



HAL
open science

Visual exploration of reaching space during left and right arm movements in 6-month-old infants

F. Morange-Majoux, E. Devouche, C. Lemoine-Lardennois, E. Orriols

► To cite this version:

F. Morange-Majoux, E. Devouche, C. Lemoine-Lardennois, E. Orriols. Visual exploration of reaching space during left and right arm movements in 6-month-old infants. *Psychologie Française*, 2019, 64, pp.55 - 70. 10.1016/j.psfr.2017.06.003 . hal-03486751

HAL Id: hal-03486751

<https://hal.science/hal-03486751>

Submitted on 20 Dec 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial 4.0 International License

**LA COORDINATION VISUO-MANUELLE CHEZ LE BEBE DE 6 MOIS :
L'EXPLORATION VISUELLE DIFFERE-T-ELLE EN FONCTION DE LA MAIN
UTILISEE ?**

**VISUAL EXPLORATION OF REACHING SPACE DURING LEFT AND RIGHT
ARM MOVEMENTS IN 6-MONTH-OLD INFANTS**

Françoise MORANGE-MAJOUX^{1*}, Emmanuel DEVOUCHE^{1,2}, Christelle LEMOINE-
LARDENNOIS³ & Eric ORRIOLS⁴

¹ Université Paris Descartes, Institut de Psychologie, Laboratoire de Psychopathologie et
Processus de Santé (EA 4057), France

² Unité de recherche en Psychiatrie et Psychopathologie, EPS Erasme, France

³ Université Paris Descartes, Institut de Psychologie, Laboratoire Vision Action Cognition
(EA 7326), France

⁴ Université Paris Descartes, Institut de Psychologie, Laboratoire Mémoire et Cognition,
INSERM S894, France.

** Address for correspondence*

F. Morange-Majoux

Université Paris Descartes, Laboratoire de Psychopathologie et Processus de Santé (EA4057)

71 avenue Edouard Vaillant

92774 Boulogne-Billancourt Cedex, France

francoise.morange-majoux@parisdescartes.fr

Françoise Morange-Majoux : développement sensori-moteur chez les enfants tout venants et
avec autisme, latéralité manuelle, développement du langage.

Emmanuel Devouche : Interactions sociales précoces, développement social

Christelle Lemoine-Lardennois: Contrôle oculo-moteur, plasticité du système oculo-moteur

Eric Orriols : réalité virtuelle, eye-tracking

1 **RESUME**

2 La préférence manuelle et la coordination visuo-manuelle émergent progressivement au cours
3 de la première année de vie du bébé avec le développement des gestes de préhension. Le but
4 de cette recherche est de déterminer si l'exploration visuelle au cours des gestes manuels varie
5 en fonction de la main utilisée, et si oui, d'en décrire précisément ses caractéristiques à l'aide
6 d'un système d'eye-tracking. Douze bébés âgés de 6 mois ont été observés dans une situation
7 de préhension (6 essais, 3 avec chaque main). La distribution du regard, la main utilisée, son
8 mouvement, son ouverture et sa position ont été codés à l'aide du logiciel The observer ®.
9 Les résultats montrent que les bébés explorent leur espace de préhension différemment en
10 fonction de la main utilisée : ils regardent plus l'objet lorsqu'ils utilisent la main droite et plus
11 autour de l'objet lorsqu'ils utilisent leur main gauche témoignant d'une coordination visuo-
12 manuelle asymétrique précoce.

13

14 **Mots-Clefs** : Latéralité manuelle, coordination visuo-manuelle, exploration visuelle, enfant,
15 système d'eye-tracking.

16

17 **ABSTRACT**

18 Infant's manual laterality and eye-hand coordination emerge during the second part of the first
19 year of life with the development of reaching. Nevertheless, little is known about the potential
20 asymmetric characteristics of this coordination. The aim of this study was to describe visuo-
21 spatial exploration in 6-month-old infants during reaching, according to the hand used. More
22 specifically, we examined if the use of the left or the right hand was linked to a specific type
23 of visual exploration. Gaze direction during goal-directed reaching towards an object placed
24 on the table was measured with a remote ASL 504 eye tracker (Bedford MA). Twelve babies
25 aged 6 months were observed during six reaching sessions, alternating three sessions with an
26 object on the left side of the subject and three with an object on the right side. Gaze direction
27 and some hand variables (hand activity, hand opening and hand position from the body) were
28 coded with The Observer software. Results showed that babies visually explore their reaching
29 space differently according to the hand used: they look more at the object when they use their
30 right hand and more around the object when they use their left hand; they also look more
31 often at their left hand than at their right one. These results suggest that an asymmetric visuo-
32 manual coordination exists as early as 6 months : vision seems to support (1) left hand during
33 reaching for evaluate distances from object to baby by means of visual feedbacks and (2) right
34 hand for identify what sort of object is. Results are discussed in light of manual specialization
35 and specific hemispheric skills at this age.

36 **Key-words:** Manual laterality, visuo-manual coordination, visual exploration, infant, eye-
37 tracking

38

39

40 **1. INTRODUCTION**

41 Object visuomotor exploration plays a central role in early cognitive development: infants
42 learn about their physical environment, acquire knowledge to plan future actions and develop
43 sensorimotor coordination from these visuomotor experiences. The aim of this paper was to
44 describe how vision participates in reaching, around 6 months, when this hand activity is
45 well-established but not yet automated. More particularly, we analyzed visuo-spatial
46 exploration according to the hand used, in order to evaluate if specific visual strategies could
47 be assigned to manual laterality. In order to specify how visuo-motor coordination is
48 organized, we also observed visuo-spatial exploration according to the movement of the hand,
49 its opening and its position to the object.

50 The development of eye-hand coordination like in reaching is a good neuroscientist tool,
51 widely used to infer relationships between brain and behavior (Luna, Velanova, & Geier,
52 2008). According to the traditional view of infant reaching development, infants use vision, at
53 first, to guide the hand towards the target when they begin to reach, around the age of 4
54 months (Piaget, 1952; White, Castle, & Held, 1964), and then they use the visual error
55 between hand and target to correct their ongoing reaches (Bushnell, 1985), when the first
56 successful reaches (grips) appear around 5 months. Between 5 and 7 months, major
57 developments occur in the timing of infant manual anticipation (such as opening of the hand
58 during the movement), indicating that grasp control shifts from being manually guided to
59 being visually guided (Witherington, 2005). However, some results challenge this traditional
60 point of view: one of the most notable is that sight of the hand is not necessary to make
61 successful grasps; Clifton, Muir, Ashmead, and Clarkson (1993) have found that infants from
62 1.5 to 5 months (6 to 25-weeks-of-age) touched objects as in the light as in the dark without
63 kinematic differences in reaching (Clifton, Rochat, Robin & Berthier, 1994). Moreover,
64 infants are capable of completing even relatively complex reaches, such as catching a moving

65 object, without visual feedback of the hand (Berthier, Clifton, Gullapalli, McCall, & Robin,
66 1996; McCarty *et al.*, 2001). Kinematic changes in reaching in the dark have been reported
67 only in infants aged 15 months (Carrico *et al.*, 2008). However, the fact that infants can reach
68 in the dark does not mean that they don't use vision when it is available (in the light). We can
69 suppose that improvement in reaching is probably the result of general improvements in the
70 use and the integration of different perceptual information in order to make finer a more
71 reliable movements: infants probably use first, proprioceptive information and then visual
72 information, which will become more and more indispensable to modulate reaching during
73 their early development (Thelen *et al.*, 1993; von Hofsten, 1993). We need to have a better
74 understanding of the role played by vision, especially during the onset of prehension, around
75 6 months, by differentiating the hand used, which regrettably was not mentioned by the
76 previous authors.

