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# The Temporal Dependency Hypothesis: Previous Look Durations Predict Next Look Durations

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# THE TEMPORAL DEPENDENCY HYPOTHESIS: PREVIOUS LOOK DURATIONS PREDICT NEXT LOOK DURATIONS

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Studies of cognitive, perceptual, and socio-emotional development in infancy have made extensive use of looking time as an outcome measure. These procedures typically rely on assessing infant looking; investigators have primarily focused on mean looking times for groups of infants. This practice, however, obscures information about the *individual looks of individual infants*. This project addressed this gap by testing the temporal dependency hypothesis: The duration of an infant's successive looks at a target are positively predicted by the duration of the infant's previous looks at that target. Temporal dependency was found in the Face-to-Face/Still-Face procedure at 6 months ($n$ = 109); the duration of successive looks at the parent were predicted by the duration of previous looks at the parent. Each individual infant's level of temporal dependency predicted joint attention on the Early Social Communication Scales (ESCS) at 9 months, but did not predict measures of joint attention on the ESCS at 6 and 12 months, language on the Mullen Scales of Early Learning at 12, 24, or 36 months, or temperament assessed with the Infant Behavior Questionnaire at 12 months. Temporal dependency was also found in an infant-controlled habituation procedure at 6 months ($n$ = 92); the duration of successive looks at a recorded face were predicted by the duration of previous looks at the recorded face. In two contexts, individual infant looks were predictable; past behavior constrained current behavior. Non-random variation due to temporal dependency is an

under-appreciated influence on looking behavior in both interactive and non-interactive contexts.

## TABLE OF CONTENTS

## LIST OF FIGURES

## LIST OF TABLES

# Chapter 1

# Introduction

A large number of developmental studies rely on assessing infant looking. Infant looking times are used to investigate early social and emotional development in procedures such as the Face-to-Face/Still-Face (FFSF; Mesman, van IJzendoorn, & Bakermans-Kranenburg, 2009; Tronick, Als, Adamson, Wise, & Brazelton, 1978). Infant looking times also serve as a primary tool to investigate early cognitive and perceptual development in procedures such as infant-controlled habituation (Horowitz, Paden, Bhana, & Self, 1972). However, investigators have primarily focused on measures of mean looking times for groups of infants. In these and similar procedures, there has been little consideration of the durations of the *individual looks of individual infants*.

## Individual Looks

This dissertation tests a *temporal dependency* hypothesis: The duration of an infant's successive looks at a target can be predicted by the duration of previous looks at that target (see Figure 1). Temporal dependency suggests that *individual look durations* might not be randomly determined in the moment, but instead reflect infants' active structuring of their own looking over time. If this is the case, temporal dependency should not only be present during social interaction with a parent, but also when that interaction is interrupted. Further, temporal dependency should also be present when viewing social-stimuli that do not involve direct interaction.

During infancy, looking serves as a window into the development of attention and regulatory strategies. In the following sections, more traditional measures of looking time are reviewed with respect to temporal dependency in both parent-child interaction and infant-controlled habituation procedures. Then the relationships between temporal dependency and traditional measures are described for both procedures. Finally, potential outcomes in the areas of attention, language, and temperament which could be predicted by temporal dependency in parent-child interaction are discussed.

**Parent and Infant Interaction**

**Overall Looking Measures.** Looking behavior is typically used as a measure of engagement and attention in infant protocols that involve infant-parent interaction. Looking behavior is often quantified as the proportion of time each infant spends in a behavior (Bertin & Striano, 2006; Cohn & Tronick, 1983; Ellsworth, Muir, & Hains, 1993; Striano & Liszkowski, 2005; Weinberg & Tronick, 1996). This approach creates an overall measure of looking behavior calculated as a proportion of an interaction. Data analysis focuses on aggregated looking time; however, complex relationships may be occurring at the level of individual looks.

Overall measures of looking for a given infant are composed of a series of individual looks. However, individual look durations are typically ignored. When a proportion is calculated for each infant, the variability from an individual look to the next is ignored. This project specifically addresses this type of non-random variability in looking behavior by testing temporal dependency.

**Temporal Dependency.** A long-standing contention has been that infant looking during interaction is a more or less random process. Kaye and Fogel (1980) found that times between an infant's successive looks at their mother were distributed randomly (following a Poisson distribution). This suggests that any structure of looking over time appears due to random runs of behavior. There is growing evidence, however, that the duration of looking in infancy is not a random process. In the context of social interaction, Messinger, Ekas, Ruvolo, and Fogel (2012) found that the durations of successive infant looks *at* the parent's face during a social interaction were positively predicted by the durations of previous looks at the parent. That is, longer looks tended to be preceded by longer looks, and shorter looks by shorter looks. The duration of a look at the parent could be predicted from the duration of the previous two looks at the parent. The duration of a look away from the parent could be predicted from the duration of the previous two looks away from the parent. This consistency suggests that there is a meaningful structure to infant looks. However, this was only examined during an interaction; accordingly, the source of the effect in these findings is difficult to ascertain.

Temporal dependency may be an infant-driven process or a property of the interaction between a parent and infant. The FFSF protocol provides a contrast between the temporal dependency during interaction (face-to-face and reunion episodes) and temporal dependency without interaction (still-face episode). If temporal dependency is unaffected by the still-face, it would suggest that temporal dependency is relatively consistent with or without parental interaction. If temporal dependency is affected by the still-face, it would suggest that temporal dependency is permeable to the influence of parental interaction. This dissertation explores these complementary possibilities by examining the differences in temporal dependency between face-to-face interaction and the period of maternal non-response that constitutes the still-face during the FFSF protocol. In addition to this contrast of the presence and absence of interaction, temporal dependency might also be a more general process, common to other procedures employing looking behavior.

**Looking Away From Partners.** Durations of looks away from a parent exist in parallel to durations of looks at a parent. In studies of infant attention during social interaction, looking measures tend to focus on periods of attention to a partner or periods of shared attention. However, crucial information may also be contained in the looks away from a social partner. Previous findings suggest that durations of successive infant looks *away* from the parent's face are predicted by the durations of previous looks away from the parent (Messinger et al., 2012). This temporal dependency existed in parallel for both looks at and away from a parent, but these looks do not directly influence each other. Given these findings, this dissertation will focus on confirming this parallel relationship, further examining the relationship between the consistency of looks at and away from the mother, and determining whether the consistency of looks away from the parent is also unaffected by a still-face perturbation.

**Infant-Controlled Habituation**

The FFSF protocol provides an experimental control for maternal interaction, which facilitates examination of temporal dependency with and without the parent's influence. However, the still-face episode nevertheless occurs in the presence of the parent in a situation typical of interaction. To address this issue, I will not only examine temporal dependency during face-to-face interaction, but also temporal dependency during presentation of video stimuli. These video stimuli remove the contingency present in interaction while retaining similar visual properties. This type of video stimuli is commonly utilized in habituation-based procedures and provides a valuable contrast to the FFSF.

**Visual Habituation.** Visual habituation is the process by which an individual becomes desensitized to a repeatedly presented visual stimulus, which is accompanied by a decline in looking to that stimulus, and it has a long and extensive history of use in infant populations (see Colombo & Mitchell, 2009). In an infant-controlled visual habituation procedure, these stimulus presentations are broken into a series of trials, defined as a set of individual looks demarcated by a look away from the stimulus for a set duration (e.g., 2 seconds; Horowitz et al., 1972). A principal measure from habituation is the time required to habituate (typically defined as falling below 50% of the time spent looking at the stimulus when first presented). Other common habituation measures include the percentage of decrement in total looking time from first presentation to habituation and the degree of dishabituation, the increase in look duration when a different stimulus (i.e., a test stimulus) is presented. The rate of habituation (DeLoache, 1976) and overall duration of looks (Colombo & Mitchell, 1990) have also both been used to describe infants in this paradigm.

**Individual Differences.** Within the habituation paradigm, individual differences in looking have been measured using several methods. The rate of habituation varies between infants (Gilmore & Thomas, 2002), suggesting meaningful variation between infants in their looking behavior. The case for individual differences is further bolstered by differences in individuals' developmental trajectories of habituation rate (Colombo, Shaddy, Richman, Maikranz, & Blaga, 2004). In habituation and related tasks, infants can be divided into those who tend to have shorter looks to stimuli (*short-lookers*) and those who tend to have longer looks to stimuli (*long-lookers*). In habituation tasks, short-lookers have been found to have a faster processing speed (as assessed through looking time in featural and global discrimination tasks) than long-lookers (Colombo, Mitchell, Coldren, & Freeseman, 1991), but generally these investigations have focused on overall differences in looking time and its relation to other measures. In a familiarization task, Jankowski and Rose (1997) examined patterns of individual looks in short- and long-lookers. They found that short-lookers exhibited a greater number of individual looks, displayed more frequent shifting of looks between elements of the stimuli, and distributed their attention over a larger area of the stimulus than long-lookers. While these studies examine variables describing the overall character of looks per infant, they do not directly examine the sequence or relationship between individual looks. This dissertation explicitly investigates the relationship between individual looks to better understand patterns of looking.

**Temporal Dependency.** Habituation outcomes share many of the characteristics of measures of parent and infant interaction, in that the unit of analysis is typically a summary of behavior over an experiment. The typical experimental outcome for habituation is recovery from habituation. This is quantified as how much an infant's looking time increases when a test stimulus is presented. However, this calculation discards information about individual looks. The structure of habituation and individual looks has begun to be described (Richards, 2010; Richards & Cronise, 2000; Richards & Gibson, 1997). Using less structured viewing of video stimuli, Richards and Gibson (1997) found that individual look durations have a log-normal distribution, which is consistent with others' findings (Anderson, Choi, & Lorch, 1987; Crawley, Anderson, Wilder, Williams, & Santomero, 1999; Richards, 2010).

This project specifically examines the relationship between each look duration and the duration of looks immediately previous to it—their temporal dependency. In contrast to temporal dependency in face-to-face interaction, infant-controlled habituation entirely removes any effect of interaction with a partner. If temporal dependency is present in both the FFSF and infant-controlled habituation procedures, it will speak to the generality of temporal dependency as a measure of an infant's degree of self-structuring.

