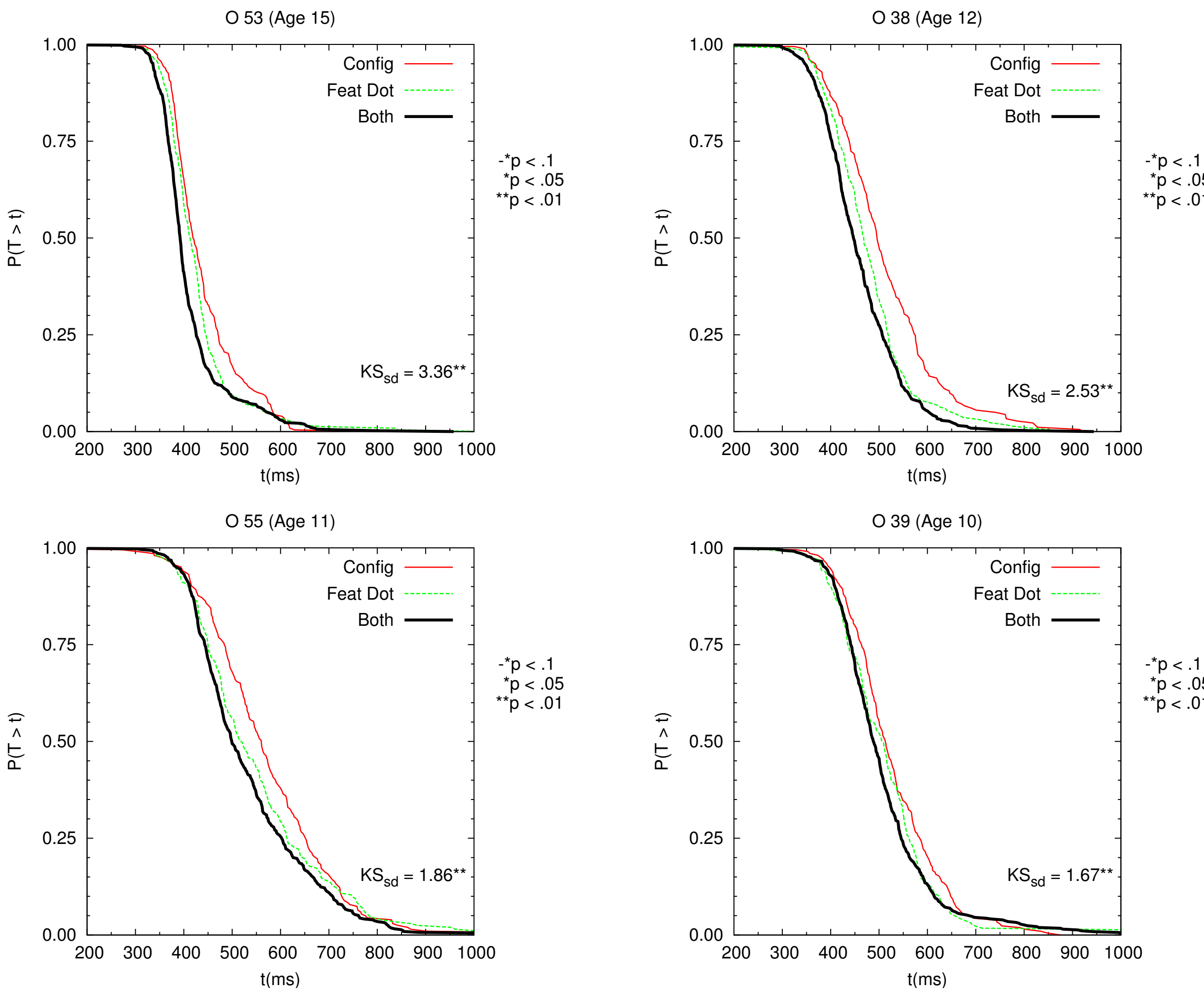

Figure 3.7: Experiment 2: Children (1 of 2): Survivor Functions and Kolmogrov-Smirnov tests for Reliable Orderings on Single and Double-Target Trials

