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RESEARCH ARTICLE

The development of visual attention in early infancy: Insights from a free-viewing paradigm

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Abstract

Theories of visual attention suggest a cascading development of subfunctions such as alertness, spatial orientation, attention to object features, and endogenous control. Here, we aimed to track infants' visual developmental steps from a primarily exogenously to more endogenously controlled processing style during their first months of life. In this repeated measures study, 51 infants participated in seven fortnightly assessments at postterm

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ages of 4–16 weeks. Infants were presented with the same set of static and dynamic paired comparison stimuli in each assessment. Visual behavior was evaluated by a newly introduced scoring scheme. Our results confirmed the suggested visual developmental hierarchy and clearly demonstrated the suitability of our scoring scheme for documenting developmental changes in visual attention during early infancy. Besides the general ontogenetic course of development, we also discuss intra- and interindividual differences which may affect single assessments, and highlight the importance of repeated measurements for reliable evaluation of developmental changes.

1 | INTRODUCTION

Visual attention enables us to focus the capacities of the visual system on a small fraction of the enormous amount of information provided by our photoreceptors. This prioritizes the processing of attended aspects while suppressing irrelevant information (e.g., Carrasco, 2011; Daliri et al., 2016; Kozyrev et al., 2019; Malek et al., 2017; Theeuwes, 1993). Visual attention has been the subject to thousands of studies highlighting various behaviors and functions that influence how and what we select as targets for exploration (for reviews, see, e.g., Carrasco, 2011; Desimone & Duncan, 1995; Moore & Zirnsak, 2017). Thirty years ago, Posner and Petersen (1990) introduced a model dividing the attention system into three distinct functions, that is, (a) *alerting*, (b) *spatial orienting*, and (c) *executive control*, mediated by separable anatomical and functional cortical networks (Fan et al., 2002; Petersen & Posner, 2012; Posner & Petersen, 1990; for reviews on cortical networks associated with attention, see, e.g., Colombo, 2001; Moore & Zirnsak, 2017; Posner & Rothbart, 2007). (a) *Alerting* is hypothesized to be mediated by the parietal and frontal cortex and the locus coeruleus (e.g., Heilman et al., 1985; Marrocco & Davidson, 1998) and refers to both attaining and maintaining a high level of arousal. Alertness prepares the organism for information processing and consists of tonic and phasic aspects. Tonic alertness constitutes a general intrinsic level of wakefulness (i.e., "vigilance"). Phasic alertness refers to the ability to modulate the level of arousal in reaction to external stimulation (e.g., following a warning signal; Posner, 2008; Sturm & Willmes, 2001). (b) *Spatial orienting* refers to the process of selecting targets for exploration and is associated with the activity in the parietal areas, the superior colliculus and the frontal eye fields (Corbetta et al., 1998, 2000; Thompson et al., 2005). (c) *Executive control* entails volitional processes that aim to resolve behavioral conflict between competing information by selecting targets, and by switching between stimuli and inhibiting responses to distracting information. Cortical areas involved in executive control are the lateral prefrontal cortex and anterior cingulate cortex (e.g., Botvinick et al., 2001; Bush et al., 2000).

Research on visual attention and its development in infancy has revealed unique characteristics in information processing as a result of cortical maturation, suggesting that visual attention shows rapid development throughout the first year of life (for reviews, see, e.g., Amso & Scerif, 2015; Braddick & Atkinson, 2011; Canejero & Rueda, 2017; Colombo, 2001; Reynolds & Romano, 2016). Research on distinct functions of visual attention in infancy suggests a mainly exogenously controlled and reflexive style of attentive guidance within the first 3 months of life, with infants primarily attending to salient stimulus features such as increased contrast or stimulus borders (e.g., Reynolds, 2015). This literature suggests that it is not until 3–6 months of age that infants begin to develop endogenous control of visual behavior (e.g., Canejero & Rueda, 2017; Reynolds, 2015).

Based on definitions and models of visual attention, such as the one proposed by Posner and Petersen (1990) mentioned earlier, Colombo (2001) introduced a conceptualization of four distinct subfunctions of visual attention that highlight the developmental progress as a result of cortical maturation during the first year(s) of life: (a) *alertness*, (b) *spatial orienting*, (c) *attention to object features*, and (d) *endogenous control*. Besides a definition of relevant and well-documented functional changes, Colombo (2001) took evidence of cortical developmental processes into account to suggest a hierarchical idea of three critical periods for attention development in infancy. The timing of the most significant changes in behaviors led Colombo (2001) to propose the following sequence of visual development in infancy that are associated with the four subfunctions given above: 0–2 months of age are related to *alertness*; 2–3 to 6 months to *spatial orientation* and *attention to object features*; and 5–6 months and older to *endogenous control*. This idea of a developmental cascade is supported by a large body of literature on both onset and stabilization of specific behavioral and physiological indicators of respective subfunctions (for reviews, see, e.g., Amso & Scerif, 2015; Braddick & Atkinson, 2011; Colombo, 2001; Reynolds & Romano, 2016).

In our current study, we aim to track infants' developmental trajectory of visual attention with respect to the proposed subfunctions using a single free-viewing task. This approach allows us to systematically document both the age-specific visual behaviors in infants and the developmental cascade with the same task. The extraneousness potentially caused by task dissimilarities can be ruled out. To the best of our knowledge, this is the first such attempt in the field. In the next paragraphs, we summarize Colombo's framework of visual attention during infancy, its changes over time, as well as developmental aspects of cortical functioning. Based on this theoretical background, we will then introduce a scoring system which integrates different observable behaviors into one composite score of visual attention, and will enable the evaluation of developmental trajectories and specific processing styles.

1.1 | Alertness

At the beginning of extrauterine life, infants spend <20% of the time in alert states (e.g., Prechtl, 1974; Thoman, 1975; for reviews, see, e.g., Colombo & Horowitz, 1987; Wolff, 1965, 1987). The behavioral state, however, modulates an individual's readiness to engage with the environment. Thus, the relation between alertness and attention is interdependent during infancy (e.g., Gardner & Karmel, 1984; Gardner et al., 1986). The so-called orienting reflex, that is, a reorientation of the "spotlight of attention" toward changes in the visual field, allows an individual to explore novel stimuli or objects and is considered to involve both alerting and selecting (e.g., Ruff & Rothbart, 2001). Studies on behavioral states revealed that the time spent in higher levels of alertness increases substantially within the first 2–3 months postterm (e.g., Prechtl, 1974; Wolff, 1965), which is in line with the suggestion of a maturation of the orienting reflex within the same period of development (Graham et al., 1983). Orienting toward salient stimuli, however, does not necessarily trigger further exploration, but precedes exploratory behavior of any kind (e.g., Sokolov, 1963).

1.2 | Spatial orientation and attention to object features

Although infants are able to orient toward spatial targets from a very early age onward, their initial explorative behavior is primarily driven exogenously, as indicated by various behavioral characteristics of object attention, for example, prolonged fixations, less intensive scanning of objects, and a lack of interstimulus shifting: (a) within the first weeks of life, infants tend to focus their attention on one salient feature of a stimulus; scanning between object features was found to develop rapidly at around 2 months of age (e.g., Bronson, 1990, 1991, 1994; Hunnius et al., 2006; Salapatek, 1975); (b) prior to 1.5 months of age, infants were reported to restrict their fixations to a smaller area of the stimulus than from 2.5 to 3 months of age (e.g., Leahy, 1976); (c) until approximately 3 months of age, attention seems to be primarily drawn to stimulus borders and/or external contours (e.g., Bronson, 1990; Hainline, 1978); (d) infants in the early neonatal period show fixations of long durations, with only rare interruptions of gaze (e.g., Stechler & Latz, 1966). Once engaged with an object or a stimulus, young infants show difficulties in shifting attention from a currently fixated to a competing stimulus (e.g., Hood, 1995; Hopkins & van Wulfften-Palthe, 1985). Notably, the experimental approaches and stimuli used in the previous studies were heterogeneous. For example, Bronson (1990) used static and animated geometric figures, Hunnius et al. (2006) applied video recordings of the mother's face and dynamic abstract stimuli, while Hopkins and van Wulfften-Palthe (1985) focused on observation of the viewing behavior when the infant was alone or interacting with a caregiver. As different as the approaches were, no study by far has yet allowed a systematic investigation of the ontogeny of the subfunctions of visual attention in early infancy, namely, the emergence of and the transitions between age-specific visual processing styles.