**Theoretical Framework of Temporal Dependency**

A dynamic systems perspective focuses on the prediction of sequences of individual actions in context (Thelen & Smith, 1996). The current examination of the structure of individual looks is informed by this dynamic systems perspective in its theoretical orientation and analytic approach. This dissertation focuses on the course of individual behaviors in the presence and absence of parental interaction rather than differences between groups. It characterizes the degree of consistency between look durations. This dissertation furthers this perspective in the study of infant behavior through its detailed examination of individual look durations.

**Predicting Language, Temperament, and Attentional Outcomes**

Looking behavior in infancy, either alone or in combination with other measures, predicts outcomes later in development. Dougherty and Haith (1997) found that speed of cognitive processing, as indexed by mean look durations, at 3.5 months was predictive of subsequent cognitive testing at 4 years. Sigman, Cohen, and Beckwith (1997) found that the duration of looking at checkerboard patterns in infancy was predictive of IQ testing at 18 years of age. Similar patterns were replicated by Fagan, Holland, and Wheeler (2007) using selective attention to two stimuli to predict IQ testing up to 21 years of age.

Patterns of looking have also been used to predict language and temperamental outcomes. Kannass and Oakes (2008) found that early (but not concurrent) looking to play objects predicted vocabulary level at 31 months. Hill and Braungart-Rieker (2002) indicated prediction of 3-year outcomes, which may be linked to temperamental characteristics related to regulation. Temporal dependency, in turn, may also function in a manner similar to these measures of looking behavior in predicting subsequent outcomes. Examining the prediction to other attentional constructs is also key, as the consistency of looking durations may be tapping related constructs or later forms of the same attentional process. Accordingly, the predictive ability of temporal dependency to language, temperamental, and attentional outcomes was assessed.

**Hypotheses**

This dissertation tests the temporal dependency hypothesis in two contexts: the FFSF and infant-controlled habituation. The temporal dependency hypothesis states that the durations of an infant's previous looks at a target will predict the duration of their next look at the target.

**Hypothesis 1: Temporal dependency will be present in successive looks at the parent, and the degree of that relationship will not change in the presence or absence of parental interaction (still-face perturbation).** I will test for temporal dependency in successive looks at the parent (*Look At*) during the FFSF protocol as a whole. I will simultaneously contrast the strength of temporal dependency between the still-face and interaction (face-to-face and reunion episodes combined) and between the initial interaction (face-to-face) and the interaction following a perturbation (reunion). I anticipate that temporal dependency (one previous *Look At* duration predicting successive look durations) will be present in the FFSF protocol, and that there will be no interaction between episode (play, still-face, and reunion) and temporal dependency.

**Hypothesis 2: Temporal dependency will be present in successive looks away from the parent, and the degree of that relationship will not change in the presence or absence of parental interaction (still-face perturbation).** I will test for temporal dependency in successive looks away from the parent (*Look Away*) during the FFSF protocol as a whole. I will simultaneously contrast the strength of temporal dependency between the still-face and interaction (face-to-face and reunion episodes combined) and between the initial interaction (face-to-face) and the interaction following a perturbation (reunion). I anticipate that temporal dependency (one previous *Look Away* from parent duration predicting successive *Look Away* from parent durations) will be present in the FFSF protocol, and that there will be no interaction between episode (play, still-face, and reunion) and temporal dependency. Finally, as in Messinger et al. (2012), I anticipate that there will be no predictive cross-influence between successive *Look At* and *Look Away* durations.

**Hypothesis 3: Temporal dependency will be present in successive looks to a video-recorded face during a habituation task.** I will test temporal dependency over the course of an infant-controlled habituation procedure, in which infants were presented with video-recorded faces speaking with infant-directed speech. I hypothesize that temporal dependency (one previous look duration predicting successive look durations) will also exist for looks toward these stimuli.

**Hypothesis 4: Temporal dependency will be predictive of attentional, temperamental, and language outcomes.** I will test whether the degree of temporal dependency for each infant is predictive of longer-term outcomes, beyond the immediate relationship between the duration of successive looks at and away from the parent. I anticipate that the degree of temporal dependency in *Look At* and *Look Away* will be predictive of attention at 6, 9, and 12 months, temperament at 12 months, and language at 12, 24, and 36 months.

## Chapter 2

## Method

In the current study, the temporal dependency hypothesis was tested in two procedures. The first involved live interaction with a caregiver and perturbation of that interaction in the Face-to-Face/Still-Face procedure (Tronick et al., 1978). The second involved repeated presentations of a pre-recorded display within an infant-controlled habituation procedure (Horowitz et al., 1972).

### Participants

Both the Face-to-Face/Still-Face and infant-controlled habituation studies included a diverse sample of participants from a major metropolitan area. A summary of their demographic characteristics is presented in Table 1, and specific characteristics of each sample are summarized below.

**Face-to-Face/Still-Face (FFSF).** 109 parents and their six-month-old infants were recruited. Infants had no sensory or motor impairments that impeded completion of activities, or identified metabolic, genetic, or progressive neurological disorders. All infants had a gestational age between 37 and 41 weeks and a birth weight of at least 2500 grams.

**Infant-Controlled Habituation.** 92 six-month-old infants were recruited. All infants were healthy and born full-term, weighing at least five pounds, and had an APGAR score of at least 9.

### Procedure

The target variable for both procedures was an infant's "look," defined as a period of visual fixation at a target, ending when the infant looked away from that target for any period of time. The durations of successive looks at the parent and looks away from the parent (to any non-target area of the environment) were calculated for the FFSF, and the durations of looks at the target were calculated for infant-controlled habituation.

**Face-to-Face/Still-Face (*n* = 109)**. Temporal dependency was examined during the FFSF protocol. This interaction took place between the parent and infant for a total of eight minutes. The parent was seated facing her infant and instructed to play with her child as she would at home for three minutes (face-to-face), then to stop interacting and adopt a flat face for two minutes (still-face), then begin interacting again for three minutes (reunion). The entire procedure was video-recorded with cameras facing the infant and the parent's faces, as well as an overall view of both partners. Infant *Look At* and *Look Away* durations were reliably coded by trained experts (*ICC* = .83, *SD* = .06, 25% of infants).

***Outcome Measures.*** To assess the relationship between temporal dependency and subsequent outcomes, infants from the FFSF procedure were used. These infants had longitudinal measures of attention, language, and temperament. The Early Social Communication Scales (ESCS) were used to assess attention at 6, 9, and 12 months. The Infant Behavior Questionnaire Short Form (IBQ) was used to assess temperament at 12 months. The Mullen Scales of Early Learning (MSEL) were used to assess language at 12, 24, and 36 months. Bayesian estimates of each infant's *Look At* and *Look Away* temporal dependency (the fixed slope of the previous *Look At* and *Look Away* duration plus that infant's estimated variation from that slope, controlling for the other terms in the model) were obtained from both the final models and a model which included only the face-to-face episode. These estimates were then used as predictors of the outcome measures.

*Early Social Communication Scales* (ESCS; Mundy et al., 2003). The abridged form of the ESCS was used to assess nonverbal triadic communication at 6, 9, and 12 months. This version took approximately 20 minutes to administer and included three trials each of several toys presented to the infant, designed to elicit requests and comments. Initiating Joint Attention was used in outcome analyses, which was coded when an infant initiated eye contact with the tester while manipulating a toy (while static, active, or being presented by the child), shared alternated eye contact between a distal, active mechanical toy and the tester, or pointed to a distal object. I employed the rate of Initiating Joint Attention per minute in analyses, as it has exhibited associations with outcome measures in previous research (Ibañez, Grantz, & Messinger, 2012; Mundy et al., 2007).

*Infant Behavior Questionnaire – Short Version* (IBQ; Rothbart, 1981) The IBQ assesses 6 domains of infant temperament (Activity Level, Soothability, Fear, Distress to Limitations, Smiling and Laughter, and Duration of Orienting) between 3 and 12 months. I employed the short version of this questionnaire as a measure of parent-reported temperament. The subscales of this measure were used to generate four summary scores used in our outcome analyses. These subscale scores included Activity Level, Total Distress (Combining Fear, Soothability, and Distress to Limitations), Duration of Orienting, and Smiling and Laughter.

*Mullen Scales of Early Learning* (MSEL; Mullen, 1995). The MSEL are a measure of cognitive function that consists of a gross motor scale along with four cognitive scales assessing visual reception, fine motor skills, receptive language, and expressive language abilities. The MSEL are suitable for children ranging in age from birth through 68 months. I employed the receptive and expressive language subscales of this measure in order to assess language outcomes. Mullen (1995) reported test-retest reliability for ranging from .71 to .79, inter-scorer reliability ranging from .98 - .99 across the scales, and construct validity with the MSEL composite score and the Bayley MDI (.70), with strong correlations reported between specific cognitive scales and established tests of language development (Mullen, 1995).

**Infant-Controlled Habituation (n = 92).** Temporal dependency was examined during an infant-controlled habituation protocol. Infants were presented with a looped audiovisual display of an actor speaking with positive affect (infant-directed speech) for a minimum of 10 and a maximum of 23 discrete trials ($M$ = 12.78, $SD$ = 2.69). Trials commenced when the infant looked at the screen and lasted until the infant looked away for 1.5 s, or until the maximum trial length of 60 s had elapsed (Bahrick, Lickliter, & Castellanos, 2012; Bahrick, Lickliter, Castellanos, & Vaillant-Molina, 2010; Bahrick, Lickliter, & Flom, 2006). The data was cleaned of looks less than .1 seconds as these represented artifacts in collection. Data was drawn from two infant-controlled habituation studies which differed in the stimuli presented. The first study presented participants with a video clip of a single female actor, looped every 18 seconds. The second study presented participants with a video clip of 6 actors of a single gender for 7 seconds each, looped every 42 seconds. The two studies were otherwise identical, and potential differences between studies were examined.

