DEVELOPMENTAL NEUROPSYCHOLOGY, *34*(2), 159–174

ISSN: 8756-5641 print / 1532-6942 online
DOI: 10.1080/87565640802646734

Psychology Press
Taylor & Francis Group

Maternal DHA Levels and Toddler Free-Play Attention

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We investigated the relationship between maternal docosahexaenoic acid (DHA) levels at birth and toddler free-play attention in the second year. Toddler free-play attention was assessed at 12 and 18 months, and maternal erythrocyte (red-blood cell; RBC) phospholipid DHA (percentage of total fatty acids) was measured from mothers at delivery. Overall, higher maternal DHA status at birth was associated with enhanced attentional functioning during the second year. Toddlers whose mothers had high DHA at birth exhibited more total looking and fewer episodes of inattention during free-play than did toddlers whose mothers had low DHA at birth. Analyses also provided further information on changes in attention during toddlerhood. These findings are consistent with evidence suggesting a link between DHA and cognitive development in infancy and early childhood.

As psychologists come to better understand the development of attention in infancy and toddlerhood, there has been keen interest in relating this knowledge to applied research and using traditional laboratory measures of attention as an indicator of cognitive development. One such example has been the use of such measures to study the effects of early nutritional status on neurobehavioral outcomes.

In particular, measures of early attention have figured prominently in recent studies of the effects of long-chain polyunsaturated fatty acids (LC-PUFAs) on infant development. Docosahexaenoic acid (DHA) is an LC-PUFA and is found in foods such as fatty fish (e.g., halibut, mackerel, and salmon) and eggs (notably, DHA-enriched eggs) (Kris-Etherton et al., 2000). DHA is an important component of cell membranes, especially in the central nervous system. It is present in high concentrations in the retina (Anderson, Maude, & Zimmerman, 1975) and brain (Clandinin et al., 1980a, 1980b), and human autopsy studies have revealed increases in DHA in the frontal ce-

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This research was made possible by a grant from OmegaTech Inc./Martek Biosciences (OMT-2000-02).

rebral cortex between 2 years and adulthood (Carver, Benford, Han, & Cantor, 2001). Researchers have speculated that DHA has functional roles in visual and neural processes (Innis, 2003). For example, maternal supplementation studies have revealed that infants of mothers who received DHA supplementation had better visual acuity than did infants of mothers in a control group (e.g., Judge, Harel, & Lammi-Keefe, 2007b). DHA is accumulated in humans during gestation (Dutta-Roy, 2000) and infancy through breast feeding (Putnam, Carlson, DeVoe, & Barness, 1982) and, since 2002, through U.S. infant formulas. This period of DHA accumulation (Clandinin et al., 1980a, 1980b; Martinez, 1992) overlaps with a period of rapid brain development in human infants (e.g., Huttenlocher, 1990; Matsuzawa et al., 2001; Tsekhmistrenko & Vasil'eva, 2001). Recent review articles (e.g., Cheatham, Colombo, & Carlson, 2006; Eilander, Hundscheid, Osendarp, Transler, & Zock, 2007; McNamara & Carlson, 2006; Mitmesser & Jensen, 2007; Wainwright & Colombo, 2006) have focused on the potential effects of LC-PUFAs on infant development and possible underlying mechanisms.

Researchers have sought to better understand the relation between DHA and infant development, and the goal of the present study was to examine the relation between maternal DHA status at delivery, assessed by measuring maternal red blood cell (RBC) phospholipid DHA, and attention during free-play in toddlerhood. Maternal RBC phospholipid DHA increases with maternal DHA supplementation (Montgomery, Speake, Cameron, Sattar, & Weaver, 2003; Helland et al., 2001) supporting the use of this measurement as an indicator of maternal status. In particular, we consider that maternal RBC phospholipid DHA at the time of delivery reflects the availability of maternal DHA for transfer to the fetus.

A general summary of the development of early attention will be presented first, followed by a brief review of interdisciplinary work on LC-PUFAs and cognitive development and the rationale for the current study.

THE DEVELOPMENTAL COURSE OF EARLY ATTENTION

Attention is a multifaceted construct, and an understanding of the developmental course of attention is important for at least three reasons. First, there are striking changes in attentional responding in infancy and early childhood. Second, these developmental changes in behavior are believed to reflect developmental changes in the functions of attention and corresponding neurological change. Third, different measures of attention and measures of attention at different points in time reflect different underlying mental processes (e.g., information processing, attention span).