77 In adults, specific visuo-manual asymmetries are reported: when the subject reaches towards
78 an object with his/her left hand, his/her eye movements end up earlier on the object and peak
79 velocity (of eye movements) is reached earlier than when (s)he reaches with his/her right hand
80 (Lavrysen *et al.*, 2008) and saccades reached the target earlier when accompanying left-
81 compared to right-hand movements (Helsen *et al.*, 1998a, 1998b; Carnahan *et al.*, 1993).
82 Goal-directed one hand movements are predominantly controlled by the contralateral cerebral
83 hemisphere. Traditionally, functional hemispheric specialization is described as right
84 hemisphere advantage for movement planning and/or attentional aspects and left hemisphere
85 advantage for processing information during ongoing movement (Hodges *et al.*, 1997;
86 Carson, 1989). Asymmetries of eye-hand coordination could be explained by the fact that the
87 right hand/left hemisphere system may have higher efficiency in utilizing response-produced
88 feedback (Elliott & Chua, 1996). This hemispheric specialization also impacts lateral hand
89 use: The right hand is involved in the temporal organization of perceptual and/or motor

90 information, during ongoing movements (Flowers, 1975; Bradshaw, Bradshaw, & Nettleton,
91 1990; Haaland, Elsinger, Mayer, Durgerian, & Rao, 2004), and in the planning of sequential
92 acts that require response selection, preparation and/or retrieval (Verstynen, Diedrichsen,
93 Albert, Aparicio, & Ivry, 2005). The left hand is involved in the spatial planning of a task and
94 in the allocation of attention in space (Carson, 1989; Hodges, Lyons, Cokell, Reed, & Elliott,
95 1997; Sainburg, 2002). In this perspective, a manual specialization can be defined
96 independently of handedness: the preferred hand is not always the most relevant according to
97 task specificities : right-handers perform more rapid and accurate reaches with their left hand in
98 a pointing task whereas left-handers are more efficient with their right hand in a fine building
99 task (Gonzalez & Goodale, 2009 ; Lavrysen *et al.*, 2003).

100 If the development of handedness is widely studied, infants' early manual specialization is
101 less documented and eye-hand coordination asymmetries have as far as we know never been
102 studied. Some infant studies (von Hofsten, 1979, 1991; Morange-Majoux, Pez , & Bloch,
103 2000; Hopkins & Ronqvist, 2002; Ronqvist & Domellof, 2006) have shown differences in
104 the kinematics of right- and left-hand movements: right-hand trajectories are smoother, with
105 fewer corrections and fewer movement units -identified kinematically as multiple segments of
106 acceleration and deceleration- than left-hand trajectories. Differences also appear in the
107 quality of movements: pre-reaching movements are more often performed by the left hand,
108 whereas reaching and grip movements are more often performed by the right hand (Morange-
109 Majoux, Pez , & bloch, 2000; Morange-Majoux & Dellatolas, 2010). Finally, infants with a
110 congenital muscular torticollis develops a hand preference on the opposite side to head-tilt.
111 Authors concluded that an increased visual control of the hand during early childhood seems
112 to modulate handedness (Ocklenburg et al., 2010). Such observations are compatible with the
113 position that the right hemisphere controls close-loop movements dependent on sensory

114 feedback, and the left hemisphere open-loop movements based on well-established motor
115 programs (Haaland & Harrington, 1989).

116 The Dual Visuomotor Channel theory proposes that visually guided reaching consists of two
117 temporally integrated movements, the Reach and the Grasp, each mediated by separate
118 visuomotor pathways, from occipital to parietofrontal neocortex (Arbib, 1981; Jeannerod,
119 1981, 1999; Rizzolatti *et al.*, 1998; Tanné-Gariépyetal., 2002; Culham & Valyear, 2006;
120 Cavina-Pratesi *et al.*, 2010; Filimon, 2010; Karl & Whishaw, 2013). Thus, the initial phase of
121 a reach, mediated by a dorsomedial pathway, serves to transport the hand to the general
122 vicinity of a target and is in relation with the target's extrinsic properties, i.e. localization and
123 orientation (*where* pathway). The later phase (grasp), mediated by a dorsolateral pathway, is
124 devoted to close the hand, in relation with the target's intrinsic properties, with controlled
125 visual guidance of the hand on the target object, i.e. size and shape (*what* pathway) (Arbib,
126 Iberall, & Lyons, 1985; Jeannerod, 1981). We have hypothesized that pre-reaching
127 movements could play a localization role, i.e., provide information concerning the distance of
128 the object from the body, and that the grip movement could be implied in accuracy. The
129 behavioral differences between the two hands, observed in babies, could confirm an
130 asymmetry in information processing between left and right hands: the left hand would be
131 more involved in the "*where*" pathway and the right one in the "*what*" pathway.

132 As stated above, eye-hand coordination shows early hemispheric asymmetries (Lavrysen *et*
133 *al.*, 2008) even though at these ages, the use of the right-or the left-hand is task-dependent and
134 could be in relation with hemispheric specialization (Arbib, 1981; Morange-Majoux &
135 Dellatolas, 2010). If seeing his/her hand seems to be not necessary for an infant to grasp an
136 object at 6 months (Clifton *et al.*, 1993, Berthier & Carrico, 2010) this does not mean that
137 vision does not take a part when it is available. In this perspective, vision could not only
138 participate in reaching but also select differentiate useful information according to the hand

139 used. We hypothesized that vision could provide more specifically (1) spatial object
140 information when the infant uses his left hand and (2) intrinsic object information when the
141 infant uses his right hand. If vision participates to the onset of manual specialization, looks
142 will be more centered on the object when the right hand is used and looks will be more widely
143 distributed around the object when the left hand is used. In order to test these hypotheses, we
144 described spatial distribution of looks (on or around the object) during all the reaching
145 (including movement and no movement moments) according to the hand used, hand
146 anticipation and hand localization.