Videos were presented using Panasonic videocassette players and displayed on a color monitor; audio was presented from a centrally-located speaker. Infants sat approximately 55 cm from the monitor in a standard infant seat. A primary and secondary observer behind the monitor viewed infants through apertures in a black curtain and coded the duration of looks. Data from primary observers were used for analyses. Data from the secondary observers (for 20% of infants) were used to calculate inter-observer reliability, *ICC* = .83, *SD* = .14.

# Chapter 3

## Data Cleaning and Preliminary Analyses

### Face-to-Face/Still-Face

I first confirmed that look durations followed a lognormal distribution for the planned analyses of log-transformed durations (Messinger et al., 2012; Richards & Cronise, 2000). The distribution of *Look At* durations in the FFSF had a moderate positive skew, *Skewness* = 5.26, *SE* = .03, and was highly kurtotic, *Kurtosis* = 45.30, *SE* = .07. A log transformation resulted in a distribution which was neither heavily skewed, *Skewness* = .05, *SE* = .03, nor kurtotic, *Kurtosis* = .13, *SE* = .07, suggesting that *Look At* durations in the FFSF followed a lognormal distribution.

The distribution of *Look Away* durations in the FFSF had a moderate positive skew, *Skewness* = 4.98, *SE* = .03, and was highly kurtotic, *Kurtosis* = 41.17, *SE* = .07. A log transformation resulted in a distribution which was neither heavily skewed, *Skewness* = -.25, *SE* = .03, nor kurtotic, *Kurtosis* = -.63, *SE* = .07, suggesting that *Look Away* durations in the FFSF also followed a lognormal distribution.

### Infant-Controlled Habituation

The distribution of successive look durations in infant-controlled habituation had a slight positive skew, *Skewness* = 2.97, *SE* = .04, and was highly kurtotic, *Kurtosis* = 10.02, *SE* = .08. A log transformation resulted in a distribution which was neither heavily skewed, *Skewness* = -.23, *SE* = .04, nor kurtotic, *Kurtosis* = .27, *SE* = .08, suggesting successive look durations in infant-controlled habituation followed a lognormal distribution.

Models included a variable indexing habituation. This variable summarized the overall decrease in looking time over successive looks (e.g., first look, second look, third look, etc.) in the infant-controlled habituation procedure. This variable was also log transformed to account for variation in the length of the infant-controlled habituation procedure. The transformed variable, *Skewness* = -.69, *SE* = .04, *Kurtosis* = -.08, *SE* = .08, showed a slight improvement over the original measure, *Skewness* = .85, *SE* = .04, *Kurtosis* = .22, *SE* = .08.

# Chapter 4

## Results

Multilevel modeling was used to estimate the association between the durations of successive looks (level 1) nested within infants (level 2). This approach was used to predict successive looks on the basis of previous looks. The same temporal dependency terms and modeling process were used to evaluate temporal dependency in the FFSF and infant-controlled habituation procedures. Nested model comparisons (i.e., change in model deviance distributed as central chi-square) were used to assess improvements in model fit. The decision to adopt a final model was based on the best fitting model, which included only statistically significant fixed parameters or those fixed parameters required to accurately model interaction effects. This method balances evidence from a multivariate model testing approach with univariate testing of the slopes of independent and control variables. This same approach was used for both the FFSF and infant-controlled habituation analyses. The final model equations for *Look At* durations in the FFSF, *Look Away* durations in the FFSF, and successive look durations in infant-controlled habituation are presented in Appendices A - C.

Hypothesis 1 posited that temporal dependency was present in *Look At* durations in the FFSF and that temporal dependency would be unaffected by the still-face. The presence of temporal dependency was tested by examining the significance of the temporal dependency term in the FFSF *Look At* final model (Model 5), which represented the predictive association between successive *Look At* durations and the previous *Look Away* durations. Whether temporal dependency was affected by the still-face was tested by: 1) examining the interaction between the face-to-face and reunion vs. still-face effect and temporal dependency in FFSF *Look At* Model 6 and 2) examining the interaction between the face-to-face vs. reunion effect and temporal dependency in FFSF *Look At* Model 6.

Hypothesis 2 posited that temporal dependency was present in successive *Look Away* durations in the FFSF and that temporal dependency would be unaffected by the still-face. The presence of temporal dependency was tested by examining the significance of the temporal dependency term in the FFSF *Look Away* final model (Model 9), which represented the predictive association between the successive *Look Away* durations and the previous *Look Away* duration. I tested whether temporal dependency was affected by the still-face by: 1) examining the interaction between the face-to-face vs. reunion effect and temporal dependency in FFSF *Look Away* Model 6 and 2) examining the interaction between the face-to-face and reunion vs. still-face effect and temporal dependency in FFSF *Look Away* Model 9.

Hypothesis 3 posited that temporal dependency was present in successive looks during an infant-controlled habituation procedure. The presence of temporal dependency was tested by examining the significance of the temporal dependency term in infant-controlled habituation Model 4, which represented the predictive association between successive look durations and the previous look duration. Successive look durations predicted by at least one previous look duration was the minimum criteria for temporal dependency. The modeling for each set of analyses is summarized below.

Hypothesis 4 posited the degree of temporal dependency in the FFSF was predictive of later attentional, language, and temperamental outcomes. This was tested by examining the significance of each child's temporal dependency term in the FFSF *Look*

*At* Model 6 and the *Look Away* Model 9 in a series of regressions. Each regression predicted a single outcome with a single term for temporal dependency.

**Modeling of the FFSF**

Model building for the FFSF *Look At* and *Look Away* analyses are summarized in Tables 2 and 3.

**Looks at parent.** The FFSF *Look At* model was constructed by first generating a base or empty model (Model 1), using the mean look and random differences between infants in that mean look. This model showed non-trivial dependency between individuals, $ICC = .83$; that is, infants differed from each other in their look durations, rationalizing a multi-level modeling analysis approach. Next, a model was constructed including both the previous look duration as a predictor and random differences between infants in the strength of that prediction (Model 2), which was a significant improvement over the empty model, $\chi^2$ (3, $J = 109$) = 245.27, $p < .001$. Next, a model was constructed which added the effect of the FFSF protocol, with two dichotomous variables encapsulating the differences between the still-face episode and episodes with interaction (face-to-face and reunion), and the differences between interaction before (face-to-face) and after (reunion) perturbation of the interaction (Model 3). This model also included terms for random differences between infants in the predictive strength of each episode-based prediction. Model 3 was a significant improvement over Model 2, $\chi^2$ (9, $J = 109$) = 31.08, $p < .001$. The next model added a second previous look duration as a predictor, as well as random differences between infants in that prediction (Model 4). This was a significant improvement over Model 3, $\chi^2$ (6, $J = 109$) = 166.43, $p < .001$. However, neither of the two episode effect dichotomous variables were significant in this model,

$\beta_{30}$ = .01, SE ($\beta$) = .01, *t* (108) = 1.23, *p* = .22, $\beta_{60}$ = -.04, SE ($\beta$) = .02, *t* (108) = -1.75, *p* = .09. The final model (Model 5) dropped both episode effect variables. Model 5 was a significant improvement over Model 2, $\chi^2$ (4, *J* = 109) = 169.38, *p* < .001. While Model 4 fit better than Model 5, $\chi^2$ (11, *J* = 109) = 28.13, *p* < .001, all fixed effects were significant in Model 5. A model incorporating two interaction terms was also tested (Model 6), one between the previous look duration and the still-face contrast, and the other with the previous look duration and the face-to-face vs. reunion contrast. However, Model 6 was not a significant improvement over Model 5, $\chi^2$ (26, *J* = 109) = 33.68, *p* = .14, and neither interaction term was significant. An alternate model was also tested which assessed whether the current *Look At* duration was predicted by the previous *Look Away* duration and the interaction of this term with the previous *Look At* duration (Model 7). While this model was an overall improvement over Model 5, $\chi^2$ (18, *J* = 109) = 168.28, *p* < .001, neither the previous *Look Away* duration, $\beta_{30}$ = .01, SE ($\beta$) = .01, *t* (108) = 1.23, *p* = .22, nor the interaction term,$\beta_{60}$ = -.04, SE ($\beta$) = .02, *t* (108) = -1.75, *p* = .09, was significant. The final model (Model 5) accounted for 3.46% of the variance in the empty model (PVAF; Snijders & Bosker, 1999). In this final model, the previous look duration and the look duration two previous were predictive of a given look duration. Temporal dependency was confirmed in the FFSF for *Look At* durations, $\beta_{10}$ = .11, SE ($\beta$) = .02, *t* (108) = 6.98, *p* < .001. The results are summarized in Table 4; the prediction of *Look At* durations is depicted in Figure 2.