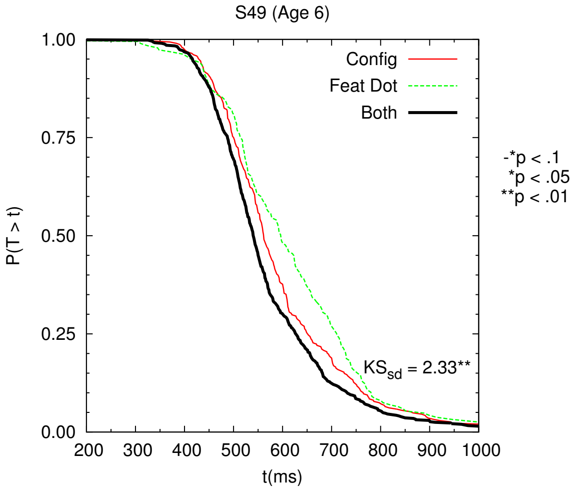

Figure 3.8: Experiment 2: Children (2 of 2): Survivor Functions and Kolmogrov-Smirnov tests for Reliable Orderings on Single and Double-Target Trials

3.3.4 Capacity

Capacity Coefficients, Miller and Grice Inequalities

Measures of capacity in Experiment 1 provided evidence of an increase in the capacity to process redundant target dot stimuli with age. The goal of Experiment 2 was to test the hypothesis that there is an increase in the capacity to process changes in configural and featural face information with age. If this hypothesis is true, the measures of processing capacity in this experiment should show similar age-related changes in processing capacity as those seen in Experiment 1. Evidence in support of this hypothesis would be : (a) an increase in the values of the capacity coefficient with age, possibly accompanied by corresponding shifts in violations of the Miller or Grice inequalities and (b) an increase in the values of the hazard ratios obtained by the Cox proportional hazards model.

Figures 3.9-3.11 plot the values of $C(t)$ (Equation 1.1) for the adult and child participants. The left axis of each panel represents the range of values of $C(t)$, which is represented by a thick dark line in each panel. Values of $C(t)$ for three of the four adults (see Figure 3.9) were greater than or equal to 1 for the shortest response times (approximately 325 - 425 ms) on the response time distribution and fell below 1 after this point in time. This was also true for the two oldest children (ages 12 and 15). One of the adult participants and the three youngest children had $C(t)$ values that remained below 1 at each point of the response time distribution. Overall, values of the capacity coefficient suggest there are age-related increases in the capacity to process face information at the shortest response times. More specifically, these values showed evidence of an increase from a limited capacity to process changes in configural and featural face information in childhood toward an unlimited to super-capacity to process these changes in adulthood.

Figures 3.9-3.11 also plot values of the Miller (Equation 1.2) and Grice (Equation 1.3) inequalities. The Miller inequality is represented by a thin dark line while the Grice inequality is represented by a thin dashed line. A violation of either inequality would be indicated by a value less than 0. There were violations of the Miller inequality for both adults and older children (ages 12 and 15) in regions of the RT distribution where $C(t)$ was greater than 1. These violations of the Miller inequality support the inference of unlimited to super-capacity processing at points in the response time distribution where $C(t)$ was greater than 1. There were violations in the Grice inequality for one of the adult participants and three of the younger children (ages 6, 10 and 11) where $C(t)$ approached .50, which is consistent with an inference of mild to moderate limitations in processing capacity. Overall, violations in the Miller and Grice inequalities provide evidence of change in processing capacity with age that is consistent with evidence from the values of the capacity coefficient. These violations suggest age-related increase in the capacity to process changes in configural and featural face information at the shortest response times shifting from a mild to moderately limited capacity in childhood toward an unlimited-capacity or super-capacity in adulthood.