147

148 2. METHOD

149 *2.1.Participants:* Twelve healthy 6-month-old (mean age 6 months, 3 days, ranging from 5
150 months, 20 days to 6 months, 23 days) full-term infants participated in this study (6 males,
151 6 females). Ten additional infants were tested, but their data were not included in the final
152 sample, six infants due to technical eye-tracking impairments, two infants because they did
153 not try to reach the object, and two infants due to fussiness. They were all recruited from
154 birth lists in the 13th and 14th districts of Paris. All mothers signed an informed consent
155 form, guaranteeing general anonymous treatment of information. Parents' handedness was
156 controlled (Edinburgh handedness inventory) : 22 were right-handers and 2 were left-
157 handers

158 *2.2.Eye-tracking system:* An eye-tracker was used to study very accurately visual exploration
159 of the baby when he/she had to reach an object. Eye-tracking techniques, in the context of
160 action, allow to measure how infants explore their physical world, and in particular where
161 and what they look at, how they observe the scene spatially (object, around the object) and
162 how many time they look at these parts of the scene, in order to define what strategies they
163 develop when they want to reach an object. Eye-tracking can provide key insights into

164 real-time dynamics of perception and action, for infants interact with the environment by
165 the second or the minute. Such rich and detailed information can directly inform about
166 coordination between cognitive, motor and perceptual processes, and more generally
167 enrich theories on the development of asymmetries (Corbetta, Guan, & Williams, 2012).
168 For this study, we used a remote eye tracker developed by ASL (model R6) that provided
169 eye position coordinates. Head position was recorded with a magnetic tracker, Flock of
170 Birds (Ascension, Burlington, VT) that provides head position coordinates. The ASL
171 system can track eye movements directed at scenes defined in 3-dimensional space and
172 spatially fixed (3D objects located within reaching distance as described in Corbetta *et al.*,
173 2012). Furthermore, the system was configured to record gaze position on a horizontal plan
174 (scene plan), i.e. the table in the present study. Using both head position data and gaze
175 vector position data, the system determines where on the surface the subject is looking
176 (Eye-Trac 6 Control Unit and User Interface Software Reference Manual, pp 68). The only
177 constraint was baby's head had to remain stable.

178 *2.3.Apparatus:* The experimental apparatus was composed of an eye-tracking system, a scene
179 camera above the baby, a minibird eye-tracker, a front webcam, two computers and three
180 control screens. All components of the experimental apparatus were synchronized and
181 linked (Figure 1).

182 - Insert Figure 1 about here -

183 Eye-tracking system included a remote optics eye camera that allowed the infant
184 approximately one square foot of head movement and eliminated the need for head
185 restraint. This eye-tracker was placed in front of the infant, on the table, at a distance of 50
186 cm. The infant's line of gaze was measured by computing the pupil-corneal reflection at a
187 sampling rate of 50 Hz (Figure 1C). The accuracy level was about 0.5° of visual angle,

188 and the resolution was about 0.25° of visual angle. Performance of both eyes was
189 measured.

190 A scene camera (ceiling camera), placed above the table, captured the table during the
191 experiment and gave us a still shot of the scene. Live recording of the table was
192 synchronized on line with the remote optics eye camera by computer which calculated the
193 superimposition of specific gaze position (symbolized by two crossing lines) and a still
194 shot of the table (Figure 1A). ASL system was conceived to create a plane projection of
195 gaze direction vectors and to compute the correlation between calibration points and gaze
196 direction vectors simultaneously measured. Spatial coordinates were then translated into
197 eye-tracking coordinates during the calibration phase and calibration points were linked to
198 the still shot of the scene (see Calibration phase section below).

199 The scene camera also captured the infant's hands activity. The recording was used for
200 coding hands activity (Figure 1A and 2) with The Observer © software (see Coding
201 section). Moreover, the superimposition of the still shot with the gazes gave an indication
202 of when infants looked at their hands.

203 - Insert figure 2 about here -

204 Head position was recorded with a magnetic tracker, Flock of Birds (Ascension,
205 Burlington, VT). This device has a Mini Bird head tracker that provides head position
206 coordinates, so that the ASL pan/tilt camera can reconnect to the eye, in case of rapid head
207 movements (see Gredebäck *et al.*, 2002 and Aslin & Murray, 2004). (see figure .1B)

208 Lastly, a front webcam was added and synchronized to the two other cameras to record
209 infants' behavior, facial expressions and head orientation (Figure 1B). This additional
210 camera provided information about the baby's behaviors and allowed to appreciate the
211 consistency with information of remote eye-tracking detection.

212 The three videos were all captured with the same computer to obtain a synchronized video
213 recording throughout the experiment (Figure 1).

214 *2.4. Material:* the object to reach was a 2.5 x 2 cm² little yellow Kinder© chick graspable by 6-
215 months-old infants. This toy was placed in front of the infant, on the table, at a distance of
216 25 cm, just at a reachable distance, inside the tracking window of the ASL system. The
217 ASL system detects accurately gaze positions on the plan (2D) but the use of a 3D object
218 generates a decrease in accuracy, due to the object's height (3D). Indeed, the space behind
219 the object could not be seen from the infant's perspective, and was called the occlusion
220 area (see figure 1). Thus any gazes at that space detected by the ASL system was in fact a
221 gaze at the object. This occlusion area was deducible (1.5 cm behind) on the basis of
222 object's height and the level of the infant's eyes. In order to determine the impact of this
223 occlusion area on our data, an analysis of the distribution of gazes around the object
224 revealed that a majority was in front of the object (88%) or on its left- or right-side (11%).
225 Gazes behind the object were thus very rare (< 1%) and kept out of the study.

226 *2.5. Procedure:* The experiment took place in a quiet room of the Psychology Department at
227 Paris Descartes University. Infants were seated on their parent's lap, facing a table with
228 their hands free to move and the body maintained against the adult to limit head
229 movements of the baby.

230 The parents remained quiet during the entire experiment (approximately 15 min).
231 Experiment procedure always contained a calibration and a test phases.

232 • *Calibration phase:* Nine calibration target points were used to calibrate the scene plan (see
233 Figure 3). These nine points were identifiable by landmarks drawn on the table. A
234 transparent flashing ball (2 cm diameter) was used during calibration phase. This ball was
235 successively positioned on the nine markers on the table in order to create a bijection of
236 any point of the scene plan onto the window defined by these nine gaze direction vectors.