**Looks away from parent.** The FFSF *Look Away* model was constructed by first generating a base or empty model (Model 1), using the mean look and random differences between infants in that mean look. This model showed non-trivial dependency between individuals, *ICC* = .88, the rationale for using a multi-level modeling approach. Next, a model was constructed including both previous look duration as a predictor and random differences between infants in the strength of that prediction (Model 2), which was a significant improvement over Model 1, $\chi^2$ (3, $J$ = 109) = 441.28, $p < .001$. Next, a model was constructed which added the effect of the FFSF protocol, with two dichotomous variables encapsulating the differences between the still-face episode and episodes with interaction (face-to-face and reunion), and the differences between interaction before (face-to-face) and after (reunion) perturbation of the interaction (Model 3). These also included terms for the random differences between infants in the predictive strength of each episode-based prediction. This was a significant improvement over Model 2, $\chi^2$ (4, $J$ = 109) = 241.21, $p < .001$. Next, I constructed a model which added a second previous *Look Away* duration as a predictor, as well as random differences between infants in that prediction (Model 4). This was a significant improvement over Model 3, $\chi^2$ (6, $J$ = 109) = 224.82, $p < .001$. An alternate model was also tested, assessing whether the current *Look Away* duration was predicted by the previous *Look At* duration and the interaction of this term with the previous *Look Away* duration (Model 5). While this model was an overall improvement over Model 4, $\chi^2$ (15, $J$ = 109) = 52.30, $p < .001$, neither the previous *Look At* duration, $\beta_{10}$ = .02, SE ($\beta$) = .03, $t$ (108) = 0.72, $p$ = .47, nor their interaction term, $\beta_{60}$ = .01, SE ($\beta$) = .04, $t$ (108) = 0.13, $p$ = .90, were significant. A model incorporating two interaction terms was next tested, one between the previous look duration and the still-face contrast, and the other with the previous look duration and the face-to-face vs. reunion contrast (Model 6). This model was a significant improvement over Model 4, $\chi^2$ (15, $J$ = 109) = 31.48, $p < .01$; however, only the interaction term between previous *Look Away* duration and the still-face contrast was significant. Next a model was constructed which included two previous *Look Away* durations, the two episode variables, and the interaction between previous Look Away duration and the still-face contrast (Model 7). This model was a significant improvement over Model 4, $\chi^2$ (7, $J$ = 109) = 20.63, $p < .01$, however, the *Look Away* two previous term was no longer significant, $\beta_{20}$ = .01, SE ($\beta$) = .01, $t$ (108) = 0.63, $p$ = .53. As this term was not required to model interactions, it was dropped from the next model (Model 8). Model 8 included one previous *Look Away* duration, the two episode variables, and the interaction between previous *Look Away* duration and the still-face contrast. Model 8 was a significant improvement over the previous nested model, Model 3, $\chi^2$ (6, $J$ = 109) = 24.00, $p < .001$. Model 7 fit better than Model 8, $\chi^2$ (7, $J$ = 109) = 221.45, $p < .001$, and the dichotomous variable contrasting the face-to-face and reunion episodes was non-significant, $\beta_{30}$ = -.03, SE ($\beta$) = .01, $t$ (108) = -1.89, $p$ = .06. This term was dropped in the final model (Model 9), which included one previous *Look Away* duration, the still-face contrast, and the interaction between previous *Look Away* duration and the still-face contrast. Model 9 was a significant improvement over the previously nested model, Model 2, $\chi^2$ (6, $J$ = 109) = 24.00, $p < .001$. While Model 7 fit better than Model 9, $\chi^2$ (13, $J$ = 109) = 40.35, $p < .001$, all fixed effects were significant in Model 9. The *Look Away* final model accounted for 11.11% of the variance in the empty model (PVAF; Snijders & Bosker, 1999). In the final model, the *Look Away* duration one previous, the still-face contrast, and their interaction term were significant. The *Look Away* durations were longer in the still-face compared to the face-to-face and the reunion. During the still-Face episode, there was a smaller effect of temporal dependency compared to the face-to-face and reunion episodes. Temporal dependency was found in the FFSF for successive looks away, $\beta_{10}$ = .05, SE ($\beta$) = .02, $t$ (108) = 2.94, $p$ < .01. The results are summarized in Table 5; the prediction of *Look Away* durations is depicted in Figure 3.

**Modeling Infant-Controlled Habituation**

Infant-controlled habituation model building is summarized in Table 6. The infant-controlled habituation model was constructed by first generating a base or empty model, using the mean look and random differences between infants in that mean look (Model 1). This model showed non-trivial dependency between individuals, *ICC* = .76, the rationale for using a multi-level modeling approach. Next, a model was constructed including both previous look duration as a predictor and random differences between infants in the strength of that prediction (Model 2), which was a significant improvement over Model 1, $\chi^2$ (3, $J$ = 92) = 344.80, $p$ < .001. Next, a model was constructed adding the effect of the infant-controlled habituation protocol, the log-transformed look number, which summarized the gradual decline in looking time documented in habituation protocols (Model 3). This model also included terms for random differences between infants in the predictive strength of look number. This was a significant improvement over Model 2, $\chi^2$ (4, $J$ = 92) = 106.51, $p$ < .001. The final model included a second previous look duration included as a predictor, as well as random differences between infants in that prediction (Model 4). This was a significant improvement over Model 3, $\chi^2$ (5, $J$ = 92) = 142.84, $p$ < .001. An alternate model which included an interaction term between the previous look duration and look number was also tested (Model 5). This model was not a significant improvement over Model 4, $\chi^2$ (6, $J$ = 92) = 4.83, $p$ = .57. The final model accounted for 10.81% of the variance in the empty model (PVAF; Snijders &

Bosker, 1999). In the final model, the previous look duration, the look duration two previous, and look number were predictive of a given look duration. Temporal dependency was confirmed in infant-controlled habituation for look durations, $\beta_{10}$ = .09, SE ($\beta$) = .05, *t* (91) = 4.43, *p* < .001. The results are summarized in Table 7; the prediction of look durations is depicted in Figure 4.

**Prediction of Outcomes from FFSF Temporal Dependency**

To assess the predictive strength of temporal dependency in the FFSF, I obtained estimates of $r_{1i}$ under an empirical Bayesian approach (as implemented in Bryk & Raudenbush, 1992) from the models of successive looks at and away from the parent. This represents the residual between the temporal dependency parameter and each infant's estimated difference from that parameter. This residual is essentially an estimate of an individual's temporal dependency, the degree to which an individual infant's looks were predicted the previous look, controlling for the effects of episode.

To describe their general relationship, the correlation between the obtained estimates of temporal dependency in the *Look At* and *Look Away* models was examined. In an exploratory analysis, temporal dependency in the *Look At* model was moderately correlated with that same infant's temporal dependency in the *Look Away* model, *r* (107) = .25, *p* < .01. I then used these estimates to predict outcome measures. Temporal dependency of successive looks at the parent was not predictive of attentional, temperamental, or language measures. Temporal dependency of successive looks away from the parent predicted initiating joint attention at 9 months of age, *B* = 2.77, *SE* = 1.33, *t* (53) = 2.07, *p* = .04, $R^2$ = .08, but was otherwise not predictive of attentional, temperamental, or language measures. All predictions are summarized in Table 8 and 9.

# Chapter 5

## Discussion

This innovative project adds a potential new 'rule that babies look by' to those set out by Haith (1980) over 20 years ago. This new rule is temporal dependency: the duration of a previous look at a target will predict the duration of the next look at the target. This project was the first to empirically test temporal dependency during and following the experimental perturbation of interaction in the FFSF, and to further test for temporal dependency in the viewing of non-contingent video-recorded face stimuli. This dissertation confirmed temporal dependency in the duration of looks to the mother in the FFSF, which was unaffected by the mother adopting a still-face. Temporal dependency in the duration of looks away from the mother in the FFSF was attenuated by the mother adopting a still-face. Temporal dependency in the duration of looks to a video-recorded face was confirmed in an infant-controlled habituation procedure. In subsequent sections, I will discuss the interpretation of temporal dependency in the FFSF and the impact of the still-face on the consistency of look durations, and I will expand this discussion into temporal dependency outside of interaction with the infant-controlled habituation procedure.

### Temporal Dependency in the FFSF

The current study replicated the presence of temporal dependency in face-to-face interaction. As in Messinger et al. (2012), temporal dependency existed both in the duration of looks at the parent and away from the parent. *Look At* durations were associated with previous *Look At* durations. *Look Away* durations were associated with previous *Look Away* durations. These findings add to the argument that the pattern of look durations are not random, as has been previously suggested (Kaye & Fogel, 1980; Peery & Stern, 1976). Temporal dependency may have been missed in these previous analyses, as they examined rates and the overall distribution of look durations respectively—they did not examine the direct associations between the duration of individual looks.

The temporal dependency of *Look At* and *Look Away* were independent. The duration of a given *Look At* the parent was not predicted by how long they had just looked away from the parent. In parallel, the duration of a given *Look Away* from the parent was not predicted by how long they had just looked at the parent. The independence of *Look At* durations from *Look Away* durations is a key replication from Messinger et al (2012). In an exploratory analysis, an infant's mean level of temporal dependency in looks at the parent was associated with temporal dependency in looks away from the parent.

In combination, these finding suggest that consistency in *Look At* and *Look Away* are independent processes when predicting individual look durations. However, the overall levels of temporal dependency in *Look At* and *Look Away* durations were associated, suggesting relative stability in temporal dependency within infants. The differences between the temporal dependency of *Look At* and *Look Away* are further elaborated when we consider how they are impacted during a parent still-face.

**Parental Influence on Looking Away Temporal Dependency.** In the current study the consistency of the durations of looks at a social partner was unaffected by the still-face, in an experimental procedure designed to eliminate parental interaction . By contrast, the consistency of the durations of looks away from a social partner *was* affected by the still-face—that is, stronger temporal dependency was associated with parent interaction. Decreases in looking over the still-face are well documented (Ekas, Haltigan, & Messinger, 2013; Mesman et al., 2009), but these reflect overall gaze levels over the course of the procedure. The current findings suggest that temporal dependency in *Look At* durations is not influenced by interaction with the parent. By contrast, temporal dependency in *Look Away* durations was influenced by the still-face episode. Specifically, the consistency of *Look Away* durations decreased when the parent stopped interacting with the infant. This finding suggests that interaction with a parent increases the strength of temporal dependency in looks away from the parent. In contrast to looking at the parent, the consistency of looks away from the parent is permeable to the influence of a social partner. This contrast suggests that interaction might serve more to maintain a pattern of regulatory behavior in averting attention from a social partner than maintaining attention to that social partner. These findings collectively indicate the complex influence of social partners in looking behavior. This influence emphasizes the importance of considering both looks at and away from a social partner. The key unanswered question from these FFSF findings is whether temporal dependency exists when no social partner is present to influence infant looking.

**Temporal Dependency in Infant-Controlled Habituation**

The current study expanded upon findings from social interaction by examining temporal dependency in looking behavior in the context of video-recorded face stimuli during an infant-controlled habituation procedure. This procedure removed the effects of a social interaction context (parent facing the child). Temporal dependency was found in duration of looks to a video-recorded face during this habituation procedure. Temporal dependency—a measure of consistency—existed above and beyond the effect of the habituation itself (i.e., the duration of looks declining over the course of the protocol), and it did not interact with this decline in look durations. These findings help to establish temporal dependency of looks at a target as a process, which exists in looking behavior outside the context of social interaction. One limitation of the infant-controlled habituation procedure employed in this dissertation is that while there is no influence of a social partner, the number of trials an infant receives is contingent upon their looking behavior. Further, the triggering of a new trial is triggered by a look away of over 1.5 seconds, which could potentially condition infants to look away to produce a new trial. The extent to which this extends to processes that are wholly non-contingent on infant behavior, whether through a social partner or stimuli presentation based on their behavior, may be a fruitful avenue for further exploration.