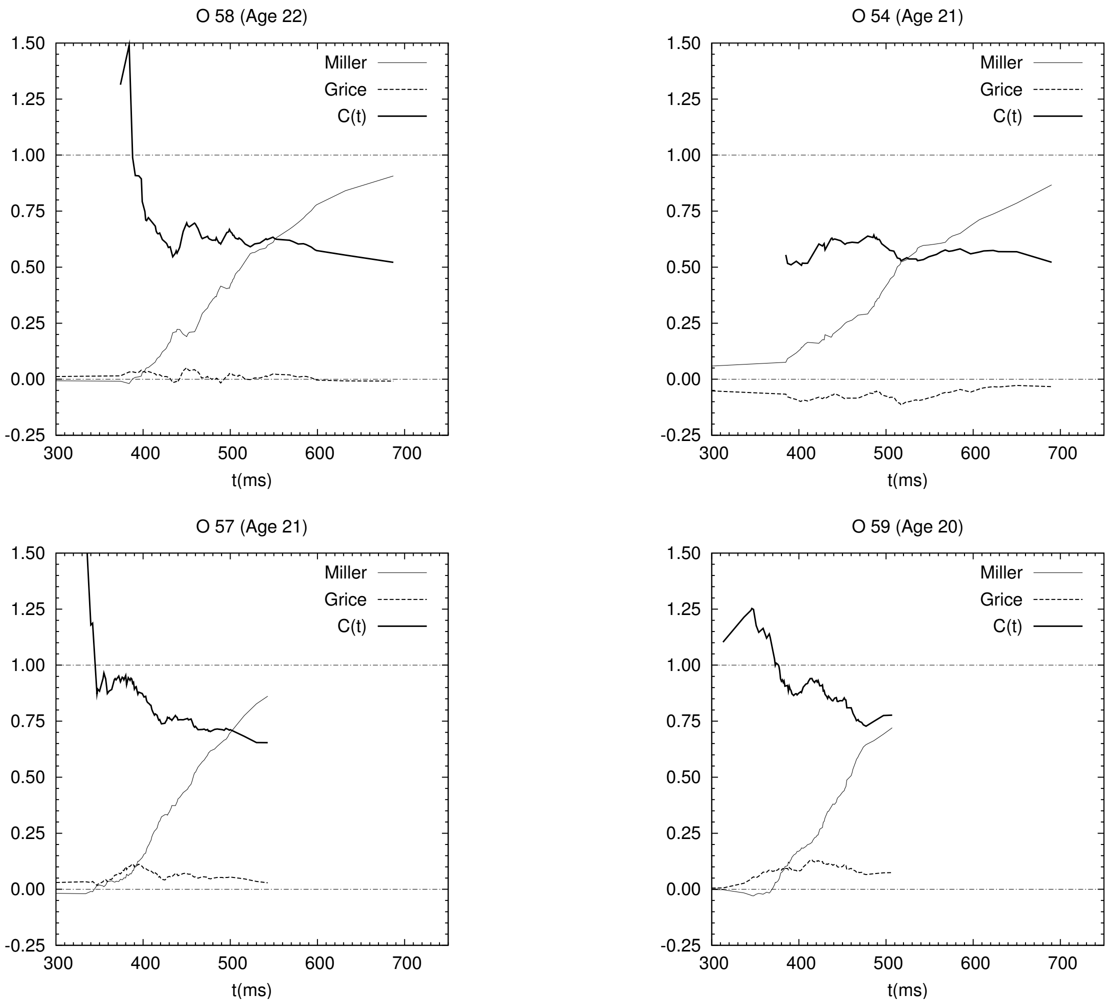

Figure 3.9: Experiment 2: Adults: Capacity Coefficients, Miller and Grice Inequalities. Lines are drawn at values of 1 and 0 on the Y axis. Values of $C(t) < 1$ indicate limited processing capacity, values of $C(t) = 1$ indicate unlimited processing capacity and values of $C(t) > 1$ indicate super-processing capacity. Values of the Grice inequality < 0 indicate limited processing capacity and values of the Miller inequality < 0 suggest extreme super processing capacity.