The ability to shift attention between competing stimuli was found to improve significantly within the first 3–4 months concerning frequency and latency of disengagement (Atkinson, 1992; Atkinson et al., 1992; Butcher et al., 2000; Hood & Atkinson, 1993; Hunnius et al., 2006). Typically, studies examining the ability to shift attention use a "disengagement" paradigm, with a central fixation stimulus. Once this stimulus is foveated, (a) it disappears, and is replaced by a stimulus in the peripheral visual field (i.e., noncompetition/gap condition), or (b) a second stimulus is added in the peripheral visual field (i.e., competition/overlap condition). The most frequently reported criteria for evaluating disengagement are the frequency of shifts to the peripheral targets and the latency of disengagement. Evidence suggests that during periods of "obligatory attention" (Stechler & Latz, 1966) or "sticky fixations" (Hood, 1995), infants are not truly in control of their oculomotor behavior, but are stuck to the stimulus while attention may be dissociated from fixation (e.g., Greenberg & Weizmann, 1971; Hopkins & van Wulfften-Palthe, 1985). The ability to look away from an object (i.e., terminating attention and diverting gaze from a foveated stimulus) seems to be present from the very first days of life onward, and may not be related to the phenomena reviewed earlier (e.g., Hendry et al., 2019; Stechler & Latz, 1966).

A comparison of two behaviors related to object attention, that is, object scanning and disengagement from a central to a competing peripheral stimulus, suggests that both processes develop rapidly but independently of each other until approximately 4 months of age. Object scanning, however, may stabilize slightly earlier than disengagement in the majority of individuals (Hunnius et al., 2006). Applying two different tasks, Hunnius and colleagues revealed intraindividual developmental differences in the emergence and stabilization of these two subfunctions, yet did not report on potential changes in the infants' predominant processing style over time.

1.3 | Endogenous attention

The ability to direct and allocate attention voluntarily in a controlled and goal-oriented way includes aspects of strategic scanning, interstimulus shifting, maintaining attention to task-relevant information, and inhibiting attentional shifts toward distracting stimuli through executive control. As such, endogenous attention has been suggested to mediate the subfunctions of attention in terms of internal purposes and task-related goals (e.g., Colombo, 2001; Colombo & Cheatham, 2006). Rudimentary forms of endogenous control may also be reflected in the ability to hold attention on a particular task, which is also prerequisite to remain focused in the presence of distractions. One of the main topics of research on endogenous attention during infancy has been the assessment of distinct attention phases through the evaluation of heart rate changes (e.g., Graham et al., 1983; Richards, 1985; Tonnsen et al., 2018). These studies revealed that the phases of stimulus processing are reflected in systematic changes of the heart rate. Sustained attention has been suggested to reflect a voluntary form of engagement and a relevant stage for active information processing in infants (e.g., Reynolds & Richards, 2008; Richards & Casey, 1992). It is important to notice that these studies have mainly included infants aged 3 months or older.

Evidence from the visual expectation paradigm (Haith et al., 1988) demonstrates that many 3 months old infants show anticipatory eye movements as well as prestimulus EEG activity to familiar pictures (Wentworth et al., 2001). Anticipatory reactions were reported even for 2 months old infants (Wentworth & Haith, 1992). This shows the formation of expectations about where and when stimuli would appear. As these responses occur prior to stimulus onset, they are (by definition) not under exogenous control but must be governed by some form of endogenous state. These findings underline that the period between 2 and 3.5 months is critical for the rise of endogenous control.

The succession of developmental steps mentioned earlier is in line with knowledge on the timing of cortical development and functional onset of cortical systems during infancy. Reflexive orientation is thought to be driven subcortically through pathways from the retina to the superior colliculus, which locates objects and elicits foveation (e.g., Atkinson, 1984, 1992; Bronson, 1974; Johnson et al., 1991). The rapid development of processes related to spatial orientation and object attention from 2 to 3 months onward is commonly attributed to the functional onset and maturation of the posterior orienting system, which plays a vital role for the voluntary guidance of saccades (e.g., Posner & Petersen, 1990; Reynolds, 2015; Reynolds & Romano, 2016). The onset of endogenous control of attention has been associated with the maturation of frontal cortical areas and the functional onset of the anterior attention system (e.g., Posner & Petersen, 1990; Reynolds, 2015; Reynolds & Romano, 2016).

As stated earlier, the vast body of literature suggests a cascading course in both emergence and stabilization of different subfunctions of attention (e.g., Colombo, 2001; Colombo & Cheatham, 2006; Hunnius et al., 2006; Johnson, 1990; Reynolds, 2015). Figure 1 highlights the timing of development with respect to observable behaviors related to the above-reviewed subfunctions of attention, which will be particularly relevant for this study.

So far, researchers predominantly focused on single subfunctions of attention (e.g., disengagement of attention), and inferred a developmental hierarchy indirectly by summarizing findings from multiple studies of heterogeneous experimental approaches. To the best of our knowledge, there are only a few studies examining attentional development longitudinally over the first few months of life and none of those studies have used a longitudinal single-task approach with the same sample of infants to systematically evaluate behavioral changes related to the emergence of different subfunctions of visual attention. Critically, in this study viewing is unconstrained

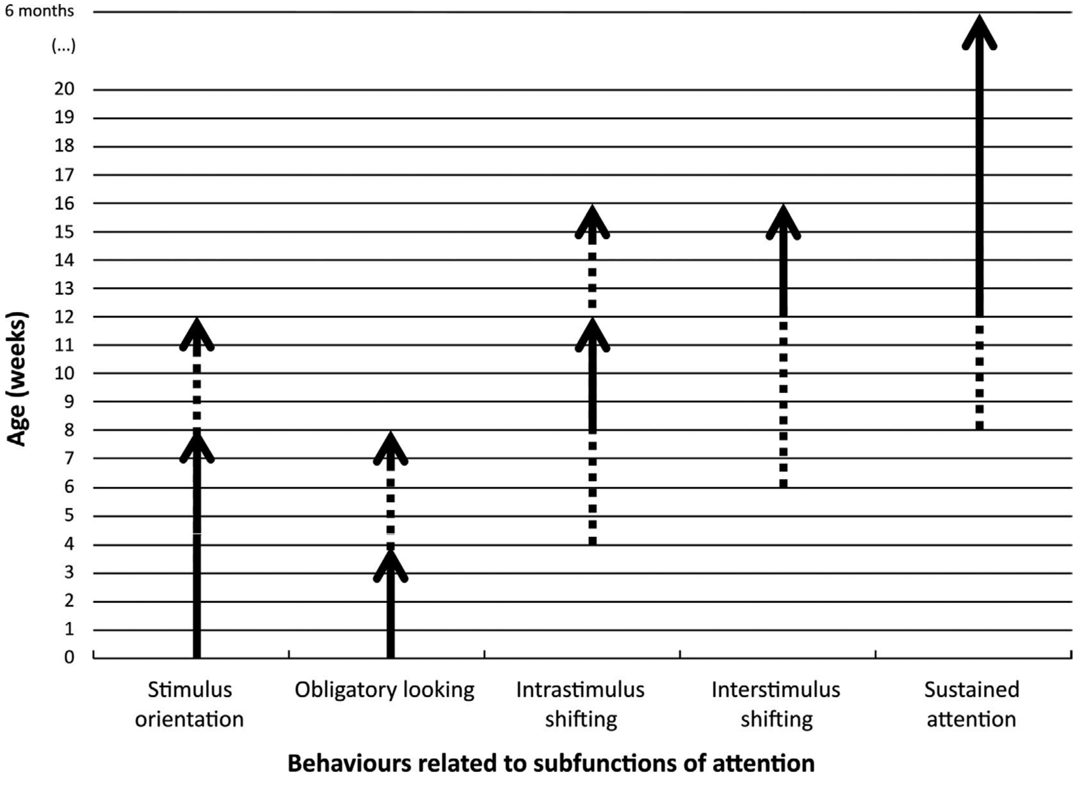

FIGURE 1 Timing of development of observable behaviors related to subfunctions of visual attention. *Note*. Based on the reviewed literature, we emphasize interindividual variation by tagging relatively broad age bands during which relevant behaviors were reported to be observable (dashed lines). Solid lines indicate the core age bands during which behaviors are expected

and potential influences of task disparities can be ruled out, as infants were presented with the same set of stimuli for seven consecutive assessments. We hypothesize that (a) we will be able to document developmental steps and the hierarchy of age-specific onsets and changes of the four subfunctions of attention (Colombo, 2001), (b) these developmental steps will be reflected in transitions of infants' dominant visual behavior from a primarily exogenously driven toward a more endogenously controlled processing style, and (c) visual processing will vary between individuals, reflecting interindividual differences in attentional development in early infancy. To test these hypotheses, we (a) introduce a hierarchical scheme to score behavioral indicators of attention within one single task, (b) evaluate its eligibility in modeling the development of visual attention in a sample of infants at low risk for deviant development, and (c) estimate the inter-rater reliability of the new scoring scheme.