**Cross-Procedure Consistency of Temporal Dependency**

Few prior studies have investigated both infant social interaction and infant perception (but see Bornstein & Arterberry, 2003; Merin, Young, Ozonoff, & Rogers, 2007; Rochat, Striano, & Morgan, 2004; Striano & Rochat, 1999). This dissertation united an infant interaction research procedure utilizing looking as a measure of social engagement with an infant perception research procedure which utilizes looking as a measure of novelty preference and discrimination. In the FFSF procedure, the duration of a *Look At* the mother was predicted by the two previous *Look At* durations, while the duration of a *Look Away* from the mother was predicted by one previous *Look Away* duration. In the infant-controlled habituation procedure, the duration of a look was predicted by the two previous look durations. Both of these procedures had two predictive previous *Look At* durations. This suggests a similar level of history in the consistency of durations of looking *at* a face exists in both the FFSF and infant-controlled habituation. A key avenue for future investigation is to measure and examine the level of temporal dependency in *Look Away* durations in infant-controlled habituation. This examination could confirm whether the still-face attenuation is consistent outside of interaction.

**Related Structures in Looking Behavior**

Temporal dependency is related to several other measures of the consistency of looking. Temporal dependency is similar to the auto-correlation component of a time-series analysis; in fact, both constructs may index self-regulatory processes (Beebe et al., 2008). There is, however, a crucial distinction. Auto-correlation refers to the association between infant behavior at a fixed second in time, *t*, and infant behavior at a previous second, *t-1* (Chow, Haltigan, & Messinger, 2010; Feldman, 2003). By contrast, temporal dependency involves associations between consecutive *events* such as looks at a target (see Figure 1). Analyses of temporal dependency thus focus on the durations of events, which are determined by the infant's actions, rather than on fixed units of time. Previous research on the sequencing of events has revealed that a gaze toward a mother precedes an infant's smile at above chance levels (Yale, Messinger, Cobo-Lewis, & Delgado, 2003). This gaze followed by a smile preference was also disrupted by the still-face, paralleling the current dissertation's findings with the temporal dependency of *Look-Away* durations. Ekas et al. (2013) found that the overall frequency of looking behavior declined logarithmically over the course of the still-face, this drop in the frequency of looking behavior increases the duration of *Look Away* durations, which may be disrupting

*Look Away* temporal dependency. However, this decline in looking behavior was different from temporal dependency as it was based on the reduction in frequency of looking at a parent: nevertheless examining the association between the decline in looking in the still-face and temporal dependency in future work may be revealing. Overall these studies of sequences of behavior provide a promising picture of how the affect of the infant, the mother, or their dyadic state might impact the consistency of behavior.

In addition to relationships with other behavior, temporal dependency may be related to other duration measures, notably $1/f$ scaling (occasionally referred to as pink or flicker noise). This long-range serial dependence between events is defined as a "form of temporal fluctuation that has a power density inversely proportional to its frequency," (p. 1837) (Gilden, Thornton, & Mallon, 1995). This $1/f$ scaling has typically been found in complex systems, that is, systems with many components whose interaction yields behavioral patterns with a component of randomness. In humans, $1/f$ scaling has been observed with simple reaction times during mental rotation, key presses, and length of holding a key press tasks, as well as neural spiking and recall (Gilden et al., 1995; Kello, Anderson, Holden, & Van Orden, 2008; Kello, Beltz, Holden, & Van Orden, 2007; Kello et al., 2010; Wagenmakers, Farrell, & Ratcliff, 2004). A key property of $1/f$ scaling is that it can be disrupted by perturbations of the system. Unlike temporal dependency, $1/f$ scaling does not characterize the consistency of associations from one duration to the next duration, but rather the overall distribution of a sequence over multiple durations. Temporal dependency reflects short-term consistency in behavior, while $1/f$ scaling reflects the overall fluctuation of behavior from a consistent state. Future research could address associations and complementarities between 1/*f* scaling and temporal dependency with a much larger dataset of *Look At* and *Look Away* durations (above 1,000 occurrences are generally required for 1/*f* scale fitting).

**Outcome Prediction and Temporal Dependency**

Previous *Look Away* durations did not predict subsequent *Look At* durations, and previous *Look At* durations did not predict subsequent *Look Away* durations. The degree of temporal dependency in *Look At* and *Look Away* durations during the FFSF varied significantly between individuals. In fact, the overall level of temporal dependency in *Look At* and *Look Away* durations were associated with each other within infants. This combination of between-individual variability and within-individual stability may point to temporal dependency as a possible predictor of later behavioral outcomes. However, temporal dependency predicted only one of the 13 outcomes examined in this dissertation. The temporal dependency of *Look Away* durations predicted a higher rate of joint attention at 9 months of age. Temporal dependency at 6 months was unrelated to later language at 12, 24, or 36 months or to temperamental characteristics at 12 months of age. This isolated association should not be given undue weight in light of the number of comparisons conducted and would need replication to be considered notable. This single significant correlation could be interpreted as greater self-structuring of looking away from a parent, reflecting a more flexible ability to redirect attention. However, the degree to which *Look Away* durations were predicted by previous *Look Away* durations was not associated with rate of joint attention at 6 or 12 months of age. If this 9 month association is not spurious, it might reflect prediction to initiating joint attention skills at an age when the rate of initiating joint attention begins a robust developmental presence (Ibañez, Grantz, & Messinger, 2012). The predictive properties of temporal dependency in this investigation were limited, but the relationship of temporal dependency of looking behavior and joint attention behavior might bear further investigation if this finding is replicated.

**Conclusions**

This project suggests several avenues for a program of research. The first involves generalization of temporal dependency effects to a wider variety of experimental contexts. Through ascertaining when temporal dependency is present, and more importantly when it is not, we can map the function of this temporal consistency. A logical next step in this line of research is to examine the temporal dependency in the most essential structure of infant gaze, ideally employing a wholly non-contingent protocol that pares stimuli down to the perceptual essentials—fixed duration viewing of schematic faces and/or checkerboard patterns. This would help establish the generality of temporal dependency as a construct. In addition to this potential path, temporal dependency can be derived from any duration data. Accordingly, a series of studies may be readily feasible to investigate the generality of temporal dependency in extant datasets. If temporal dependency is found in these datasets it may aid in the prediction of individual looks as they occur in time. This type of prediction is crucial to modeling in software simulation, machine learning, and robotic prototypes, where the central goal is to create an accurate model of human behavior. These applications may significantly advance the field of developmental science through collaborative work across disciplines (Kaye & Fogel, 1980; Meltzoff, Kuhl, Movellan, & Sejnowski, 2009; Tanaka, Cicourel, & Movellan, 2007; Triesch, Teuscher, Deák, & Carlson, 2006).

The second avenue for future research involves placing temporal dependency in the context of other constructs. Temporal dependency did not show relationships to attention at 6 or 12 months, temperament at 12 months, or linguistic measures at 12, 24, or 36 months. This limited prediction may indicate that temporal dependency reflects a basic structuring of attentional processes unrelated to later outcomes. However, the potential relationships between temporal dependency and constructs such as perceptual processing may further illuminate any predictive effect of this consistency measure. To ascertain whether temporal dependency taps meaningful individual differences in development it will be essential to examine this construct longitudinally, with a wide variety of stimuli on a gradient of social interaction (e.g., social interaction in dyads, video-recorded faces, schematic faces, video of objects producing sound, simple geometric objects and checkerboards) and a comprehensive set of outcome measures. This would facilitate comparison of temporal dependency across multiple measures and how temporal dependency might relate to trajectories of development. Overall, the temporal dependency hypothesis characterizes the consistency of looking behavior, an aspect missed in measures that collapse infant behavior over an experiment. Temporal dependency supplements well-established looking measures by accounting for non-random variance at the level of individual looks. By more fully characterizing looking behavior, temporal dependency may help us better understand how infants structure their attention.

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APPENDIX A

THE FINAL TEMPORAL DEPENDENCY MODEL FOR *LOOKS AT* THE PARENT IN THE FFSF PROCEDURE.

$$Y_{ij} = \pi_{0i} + \pi_{1i}D_{n-1\,ij} + \pi_{2i}D_{n-2\,ij} + \varepsilon_{ij}$$

$$\pi_{0i} = \beta_{00} + r_{0i}$$

$$\pi_{1i} = \beta_{10} + r_{1i}$$

$$\pi_{2i} = \beta_{20} + r_{2i} \qquad (1)$$

$$Y_{ij} = \beta_{00} + \beta_{10}D_{n-1\,ij} + \beta_{20}D_{n-2\,ij} +$$
$$(\varepsilon_{ij} + r_{0i} + r_{1i}D_{n-1\,ij} + r_{2i}D_{n-2\,ij} + r_{0i} * r_{1i}D_{n-1\,ij} + r_{0i} * r_{2i}D_{n-2\,ij} +$$
$$r_{1i}D_{n-1\,ij} * r_{2i}D_{n-2\,ij}) \qquad (2)$$

The final temporal dependency model for looks at the parent in the FFSF procedure. Equation 1 represents the final model as separate equations for Level 1 (prediction at the level of looks) and Level 2 (prediction of random differences between infants in that prediction). The first equation describes predictors of change in *Look At* durations at Level 1. Subsequent equations describe variation in those predictors at Level 2. Equation 2 represents a combined model, which merges Level 1 and Level 2. $Y_{ij}$ represents the duration in seconds of successive looks at the parent, the *j*th in a series of looks for infant *i*. $\beta_{00}$represents the mean intercept of *Look At* durations in seconds, and $r_{0i}$ represents random differences between infants from that mean. $\beta_{10}$ is the mean slope of change in *Look At* durations for every one second change in the previous *Look At* duration, and $r_{1i}$ represents random differences between infants in that change. $\beta_{20}$ is the mean slope of change in *Look At* durations for every one second change in the Look At duration two previous, and $r_{2i}$ represents random differences between infants  in that change. $\beta_{10}$ and $\beta_{20}$ index temporal dependency. $\varepsilon_{ij}$ is unexplained residual variance in for the *j*th *Look*

*At* duration for the *i*th infant. Additionally, the covariances of all random effect terms ($r_{0i}$ - $r_{3i}$) are included in this model.