237 For each calibration point, the experimenter A (standing behind the remote optic eye
238 camera) placed the ball on the marker; when a gaze on the ball was detected by the eye-
239 tracker, experimenter B approved manually on the computer the calibration point
240 measured. This procedure was repeated for each calibration points. At the end, each of the
241 calibration point coordinates were translated into visual vectors coordinates and linked to
242 a scene plan image (scene camera recorded continuously the same scene). In practice, a
243 cross appeared on the scene plan video recording each time an infant looked on the table
244 (Figure 1)

245

246 - Insert Figure 3 about here -

247 -

248 • *Test phase:* The little yellow chick was placed on the table, on the right or on the left side
249 of the baby, inside the scene plan, out of sight of the baby by using a cardboard. An
250 experimenter stood behind the remote optic eye camera in order to present the test object
251 to the infants. Six trials were performed, alternatively on the left and the right sides of the
252 infant in order to induce ipsilateral movements (Fagard, Spelke, & Von Hofsten, 2009;
253 Morange & Bloch, 1996; Morange-Majoux *et al.*, 2012). First side of presentation was
254 counterbalanced across infants. At the beginning of each trial an experimenter positioned
255 a large piece of cardboard (40x60 cm) in front of the baby and a second experimenter
256 placed the object behind the cardboard, on the table, in the left or right position (the
257 cardboard was large enough to hide both possible positions of the object). At this stage,
258 the object and its position were hidden by the cardboard. Then the first experimenter
259 removed the cardboard, thus uncovering the object. The trial began with the first look at
260 the object (as identified by the eye tracker), and ended at the *first* contact between the
261 hand tested and the object (not after reaching or grip because it would have been

262 impossible to determine if the subject looked at the object or his hand). Both eye and hand
263 activities were recorded during the trial.

264 *2.6.Coding:* Both hand and eye activity data collected by ASL system were coded with the
265 Observer XT10© software on the video given in Figure 1A, which combined scene video
266 recording and eye tracking point's projection. We chose to recode eye activity initially
267 coded by ASL system with the Observer XT10© software in order to (i) check data and (ii)
268 avoid erroneous data. (i) for example, when the subject looked at the experimenter, ASL
269 system lost looks. Nevertheless, with the video given in figure 1A, we reconsidered these
270 lost data and coded them as looks at the experimenter with Observer XT10© software. (ii)
271 for example, when ASL system identified looks at baby's hand, we systematically checked
272 with the video given in figure 1A if the hand was posed on the table or aloft. Because of
273 the position of the scene camera above the hands of the baby, when the hand was aloft,
274 ASL system identified a look on the hand whereas the look was under the hand on the
275 table. In this case (very few situations), the look at the hand was reconsidered and coded as
276 a look at the table with Observer XT10© software. Time-position data were sampled at 25
277 Hz (25 images per second). Looks and both hands were coded independently, by two
278 independent observers, blind to the condition and hypotheses. The inter-rater reliability of
279 the two coders, based on all trials, was 99% for eye coding and 96% for movement coding.
280 Contentious trials were re-examined by both experimenters and re-coded together until a
281 100% inter-rater agreement was eventually reached.

282 ➤ Look durations were coded during all the trial according to five areas: (1) on the
283 object (with a radius of 0.5 cm around the object), (2) around the object (radius
284 ranging from 0.5 cm to 5 cm), (3) on the table (i.e. elsewhere outside the 5 cm
285 radius), (4) on the right hand and (5) on the left hand. A look was detected when a

286 cross (intersection between a horizontal line and a vertical line) appeared on the
287 video: this intersection being a staring (looking) point (see Figure 1A).

288 ➤ Right- and left-hand durations were coded during all the trial according to three
289 hand characteristics: (1) hand activity (during the trial baby could move or not
290 his/her arm towards the object); (2) hand opening (widely opened or not) and (3)
291 localization of the hand with respect to the baby's body (the hand of the baby could
292 be near him or near the object; we defined two modalities allocentered and
293 egocentered: the boundary between the two modalities was defined by the median
294 distance between the body and the object). The word "hand" used in the results
295 section always refers to the ipsilateral hand according to the object's position.
296 Analyzes performed on the contralateral hand were systematically specified.

297 All these codings allowed to analyze visuo-spatial distribution according to specific hand
298 parameters in order to qualify and potentially precise eye-hand coordination.

299 *2.7. Statistics:* Given that trials (72; 36 performed with the left hand, 36 performed with the
300 right hand) did not have the same durations, they were analyzed according to the total
301 duration of the trial in terms of percentages (proportions of time), by mean of a two way
302 repeated measures ANOVA with hands (right / left) and object position (right / left) as
303 within subject factors, and with partial eta squared values (η^2_p) as an index of effect size.
304 For each measure we computed a Shapiro-Wilk test to determine whether the hypothesis
305 of normality could be rejected. Chi square test was used to analyze cross-tabulated data,
306 with Cramer's V as an index of effect size. All analyses were done with Stata 14.

307

308 3. RESULTS

309 3.1. Hand characteristics

310 All right side objects were reached by the right hand (and reciprocally the left side objects
311 were reached by the left hand.

312 *3.1.1. Hand activity:* On average, infants did not move their hands during 37% of the trial's
313 time (ranged from 3,8% to 96,2%). Shapiro-Wilk tests computed for each of the four
314 measures were all non-significant (all p-values above .08). The two-way repeated measures
315 ANOVA conducted on the *proportion of time during which the hand remained stationary*
316 revealed no significant effect of object position ($F(1,11) < 1$; $p = .94$; $\eta^2_p < .001$), but a significant
317 effect of the hand: the left hand remained more often stationary than the right one (47% vs
318 30%; $F(1,11) = 6.60$; $p = .028$; $\eta^2_p = .40$; Figure 4) during a trial. A specific analysis carried out
319 on the contralateral hand revealed that, an object placed on the right side significantly
320 increased right hand activity and strongly reduced left hand activity (difference of 25 points
321 between both hands, 50% vs 25%), whereas a presentation on left side activated both hands in
322 the same way ($F(1,11) = 5.16$; $p = .047$; $\eta^2_p = .34$). Furthermore, only 9% of trials with left
323 reachings were performed without stationary hand moments, whereas 33% of trials with right
324 movements did not include any stationary hand moments. In other words, babies kept his/her
325 hand stationary more often during their left- than their right -hand reachings.

326 - Insert Figure 4 about here -

327 Last, we examined how many trials started with no movement of the hand -left or right- (all
328 trials began with a look on the table). Analysis showed that 74% of left movements were
329 initiated first by a look during which the hand did not move, against 47% for the right hand
330 (difference of 26.3%; IC95% = (3.4; 45.6)). Babies tended to move their right hand
331 immediately towards the object, as soon as they looked at it, in half of the right hand
332 movements.

333 3.1.2. *Hand opening*: On average, infants' hands were widely opened 89% of the time.
334 Shapiro-Wilk test was significant for one measure (right hand / object right; $p=.0241$). The
335 two-way repeated measures ANOVA, conducted on the *proportion of time where the hand*
336 *was wide open*, revealed no significant effect, neither of the hand ($F(1,11)=1.33$; $p=.27$;
337 $\eta^2_p=.11$), nor of the object's position ($F(1,11)=1.11$; $p=.32$; $\eta^2_p=.09$), suggesting that
338 movements have the same profile, whichever hand is used.