2 | METHODS

2.1 | Participants

From 2015 to 2017, 51 newborn babies (26 females, 25 males) and their families resident in or near Graz (Austria) were recruited for participation in our prospective longitudinal study

"Early Human Development: Pilot Study on the 3-Month-Transformation" (Marschik et al., 2017) on neuromotor, visual, and verbal development. All infants were Caucasian in origin and their families were monolingual German speaking. All parents had completed high-school level or higher education. Infants were at typical likelihood for developmental disorders according to the following inclusion criteria: uneventful pregnancy, uneventful delivery at term age (>37 weeks gestation), singleton birth, appropriate birth weight, uneventful neonatal period, inconspicuous hearing, and visual development (see Table 1 for further information). Besides, no mother presented current or a history of alcohol or substance abuse. In the neonatal period, infants were tested in fortnightly intervals, from 4 to 16 weeks postterm age. Postterm ages for the seven consecutive assessment sessions 1–7 were 28(±2) days, 42(±2) days, 56(±2) days, 70(±2) days, 84(±2) days, 98(±2) days, and 112(±2) days. One infant was excluded from the analysis due to strabismus diagnosed in the third assessment session, resulting in a final sample size of $N = 50$.

The study was conducted according to the guidelines laid down in the Declaration of Helsinki and was approved by the Institutional Review Board of the Medical University of Graz (Austria). Parents were informed about all experimental procedures and the purpose of the study. Written informed consent was obtained from a parent for each infant before any assessment or data collection.

2.2 | Materials

The assessment of the developmental trajectory of visual attention was one of three modules of an assessment session. The same procedure was taken at each of the seven consecutive assessment sessions (Marschik et al., 2017).

Infants were presented with eight gray scale paired comparison stimuli (see Figure 2) created with the GNU Image Manipulation Program (GIMP). We used six static stimuli and two dynamic stimuli consisting of pairs of pictures and motion segments against a gray

TABLE 1 Sample core data

					Percentiles		
$N = 50$	**Mean**	***SD***	**Min**	**Max**	**25**	**50**	**75**
Gestational age (weeks)	39.16	1.11	37	41	38	39	40
Birth weight (g)	3455	343	2500	4416	3272	3454	3680
Birth length (cm)	51.60	1.96	47	56	50	51	53
APGAR score							
1 min	8.90	0.80	4	10			
5 min	9.86	0.61	6	10			
10 min	9.96	0.20	9	10			

Note: The APGAR score (Apgar, 1953) was developed to evaluate a newborn's health condition and the potential need of neonatal care based on five categories (*A*ppearance, *P*ulse, *G*rimace, *A*ctivity, *R*espiration). A score ≥7 is considered normal, scores ranging between 4 and 6 are classified as fairly low, and scores ≤3 as critically low (Apgar, 1953; Casey et al., 2001). The APGAR test is routinely applied three times, that is, 1, 5, and 10 min after birth.

Abbreviation: *SD* = standard deviation.

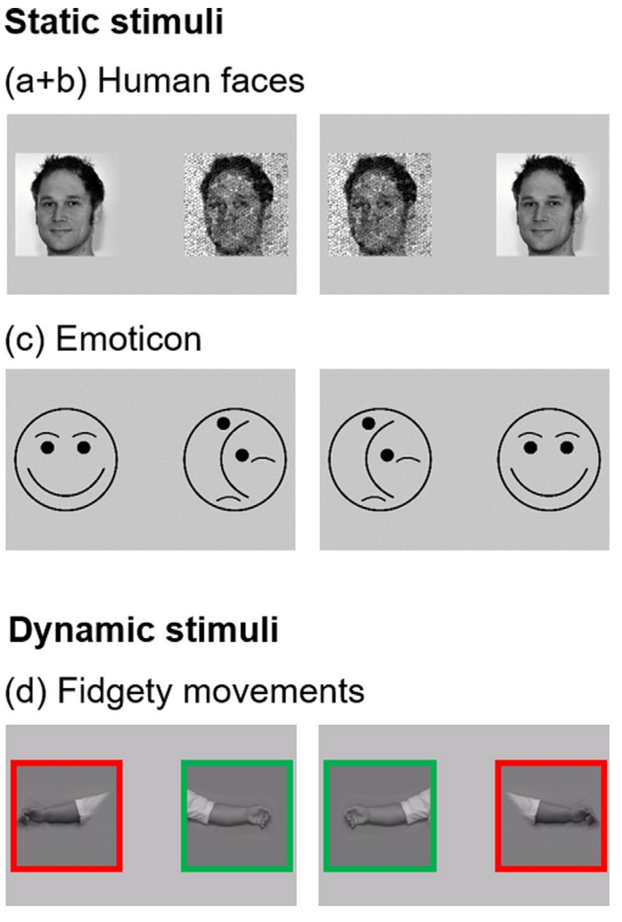

FIGURE 2 Stimulus categories used in the assessment of the developmental trajectory of visual attention. *Note*. (a+b) Human faces. Stimuli (b) with a female human face and its mosaic counterpart are not shown in the figure due to the absence of the personal consent of presentation. (c) Emoticon. (d) Fidgety movements. The colored frames are demonstrated here to illustrate the difference of the stimuli and do not exist during the experimental presentations. The green frame indicates the movement sequence with normal fidgety movements in the wrist, while the red frame the sequence without fidgety movements

background. Based on a substantial body of literature demonstrating that infants prefer to track faces and face-like stimuli over nonface stimuli (e.g., Frank et al., 2014; Goren et al., 1975; Johnson et al., 1991; Reynolds & Roth, 2018), we chose static stimuli displaying either human faces (Figure 2a+b) or face-like emoticons (Figure 2c). The human faces showed: (a) a male adult with dark hair and dark eyes versus a mosaic transformation of the original picture and (b) a female adult face (not shown in the figure) with dark hair and dark eyes versus its mosaic transformation. The smiling emoticons consisted of five facial components (eyes, eyebrows, mouth) within a circle versus scrambled smiling emoticon with displaced and rotated facial components (see Figure 2c).

The two dynamic stimuli (see Figure 2d) were paired videos of motion segments with isolated continuous *fidgety movements* versus motion segments without *fidgety movements* of a 3-month-old infant against a gray background (see next for descriptions on *fidgety movements*). Investigating infants' visual attention to fidgety versus nonfidgety hand–forearm movements were a component of an umbrella project profiling infant cross-domain neurofunctional development during the first months of life (Marschik et al., 2017; Reich et al., 2021). These dynamic stimuli were embedded in the same experimental paradigm with the static stimuli (see Study design and procedure). Although studying infants' visual attention to the fidgety movements (FMs) is not the focus of this study, our data analysis revealed comparable oculomotor behavioral scores for both the static and the dynamic stimuli. That is, the infants' visual attentional behavior of interest was not affected by the types of stimuli (see Results for more details). We hence decided to involve and report these data which, on one hand, strengthen the statistical power of the study, and on the other hand, remain true to the actual experimental paradigm applied. Fidgety movements are age-specific movements of the shoulders, wrists, hips, and ankles in typically developing infants from approximately 8 to 16 weeks. They are of small amplitude, moderate speed, and variable acceleration, and are continually observable during active wakefulness (Einspieler et al., 2004). Watching FMs in the own hands and wrists (i.e., termed *hand regard*) is a typical infant behavior from 2 to 6 months of age, which has been associated with the maturation of the visual system (e.g., Einspieler et al., 2016, 2019; Ferrari et al., 2016; Prechtl et al., 1997).