The developmental course of visual attention (i.e., looking) is complex, and there are increases and decreases in how long infants and toddlers fixate stimuli at different points in development (Colombo, Harlan, & Mitchell, 1999; Colombo, 2001; Courage, Reynolds, & Richards, 2006; Ruff & Rothbart, 1996). Such changes are thought to correspond to underlying changes in the attentional systems guiding behavior (Colombo, 2001, 2002). For example, the decrease in infant visual attention during habituation tasks in the middle of the first year (e.g., between 3 and 8 months) is thought to reflect underlying changes in spatial and object attention and developments in the dorsal and ventral visual pathways. In this context, shorter looking (which appears to reflect both greater efficiency in information processing and greater facility with lower-order attentional components such as disengaging and shifting) is regarded as more mature or sophisticated attentional responding (Colombo, 2001, 2002; Colombo & Cheatham, 2007; Courage et al., 2006).

Later in infancy, however, more internally driven (i.e., *endogenous*) influences play a central role in the allocation of infant attention. Although endogenous influences on the control of eye movements and shifts in attention corresponding to developments in cortical areas (e.g., frontal eye fields, parietal cortex, and prefrontal cortex, see Johnson, 1997, and Johnson, 2005, for reviews) may appear within the first 6 months of life (Csibra, Tucker, & Johnson, 2001; Richards, 2001; Wentworth, Haith, & Karrer, 2001), higher-level endogenous control of attention (i.e., top-down, voluntary, self-regulated control) appears late in the first year (Colombo, 2001; Posner, Rothbart, & Thomas-Thrapp, 1997; Ruff & Rothbart, 1996). Endogenous attention during infancy and early childhood is primarily studied in the context of free-play, where behavioral measures are indicators of constructs such as attention span, distractibility, and perseverance. Behaviorally, there are increases in infants' and toddlers' abilities to hold and maintain their attention (i.e., increases in looking duration) and decreases in measures of distractibility (e.g., Kannass & Oakes, 2008; Ruff & Capozolli, 2003). These endogenous functions presumably correspond to maturation of frontal structures and pathways (Diamond, 1991; Diamond & Taylor, 1996; Posner et al., 1997; Posner, Rothbart, Thomas-Thrapp, & Gerardi, 1998; Ruff & Rothbart, 1996). Development of the frontal cortex proceeds at a slower rate in comparison to other brain structures. For example, Huttenlocher (1990) found that at 2 years of age, neuronal density in the frontal cortex is approximately 55% above the adult mean, whereas at 5 months of age neuronal density in the visual cortex is at adult levels. Huttenlocher (1990) proposed a correspondence between anatomical changes in the brain and function development, such as changes in visual behaviors and binocular interactions (e.g., stereopsis, steroacuity) and changes in the visual cortex during the first 4 months of life, and suggested that plasticity remains longer in the middle frontal gyrus (which comprises approximately 1/3 of the frontal lobe) given that synaptic elimination occurs later at about 7 years of age.

Recently, researchers have begun to use MR imaging with healthy developmental samples, but imaging research with infants and toddlers remains rare. MR imaging has revealed that frontal lobe volume increases during infancy and early childhood (Kanemura, Aihara, Aoki, Araki, & Nakazawa, 2003; Matsuzawa et al., 2001). Notably, Matsuzawa et al. investigated changes in gray and white matter volumes in infants (1 month to 2 years) and children (2 to 10 years). Developmentally, children had greater overall brain volumes than did infants and gray matter volumes were greater than white matter volumes, but the age differences in total brain volume were smaller for gray matter than for white matter. Analysis of brain volumes in the frontal and temporal lobes revealed that there was a greater difference between infants and children for frontal volumes than for temporal volumes, and there was a larger difference between gray matter and white matter volumes in the frontal lobe than in the temporal lobe. Psychophysiological research with 8-month-old infants has revealed that frontal EEG measures were related to duration of endogenous (voluntary, internally controlled) attention in a peek-a-boo paradigm, suggesting that this type of attention is associated with the anterior attentional system (Stroganova, Orekhova, & Posikera, 1998).

Consistent with adult models of endogenous attention, developmental theory suggests that endogenous attention reflects the integrated control of lower-order attentional components (arousal, visuospatial, and object-oriented functions) in concert with working and long-term memory as mediated through the development of medial-temporal and frontoparietal pathways (see Colombo & Cheatham, 2007). In the context of more endogenously driven visual attention, longer looking (which is indicative of less distractibility or a longer attention span) is regarded as more mature or sophisticated attentional responding (Colombo, 2001; Colombo & Cheatham, 2007; Courage et al., 2006), and research has revealed a positive relation between attention measured in a free-play task (presumably tapping endogenously controlled attention) and later cognitive skills (e.g., IQ, vocabulary) (Kannass & Oakes, 2008; Kopp & Vaughn, 1982; Ruff, 1990). Thus, at different points of time and in different types of tasks, multiple systems (arousal, visuospatial, object-oriented, and endogenous functions) guide attention; the degree to which these systems influence attentional responding may change according to development and the type of task used to measure attention.