APPENDIX B

THE FINAL TEMPORAL DEPENDENCY MODEL FOR *LOOKS AWAY*

FROM THE PARENT IN THE FFSF PROCEDURE

$$Y_{ij} = \pi_{0i} + \pi_{1i} D_{n-1\,ij} + \pi_{2i} SF\ vs.FF\ \&\ RE_{ij} + \pi_{3i} SF\ vs.FF\ \&\ RE * \ D_{n-1\,ij} + \varepsilon_{ij}$$

$$\pi_{0i} = \ \beta_{00} + r_{0i}$$

$$\pi_{1i} = \ \beta_{10} + r_{1i}$$

$$\pi_{2i} = \ \beta_{20} + r_{2i}$$

$$\pi_{3i} = \ \beta_{30} + r_{3i} \qquad (1)$$

$$Y_{ij} = \beta_{00} + \beta_{10} D_{n-1\,ij} + \beta_{20} SF\ vs.FF\ \&\ RE_{ij} + \beta_{30} SF\ vs.FF\ \&\ RE_{ij} * D_{n-1_{ij}} + (\varepsilon_{ij} + r_{0i} + r_{1i} D_{n-1\,ij} + r_{2i} SF\ vs.FF\ \&\ RE_{ij} + \ r_{3i} SF\ vs.FF\ \&\ RE * D_{n-1_{ij}} + r_{0i} * r_{1i} D_{n-1\,ij} + r_{0i} * r_{2i} SF\ vs.FF\ \&\ RE_{ij} + r_{0i} * \ r_{3i} SF\ vs.FF\ \&\ RE * D_{n-1_{ij}} + r_{1i} D_{n-1\,ij} * r_{2i} SF\ vs.FF\ \&\ RE_{ij} + r_{1i} D_{n-1\,ij} * \ r_{3i} SF\ vs.RE * D_{n-1_{ij}} + r_{2i} SF\ vs.FF\ \&\ RE_{ij} * \ r_{3i} SF\ vs.FF\ \&\ RE * D_{n-1_{ij}}) \qquad (2)$$

The final temporal dependency model for looks away from the parent in the FFSF procedure. Equation 1 represents the final model as separate equations for Level 1 (prediction at the level of looks) and Level 2 (prediction of random differences between infants in that prediction). The first equation describes predictors of change in *Look Away* durations at Level 1. Subsequent equations describe variation in those predictors at Level 2. Equation 2 represents a combined model, which merges Level 1 and Level 2. $Y_{ij}$ represents the duration in seconds of successive looks away from the parent, the *j*th in a series of looks for infant *i*. $\beta_{00}$ represents the intercept of *Look Away* durations, $r_{0i}$ represents random differences between infants from that intercept. $\beta_{10}$ is the slope of change in *Look Away* durations for every one second change in the previous *Look Away* duration, $r_{1i}$ represents random differences between infants in that change. $\beta_{10}$ indexes temporal dependency. $\beta_{20}$ is the slope of change in *Look Away* durations due to parental still-face relative to the face-to-face and reunion, $r_{2i}$ represents random differences between infants in that change. $\beta_{30}$ is the slope of change in *Look Away* durations for every one second change in the previous *Look Away* duration during parental still-face relative to the face-to-face and reunion, $r_{3i}$ represents random differences between infants in that change. $\varepsilon_{ij}$ is unexplained residual variance in for the *j*th *Look Away* duration for the *i*th infant. Additionally, the covariances of all random effect terms ($r_{0i}$ - $r_{3i}$) are included in this model.

APPENDIX C

THE FINAL TEMPORAL DEPENDENCY MODEL FOR *LOOKS AT* IN THE INFANT-CONTROLLED HABITUATION PROCEDURE

$$Y_{ij} = \pi_{0i} + \pi_{1i}LG10\ Count_{ij} + \pi_{2i}D_{n-1\,ij} + \pi_{3i}D_{n-2\,ij} + \varepsilon_{ij}$$

$$\pi_{0i} = \beta_{00} + r_{0i}$$

$$\pi_{1i} = \beta_{10} + r_{1i}$$

$$\pi_{2i} = \beta_{20} + r_{2i}$$

$$\pi_{3i} = \beta_{30} + r_{3i} \qquad (1)$$

$$Y_{ij} = \beta_{00} + \beta_{10}LG10\ Count_{ij} + \beta_{20}D_{n-1\,ij} +$$

$$(\varepsilon_{ij} + r_{0i} + r_{1i}LG10\ Count_{ij} + r_{2i}D_{n-1\,ij} + r_{3i}D_{n-2\,ij} + r_{0i} *$$

$$r_{1i}LG10\ Count_{ij} + r_{0i} * r_{2i}D_{n-1\,ij} + r_{0i} * r_{3i}D_{n-2\,ij} + r_{1i}LG10\ Count_{ij} *$$

$$r_{2i}D_{n-1\,ij} + r_{1i}LG10\ Count_{ij} * r_{3i}D_{n-2\,ij} + r_{2i}D_{n-1\,ij} * r_{3i}D_{n-2\,ij}) \qquad (2)$$

The final temporal dependency model for looks in the infant-controlled habituation procedure. Equation 1 represents the final model as separate equations for Level 1 (prediction at the level of looks) and Level 2 (prediction of random differences between infants in that prediction). The first equation describes predictors of change in look at durations at Level 1. Subsequent equations describe variation in those predictors at Level 2. Equation 2 represents a combined model, which merges Level 1 and Level 2. $Y_{ij}$ represents the duration in seconds of successive looks, the *j*th in a series of looks for infant *i*. $\beta_{00}$ represents the intercept of look durations, $r_{0i}$ represents random differences between infants from that mean. $\beta_{10}$ is the slope of change in look duration for every one unit change in a count of looks over the course of habituation, $r_{1i}$ represents a random differences between infants in that change. $\beta_{20}$ is the slope of change in look durations for every one second change in the previous look duration one previous, $r_{2i}$ represents random differences between infants in that change. $\beta_{30}$ is the slope of change in look durations for every one second change in the look duration two previous, $r_{3i}$ represents random differences between infants in that change. $\beta_{20}$ and $\beta_{30}$ index temporal dependency. $\varepsilon_{ij}$ is unexplained residual variance in for the *j*th Look At duration for the *i*th infant. Additionally, the covariances of all random effect terms ($r_{0i}$ - $r_{4i}$) are included in this model.

## Figures

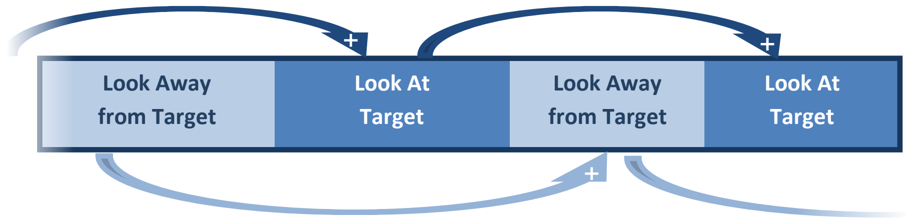


*Figure 1.* An illustration of the temporal dependency model. The durations of successive looks at a target are predicted by the duration of past looks at that same target. The durations of successive looks away from a target are predicted by the duration of past looks away from that same target. One previous duration prediction is illustrated.

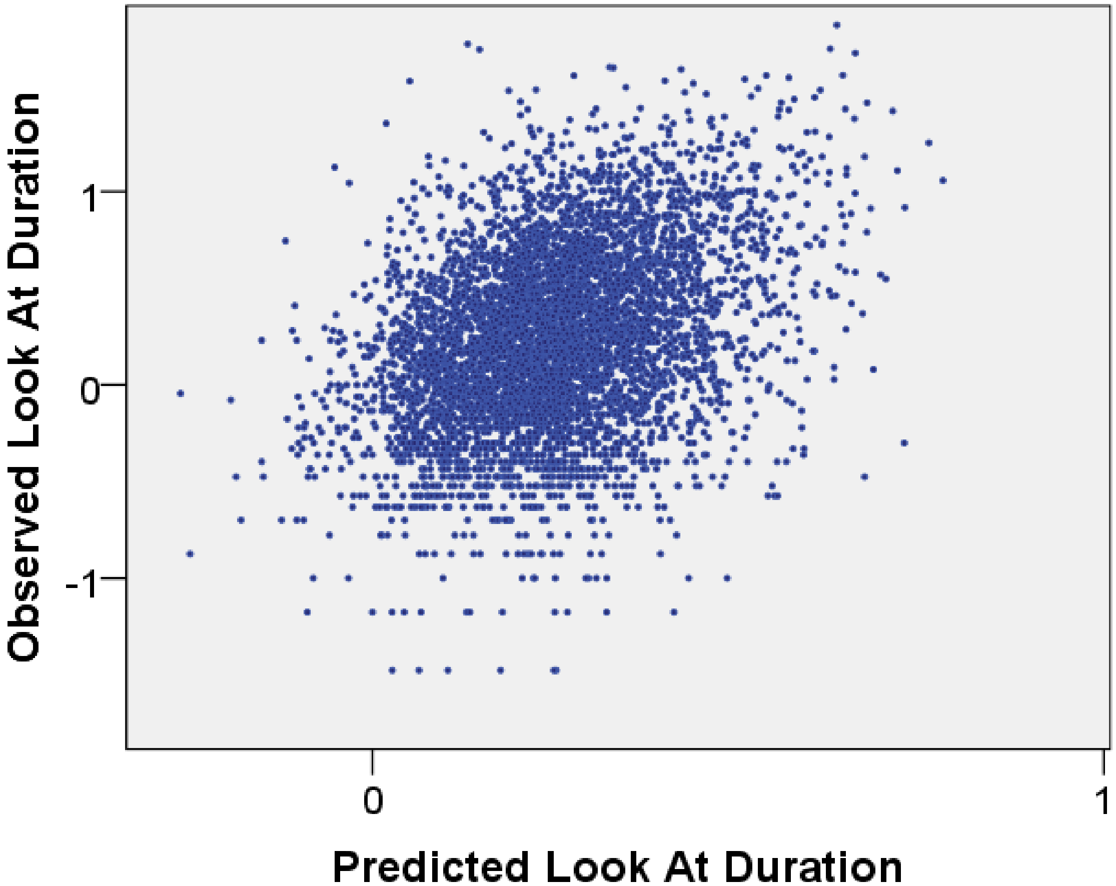


*Figure 2.* The relationship of observed *Look At* parent durations and those predicted by the final model for each episode of the FFSF. The final model included terms for the *Look At* duration one previous and the *Look At* duration two previous.