For each stimulus pair, we created a flipped version in which the positions of the two pictures/videos were exchanged. All pictures were of the same size and comparable in color distribution and luminance. By diversifying stimuli, we aim to avoid habituation while ensuring homogeneity and comparability of the materials.

2.3 | Study design and procedure

The study was conducted at iDN's BRAIN*tegrity* laboratory at the Medical University of Graz (Austria). The infants' gaze and the screen content were synchronously video recorded using a Microsoft LifeCam VX-2000 with a resolution of 640×480 pixels at 30 frames per second and Live Screen Capture (Corel Corporation). The camera was mounted on top of a 22-inch stimulus monitor (Dell P2210, 1680 × 1050 pixels, response time: 5 ms, refresh rate: 60 Hz) positioned on a height-adjustable table. Infants were seated in a baby car seat on their parent's lap in a dimly lit room. The camera's tilt angle was optimized to mainly capture the infant's face. The viewing distance was approximately 55 cm, resulting in a stimulus size of ~46.6° (horizontally) × ~30.1° (vertically), and a picture size of 17.5° × 17.5°. The infants' line of sight was approximately 5–10 cm above the monitor's center. The experimental procedure was started when the infant was in a good mood and in a state of active wakefulness. A number of experimental runs had to be excluded due to changes in the infant's mood or behavioral state (see Results next).

The experimental paradigm consisted of two blocks. In Block 1, six static stimuli (stimuli a–c; see Figure 2) were presented. This was followed by the presentation of two dynamic stimuli (stimuli d) in Block 2. The order of stimuli and the positions of the pictures/videos were randomized within each block. Each stimulus was presented for 10 s, preceded by a blank (presentation duration: 2 s) and a fixation display (presentation duration: 2 s). Thus, an assessment consisted of eight trials (Block 1 followed by Block 2), that is, eight successions of a blank, a fixation display, and a stimulus display (duration per trial: 14 s). The total duration per assessment amounted to 112 s (see Figure 3). During the experimental procedure the laboratory was darkened.

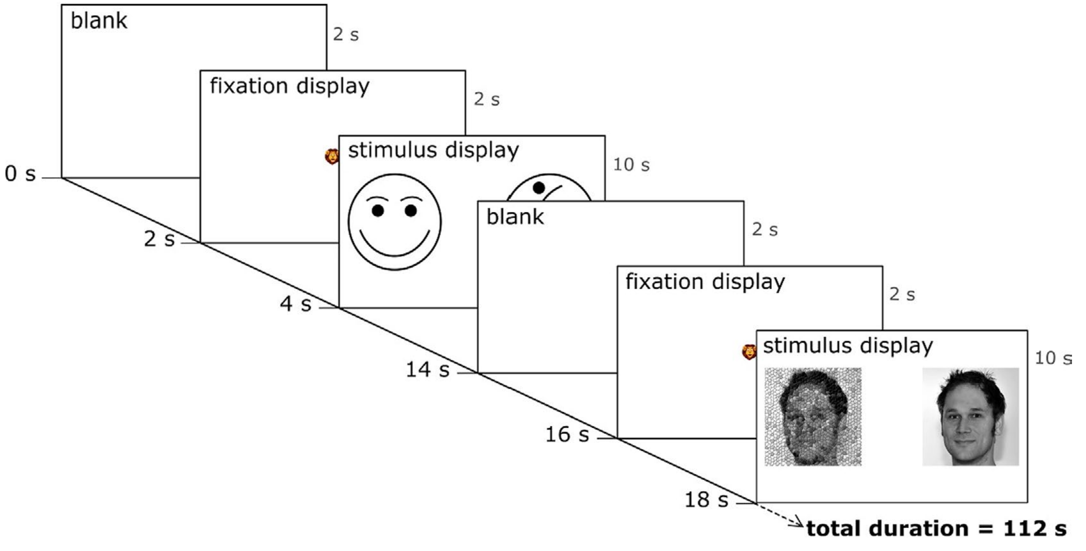

FIGURE 3 Experimental procedure showing two consecutive trials

2.4 | Behavioral scoring of visual attention

The literature reviewed earlier indicates a hierarchy of attentional development (e.g., Amso & Scerif, 2015; Braddick & Atkinson, 2011; Colombo, 2001; Reynolds & Romano, 2016). In line with the temporal sequence proposed by Colombo (2001), we introduce a hierarchic conceptualization of this theoretical model to score the four most important subfunctions of attention during infancy (i.e., alertness, spatial orienting, attention to object features, sustained attention) in one single task (Figure 4). The scoring system is divided into four functional units (I–IV), which we consider hierarchical with respect to their temporal onset and maturation. Each unit consists of specifications of theoretical functions, their behavioral (i.e., observable) characteristics, and preconditions for transiting to the next unit, respectively. Behaviors indicating the absence of an underlying subfunction are scored 0, while behaviors indicating the presence of specific subfunctions are scored at least 1 point. As object attention consists of multiple independent functions and is known to be mediated by endogenous control, we arranged behaviors of unit III according to their complexity, with increasing scores ranging from 1 to 4. Within each functional unit, the list of behavioral characteristics is considered exhaustive for observer-based behavioral evaluation in paired comparison tasks. For each trial, an infant's score may range between 0 and 7 points (Figure 4):

- 0 points (no response): the infant does not show any detectable response to stimulus onset.
- 1 point (unspecific response): the infant reacts to stimulus onset (transition to unit II), but only unspecifically (i.e., signs of alerting/brightening, but no saccade toward peripheral stimuli detectable).
- 2 points (stimulus orientation): the infant orients toward stimulus (transition to unit III), but averts gaze; total fixation duration <1000 ms.
- 3 points (obligatory looking): the infant orients toward and fixates on stimulus, but does not show active scanning behavior (i.e., staring).
- 4 points (intrastimulus shifting): the infant actively scans at least one of the peripheral stimuli (i.e., within-picture saccade(s) detectable).