In adults, the contributions of endogenous (i.e., top-down, internally driven, voluntary) and exogenous (externally driven, automatic) influences on attention have typically been studied in a cost/benefit or valid/invalid cueing orienting paradigm (e.g., Berger, Henik, & Rafal, 2005; Mayer, Dorfinger, Rao, & Seidenberg, 2004; Posner, Rafal, Choate, & Vaughn, 1985). In infancy and toddlerhood, endogenously (i.e., internally) controlled attention (and constructs such as attention span, distractibility, and perseverance) is typically assessed using free-play paradigms in which infants are given objects to explore. In general, the free-play paradigms can be characterized as either presenting competition for attentional focus (*competitive* context) or presenting little to no competition for attentional focus, such as the presentation of a single target (or focal) stimulus (*noncompetitive* context).

For the current study, the literature on attention in the competitive context is most relevant. In this context, the infant is presented with both target (or focal) stimuli and distracting stimuli. The infant may either maintain attention to a particular stimulus (the "target" or focal stimulus) and resist attending to the other stimuli (the "distractors"), or distribute his or her attention among the various stimuli (Desimone & Duncan, 1995; Ruff & Lawson, 1990). During infancy and early childhood, the ability to allocate attention in the face of such competition is assessed in *distractibility* and *multiple object free-play* tasks. In both, the competition for attentional focus is similar to the competition infants and young children encounter in their everyday explorations. In distractibility tasks (e.g., Colombo et al., 2004; Lansink & Richards, 1997; Kannass, Oakes, & Shaddy, 2006; Oakes & Tellinghuisen, 1994; Ruff, Capozzoli, & Saltarelli, 1996), the infant is presented with a target stimulus, and then a distracting event is presented intermittently in the periphery. Research has shown that 10-month-old infants are more distractible than 26- and 42-month-old toddlers, presumably due to developmental changes in self-regulatory skills (Ruff & Capozzoli, 2003), and there is stability of distractibility between infancy and toddlerhood (Kannass et al., 2006).

In multiple object free-play tasks, the infant is presented with several objects simultaneously, presumably creating a context of distraction (e.g., Kannass et al., 2006; Power, Chapieski, & McGrath, 1985; Ruff & Lawson, 1990). As the infant explores a particular toy, the surrounding toys (which are not under current investigation) act as distractors and potential targets of attentional focus. Measures of attention in this context include the number of shifts in attention and the duration of looking. Across development infants, toddlers, and preschoolers become more effective at maintaining their focus (e.g., Lansink, Mintz, & Richards, 2000; Ruff, Capozzoli, &Weissberg, 1998; Ruff & Lawson, 1990). Measures of free-play attention are related to measures of distractibility at 31 months, but there is no consistency across these tasks at 9 months (Kannass et al., 2006), which is consistent with other research showing developmental change in consistency in attention allocation across tasks (Ruff, Capozzoli, & Weissberg, 1998). Moreover, typically developing preschoolers are more effective than are preschoolers with attention deficits at "holding" or maintaining their attention during multiple object free-play

(Alessandri, 1992; Campbell, Breaux, Ewing, & Szumowski, 1984; DeWolfe, Byrne, Bawden, 2000; Roberts, 1990).

An understanding of the attentional systems (i.e., visuospatial, object-oriented, endogenous functions) guiding behavior at different points in development is important because a single measure of attention (e.g., looking) may tap discrete underlying processes when measured at different points in development or discrete processes in different tasks at the same point in development (Colombo & Janowsky, 1998). Such information is particularly relevant for interdisciplinary studies using measures of attention as a developmental outcome.