339 3.1.3. *Hand position from the body*: On average, 47% of infants' manual activity was
340 distributed near the object (allocentered). Shapiro-Wilk tests computed for each of the four
341 measures were all not significant (all p-values above .20). The two-way repeated measures
342 ANOVA conducted on the *proportion of time the hand was allocentered* revealed no
343 significant effect, neither for the hand ($F(1,11)<1$; $p=.54$; $\eta^2_p=.04$), nor for the object position
344 ($F(1,11)<1$; $p=.66$; $\eta^2_p=.02$).

345 **3.2. Visuo-spatial exploration during a trial**

346 Automatic detection of staring points by ASL system was performed, on average, 47% of the
347 total duration of trials (ranging from 29% to 86% depending on the infant). No difference was
348 found across trials. As described in Method section, we have recoded all eye-tracking data
349 with Observer XT10© in order to check ASL detection. Five areas into the scene plan where
350 babies could look at were defined: on the object, around the object, on the table, on their left
351 hand and on their right hand. In order to examine specifically missing data, we have
352 completed our analysis by adding babies' looks at the experimenter from the front webcam
353 video (Figure 1B) with Observer XT10© software. Results showed that babies looked at the
354 experimenter on average 15% of the total duration of trials, reducing missing data to 38%.

355

356 Figure 5 illustrates the distribution of gazes at the different areas of the scene plan according
357 to the hand used. When infants used their left hand, they tended to look more around the
358 object and at their left hand, whereas when they used their right hand, their looks were more
359 equally distributed toward the object and around it. Otherwise, infants tended to look at their
360 ipsilateral hand in presence of a lateral reachable object. The two distributions were found to
361 be significantly different (*Chi square* = 17.64, $p=.014$, *Cramer's V* = 0.30).

362 - Insert Figure 5 about here -

363 In order to appreciate more accurately vision control on the different phases of the reaching,
364 we have examined hand activity during the trial:

365 *3.2.1. When the hand was remained stationary:* Figure 6 presents the distribution of gazes on
366 the different areas of the scene plan when the hand ipsilateral to the object did not move. The
367 most remarkable result is that infants looked at mainly around the object when the object was
368 placed on the left side, and never at their right hand. On the contrary, their looks were more
369 localized on the object when the object was in the right side. The two distributions were found
370 to be significantly different (*Chi square* = 22.59, $p<.02$, *Cramer's V* = 0.34).

371 - Insert Figure 6 about here -

372 *3.2.2. During hand movement:* Figure 7 presents the distribution of gazes during right- and
373 left movement. Results showed that whatever the hand used, babies' looks were equally
374 distributed between object and around it. The most notable result is that babies looked at more
375 their left hand when they performed a reaching with the left hand than their right one when
376 they performed a reaching with this one. Both distributions were significantly different (*Chi*
377 *square* = 32.64, $p<.01$, *Cramer's V* = 0.40).

378 - Insert Figure 7 about here -

379 The last analysis was dedicated to examine more accurately gazes on the hands and to answer
380 to this question: when an infant looks at his hands, what do the hands do ? We compared
381 proportion of time during which the infant looked each hand considering position, activity and
382 anticipation of hands. For this analysis, two infants were excluded, because they never looked
383 at their hands. Shapiro-Wilk tests ran on the 6 distributions revealed that the hypothesis of
384 normality could be rejected for two measures (left hand allocentered and left hand open;
385 respectively $p=.022$ and $p=.029$). When an infant looked at his hand, it was moving half of the
386 time, with no significant differences between hands (respectively 54% for the left hand and
387 45% for the right hand; $t(9)<1$; $p=.68$) and allocentered, on average, 70% of the time, with no
388 significant differences between left and right hands (respectively 71% and 68%; $t(9)<1$;
389 $p=.62$). Finally, the hand was open 82% of the time, with a left hand more often open (96%)
390 than the right hand (68%), a 28 points difference however not significant ($t(9)=1.74$, $p=.12$).

391

392 4. DISCUSSION

393 The present study aimed to describe how babies visually explore their reaching space in the
394 presence of a target-object and to determine if this visual exploration varies according to the
395 hand used and some hand characteristics (manual anticipation, hand activity, hand / object
396 position). This original eye-tracking design allowed us to investigate new levels of analyses,
397 by examining precisely the distribution of infant gazes when an object was presented to be
398 caught. In this context, this study provides the first description, with a remote eye-tracker, of
399 visuospatial exploration of the infant's reaching space during a movement, according to the
400 hand used. Several results can be discussed and some conclusions may be drawn.

401 First, result stationary hand s showed a greater activity of the right hand, whatever the
402 location -right or left- of the object. This was confirmed by the high proportion (1/3) of trials

403 with right hand reaching, always in movement stationary hand. In a previous study, we had
404 shown that the right hand was always more in motion than the left one (Morange-Majoux *et*
405 *al.*, 2000). Thus, a context of reaching stimulates right hand movements. This is attested by
406 others studies (Rönnqvist & Domellöf, 2006; Michel *et al.*, 2006), showing an increase in
407 right hand use from the age of 6 months, interpreted as the onset of right handedness. In our
408 study, the greater activity of the right hand probably confirms the beginning of this manual
409 asymmetry.

410 Second, results about visuospatial exploration provide a great contribution to our
411 understanding of visuo-manual coordination. Visual exploration of the reaching space is
412 mainly dominated by two sources of exploration: the space all around the object and the
413 object itself. The significant result is that an infant does not explore in the same way his
414 reaching space, according to the hand used and to its activity. During moments where the
415 hand remained stationary, infants visually explore the space around the object placed on the
416 left side and look at specifically the object placed on the right side. When they perform a
417 reaching, their looks are more equally distributed toward the object and around it. We can
418 assume that looking at the object allows the infant to learn more about the object's physical
419 characteristics before contacting an object with the right hand. This is compatible with the
420 better ability of the right hand to catch and manipulate objects observed in previous studies
421 (Michel & Harkins, 1986; Corbetta *et al.*, 2006; Michel *et al.*, 2006). We can also hypothesize
422 that looking around the object brings information about its location and its distance from the
423 body, before reaching it with the left hand. These differences between the two hands, on the
424 visuospatial exploration of reaching space, reveal not only *asymmetric* visuo-manual
425 coordination as early as 6 months, but also specific *strategies* according to the steps of
426 reaching. The well-known studies about hemispheric specialization can enlighten these
427 results: indeed, the right hemisphere holds an advantage in movement planning and/or

428 attentional aspects (Hodges *et al.*, 1997; Carson, 1989), whereas the left hemisphere is faster
429 at processing information during the ongoing movement; this information could be either
430 visual or non-visual (Buekers & Helsen, 2000; Elliott *et al.*, 1999; Roy *et al.*, 1994; Lavrysen
431 *et al.*, 2003). In this context, when the baby has to perform a left hand movement (right
432 hemisphere), his/her gazes are distributed all around the object, especially before the
433 movement, during moments where the hand remained stationary, to evaluate the object's
434 location. When the baby performs a right hand movement, most gazes are focused on the
435 object, from the beginning to the end of the trial.