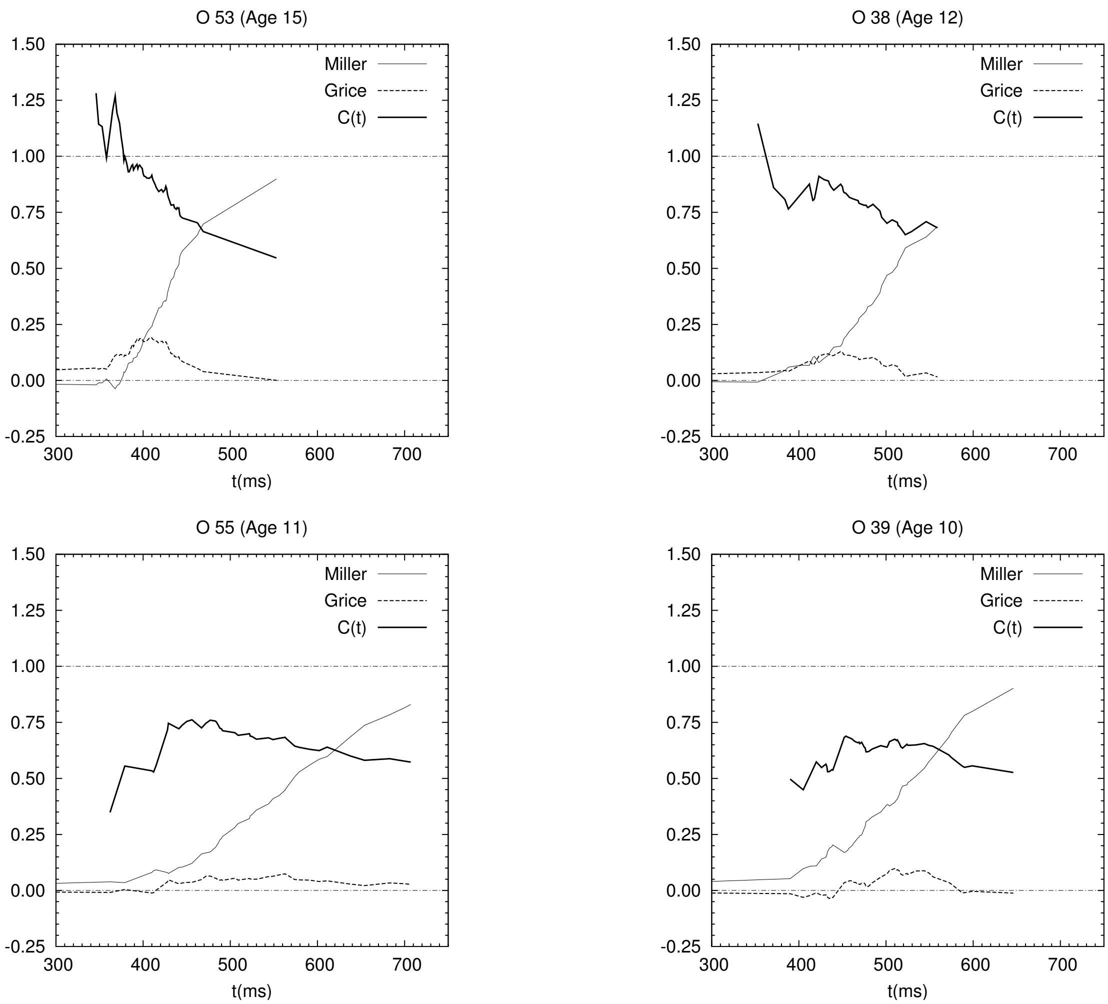

Figure 3.10: Experiment 2: Children (1 of 2) : Capacity Coefficients, Miller and Grice Inequalities. Lines are drawn at values of 1 and 0 on the Y axis. Values of $C(t) < 1$ indicate limited processing capacity, values of $C(t) = 1$ indicate unlimited processing capacity and values of $C(t) > 1$ indicate super-processing capacity. Values of the Grice inequality < 0 indicate limited processing capacity and values of the Miller inequality < 0 suggest extreme super processing capacity.