INTERDISCIPLINARY RESEARCH ON LC-PUFAS AND INFANT COGNITIVE DEVELOPMENT

Interdisciplinary research on LC-PUFAs and infant development has generally used one of two types of outcome measures of infant cognitive development, standardized measures of development (e.g., the Bayley Scales of Infant Development) and laboratory measures of development (e.g., habituation and novelty preference paradigms, means–end behavior). The research using standardized measures of infant development has yielded somewhat mixed results, with some studies reporting higher standardized outcome scores for infants and young children who received LC-PUFA supplementation in comparison to control groups (e.g., Agostoni et al., 1995; Birch et al., 2007; Birch, Garfield, Hoffman, Uauy, & Birch, 2000; Carlson, Werkman, Peeples, & Wilson, 1994; Dunstan, Simmer, Dixon, & Prescott, 2008; Helland, Smith, Saarem, Saugstad, & Drevon, 2003) and other studies reporting no group differences (e.g., Lucas et al., 1999; Auestad et al., 2003; Makrides, Neumann, Simmer, & Gibson, 2000). A recent analysis of children previously enrolled to receive DHA as infants investigated visual acuity and cognitive (IQ) differences among 4-year-old children who, as infants, were fed either a control formula (no DHA or ARA, arachidonic acid, an omega 6 fatty acid), a formula supplemented with .35% DHA, or a formula supplemented with .36% DHA and .72% ARA through 17 weeks of age (Birch et al., 2007). A fourth group of children were breast fed as infants. The results revealed better right eye acuity for children who were in the DHA and breast-fed groups as infants than children who were in the control group as infants. Children who were fed the control formula as infants had lower verbal IQ scores than did children who were breast fed as infants. Children who were fed a DHA-containing formula as infants had IQ scores that did not differ from the breast-fed group or the control group.

Observational studies have also revealed associations between early DHA exposure or status and developmental benefits of LCPUFAs (e.g., Colombo et al., 2004; Cheruku, Montgomery-Downs, Farkas, Thoman, & Lammi-Keefe, 2002; Malcolm, McCulloch, Montgomery, Shepherd, & Weaver, 2003; Bakker, Hornstra, Blanco & Vles, 2007; Jacobson et al., 2008). For example, Jacobson et al. (2008) studied a group of Inuit infants and mothers in Canada (Arctic Quebec), where the typical Inuit diet includes a substantial amount of fish and sea mammals. Blood samples were taken from the umbilical cord after it was severed, and infant development was assessed using the Teller Visual Acuity Card test (at 6 and 11 months), the Fagan Test of Infant Intelligence (at 6 and 11 months), and the Bayley Scales of Infant Development (at 11 months). Higher levels of DHA were associated with better acuity and greater novelty preferences scores at 6 months and higher Bayley scores at 11 months. Hibbeln et al. (2007) studied the association between maternal seafood consumption and developmental outcome and used surveys about eating patterns to divide mothers into three groups (no seafood, 1–340 g per week, more than 340 g per week). Mothers also completed questionnaires about their children's development, attention, and social–emotional skills. Children were given the Wechsler Intelligence Scale for Children. Greater seafood intake was associated with a lower risk of suboptimal child development outcome.

Most relevant to the current project is research using laboratory measures of development. For example, interdisciplinary research on LC-PUFAs and infant visual attention has revealed that preterm infants who were fed DHA-supplemented formulas exhibited shorter looking during the Fagan Test of Infant Intelligence, suggesting enhanced information processing (e.g., Carlson & Werkman, 1996; Werkman & Carlson, 1996). Other research has shown that term infants who received supplemented formula demonstrated greater problem-solving skills (as assessed in a means–ends task in which infants have to complete a sequence of actions in order to retrieve a hidden object) at 10 months of age (Willatts, Forsyth, DiModugno, Varma, & Colvin, 1998). Recent research on maternal supplementation has revealed that infants of mothers who ate a DHA-supplemented functional food (a DHA-supplemented cereal bar) had better visual acuity at 4 months and higher problem- solving scores at 9 months, although there were no differences in looking during the Fagan (Judge, Harel, & Lammi-Keefe, 2007a).

A previous report on the current sample revealed that infants of mothers with high levels of DHA at delivery exhibited more sophisticated looking during habituation than infants of mothers with low levels of DHA at delivery (Colombo et al., 2004). Moreover, this study was the first to use endogenous measures of attention as outcome measures during the toddler period. As toddlers, infants of mothers with low levels of DHA at delivery (1) exhibited a decrease in measures of attention span (as measured in a single object free-play task, a noncompetitive attention task) between 12 and 18 months (which is inconsistent with a typical developmental trajectory) and (2) turned more quickly to a distracting event in a distractibility paradigm (i.e., they were more distractible) than were infants of mothers with high levels of DHA at delivery.

In summary then, there is evidence that higher DHA exposure during gestation and infancy is related to more sophisticated attending during habituation and familiarization tasks, better problem-solving skills, longer attention spans in a noncompetitive attention task, and less distractibility. Little is known, however, about how DHA relates to other measures of endogenous attention, such as attention during multiple object free-play.