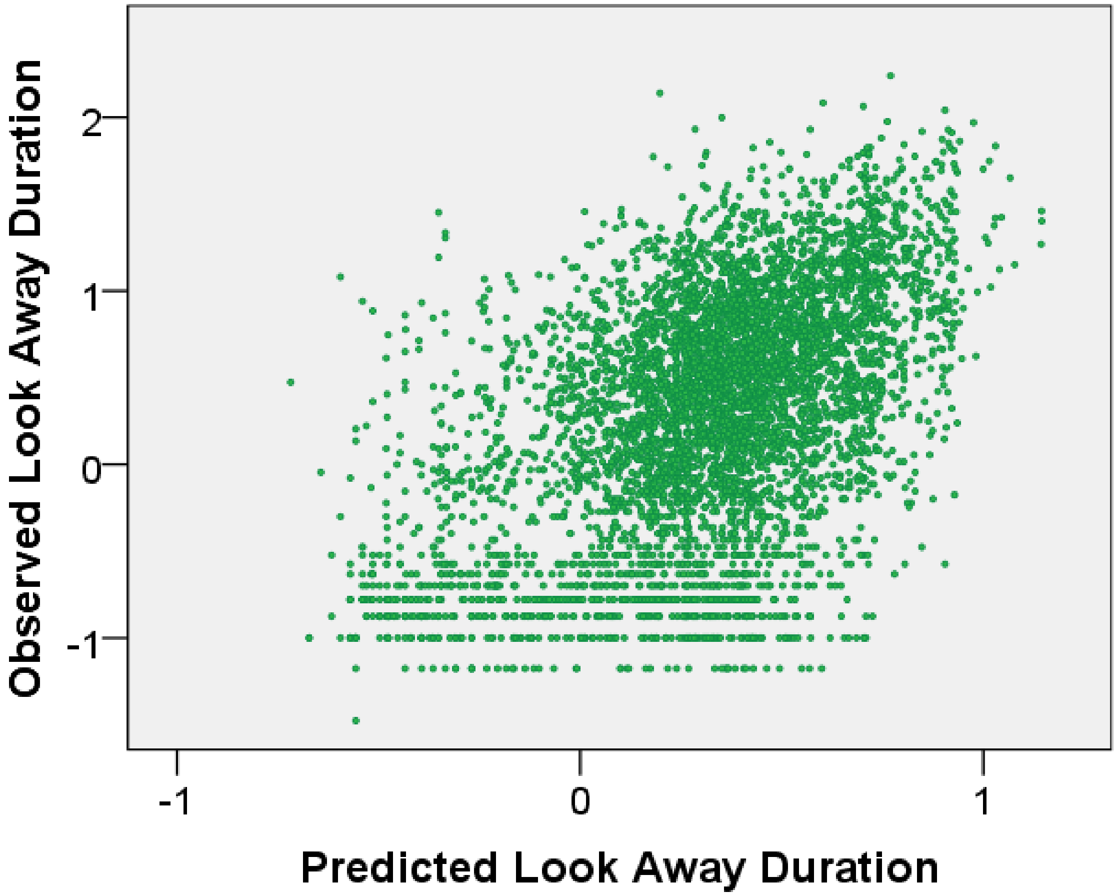


*Figure 3.* The relationship of observed *Look Away* from parent durations and those predicted by the final model for each episode of the FFSF. The final model included terms for the *Look Away* duration one previous, the still-face vs. face-to-face and reunion, and the interaction of these terms.

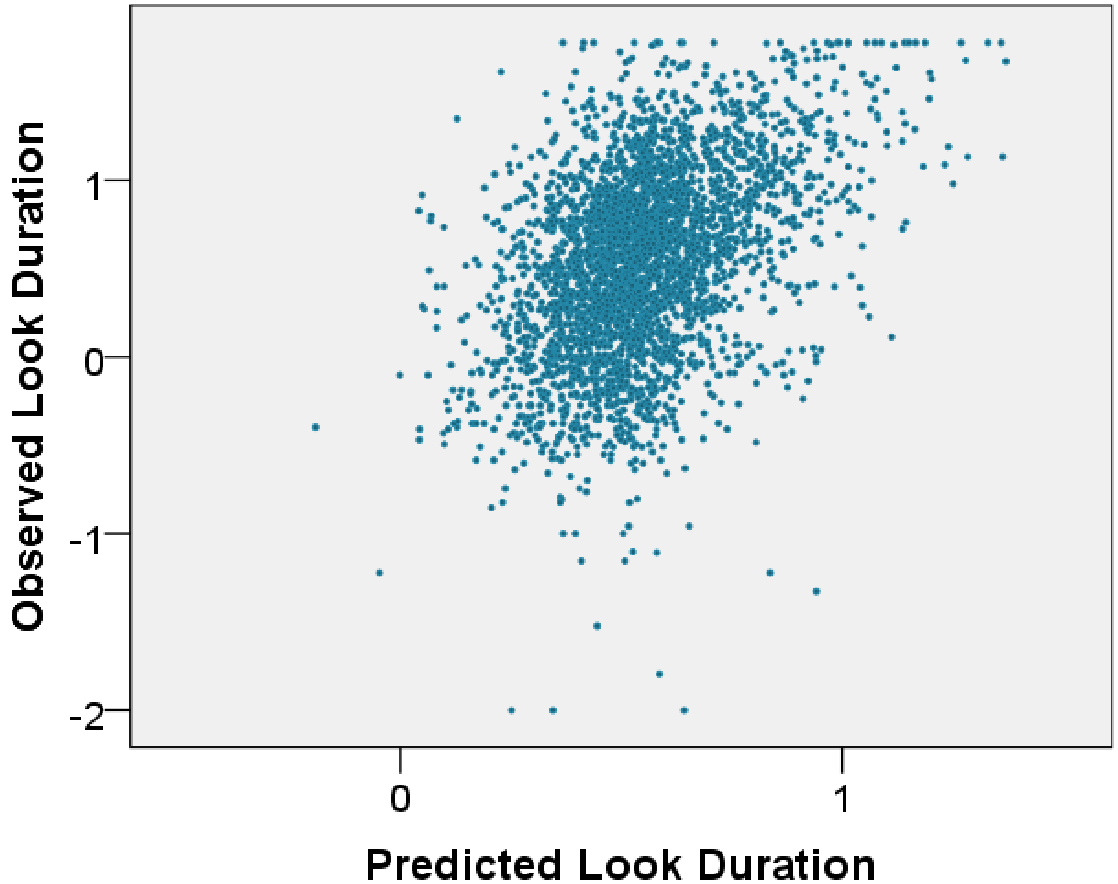


*Figure 4.* The relationship of observed *Look At* stimuli durations and those predicted by the final model. The final model included terms for the *Look At* duration one previous, the *Look At* duration two previous, and the habituation effect. Individual look durations were predicted by previous look durations above and beyond the presence of a habituation effect.

## Tables

Table 1. *Demographic Characteristics of Both Infant Samples*

| | FFSF | Habituation |
|---|---|---|
| Racial/Ethnic Group | | |
| Hispanic | 24 (22.02 %) | 81 (88.04%) |
| Non-Hispanic White | 70 (64.22%) | 6 (6.52 %) |
| African American | 4 (3.67%) | 1 (1.09%) |
| Asian/Unknown/Other | 11 (10.09%) | 4 (4.35%) |
| Gender | | |
| Female | 44 (40.37%) | 43 (46.74%) |

Table 2. *Summary of FFSF Look At Model Building*

| *Model* | $\sigma^2$ | $\tau_{00}$ | $\chi^2$ *vs. Previous Model* | *df* | *p* |
|---|---|---|---|---|---|
| 1. Empty Model | .1948 | .0215 | - | - | - |
| 2. Look Duration One Previous and its Random Effect | .1896 | .0210 | 245.27 | 3 | < .001 |
| 3. Look Duration One Previous and Episode Contrasts and their Random Effects | .1869 | .0199 | 31.08 | 9 | < .001 |
| 4. Look Duration One Previous, Two Previous, Episode Contrasts and their Random Effects | .1858 | .0198 | 166.43 | 6 | < .001 |
| 5. Look Duration One Previous, Two Previous, and their Random Effects (*Final Model*) | .1884 | .0201 | 169.38 | 4 | < .001 |
| 6. Look Duration One Previous, Two Previous, Episode Contrasts, the Interaction of Look Duration One Previous and the Episode Contrasts, and their Random Effects | .1851 | .0198 | 33.68 | 26 | .14 |
| 7. Look Duration One Previous, Two Previous, Look Away One Previous, and Episode Contrasts and their Random Effects | .1767 | .0206 | 168.28 | 18 | < .001 |