436 In previous studies (Morange *et al.*, 1996; Morange-Majoux *et al.*, 2000; 2010; Morange-
437 Majoux, 2011), we have shown a lateralization of reaching development : babies use more
438 often their left hand to perform approach movements, whereas they use more often their right
439 hand to perform grip movements. These results have been interpreted as evidence for manual
440 specialization as early as 4-month-olds, The present study brings evidence that vision
441 participates to manual specialization, in a harmonious, coordinated way: vision is used to
442 explore all the reaching space when the left hand contributes to evaluate distance and
443 location; while vision is used to examine an object, when the right hand is used to determine
444 the object's intrinsic properties. In other words, there is an early asymmetric visuomotor
445 coordination, probably supported and mediated by different sensorimotor channels (Karl &
446 Whishaw, 2013; 2014).

447 These results can be compared to researches in adults, which have demonstrated a
448 specialization in the use of both hands (Carson, 1989; Bradshaw & Nettleton, 1990; Hodges *et*
449 *al.*, 1997; Sainburg, 2002; Bradshaw *et al.*, 1990; Haaland *et al.*, 2004) and in visuo-manual
450 coordination (Lavrysen *et al.*, 2008). They are in agreement with the dual visuomotor channel
451 theory, which proposes that visually guided reaching consists of two movements, a first one,
452 which transports and guides the hand in relation to the extrinsic features (location) of the

453 target, while another one opens, shapes and closes the hand on the target, in relation with its
454 intrinsic features (size, shape). In this perspective, our study shows that each movement is
455 allocated to a specific hand. One prediction of the dual visuomotor channel theory of
456 reaching, is that development should feature independence in the maturation of the two
457 movements. Researches have shown that movements to locate object occur before movements
458 to grip objects (Von Hofsten, 1984; Savelsbergh & van der Kamp, 1994; Morange & Bloch,
459 1996; Morange-Majoux *et al.*, 2000; 2010). During development, reaching and grasping
460 become integrated in a seamless visually guided act. We argue that these behavioral
461 differences between the two hands, observed in babies, could confirm an asymmetry in
462 information processing between the left and the right hands: the left hand would be more
463 involved in the “*where*” pathway and the right one in the “*what*” pathway.

464 Third, another notable result concerns gazes on the left hand (31%), especially during moving
465 moments. It will be interesting in a future study to determine at what time during the trial
466 these looks on the left hand *in progress* appear. Numerous researchers have investigated the
467 role of vision in prehension (Bushnell, 1985; Carrico et al., 2008; Berthier *et al.*, 2010;
468 Hofsten, 1991): some of them propose that infants use sight of the hand to guide early
469 reaching (Piaget, 1952; Bushnell, 1985), others consider that sight of the hand is not necessary
470 to make successful grasps (Clifton et al., 1994; Carrico et al., 2007). As we have suggested,
471 babies use visual information when it is available even if babies can reach objects without the
472 sight of their hand. Our results show that when babies can see their hands, they significantly
473 look at their left hand more than their right hand during reaching. This increase of gazes at the
474 left hand could be interpreted as a great left hand expertise for visuospatial processes: infants
475 look at the most visuo-spatially adapted hand in order to evaluate distances (i.e. from their
476 hand to the object) and localize an object. Furthermore, analyzes regarding the number of
477 wig-wag between an object and the left hand is twice higher than with the right hand

478 confirming its role to evaluate distances. These results allow us to draw a complex
479 asymmetric visuo-manual coordination, which appears as early as 6 months: when babies use
480 their left hand they tend to look at around the object before to initiate their reaching in order
481 to evaluate and determine the distance, then they perform their movement while looking their
482 left hand and doing wig-wag between object and the left hand. When babies use their right
483 hand, they tend to look at around and on the object, before and during the movement. Vision
484 supports left hand during reaching for evaluate distances by means of visual feedbacks. This
485 visuo-manual coordination appears still integrated and favors knowledge about physical
486 environment. This visuo-manual coordination probably finds its origin in hemispheric
487 specialization, as Lavrysen and collaborators (2008) have suggested. The left hand system
488 may be more effective at using visual feedback and retro-control via right hemisphere and the
489 right hand system may be more effective at using feedforward and predictive control via left
490 hemisphere (Roy and Kalbfleisch, 1994). Previously, we have showed that left-hand made
491 numerous changes in direction suggesting a spatial scanning, such adjustments requiring more
492 time (Morange-Majoux et al., 2000). Results achieved in the dark or without visual feedback
493 of the hand (Berthier *et al.*, 1996; McCarty *et al.*, 2001) are not contradictory with our results:
494 at this age, vision is not used to guide movement but probably more to inform the baby on
495 object extrinsic properties (where it is ?) and intrinsic properties (what is it ?). It would be
496 interesting to examine manual laterality in the dark and in particular, to determine if the use of
497 the left hand is disturbed or not (without possibility of visual feedbacks) and to compare
498 kinematics of left- and right reaching in light and dark in order to examine not only the onset
499 of visuo-manual coordination but also its asymmetry. Moreover, it will be interesting to
500 describe longitudinally the development of the role of vision according to the hand used.

501 In addition, results showed that when an object is presented in front of a baby, his/her hands
502 are, most of the time, widely open, indicating that the baby is ready to reach out to the object,

503 which confirms what had been observed in others studies ((Fagard, 2000; Fagard & Pezé,
504 1997; Hofsten & Fazel-Zandy, 1984). Sacrey and Whishaw (2010) have shown that collection
505 (hand shape in which digits are lightly flexed and closed) becomes increasingly prominent
506 from 1 to 6 months. It replaces a clenched fist that was typically held proximal to the upper
507 torso. This collation development is probably the precursor of other hand shaping movements,
508 like skilled movements of grasping and reaching.

509 In conclusion, we argue that eye-tracking may be used in the context of action. It raises novel
510 questions about the development of visuo-manual coordination. It allows to explore with good
511 accuracy where infant direct their gaze on a scene (Corbetta *et al.*, 2012), what they look at
512 and how many times they do so. We are aware that the loss of eye-tracking data (38%) during
513 head turns or others behaviors preventing eye capture is a serious limitation of our study.
514 Head-mounted eye-trackers do show advantages to study infant perception in more natural
515 and less-constrained environments (Corbetta *et al.*, 2012).