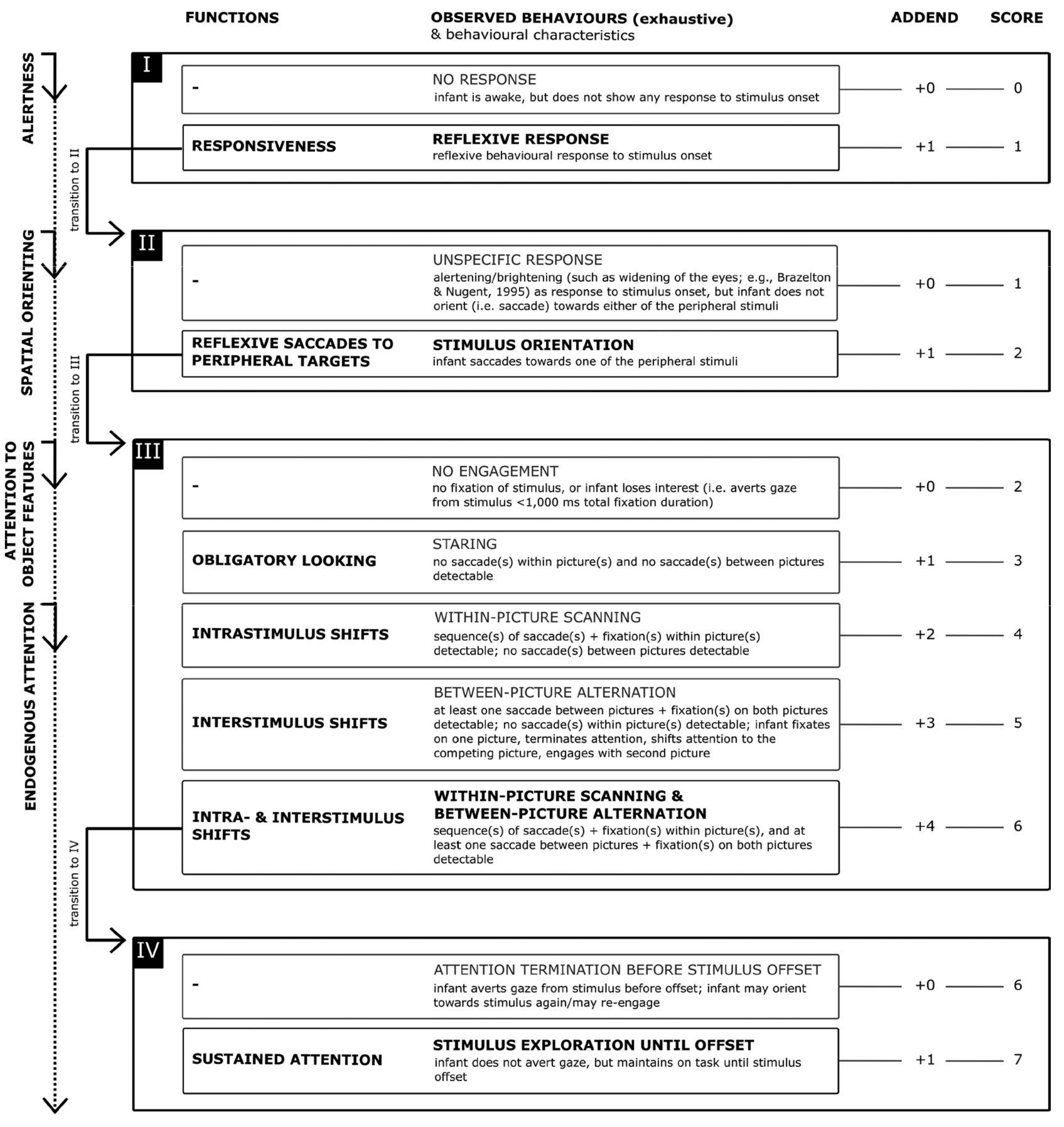

FIGURE 4 Scoring system for evaluating visual attention in paired comparison tasks. *Note*. The vertical arrow on the far left represents the temporal onset of the four relevant subfunctions proposed by Colombo (2001). Units I–IV each comprises age-specific functions, observed behaviors, and their characteristics. Units I–IV are increasing in complexity of the functions. The observable behaviors and their characteristics constitute preconditions for transiting to the next unit. The addend for each behavior indicates the number to add to the subscore. The score represents the total per experimental trial

- 5 points (interstimulus shifting): the infant shifts attention between the peripheral stimuli (i.e., between-picture saccade(s) detectable), but does not show active scanning behavior within pictures.
- 6 points (intra- and interstimulus shifting): the infant actively scans the peripheral stimuli (i.e., within-picture saccade(s) detectable), and shifts attention between the peripheral stimuli (i.e., between-picture saccade(s) detectable) (transition to unit IV), but terminates attention (i.e., averts gaze) before stimulus offset.

- 7 points (intra- and interstimulus shifting, sustained attention): the infant actively scans the peripheral stimuli (i.e., within-picture saccade(s) detectable), shifts attention between the peripheral stimuli (i.e., between-picture saccade(s) detectable), and maintains on task until stimulus offset.

Behavioral scoring was performed offline by replaying the video recordings. If necessary, playback speed was reduced, or recordings were evaluated frame by frame. The infant's head (face and eyes) was seen on the video recordings. The accompanying person (i.e., the parent) was outside the camera frame and could not be seen. All recordings were rated by the first author (MK-T, Rater 1), and a randomly chosen 10% of the dataset were coded by two additional raters (coauthors IK-T and LL, Raters 2 and 3), who were also part of the research team and instructed by Rater 1 with respect to both the purpose of the study and the behavioral scoring scheme. To estimate the reliability of this behavioral evaluation, Raters 2 and 3 independently evaluated the sub-dataset (independent ratings), and in a second step, discussed disagreements until consensus was achieved (consensus rating). Although with regard to the behavioral scoring, raters had no information about either the identity and/or the exact age of the participants, we cannot fully rule out a potential bias with respect to the infant's age (i.e., 16-week-old infants appear differently than 4-week-olds).

2.5 | Statistical analysis

Interrater reliability assessments and statistical analyses were conducted using IBM SPSS Statistics 25 (SPSS, Inc.). The significance level was set at 5%. Interrater agreement was analyzed using the intraclass correlation coefficient (ICC). As we were interested in a high generalizability of the ICC results, we applied an absolute agreement, two-way random effects model (e.g., Koo & Li, 2016).

In order to include individuals with missing data points in the analysis of time-associated growth and shape of developmental trajectory instead of repeated measures ANOVA, we fitted a series of linear mixed models (Heck & Thomas, 2020; Heck et al., 2014) by restricted maximum likelihood. Model selection was based on the Akaike information criterion (AIC) and the Bayesian information criterion (BIC) (e.g., Burnham & Anderson, 2004; Vrieze, 2012). In addition, we evaluated the frequency of specific behaviors (i.e., different attentional functions; Figure 4) with respect to age-related predominance and chronology. Changes in frequency of observed behaviors and predominant behavioral characteristics were analyzed qualitatively and reported descriptively.

3 | RESULTS

Nineteen infants of the sample completed all seven assessments; for the remaining 31 infants, data were partially missing due to nonattendance (e.g., illness) or nonevaluability (e.g., fussiness, sleepiness). In total, data from 301 assessment sessions (=86%) and 2224 trials were available and of sufficient quality for analysis. The average score across assessment sessions was 4.34 (SD = 1.85). The number of participants and available trials per session and the descriptive statistics are given in Table 2.

Mean scores and standard deviations were comparable for the stimuli presented on the left or right side of the screen (left: M = 4.35, SD =1.85; right: M = 4.34, SD = 1.84). Differences

TABLE 2 Data availability and descriptive statistics for the seven consecutive assessments

Assessment session	Age (weeks)	Number of participants	Number of trials	Mean score (*SD*)	Range of mean scores
1	4	36	258	2.59 (1.53)	0.88–4.38
2	6	41	286	3.23 (1.49)	0.33–4.75
3	8	42	298	3.83 (1.52)	2.43–5.67
4	10	42	318	4.21 (1.65)	1.63–5.50
5	12	47	349	4.69 (1.74)	1.88–6.38
6	14	44	333	5.31 (1.38)	4.00–6.63
7	16	49	382	5.80 (1.36)	1.75–7.00

Abbreviation: *SD*, standard deviation.

between static ($M = 4.38$, $SD = 1.92$) and dynamic stimuli ($M = 4.23$, $SD = 1.93$) were also not significant. That is, behavioral scores were not affected by the types of stimuli nor their left–right presentation positions on the screen. Consequently, further analyses, if not otherwise indicated, were based on individual scores collapsed across stimuli for each assessment session.

3.1 | Interrater reliability

First, we evaluated the agreement across the three raters. The ICC (absolute agreement, two-way random effects model) for the three independent ratings was .834 (single measures; 95% confidence interval = .802–.862) indicating good reliability. Second, the consensus rating from Raters 2 and 3 was correlated with the rating of Rater 1. This resulted in an ICC of .940 (single measures; 95% confidence interval = .924–.953), indicating excellent reliability (Portney & Watkins, 2000).

3.2 | Growth model of development of visual attention

To examine whether the mean scores changed as a function of age and to estimate the slope of development (i.e., the growth trend), we specified a series of linear mixed models with the total score as dependent variable.

3.2.1 | Model 0

In a first step, we fitted a "null model," which only took the repeated measures of the score into account (with subjects as random effect), but did not consider any time-related variables (AIC = 8994.98, BIC = 9006.40). With this simple model, we aimed to partition the variance of scores for each infant and assessment (averaged across trials) into its within- and between-subjects (Level 1: infants vs. Level 2: assessments) components (e.g., Singer & Willett, 2003). Without predictor variables, the grand mean of the overall score was 4.35, the estimate for Level 1 variance was 3.25 (Wald $Z = 32.97$, $p < .001$), and the estimate for Level 2 variance was 0.16 (Wald $Z = 3.36$, $p = .001$). These estimates suggest that the between-individuals proportion of variance in the scores amounted to no more than 4.8% (Level 2 variance/[Level 2 variance + Level 1 variance]) (Heck et al., 2014).