The current project investigated how maternal DHA at delivery relates to endogenous attention at 12 and 18 months of age. Attention and inattention were measured during a *multiple object* free-play paradigm. Measures of habituation, single object attention, and distractibility using this sample have been previously reported (see Colombo et al., 2004). Therefore, all of the data and all of the analyses are original in the current project. Originally, the participants were a subsample from a larger study of the effects of DHA levels on gestation (see Smuts et al., 2003) and cognitive outcome (Colombo et al., 2004). The original pregnancy study was a double-blind, controlled clinical trial (RCT) investigating the effects of a low level of DHA supplementation during the last trimester on pregnancy outcomes. Women were randomly assigned to either a high DHA egg condition (135 mg DHA per egg) or a regular egg condition (35 mg DHA per egg) and were blind to their condition assignment. The results revealed a statistically significant 6-day increase in gestation and a small but significant increase in the RBC phospholipid DHA levels of 0.43% of total fatty acids in the high DHA egg condition compared to the controls. Notably, there were no group differences in maternal RBC DHA levels at delivery or in any other measures (see Smuts et al., 2003 for more details). The small difference in DHA in the high compared to the ordinary eggs

(~100 mg DHA/day) but also the high variability in maternal RBC DHA were likely contributors to this lack of effect. For example, 49% of the variance in maternal RBC DHA at the time of delivery was explained by RBC DHA when the women were enrolled.

METHOD

Participants

The toddlers in the present project were part of a longitudinal study of attention in infancy and toddlerhood; additional details on the sample can be found in Colombo et al. (2004). As noted previously, the original trial was designed to look at pregnancy outcomes (Smuts et al., 2003). Only a small sample of women at the end of the study ($N = 100$) were invited to enroll their newborns for a study of attention and 70 participated. Of this number, 49 toddlers remained in the study and participated in the 12- and 18-month sessions. Two toddlers were excluded because of fussiness, and two toddlers were excluded due to experimenter error. The final sample consisted of 45 toddlers (18 females and 27 males). The average age was 53.15 weeks (*SD* = 1.94) at the 12-month session and 79.24 weeks (*SD* = 2.88) at the 18-month session. Thirty-eight toddlers were African American, 1 toddler was Hispanic, and 6 toddlers were Caucasian, as reported by the mothers.

The same classification of high and low DHA based on a median split of maternal RBC DHA levels at delivery (reported in Colombo et al., 2004; see Smuts et al., 2003 for the method of determining RBC phospholipid DHA) was used; recall that in the original pregnancy study, Smuts et al. (2003) found no effect of supplementation on maternal RBC DHA levels at delivery. The median value for maternal DHA in Colombo et al. was 5.35 g DHA per 100 g of fatty acid. See Table 1 for

TABLE 1
Sample Characteristics

	Low Maternal DHA		*High Maternal DHA*		
	Mean	*SD*	*Mean*	*SD*	*t statistic*
Gestation length (weeks)	39.18	1.30	39.34	1.69	.36
Apgar score (1 min)	8.00	1.30	7.48	1.66	1.15
Apgar score (5 min)	8.95	.22	8.52	1.05	1.80
Birth weight (g)	3190.50	314.73	3282.80	440.49	.79
Length (cm)	50.22	2.06	50.60	2.60	.53
Head circumference (cm)	33.62	.97	33.86	1.64	.57
Toddlers' age at 12 months	53.52	2.49	52.84	1.32	1.17
Toddlers' age at 18 months	78.47	2.01	79.86	3.33	1.63
Mother's education (yr)	11.50	0.89	12.00	1.50	1.31
Father's education (yr)	11.85	0.49	12.00	1.72	.38
Mothers' PPVT–R standardized score	92.35	17.66	87.10	12.10	1.10
Maternal DHA level at delivery (g DHA per 100g of fatty acid)	4.66	0.49	6.19	0.59	9.42*

*$p < .05$; all other t statistics were not significant. DHA: docosahexaenoic acid; PPVT–R: Peabody Picture Vocabulary Test–Revised.

the mean values of maternal RBC DHA levels at delivery in the present sample; an independent samples *t*-test revealed a significance difference between the groups, t (43) = 9.42, $p < .01$. Twenty-five toddlers from the high maternal DHA group ($N = 15$ from the supplemented group in Smuts et al., 2003) and 20 toddlers from the low maternal DHA group ($N = 11$ from the supplemented group in Smuts et al., 2003) participated in the 12- and 18-month free-play sessions. The mothers of 40 toddlers agreed to take the Peabody Picture Vocabulary Test–R (PPVT), a standardized measure of receptive vocabulary that correlates with IQ. Characteristics of the sample are reported in Table 1. Preliminary analyses also indicated that there were no differences between the groups on potentially confounding variables such as demographic variables (e.g., maternal receptive vocabulary, parents' education), medical variables (e.g., gestation length, APGAR scores, birthweight and length, head circumference), or age at testing (see Table 1). The majority of infants were formula-fed (high maternal DHA group, $N = 22$, low maternal DHA group, $N = 17$), and the study took place before commercially available formulas contained DHA.