516 **References**

- 517 Arbib, M.A. (1981). Perceptual structures and distributed motor control, in Brooks, B. (Ed)
518 *Handbook of Physiology*, Section1, Vol.2, Part2, (pp. 1449–1480). Bethesda, MD:
519 American Physiological Society.
- 520 Arbib, M., Iberall, A., & Lyons, T.D. (1985). Coordinated control program for movements of
521 the hand, in hand function and the neocortex, *Experimental Brain Research*
522 *Supplementum*, 10, 111–129.
- 523 Aslin, R.N., & McMurray, B. (2004). Automated corneal-reflection eye tracking in infancy:
524 Methodological developments and applications to cognition, *Infancy*, 6, 155–163.
- 525 Berthier, N.E., Clifton, R.K., Gullapalli, V., McCall, D.D., & Robin, D.J. (1996). Visual
526 information and object size in the control of reaching, *Journal of Motor Behavior*, 28,
527 187–197.
- 528 Berthier, N.E., & Carrico, R.L. (2010). Visual information and object size in infant reaching,
529 *Infant Behavior & Development*, 565-566.
- 530 Bradshaw, J.L., Bradshaw, J. A., & Nettleton, N.C. (1990). Abduction, adduction and hand
531 differences in simple and serial movements, *Neuropsychologia*, 28, 917–931.
- 532 Bushnell, E.W. (1985). The decline of visually guided reaching during infancy. *Infant*
533 *Behavior and Development*, 8(2), 139-155.
- 534 Buekers, M.J., & Helsen, W.F. (2000). Vision and laterality: does occlusion disclose a
535 feedback processing advantage for the right hand system? *Cortex*, 36(4), 507-519.
- 536 Carnahan, H., Roy, E., & Elliott, D. (1993). Eye, head and hand coordination while pointing
537 with the left and right hands, *Journal of Human Movement Studies*, 25, 1–10.
- 538 Carrico, R.L., & Berthier, N.E. (2008), Vision and precision reaching in 15-month-old infants,
539 *Infant Behavior & Development*, 31, 62-70.

- 540 Carson, R.G. (1989). Manual asymmetries: feedback processing, output variability and spatial
541 complexity: resolving some inconsistencies, *Journal of Motor Behavior*, 21, 38–47.
- 542 Carson, R.G., Goodman, D., Chua, R., & Elliott, D. (1993). Asymmetries in the regulation of
543 visually guided aiming, *Journal of Motor Behavior*, 25, 21–32.
- 544 Cavina-Pratesi, C., Ietswaart, M., Humphreys, G.W., Lestou, V., & Milner, A.D. (2010).
545 Impaired grasping in a patient with optic ataxia: primary visuomotor deficit or secondary
546 consequence of misreaching? *Neuropsychologia* 48, 226–234.
- 547 Clifton, R.K., Muir, D.W., Ashmead, D.H., & Clarkson, M.G. (1993). Is visually guided
548 reaching in early infancy a myth? *Child Development*, 64, 1099–1110.
- 549 Clifton, R.K., Rochat, P., Robin, D.J., & Berthier, N.E. (1994). Multimodal perception in the
550 control of infant reaching, *Journal of Experimental Psychology, Human Perception and*
551 *Performance*, 20, 876–886.
- 552 Colombo, J., (1993). *Infant cognition: Predicting later intellectual functioning*. Newbury Park,
553 CA Sage.
- 554 Corbetta, D., Guan, Y., & Williams, J.L. (2012). Infant Eye-Tracking in the Context of Goal-
555 Directed Actions, *Infancy*, 17(1), 102-125.
- 556 Culham, J.C., & Valyear, K.F. (2006). Human parietal cortex in action, *Current Opinion in*
557 *Neurobiology*, 16, 205–212.
- 558 Elliott, D., & Chua, R. (1996). Manual asymmetries in goal-directed movement, *Manual*
559 *Asymmetries in Motor Performance*. CRC Press, Florida, (pp.143–157).
- 560 Elliot, D., Elliott D., Heath M., Binsted G., Ricker K.L., Roy E.A., & Chua R. (1999). Goal-
561 directed aiming: correcting a force-specification error with the right and left hands,
562 *Journal of Motor Behavior*, 31:309–324.

563 Fagard, J. (2000). Linked proximal and distal changes in the reaching behaviour of 5- to 12-
564 month-old human infants, grasping objects of different sizes, *Infant Behavior and*
565 *Development*, 23, 317–329.

566 Fagard, J., & Pez , A. (1997). Age changes in interlimb coupling and the development of
567 bimanual coordination, *Journal of Motor Behavior*, 29, 199–208.

568 Fagard, J., Spelke, E. & von Hofsten, C. (2009). Reaching and grasping a moving object in 6-,
569 8-, and 10-month-old infants: Laterality and performance, *Infant and Behavior*
570 *Development*, 32; 132-147.

571 Falck-Ytter, T., Gredeback, G. & von Hofsten, C. (2006). Infants predict other people’s action
572 goals, *Nature Neuroscience*, 9, 878–879.

573 Filimon, F. (2010). Human cortical control of hand movements: parieto frontal net- works for
574 reaching, grasping, and pointing, *Neuroscientist*, 16, 388–407.

575 Flowers, K. (1975). Handedness and controlled movement, *British Journal of Psychology*, 66,
576 39–52.

577 Gonzalez, C.L., & Goodale, M.A. (2009). Hand preference for precision grasping predicts
578 language lateralization, *Neuropsychologia*, 47 (14), 3182-3189.

579 Gredeb ck, C., von Hofsten, C., & Boudreau, J.P. (2002). Infants’ visual tracking of
580 continuous circular motion under conditions of occlusion and non-occlusion, *Infant*
581 *Behavior and Development*, 25, 161–182

582 Haaland, K.Y., & Harrington, D.L. (1989). Hemispheric control of the initial and corrective
583 components of aiming movements, *Neuropsychologia*, 27, 961–969.

584 Haaland, K.Y., Elsinger, C.L., Mayer, A.R., Durgerian, S., & Rao, S.M. (2004). Motor
585 Sequence complexity and performing hand produce differential patterns of hemispheric
586 lateralization, *Journal of Cognitive Neuroscience*, 16, 621–636.