3.2.2 | Model 1

As suggested by the increase in the session means (see Table 2) and taking into consideration that developmental progress may vary across time (i.e., accelerating or decelerating slopes), we examined the shape of the growth trajectory. We therefore added both a linear (representing a constant slope) and a quadratic (representing changes in the slope over time) orthogonal time-related component as fixed effects (e.g., Guilford & Frunchter, 1978). While the estimates for the intercept ($b = 4.21$, $t = 63.73$, $p < .001$) and the linear slope ($b = 0.53$, $t = 32.74$, $p < .001$) were significant, the quadratic time component ($b = 0.00$, $t = 0.13$, $p = .899$) failed to explain growth in the score (AIC = 8124.97, BIC = 8136.38). That is, the quadratic component did not improve the regression, suggesting a constant growth rather than a change in slope over time.

3.2.3 | Model 2

As a consequence, we excluded the quadratic time-related predictor from further modeling and included only the intercept and a linear growth (i.e., the mean rate of change between two consecutive sessions) as fixed effect in the model (AIC = 8117.43, BIC = 8128.84).

3.2.4 | Model 3

Suggested by the range in mean scores per session (Table 2), we examined the possibility of between-individuals variation in intercepts and slopes. To test this, we added the slope (in addition to the intercept) as random effect at Level 2. The values of the Akaike information criterion (AIC = 8079.70) and the Bayesian information criterion (BIC = 8102.52) indicated a better fit compared to Model 2. At Level 2, the estimates for the between-infants variance of the intercepts was 0.18 (Wald $Z = 3.75$, $p < .001$) and for the between-infants variance of the slopes was 0.02 (Wald $Z = 3.17$, $p = .002$), indicating a significant amount of infant-to-infant variation in intercepts and growth rates. The estimate of the correlation between the intercepts and growth rates was $r = -.32$ (Wald $Z = -1.47$, $p = .143$), indicating no significant correlation between the variation of the intercepts and slopes.

3.3 | Onset and stabilization of attentional functions

In addition to the overall analysis based on the total score presented earlier, we evaluated the frequency of specific behaviors (i.e., different attentional functions; Figure 4) with respect to age-related predominance and chronology.

Percentages of scores 0–7 for each of the seven assessments are given in Table 3. At 4 weeks postterm age, infants showed no response to stimulus onset (i.e., a score of 0) in approximately every fifth trial. At 6 weeks of age, the chance of not responding to stimulus onset dropped to 11.5% and decreased over the next weeks down to 0.5%. The combined frequency of trials in which the infants responded unspecifically to stimulus onset (Score 1) or oriented toward one of the peripheral stimuli but averted gaze (i.e., <1000 ms total fixation duration; Score 2) was 13.2% at 4 weeks of age. It remained below 5% from 6 weeks onward (Table 3).

Infants oriented toward and fixated on stimuli in the majority of experimental trials already at 4 weeks postterm age, indicated by a score of 3 (i.e., obligatory fixation) or higher in approximately two of three trials (i.e., cumulative frequency of scores 3–7 = 67.9%; Table 3). The high frequency of scores 0 to 3 (i.e., >70%) at 4 weeks, however, indicated that infants did not engage with the stimulus in an active, goal-directed manner (Figure 5, black line at 4 weeks of age). Instead, once engaged with one of the peripheral stimuli, infants were almost twice as likely to stare (i.e., showing no within-picture saccades; score 3; 41.5% of trials) than to actively scan the picture (i.e., score 4; 21.7% of trials; Table 3).

As can be inferred from the frequencies of scores 0–7 per assessment (Table 3), from 6 to 10 weeks, intrastimulus shifting replaced staring as the most frequently observed behavior. From 12 weeks onward, staring played only a minor role since its frequency further decreased and approximated floor at 14 weeks (Figure 5).

TABLE 3 Frequency (in percent) of scores 0 to 7 per assessment across all valid trials and participants

		Score							
Assessment session	**Age (weeks)**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	4	19.3	4.3	8.9	41.5	21.7	3.1	0.8	0.8
2	6	11.5	0.7	3.8	37.1	39.2	3.1	1.0	3.5
3	8	6.4	1.3	1.7	20.5	53.4	5.0	4.0	7.7
4	10	4.7	0.3	2.2	24.8	42.8	3.5	7.9	13.8
5	12	4.0	0.3	1.7	12.3	38.7	6.3	14.9	21.8
6	14	0.3	0	0	3.9	38.7	6.9	21.0	29.1
7	16	0.5	0	1.6	2.1	19.6	6.0	29.6	40.6

Note: Darker background gray levels indicate higher frequency.

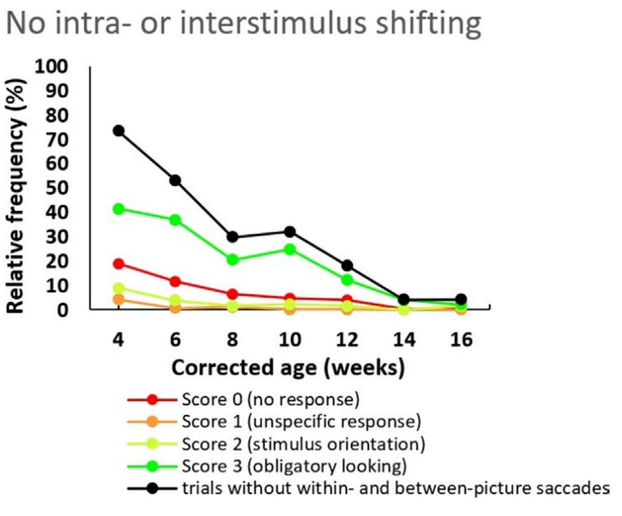

FIGURE 5 Frequency of trials scored 0–3

A change toward a more endogenously controlled style of attention during the last three assessments (i.e., 12–16 weeks) was apparent in a decrease of trials with a score of 3 or lower (Figure 5) and an increase of trials with scores of 6 and 7 (i.e., trials in which infants not only actively scanned at least one of the peripheral stimuli, but also shifted attention between the two concurrently presented stimuli; Table 3; Figure 6). At 16 weeks, the frequency of score 4 dropped reliably compared to the assessments before (Figure 6, left, green line). This, together with the increasing cumulative frequency of scores 5–7 (i.e., trials with attention shifts; Figure 6, right, black line) indicates that interstimulus shifting became the dominant visual strategy with a cumulative frequency of >70% at 16 weeks of age. Although we were able to detect a stable increase in trials with scores of 7, a proportion of 40.6% at 16 weeks (i.e., not yet dominant) indicated that sustained attention is still emerging by this age (Figure 6, purple lines).

In a final step, we examined the chronology of development of intra- and interstimulus shifting by comparing the cumulative frequency of trials involving within- and between-picture saccades (Figure 6, black lines). Our data suggested a steep increase in active scanning within the object from 4 to 8 weeks (23.3% vs. 65.1%), and a second, but shallower increase starting at 10 and leveling off at 14 weeks (Figure 6, left, black line). At the end of the fourth month, infants actively scan object features in most experimental trials (89.8%). As a contrast, the cumulative frequency of trials with interstimulus shifting is well below 10% at baseline (Figure 6, right, black line). It is only from 10 weeks onward that the frequency of trials including between-picture saccades exceeds 20%, which is comparable to the frequency of trials with intrastimulus shifting at 4 weeks. Between 10 and 16 weeks, infants develop rapidly in shifting attention between objects, with a slope comparable to the increment seen in the intrastimulus shifting between 4 and 8 weeks. The relative frequency of score 5 (interstimulus shifting without active scanning) is generally low, ranging between 3.1% and 6.9%, indicating an existing yet rare behavior in the early infancy.