Table 3. *Summary of FFSF Look Away Model Building*

| *Model* | $\sigma^2$ | $\tau_{00}$ | $\chi^2$ *vs. Previous Model* | *df* | *p* |
|---|---|---|---|---|---|
| 1. Empty Model | .3966 | .0693 | - | - | - |
| 2. Look Duration One Previous and its Random Effect | .3764 | .0702 | 441.28 | 3 | < .001 |
| 3. Look Duration One Previous, Episode Contrasts, and their Random Effects | .3544 | .0597 | 213.74 | 9 | < .001 |
| 4. Look Duration One Previous, Two Previous, Episode Contrasts, and their Random Effects | .3544 | .0073 | 224.82 | 6 | < .001 |
| 5. Look Duration One Previous, Two Previous, Episode Contrasts, Look At Duration, and their Random Effects | .3439 | .0072 | 52.30 | 15 | < .001 |
| 6. Look Duration One Previous, Two Previous, Episode Contrasts, the Interaction of Look Duration One Previous and the Episode Contrasts, and their Random Effects | .3505 | .0560 | 31.48 | 15 | < .01 |
| 7. Look Duration One Previous, Two Previous, Episode Contrasts, the Interaction of Look Duration One Previous and the Still-Face Contrast, and their Random Effects (vs. Model 4) | .3521 | .0557 | 20.63 | 7 | < .01 |
| 8. Look Duration One Previous, Episode Contrasts, the Interaction of Look Duration One Previous and the Still-Face Contrast, and their Random Effects (vs. Model 3) | .3519 | .0556 | 24.00 | 6 | < .001 |
| 9. Look Duration One Previous, Still-Face Contrast, the Interaction of Look Duration One Previous and the Still-Face Contrast, and their Random Effects (*Final Model* vs. Model 2) | .3592 | .0549 | 197.39 | 9 | < .001 |

Table 4. *Predictors of Look At Parent Durations in the FFSF Final Model*

| *Fixed Effects* | $\beta$ | *SE* | *t* | *df* | *p* |
|---|---|---|---|---|---|
| Intercept ($B_{00}$) | .26 | .02 | 17.08 | 108 | < .001 |
| Look Duration One Previous ($B_{10}$) | .11 | .02 | 6.98 | 108 | < .001 |
| Look Duration Two Previous ($B_{20}$) | .05 | .01 | 3.52 | 108 | .001 |
| *Random Effects* | *Variance* | | $\chi^2$ | *df* | *p* |
| Intercept($r_{0i}$) | | .02 | 608.57 | 108 | < .001 |
| Look Duration One Previous ($r_{1i}$) | | .01 | 122.70 | 108 | .16 |
| Look Duration Two Previous ($r_{2i}$) | | .01 | 93.82 | 108 | > .50 |
| Residual Variance ($\varepsilon_{ij}$) | | .19 | - | - | - |

*Note*: Fixed effects in this table represent the estimated mean effect in the overall sample; random effects represent the estimated variation between individual infants. Residual variance represents variance unaccounted for in the model.

Table 5. *Predictors of Look Away from Parent Durations in the FFSF Final Model*

| *Fixed Effects* | $\beta$ | *SE* | *t* | *df* | *p* |
|---|---|---|---|---|---|
| Intercept ($B_{00}$) | .46 | .02 | 18.85 | 108 | < .001 |
| Look Duration One Previous ($B_{10}$) | .05 | .02 | 2.94 | 108 | < .01 |
| Still-Face vs. Face-to-Face and Reunion ($B_{20}$) | .21 | .02 | 9.23 | 108 | < .001 |
| Look Duration One Previous by Still-Face vs. Face-to-Face and Reunion Interaction ($B_{30}$) | -.10 | .02 | -4.10 | 108 | < .001 |
| *Random Effects* | | *Variance* | $\chi^2$ | *df* | *p* |
| Intercept ($r_{0i}$) | | .23 | 611.41 | 103 | < .001 |
| Look Duration One Previous ($r_{1i}$) | | .01 | 134.10 | 103 | .02 |
| Still-Face vs. Face-to-Face and Reunion ($r_{2i}$) | | .03 | 204.99 | 103 | < .001 |
| Look Duration One Previous by Still-Face vs. Face-to-Face and Reunion Interaction ($r_{3i}$) | | .01 | 106.49 | 103 | .39 |
| Residual Variance ($\varepsilon_{ij}$) | | .36 | - | - | - |

*Note*: Fixed effects in this table represent the estimated mean effect in the overall sample; random effects represent the estimated variation between individual infants. Residual variance represents variance unaccounted for in the model.

Table 6. *Summary of Habituation Model Building*

| *Model* | $\sigma^2$ | $\tau_{00}$ | $\chi^2$ *vs. Previous Model* | *df* | *p* |
|---|---|---|---|---|---|
| 1. Empty Model | .2667 | .0268 | - | - | - |
| 2. Look Duration One Previous and its Random Effect | .2476 | .0260 | 344.80 | 3 | < .001 |
| 3. Look Duration One Previous and Habituation and their Random Effects | .2365 | .0266 | 106.51 | 4 | < .001 |
| 4. Look Duration One Previous and Two Previous and Habituation and their Random Effects (*Final Model*) | .2361 | .0256 | 142.84 | 5 | < .001 |
| 5. Look Duration One Previous and Two Previous and Habituation and the Interaction of Look Duration One Previous and Habituation and their Random Effects | .2348 | .0256 | 4.83 | 6 | .57 |

Table 7. *Predictors of Look Durations in the Habituation Final Model*

| *Fixed Effects* | *β* | *SE* | *t* | *df* | *p* |
|---|---|---|---|---|---|
| Intercept ($B_{00}$) | .57 | .02 | 29.67 | 91 | < .001 |
| Log 10 of the Look Count ($B_{10}$) | -.22 | .05 | -4.50 | 91 | < .001 |
| Look Duration One Previous ($B_{20}$) | .09 | .02 | 4.43 | 91 | < .001 |
| Look Duration Two Previous ($B_{30}$) | .06 | .02 | 2.76 | 91 | < .01 |
| *Random Effects* | *Variance* | | $\chi^2$ | *df* | *p* |
| Intercept ($r_{0i}$) | | .03 | 408.52 | 91 | < .001 |
| Log 10 of the Look Count ($r_{1i}$) | | .09 | 176.55 | 91 | < .001 |
| Look Duration One Previous ($r_{2i}$) | | .01 | 122.61 | 91 | .02 |
| Look Duration Two Previous ($r_{3i}$) | | .01 | 107.06 | 91 | .12 |
| Residual Variance ($\varepsilon_{ij}$) | | .24 | - | - | - |

*Note*: Fixed effects in this table represent the estimated mean effect in the overall sample; random effects represent the estimated variation between individual infants. Residual variance represents variance unaccounted for in the model.

Table 8. *Predictive Effects of FFSF Look At Temporal Dependency to Outcome Measures*

| *Outcome measure* | *B* | *SE* | *t* | *df* | *p* |
|---|---|---|---|---|---|
| Early Social Communication Scales | | | | | |
| Initiating Joint Attention at 6 months | .60 | 2.44 | .25 | 53 | .81 |
| Initiating Joint Attention at 9 months | 2.13 | 3.06 | .70 | 53 | .49 |
| Initiating Joint Attention at 12 months | 1.48 | 2.19 | .68 | 89 | .50 |
| Infant Behavior Questionnaire – Short Version (12 months) | | | | | |
| Activity Level | -4.46 | 2.84 | -1.57 | 49 | .12 |
| Total Distress | -3.28 | 2.96 | -1.11 | 49 | .27 |
| Duration of Orienting | -.25 | 4.08 | -.06 | 49 | .95 |
| Smiling and Laughter | -2.56 | 3.28 | -.78 | 49 | .44 |
| Mullen Scales of Early Learning | | | | | |
| Receptive Language at 12 months | -5.82 | 6.82 | -.85 | 55 | .40 |
| Expressive Language at 12 months | 8.35 | 9.59 | .87 | 55 | .39 |
| Receptive Language at 24 months | 6.67 | 15.98 | .42 | 85 | .68 |
| Expressive Language at 24 months | 1.96 | 15.31 | .13 | 85 | .90 |
| Receptive Language at 36 months | 23.92 | 22.19 | 1.08 | 83 | .28 |
| Expressive Language at 36 months | 25.70 | 19.82 | 1.30 | 84 | .20 |

*Note:* Initiating Joint Attention was assessed as a frequency of behavior per minute.

$^*p < .05$.

Table 9. *Predictive Effects of FFSF Look Away Temporal Dependency to Outcome Measures*

| *Outcome measure* | *β* | *SE* | *t* | *df* | *p* |
|---|---|---|---|---|---|
| Early Social Communication Scales | | | | | |
| Initiating Joint Attention at 6 months | .19 | 1.05 | .18 | 53 | .86 |
| Initiating Joint Attention at 9 months | 2.77 | 1.33 | 2.07 | 53 | .04* |
| Initiating Joint Attention at 12 months | .59 | 1.03 | .57 | 89 | .57 |
| Infant Behavior Questionnaire – Short Version (12 months) | | | | | |
| Activity Level | .36 | 1.37 | .26 | 49 | .80 |
| Total Distress | 1.12 | 1.40 | .80 | 49 | .43 |
| Duration of Orienting | 2.06 | 1.90 | 1.09 | 49 | .28 |
| Smiling and Laughter | 1.56 | 1.54 | 1.01 | 49 | .32 |
| Mullen Scales of Early Learning | | | | | |
| Receptive Language at 12 months | -.29 | 3.02 | -.10 | 55 | .92 |
| Expressive Language at 12 months | -2.52 | 4.23 | -.60 | 55 | .55 |
| Receptive Language at 24 months | -7.76 | 7.26 | -1.07 | 85 | .29 |
| Expressive Language at 24 months | -7.76 | 6.95 | -1.12 | 85 | .27 |
| Receptive Language at 36 months | -13.48 | 11.78 | -1.14 | 83 | .26 |
| Expressive Language at 36 months | -3.52 | 10.61 | -.33 | 84 | .74 |

*Note:* Initiating Joint Attention was assessed as a frequency of behavior per minute.

$^{*}p < .05$.