Stimuli

Previous research (e.g., Colombo et al., 2004; Ruff & Capozzoli, 2003; Ruff & Lawson, 1990) comparing infant and toddler attention have used different objects for the free-play tasks at different ages with the goal of presenting novel, developmentally appropriate stimuli at each age. For the current project, we adopted this strategy and used separate novel, developmentally appropriate stimuli at each age.

Six small toys were used in the task at each age. The toys were plastic and contained different parts that could be manipulated or produced an interesting effect. At 12 months, the toys were a bulldozer, hammer rattle, aquarium ball (clear plastic ball containing water and a plastic fish), Lego cart, baby (which fit inside the cart), and two colorful stacking blocks (which could be taken apart and put together). At 18 months, the toys were a cement truck, rain stick (a clear tube containing beads that move through inner plastic divisions of the tube), bead chaser (plastic beads that could be moved along a series of plastic connectors), Lego train, dog (which fit inside the train), and a 3-piece bee (which could be taken part and assembled).

Procedure

At both ages, multiple objects were presented in the context of a free-play task. The multiple-object task was the second task in a sequence of tasks used in the 2004 study (for a descriptions of the other tasks, see Colombo et al., 2004), and the order of task presentation was constant across ages. Both the parent and the experimenter kept their interactions to a minimum, and parents were asked to refrain from interacting and talking. Toddlers were seated on their parents' laps at a table. All sessions were recorded using a Panasonic camcorder, and a time–date generator was used to imprint the elapsed time (accurate to .1 sec) on the videos for coding purposes.

The experimenter used a standard script to present each toy. She presented the toys to the toddler one at a time and demonstrated a function of the toy (e.g., rotating the aquarium ball to make the fish move) while saying "[Toddler's name], look at this toy!" Toys were placed randomly on the table. Toddlers were then encouraged to play and allowed to freely explore and manipulate the toys for 5 minutes. If the toddler dropped a toy, the experimenter returned it and then touched all of the toys so as to not draw the infants' attention to a specific toy. Task sessions were timed using a handheld stopwatch.

Coding

Coders unaware of the hypotheses of the study viewed the sessions on large Panasonic monitors; they used the jog-shuttle dial on Panasonic VCRs to record the start and stop of toddlers' individual looks to the toys and episodes of inattention (when toddlers looked anywhere else but at the toys) using the time imprinted on the video. In addition, coders recorded the toy to which the toddler attended by noting the child's direction of gaze, as well as using other cues, such as object manipulation. Sometimes toddlers looked at more than one toy at the same time (e.g., tapping the aquarium ball with the hammer rattle); this was counted as a single look. In order to assess coder reliability at each age, two coders recorded the duration of individual looks and episodes of inattention for at least 25% of the sample, and the average correlations between the two coders at each age were .96 at 12 months and .95 at 18 months for looking, and .96 at 12 months and .94 at 18 months for inattention.

Four measures were calculated: The total duration of looking, total number of episodes of inattention, average length of looks to the toys, and total number of looks to the toys ("shifts in attention"). See Table 2 for the mean values of these measures for the high and low DHA groups. We used these measures as indicators of inattention and how long toddlers "hold" or sustain/maintain their attention to a particular stimulus in the midst of continuous competition for their attentional focus (as during multiple object play). Previous research on attention during free-play with typically developing children and those with attention problems assessed young children's looking, inattention, and toy switching as an index of their ability to maintain their attention, and this research has found that typically developing children maintain their attention for longer durations and engage in less inattention (e.g., DeWolfe et al., 2000; Roberts, 1990) and switch toys less often (e.g., Alessandri, 1992; Roberts, 1990) than do children with attentional problems. Because we were interested in capturing shifts in attention (i.e., how often the toddlers shifted their attention among the different objects) and duration of individual looks to the toys, we defined an indi-

TABLE 2
Means and Standard Deviations for All Coded Measures

		Low Maternal DHA		*High Maternal DHA*	
Measure	*Age*	*Mean*	*SD*	*Mean*	*SD*
Total looking	12	192.45	40.76	208.22	29.24
	18	231.44	29.81	255.05	24.39
Average look length	12	2.47	.71	2.54	.69
	18	3.28	.66	3.89	1.06
Total no. of looks	12	80.30	15.29	85.36	17.09
	18	72.60	15.24	69.56	17.77
Total no. of inattention episodes	12	25.45	7.98	21.72	6.62
	18	20.80	6.80	14.48	4.76

DHA: docosahexaenoic acid.

vidual look as a look to a particular toy (or an episode of inattention as a look away) that was .5 sec or longer in duration; looks to the same toy that were separated by a very short look away (i.e., less than .5 sec) were combined.