3.4 | Intraindividual fluctuations

In order to investigate transitions on an individual level, we calculated for each participant and pair of consecutive assessment sessions the difference in mean scores. In case of missing sessions,

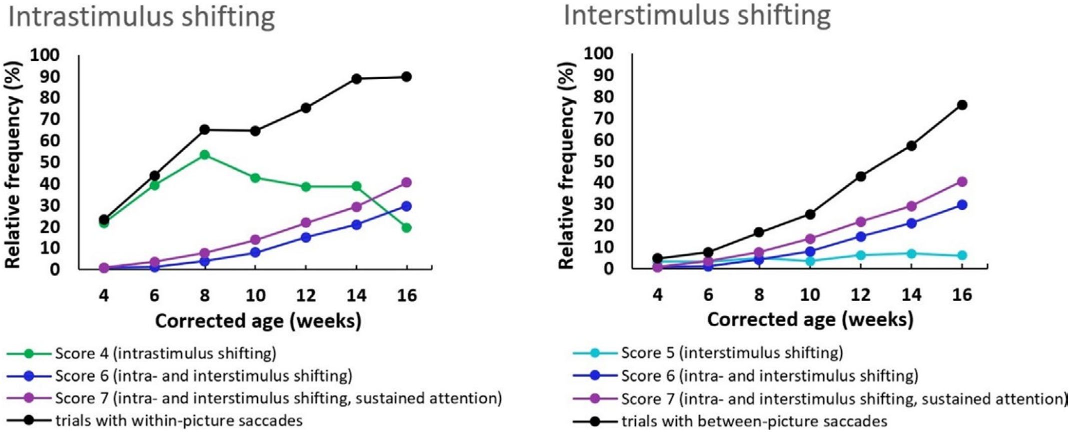

FIGURE 6 Frequency of trials with intra- and interstimulus shifting

pairs consisted of the session prior and/or the session following the missing assessment session. We counted how often the difference increased, decreased, or did not change and then calculated the proportion of paired increases and decreases.

In 174 (69.6%) of 250 assessment session pairs, mean scores increased, whereas in 67 (26.8%) pairs, mean scores decreased. There were only 9 (3.6%) assessment session pairs where the score did not change. On average, for a maximum of six such comparisons (seven sessions) per participant, we observed 3.48 ($SD = 1.05$) increases and 1.34 ($SD = 0.85$) decreases. For 44 infants, more increases than decreases were observed. For five infants, the number of increases was the same as the number of decreases. Only for one infant we observed a higher number of decreases than increases.

4 | DISCUSSION

It is commonly assumed that subfunctions of visual attention develop sequentially; this developmental cascade, however, was inferred from the comparison of data collected combining a variety of tasks, used in different samples and settings. In contrast, here we tracked the developmental steps in the same group of infants using just one paired comparison task and repeated measurements. We applied a well-established paradigm (Fantz, 1964) to the same sample across seven trials from 4 to 16 weeks of age. To the best of our knowledge, this is the first study that systematically profiled the development of different subfunctions of attention with a single task. The major benefit of using one constant paradigm in which viewing is predominantly unconstrained is that it enables us to capture the age-specific predominant processing style of infants as well as the behavioral changes over time. In the following sections, we will discuss methodological aspects of our scoring system, as well as developmental changes and individual variations.

4.1 | Methodological aspects of the scoring system

There are two major findings of note which we would like to highlight: (1) A steady increase in the overall score suggests that the scoring system successfully captures the developmental steps occurring over the 2-week intervals. During the process of modeling developmental growth, we found that a linear developmental trend fitted our data best and proved more reliable compared to considering changes in growth rate over time. This finding was further supported by comparable slopes for all the consecutive assessments. As the overall score represents a composite of behavioral characteristics associated with different constructs, the observed linear trend is in line with a hierarchy of different subfunctions of visual attention in infancy. (2) The good to excellent interrater agreement indicates that the scoring scheme is robust and suitable for observers with different levels of experience. However, less experienced observers who are only moderately familiar with the theoretical background of visual attention development may benefit from agreement ratings. The chosen model (two-way random effects) and definition (absolute agreement) is the choice when generalizing ICC results to any other raters with comparable characteristics (e.g., Koo & Li, 2016). As the model applied here is conservative, it may lead to lower estimates compared to other models.

4.2 | Developmental changes

The continuous increase in the overall score represents an observable increment of complexity in visual behavior across the seven assessments between 4 and 16 weeks of age. At around 10 weeks of age, reliable reflexive responses characterized by spatial orientation to stimulus onset stabilized, which is in line with previous findings on infants' behavioral states (e.g., Graham et al., 1983). As stated earlier, infants undergo rapid changes in the time spent in alert states which in turn suggests that during the first weeks of life, the relatively low rate of reflexive responses to stimulus onsets is a result of the organism not meeting the requirements for perceiving a change in the visual field. Although we assessed all infants during active wakefulness, we could not prevent behavioral state alteration during the experiments in some cases, especially during the first assessments.

Taking into account the predominance of scores ≤3 (i.e., absence of object scanning) during the first and second assessments (cumulative frequencies of 73.6% and 53.1%), our results indicate that until at least 6 weeks of age stimulus processing is primarily exogenously controlled. It is not until the second month of life that the inability to control visual fixation slowly disappears, and processing of stimulus details represented by sequences of within-picture saccades begins to stabilize. This change in visual processing has commonly been attributed to a decline in subcortical control and the functional onset of the posterior orienting system which inhibits the superior colliculus (e.g., Posner & Petersen, 1990; Reynolds, 2015; Reynolds & Romano, 2016), which is usually considered the starting point of emerging executive control of visual attention. Our data confirmed that processing of object features is the dominant subfunction at the age of 6–10 weeks.

From around 12 weeks onward, another significant change in processing is reflected in a rapid increase in trials scored as 6 and 7, when scanning of object features is supplemented by object comparison through alternate inspection of the two competing pictures. The ability to switch between objects fluently includes three processes, that is, engaging with one of the objects, terminating attention to the fixated object, and shifting attention to the competing object. In our experiments, spontaneous alternation occurred on average in only one of four trials until the age of 10 weeks. This finding is in line with the proposal of Hunnius et al. (2006) that object scanning stabilizes earlier than disengagement in most individuals. In contrast to Hunnius et al. (2006), who used two different paradigms to examine these two processes, our data indicate that if the stimulus material is of sufficient complexity to enable both attention to object features and object comparison (i.e., objects consisting of multiple components), object scanning (intrastimulus shifting) stabilizes earlier than object comparison (interstimulus shifting).

The trials scored as 7 started to increase substantially from 8 weeks onward, but it was only at 16 weeks, when active engagement without averting gaze before stimulus offset (i.e., sustained attention, a fundamental component of endogenous attention; score 7) became the most frequently observed behavior. This result is compatible with the findings of Haith and colleagues (e.g., Wentworth et al., 2001) using the visual expectation paradigm, which also suggest that this is a critical period for the rise of endogenous attention. Still, sustained attention appeared in less than 41% of the trials across participants by 16 weeks (Table 3).

This result supports the theory that the development of the more complex anterior attention system may extend into late infancy, and even toddlerhood (for a review, see, e.g., Reynolds & Romano, 2016). It is important to notice, however, that maturation of the anterior attention system and changes in speed of habituation may lead to a reversed pattern later in development (i.e., averting gaze before stimulus offset as the most frequently observed pattern).

In line with the literature, with our single-task longitudinal observation paradigm and the newly introduced scoring scheme, we successfully tracked and documented the general developmental course of infant visual behaviors in their first 4 months of life. Our data demonstrate the gradual shifts of predominant oculomotor patterns from reflex-like alertness (by 6 weeks of age), to increased object scanning (pronounced at 8–10 weeks), and continuously to more active engagement and complex object comparison and sustained attention (from 12 weeks onward).

4.3 | Inter- and intraindividual variations

As shown in Table 2, we observed a substantial variation in mean scores of each assessment and a significant random intercept in the final linear mixed model, indicating that the overall mean shows significant infant-to-infant variation. This confirmed that infants not only differ at the beginning of life, but that individual differences remain present in development. Additionally, we found that growth rates varied among infants, suggesting that the timing and the speed of development are also heterogeneous. The absence of a reliable covariance between intercepts and slopes adds to the challenge of predicting developmental trajectories because any single measure may fail to predict the next measurements.

As is well known, the onset of a specific attentional subfunction does not mark the stabilization of the function-related behavior. This can be inferred from steady increases in, for example, intra- and interstimulus shifting that occurred at least one to two assessment occasions before the predominant processing style became evident. This differentiation between onset and stabilization is further supported by a decrease in the score from one assessment to the subsequent one, which occurred in 26.8% of the observed assessment session pairs, and at least once in the seven assessment sessions in 40 of the 50 infants. These transient decreases may also reflect the fluctuations of the infant behavioral states affecting the oculomotor behaviors during the short experimental period.