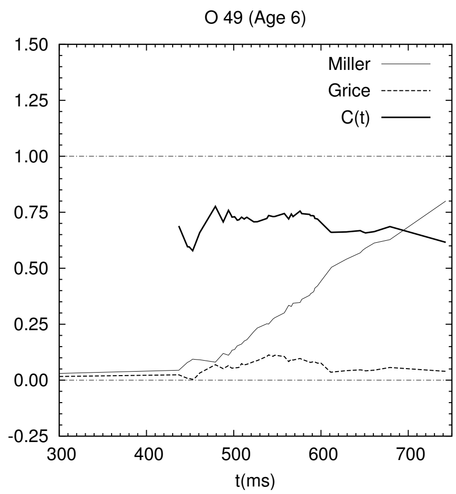

Figure 3.11: Experiment 2: Children (2 of 2): Capacity Coefficients, Miller and Grice Inequalities. Lines are drawn at values of 1 and 0 on the Y axis. Values of $C(t) < 1$ indicate limited processing capacity, values of $C(t) = 1$ indicate unlimited processing capacity and values of $C(t) > 1$ indicate super-processing capacity. Values of the Grice inequality < 0 indicate limited processing capacity and values of the Miller inequality < 0 suggest extreme super processing capacity.

3.3.5 Cox Proportional Hazards Model

Hazard ratios were estimated using the Cox model as an additional source of evidence for changes in the capacity to process face information (see Table 3.3). These ratios measured the capacity to process single changes in configural and featural face information relative to the capacity to process changes in both featural and configural face information simultaneously. Increasing hazard ratios with age would be evidence consistent with the hypothesis that there are age-related changes in the capacity to process face information.

Figure 3.12 shows a plot of the hazard ratios by age followed by a plot of the exponential transformation of these hazard ratios to the right so these ratios can be more easily interpreted as the percent increase in processing capacity with age (see Equation 2.1). Hazard ratios greater than 1 indicate greater efficiency processing redundant target face changes compared to single target face changes. The thin black line in each plot indicates the fit of the regression for all participants. The thin dotted line in each plot indicates the fit of the regression line if the two adult participants if the two adults that could potentially be outliers are not considered in the fit of the regression. These participants were qualitatively different in their performance during testing sessions, which raised some concern about their performance on this task. For example, it took these participants approximately 30 minutes longer than other adult participants to complete the task compared to other adults.

Participants of all ages had values greater than 1 and showed some benefit in processing efficiency for processing redundant target face changes compared to single-target changes. Both of the regression lines show an increase in hazard ratios with age. This increase in the hazard ratios with age maps on to an inference of an increase in the capacity to process changes in face information with age.