RESULTS

The individual cell means are reported in Table 2. The four measures (total duration of looking, number of episodes of inattention, average length of looks to the toys, total number of looks) were entered into separate ANOVAs with age (12, 18) as a within-subjects factor and maternal DHA (high, low) as a between-subjects factor. In general, toddlers of mothers with high DHA were more attentive than were toddlers of mothers with low DHA; there were also age differences in attention.

Toddlers of mothers with high levels of DHA exhibited significantly more total looking, $F\ (1, 43) = 9.00$, $p < .01$, $\eta_p^2 = .17$, and fewer episodes of inattention, $F\ (1, 43) = 13.17$, $p < .01$, $\eta_p^2 = .23$, than did toddlers of mothers with low levels of DHA. Toddlers of mothers with high levels of DHA displayed marginally longer average look lengths, $F\ (1, 43) = 3.19$, $p = .08$, $\eta_p^2 = .07$. There were no group differences in the number of looks to the toys, $F\ (1, 43) = .07$, *ns*. None of the interaction terms were significant, although the DHA × Age interaction for the analysis on the average length of looks was marginally significant, $F\ (1, 43) = 3.31$, $p = .08$, $\eta_p^2 = .07$; toddlers in both DHA groups had similar average look lengths at 12 months, but the groups diverged at 18 months, with toddlers in the high DHA group having longer average look lengths than did those in the low DHA group.

In general, toddlers were more attentive at 18 months. The toddlers displayed more total looking, $F\ (1, 43) = 41.80$, $p < .01$, $\eta_p^2 = .49$; longer average look lengths, $F\ (1, 43) = 53.19$, $p < .01$, $\eta_p^2 = .55$; fewer individual looks to the toys (i.e., fewer “shifts” in attention), $F\ (1, 43) = 13.10$, $p < .01$, $\eta_p^2 = .23$; and fewer episodes of inattention, $F\ (1, 43) = 18.22$, $p < .01$, $\eta_p^2 = .30$, at 18 months than at 12 months. In summary, there was evidence of developmental change in measures of multiple object free-play attention, and higher DHA status was associated with enhanced attentional functioning.

DISCUSSION

The current project makes important contributions to our understanding of the relation between DHA and free-play attention and the development of endogenous attention during infancy and toddlerhood. First, the results are consistent with previous research on the relations between DHA and infant development, and they suggest that measuring endogenously controlled attention in a multiple object free-play task may be an effective outcome measure for studying how LC-PUFAs may affect attentional control. For example, the current project found that toddlers of mothers with higher levels of DHA at delivery exhibited more sophisticated attentional responding. Specifically, they engaged in more looking overall (231.63 sec vs. 211.95 sec), showed fewer instances of inattentiveness (18.10 vs. 23.12 episodes of inattention), and they also tended to display longer individual looks (3.22 sec vs. 2.88 sec). Moreover, toddlers in the high DHA group tended to exhibit a greater increase in the average length of looking from 12 to 18 months, suggesting an enhanced developmental trajectory. We generally interpret the greater amount of total looking and fewer episodes of inattention as suggesting that these toddlers were better at holding or maintaining their attention to the task toys. Such differences are analogous to group differences in attention during free-play between typically developing preschoolers and preschoolers with attention problems (e.g., DeWolfe et al., 2000; Roberts, 1990).

The current results are also consistent with other research on the relations between DHA and infant cognitive development. For example, higher levels of DHA are related to more sophisticated attending during habituation and familiarization tasks, better problem- solving skills, longer attention spans in a noncompetitive attention task, and less distractibility (Carlson & Werkman, 1996; Colombo et al., 2004; Judge et al., 2007a; Jacobson et al., 2008; Werkman & Carlson, 1996; Willatts et al., 1998). Moreover, the tendency for toddlers in the high DHA group to display a greater increase in the average length of looking from 12 to 18 months is consistent with similar patterns of responding in the single object task, a noncompetitive free-play task (Colombo et al., 2004). Specifically, in a previous report on this sample, toddlers in the low DHA group exhibited a decrease in looking from 12 to 18 months whereas toddlers in the high DHA group exhibited an increase in looking, which is consistent with the normative developmental trajectory.

An important question, then, is how might DHA contribute to cognitive functioning? This is a complex question, and there are several possible ways in which DHA may affect cognitive processes. For example, Cheatham et al. (2006) recently posited that DHA may influence speed of information processing and memory, possibly through myelination and functioning of the N-methyl-D-asparate (NMDA) channels. When patients with Zellweger syndrome (who have very low levels of DHA in the brain, retina, and other tissues) received DHA supplementation, magnetic resonance imaging showed increases in myelination (Martinez, 2001). When pregnant rat dams were fed a DHA-supplemented diet, higher levels of DHA in the maternal diet affected the lipid composition in the offsprings' myelin (Haubner et al., 2007). Cheatham et al. also suggest that DHA may affect the formation of memory by facilitating the function of the NMDA channels (Nishikawa, Kimura, & Akaike, 1994) and affecting hippocampal neurotransmission (Itokazu, Ikegaya, Nishikawa, & Matsuki, 2000). The hippocampus and frontal regions are fundamental for attentional control, memory, and higher-level cognitive processes.