In short, our results show that: (a) despite a general ontogenetic course of infant visual behaviors, individual developmental trajectories are heterogeneous; (b) the emergence and stabilization of subfunctions have to be considered separately, as the functional onset does not mark an immediate shift to the next predominant visual processing style. Thus, one single assessment is not sufficient for estimating the developmental status of an infant. Reliable discrimination of different developmental trajectories requires close-meshed repeated measurements to observe the overall development of each individual infant.

4.4 | Limitations

Current research on attentional development takes both top-down and bottom-up mechanisms of attention into account (for an overview see, e.g., Amso & Kirkham, 2021; Jiang et al., 2019). The distinction between these mechanisms is not explicitly built into the models of Braddick and Atkinson (2011) and Colombo (2001) which provided the basis for our own research. Investigating the interplay between these mechanisms might require tasks different from the comparison task used here and probably older participants. For example, Bertels et al. (2017), studying infants from 8 to 12 months of age, and Tummeltshammer and Amso (2017), studying 6 and 10 months old infants, employed contextual cueing in visual search to investigate this issue (see also Werchan & Amso, 2020, for an example using a priming task with 9 months old infants).

Some of our data loss was caused by the narrow time window defined for each assessment (i.e., postterm age ±2 days). Expectably, some participating families missed appointments from time to time. However, the decision for choosing an interval of no more than 5 days per age point was made after careful consideration. To enable a close-meshed observation aiming at detailed representation of the developmental trajectories across different domains, a well-defined assessment time window is desired and required (Marschik et al., 2017).

The proposed scoring scheme is limited to overt behavior that is detectable by human observers and does not include information of high spatial and temporal resolution. A more fine-grained analysis of eye movement behavior, for instance via the use of state-of-the-art eye tracking methodology would potentially reveal detailed information about the development of oculomotor strategies going hand in hand with the development of visual attention. Currently, a high-resolution accurate tracking of oculomotor behaviors still necessitates time-consuming calibration (i.e., an increased risk for data loss). A precise calibration typically requires the participant's voluntary control of binocular vision. As demonstrated in our study, endogenous control of visual attention is only emerging in infants younger than 16 weeks. Considering also the generally brief awake and good mood period of very young infants, we decided to forgo using an eye-tracking system in this study.

The scoring scheme was specifically designed to evaluate aspects of attention reallocation within and between pictures. As such, its application is restricted to stimulus material consisting of at least two concurrently presented pictures/objects of sufficient complexity (i.e., objects consisting of multiple components). Although well established, the paradigm (i.e., paired comparison task) used in this study is limited in its capacity to examine attentional selection. The research on contextual cueing in visual search mentioned in the introduction shows that older infants are capable of selecting one item among many (see also Amso & Johnson, 2006). However, Dannemiller (2000) was able to show that infants at the age of 8 weeks were already sensitive to moving targets depending on the spatial distribution of distractors. These results demonstrate an early form of selective attention mechanisms which our paradigm does not aim to capture (see also Dannemiller, 1998, 2005).

Another issue that needs to be considered is the physiological development of the oculomotor system which takes place within the first months of life. For instance, central and visual acuity, as well as the saccadic system develop rapidly within the age range tested (Braddick & Atkinson, 2011; Courage & Adams, 1996; Hainline, Turkel, Abramov, Lemerise & Harris, 1984), which affects various aspects of visual behavior. Some of these changes are relevant for the interpretation of our results, such as eccentricity thresholds and scanning behavior.

In this work, we used the same task across all assessments. This allowed for a high degree of comparability between assessment sessions. However, this approach comes with the potential weakness that it is unclear whether the observed improved performance is due to genuine development or merely due to practice effects and experience with the stimuli. To explore this issue, we conducted an additional analysis that explicitly considered the effect of missing an assessment session. If improved performance was due to repeated exposure to the same stimuli, then missing an assessment session should have a negative effect on performance. However, this effect did not prove to be significant (see Appendix 1). Thus, we can be reasonably confident that the effects reported in this article reflect genuine development of visual attention in early infancy.

5 | CONCLUSION

In this study, we applied a single comparison task with a repeated measure design. We systematically profiled the basic visual attention development in 4- to 16-week-old infants. With our approach and newly introduced scoring scheme, we confirm previous hypotheses and clearly demonstrate a hierarchy of visual functions from exogenously controlled simple alertness to emerging endogenous sustained attention in early infancy. We provide evidence that our behavioral evaluation of oculomotor behaviors is suitable for (a) tracking developmental characteristics of all assumed subfunctions of visual attention in very young infants and (b) scorers with different backgrounds, including those not familiar with the theoretical background of visual development. In a next step, we plan to further verify the validity of the scoring system presented here with different stimuli and participants. We will explore in future studies whether our approach is suitable to study visual behavior in clinical populations adding to our knowledge on early visual development.

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APPENDIX 1

SUPPLEMENTAL ANALYSIS

Model 4

We also checked whether or not missing the previous session had an effect. In addition, we explored possible differences between the four stimulus categories by adding them as fixed effects at Level 2. With the smallest values of the Akaike information criterion (AIC = 8046.12) and the Bayesian information criterion (BIC = 8068.94), this model appeared to fit our data somewhat better than Model 3. As in the previous models, the estimates of the fixed effects were again significant for both the intercept ($b = 4.42$, $t = 57.46$, $p < .001$) and the slope ($b = 0.48$, $t = 15.79$, $p < .001$). Compared to human faces as stimuli, the dynamic and emoticon stimuli caused a lower intercept ($b = -0.38$, $t = 6.23$, $p < .001$), but a steeper slope ($b = 0.08$, $t = 2.71$, $p = .007$; (Figure A1). Missing the previous session had a negative, but nonsignificant effect on the scores of the next session ($b = -0.19$, $t = -1.81$, $p = .071$). This suggests that repeated exposure to the same stimuli did not affect performance. If any effect of practice diminishes with a larger temporal gap, this could also result in a null effect, which the present analysis cannot account for. The random effects changed only marginally from those of Model 3. The Level 1 variance estimate was 2.04 (Wald $Z = 32.57$, $p < .001$). At Level 2, the estimates for the between-infants variance of the intercepts was 0.18 (Wald $Z = 3.78$, $p < .001$), and for the between-infants variance of the slopes was 0.02 (Wald $Z = 3.15$, $p = .002$), indicating a significant amount of infant-to-infant variation in intercepts and growth rates. The estimate of the covariance between the intercepts and growth rates was $r = -.34$ (Wald $Z = -1.80$, $p = .071$), indicating no significant correlation between the variation of the intercepts and slopes.

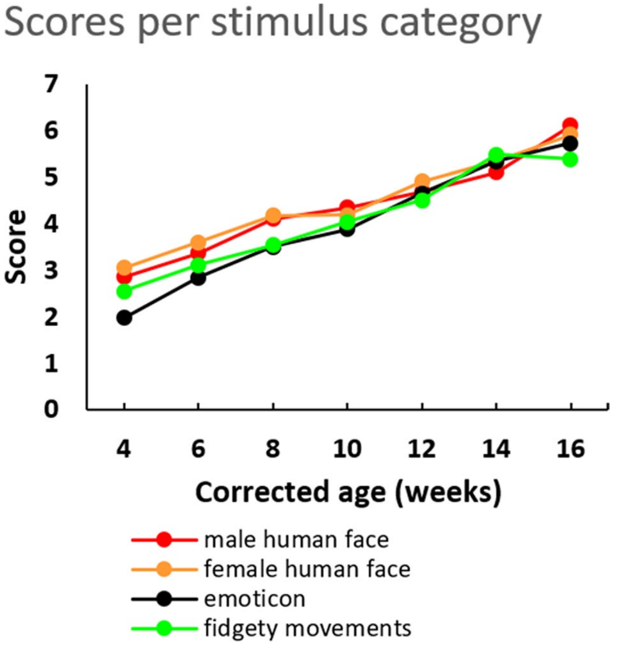

FIGURE A1 Development of scores across sessions for the four stimulus categories