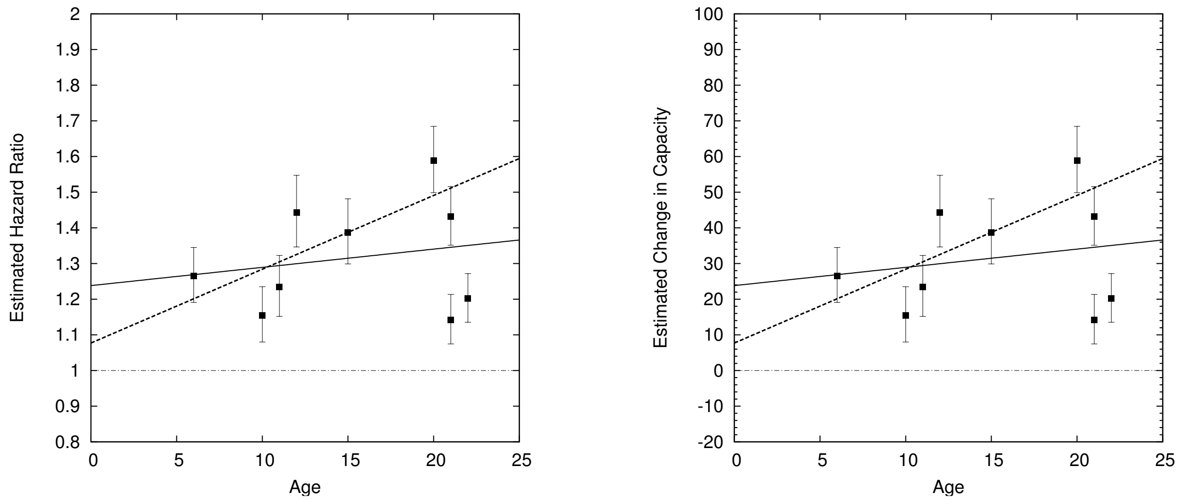

Figure 3.12: Experiment 2: Estimated Cox model hazard ratios by age. An increase in the ratios with age is evidence of an increase in the capacity to process double-target changes in face information relative to single-target changes in face information. The error bars represent the standard error from the mean. The thin black line shows the regression fit for all observers. The black dotted line shows the regression fit for all observers except outliers.

Table 3.3: Experiment 2: Cox Proportional Hazards Model for Changes in Single and Double-Target Configural and Featural Face Information.

Observer	Age	$\hat{\beta}$	SE	χ^2	Hazard Ratio
O 58	22	0.184	0.057	10.48	1.202**
O 54	21	0.133	0.061	4.77	1.142*
O 57	21	0.358	0.057	38.96	1.431***
O 59	20	0.463	0.059	62.60	1.589***
O 53	15	0.327	0.066	24.71	1.387***
O 38	12	0.367	0.070	27.88	1.443***
O 55	11	0.210	0.069	9.24	1.234**
O 39	10	0.144	0.067	4.59	1.155*
O 49	6	0.236	0.061	15.04	1.266**

$^0 - * p < .1$ $*p < .05$ $* * p < .01$ $* * *p < .001$

3.4 Discussion

Previous studies of the development of face recognition and perception have reported age-related decreases in mean reaction times and increases in mean accuracy and d' scores. These results can be interpreted as an age-related decrease in the speed and an increase in accuracy. The pattern of results obtained for overall speed and sensitivity of processing in Experiment 2 are consistent with the results of previous studies. Participants showed a general decrease in the speed of processing changes in face information with age, as well as a general increase in the sensitivity to changes in face information with age.

The main goal of this experiment was to test the hypothesis that there are age-related increases in the capacity to process face information. Researchers have suggested that improvements in processing speed, accuracy and sensitivity on face perception and recognition tasks with age might be the result of an age-related increase in the capacity to process face information. The results of this study found evidence in support for this hypothesis. Measures of the capacity coefficient generally increased with age from values of less than 1 to values equal to or greater than 1, at early points in the response time distribution. Violations of the Miller and Grice inequalities were consistent with these findings. Older Children and adult participants with values of $C(t)$ greater than 1 also showed violations in the Miller inequality indicating super capacity processing. Younger children with values of $C(t)$ less than 1 and hovering around .50 also showed violations in the Grice equality indicating mild to moderate limitations in processing capacity. Regression using the Cox proportional hazards model also provided complementary evidence supporting the hypothesis that there are age-related increases in the capacity to process face information. Participants showed

Table 3.4: Experiment 2: Cox Proportional Hazards Model for Changes in Single-Target Configural and Featural Face Information

Observer	Age	$\hat{\beta}$	SE	χ^2	Hazard Ratio
O 58	22	0.239	0.081	8.67	1.270**
O 54	21	0.696	0.091	58.61	2.005***
O 57	21	0.299	0.082	13.35	1.349***
O 59	20	0.333	0.084	15.67	1.395***
O 53	15	0.166	0.094	3.13	1.181-*
O 38	12	0.362	0.102	12.68	1.436***
O 55	11	0.139	0.100	1.95	1.150
O 39	10	0.156	0.097	2.61	1.169
O 49	6	-0.197	0.093	4.47	0.821*

[0] $- * p < .1$ $*p < .05$ $** p < .01$ $***p < .001$

an increase in the capacity to process double-target changes in configural and featural face information with age.