Because our preliminary analyses showed that there were no differences between the high and low maternal DHA groups on potentially confounding variables such as demographic variables (e.g., maternal receptive vocabulary, parents' education), medical variables (e.g., gestation length, APGAR scores, birthweight and length, head circumference), or age at testing, we believe that higher DHA status was associated with more advantageous attentional responding. An additional question asks, What is the potential influence of enhanced visual acuity on cognitive development? DHA supplementation studies with preterm infants have shown enhancement of visual acuity in young infants (e.g., Carlson, Werkman, & Tolley, 1996). The results from studies using term infants is more mixed, with some researchers finding an increase in acuity (e.g., Birch et al., 2005) and others not (Makrides, Neumann, Jeffrey, Lien, & Gibson, 2000). As suggested elsewhere (Cheatham et al., 2006), developmental systems theory (e.g., Gottlieb, 1992) would suggest that enhanced visual acuity may impact cognitive functioning. Therefore, it is possible that the enhanced attentional functions found in the high DHA group may have been contributed to by greater visual acuity.

Finally, the present project contributes to our understanding of the developmental course of attention in the second year. Compared to 12 months, at 18 months, toddlers exhibited more total looking (243.25 sec vs. 200.34 sec), longer average look lengths (3.59 sec vs. 2.51 sec), fewer individual looks to the toys (i.e., fewer shifts in attention) (71.08 vs. 82.83 individual looks to the toys), and fewer episodes of inattention (17.64 vs. 23.58 episodes of inattention). Each of these developmental differences is consistent with the general conclusion that between 12 and 18 months, toddlers develop a greater ability to hold and sustain attention when faced with multiple objects presented at one time. Specifically, the increase in the total amount of looking and the average length of individual looks to the toys suggests an increase in how toddlers hold or maintain their attention to the target task. Eighteen-month-olds exhibited fewer episodes of inattention, and they exhibited fewer individual looks to the toys, suggesting a decrease in the amount of attentional switching among the objects and better maintenance of attention.

This change in attention during multiple object free-play is consistent with increases in endogenous control over visual attention between infancy and early childhood. Even though different types of objects were used at the two ages, they were very similar to one another, and the age differences in attention allocation likely represent changes in the underlying attentional systems above and beyond any differences due to the specific objects used at the two ages. This observed change is consistent with other evidence of increases in attention allocation during free-play (e.g., Kannass & Oakes, 2008; Ruff & Capozzoli, 2003; Ruff & Lawson, 1990; Sarid & Breznitz, 1997). Kannass and Oakes (2008) measured attention in the same type of task at 9 and 31 months and found (1) increases in measures of total looking and the average length of individual looks and (2) decreases in the number of episodes of inattention and the number of individual looks across this larger age span. Ruff and Lawson (1990) found that duration of concentration in the multiple object context increased between infancy and the preschool years, where attention becomes increasingly under inhibitory control, self-regulation, and executive control and influenced by cognitive change (Ruff & Rothbart, 1996). For example, increases in inhibitory control, planning, and goal-directed activity as well as increases in the sophistication of cognitive actions and schemes may contribute to increases in attention (Ruff & Lawson, 1990; Ruff & Rothbart, 1996). Moreover, concentration and focusing of attention may increase as the cognitive demands in play sequences become more complex and require more effort and time (Ruff & Lawson, 1990).

In conclusion, the current project contributes to a growing body of evidence that suggests that traditional laboratory measures of cognitive development that tap specific cognitive processes are useful tools in interdisciplinary research and support recommendations for researchers to use tasks and paradigms that tap specific processes thought to be affected by dietary factors rather than global tests of development (Cheatham et al., 2006; Wainwright & Colombo, 2006). Additional research is needed to better understand how endogenous functions are affected by LC-PUFAs, including more experimental work in order to better understand potential causal mechanisms as well as more work that incorporates other measures of endogenous and executive functions in infancy and early childhood.

ACKNOWLEDGMENTS

The authors thank Jill Shaddy, Christa Anderson, Otilia Blaga, and the undergraduates at the University of Kansas Infant Cognition Center for their efforts to this project. They also thank the delightful participants and their parents. Portions of this research were presented at the Biennial Meeting of the Society for Research in Child Development (March 2007 in Boston, MA).

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