Chapter 4

General Discussion and Conclusions

Developmental studies of face recognition and face perception have reported that children show increases in the overall speed, accuracy and sensitivity in their responses to changes in face information. However, the mechanisms responsible for these age-related changes in performance on these tasks are unknown. Researchers have suggested that one factor that may contribute to these improvements in performance is an age-related increase in the capacity to process face information (Itier & Taylor, 2004; Carey & Diamond, 1977). The goal of this study was to test this hypothesis using theoretically-grounded measures of capacity (Townsend & Ashby, 1978; Townsend & Nozawa, 1995).

Fine-grained measures of processing capacity do exist and have been used to test processing hypotheses in adult studies of face perception (Ingvalson & Wenger, 2005). The outcomes of the two experiments presented here suggest that these measures can be informatively applied to a developmental investigation and that they provide insights into the developmental changes in visual perception and identification. The first experiment demonstrated that children could complete the necessary number of trials to use these measures of processing capacity and that interpretable inferences regarding processing capacity could be made for children using their data. The second experiment provided converging evidence in support of the hypothesis that there are age-related increases in the capacity to process face information. Measures of the capacity coefficient showed a specific shift from limited capacity processing toward unlimited or super capacity to process face information with age at early points in the response time distribution. Hazard ratios also showed an age-related shift in capacity to process configural and featural face changes with age.

Intriguingly, the results of these two experiments suggest extremely similar age-related shifts in processing. In Experiment 1 values of the capacity coefficient at early points in the response time distribution shifted with age away from values indicating limited processing capacity toward values indicating unlimited or super-capacity processing just as was true in Experiment 2. Values of the hazard ratios also showed a similar pattern in Experiment 1 indicating an age-related increase in processing capacity for redundant target stimuli just as was true in Experiment 2. The fact that both experiments showed very similar evidence for increases in processing capacity with age suggests that rather than being an age-related shift in processing capacity that is specific to faces, the shift in processing capacity might be indicative of a more general change in visual abilities.

Although this study does not provide any overt information about the mechanism responsible for the shifts in capacity, it lays the groundwork for tests of hypotheses regarding potential mechanisms. Two mechanisms that might account for these age-related differences in processing are age- and experience-dependent improvements in selective attention and the control of response selection. Although some aspects of selective attention such as orienting to abrupt onset cues appear to be fully developed quite early (Rueda, Fan & McCandliss, 2004), other aspects such as the ability to voluntarily shift attention does not appear to reach maturity until some point between mid-adolescence and adulthood (Pearson & Lane, 1991). A similar developmental time course can be seen for response selection and inhibition, which also continue to develop in childhood and adolescence. Interference from irrelevant information within stimulus presentation (Passler, Isaac & Hynd, 1985; Enns & Akhtar, 1989) and deficits in response monitoring, selection, inhibition (Davidson, Amso, Anderson & Diamond, 2006) have all been cited as factors that have a reliable impact on children's performance on visual tasks (e.g. Go-No Go, Stroop, Card Sorting, Flankers).

In conclusion, this study reported evidence of age-related increases in the capacity to process face information. Processing capacity became more efficient with age shifting from a level of limited capacity in childhood to a level of unlimited or super-capacity to process visual information in adulthood. Similar age-related shifts were seen in the capacity to process simple dot stimuli. This suggests that age-related improvements in capacity occur at a general level of the visual and/or response systems rather than at the level of a specific type of stimulus (e.g. faces). While the mechanisms responsible for age-related shifts in capacity are currently not known, one possibility is that they reflect general improvements in the ability to attend and respond to visual information with age.

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