- 587 Helsen, W.F., Elliott, D., Starkes, J., & Ricker, K.L. (1998a). Temporal and spatial coupling
588 of point of gaze and hand movements in aiming, *Journal of Motor Behavior*, 30, 249–
589 259.
- 590 Helsen, W.F., Starkes, J.L., Elliott, D., & Buekers, M.J. (1998b). Manual asymmetries and
591 saccadic eye movements in right-handers during single and reciprocal aiming
592 movements, *Cortex*, 34, 513–529.
- 593 Hodges, N. J., Lyons, J., Cockell, D., Reed, A., & Elliott, D. (1997). Hand, space and
594 attentional asymmetries in goal-directed manual aiming, *Cortex*, 33, 251–269.
- 595 Hofsten, C. (1979). Development of visually directed reaching: the approach phase, *Journal*
596 *of Human Movement Studies*, 5, 160–178.
- 597 Hofsten, C., & Fazel-Zandy, S. (1984). Development of visually guided hand orientation in
598 reaching. *Journal of Experimental Child Psychology*, 38, 208–219.
- 599 Hofsten, C. (1991). Structuring of early reaching movements: a longitudinal study, *Journal of*
600 *Motor Behavior*, 23, 280–292.
- 601 Hofsten, C. (1993). Prospective control: a basic aspect of action development, *Human*
602 *development*, 36(5), 253-270.
- 603 Hofsten, C. (2005). On the development of perception and action. In K. Connolly & J.
604 Valsiner (Eds.), *Handbook of developmental psychology*. London: Sage.
- 605 Hopkins, B., & Ronnqvist, L. (2002). Facilitating postural control: effects on the reaching
606 behavior of 6-month-old infants, *Developmental Psychobiology*, 40 (2), 168–182.
- 607 Jeannerod, M. (1981). Inter segmental coordination during Reaching at natural visual objects.
608 In Long, J. and Baddeley, A. (Eds), *Attention and performance IX*, (pp. 153–169).
609 Hillsdale, NJ: Lawrence Erlbaum Associates.

610 Jeannerod, M. (1999). Visuomotor channels: their integration in goal-directed prehension,
611 *Human.Movement.Science*, 18,201–218.

612 Karl, J.M., & Wishaw, I.Q. (2013).Different evolution are origins for the reach and the
613 grasp: an explanation for dual visuomotor channels in primate parieto frontal cortex,
614 *Frontiers of Neurology*, 4, 208.

615 Karl, J.M., & Wishaw, I.Q. (2014). Haptic grasping configurations in early infancy reveal
616 different developmental profiles for visual guidance of the Reach versus the Grasp,
617 *Experimental brain research*, 232(10), 3301-3316.

618 Lavrysen, A., Helsen, W.F., Tremblay, L., Elliott, D., Adam, J.J., Feys, P., & Buekers, M.J.
619 (2003). The control of sequential aiming movements:the influence of practice and
620 manual asymmetries on the one-target advantage, *Cortex* 39, 307–325.

621 Lavrysen, A., Elliott, D., Buekers, M.J., Feys, P., & Helsen, W.F. (2007). Eye–hand
622 coordination asymmetries inmanual aiming, *Journal of Motor Behavior*, 39, 9–18.

623 Lavrysen, A., Heremans, H., Peeters, R., Wenderoth, N. Helsen, W., Feys, P. & Swinnena, S.
624 (2008). Hemispheric asymetries in eye-hand coordination, *NeuroImage*, 39, 1938-1949.

625 Luna, B., Velanova, K., & Geier, F. (2008). Development of eye-movement control, *Brain*
626 *and Cognition*, 68, 293-308.

627 McCarty, M.E., Clifton, R.K., Ashmead, D.H., Lee, P., & Goubet, N. (2001). How infants use
628 vision for grasping objects, *Child Development*, 72, 973–987.

629 Michel, G. (1992). Maternal influences on infants hand-use during play with toys, *Behav.*
630 *Genet.* 22, 163–176.

631 Michel, G. Michel, G.F., Sheu, C.F., Tyler, A.N., & Ferre, C.L. (2006). The Manifestation of
632 infant hand-use preferences when reaching for objects during the seven- to thirteen-
633 month age period, *Developmental Psychobiology*, 48, 436–443.

- 634 Mieschke, P.E., Elliott, D., Helsen, W.F., Carson, R.G., & Coull, J.A. (2001). Manual
635 asymmetries in the preparation and control of goal-directed movements, *Brain and*
636 *cognition*, 45, 129–140.
- 637 Morange-Majoux, F. (2011). Manual exploration of consistency (soft vs hard) and handedness
638 in infants from 4 to 6 months old, *Laterality*, 16(3), 292-312.
- 639 Morange, F., & Bloch, H. (1996). Lateralization of the approach movement and the
640 prehension movement in infants from 4 to 7 months, *Early Development and Parenting*,
641 5, 81–92.
- 642 Morange-Majoux, F., Peze, A., & Bloch, H. (2000). Organisation of left and right hand
643 movement in a prehension task: a longitudinal study from 20 to 32 weeks. *Laterality: 5*
644 (4), 351–362.
- 645 Morange-Majoux, F., & Dellatolas, G. (2010). Right-left approach and reaching arm
646 movements of 4-month infants in free and constrained conditions, *Brain and Cognition*,
647 72, 419-422.
- 648 Morange-Majoux, F., Lemoine, C. & Dellatolas, G. (2012). Early manifestations of manual
649 specialization in infants: A longitudinal study from 20 to 30 weeks using reaction time,
650 *Laterality*, 18, 231-250.
- 651 Piaget, J. (1952). The origins of intelligence in the child. *New York: Routledge*.
- 652 Rizzolatti, G., Luppino, G., & Matelli, M. (1998). The organization of the cortical motor
653 system: new concepts. *Electroencephalogr. Clin Neurophysiol.* 106, 283–296.
- 654 Rönnqvist, L., & Domellöf, E. (2006). Quantitative assessment of right and left reaching
655 movements in infants: A longitudinal study from 6 to 36 months, *Developmental*
656 *Psychobiology*, 48(6), 444–459.

657 Rose, S.A., Feldman, J.F., & Jankowski, J.J. (2001a). Attention and recognition memory in
658 the first year of life: A longitudinal study of preterms and full-terms, *Developmental*
659 *Psychology*, 37, 135–151.

660 Rose, S.A., Feldman, J.F., & Jankowski, J.J. (2001b). Visual short-term memory in the first
661 year of life: Capacity and recency effects, *Developmental Psychology*, 37, 539–549.

662 Roy, E.A., & Elliott, D., (1989). Manual asymmetries in aimed movements, *Quarterly*
663 *Journal of Experimental Psychology*, 41A, 501–516.

664 Roy, E.A., Kalbfleisch, L., & Elliott, D., (1994). Kinematic analyses of manual asymmetries
665 in visual aiming movements, *Brain and Cognition*: 24.,(2), 289–295.

666 Sacrey, L.A.R., & Whishaw, I.Q. (2010). Development of collection precedes targeted
667 reaching: resting shapes of the hands and digits in 1–6-month-old human infants,
668 *Behavioural brain research*, 214(1), 125-129.

669 Savelsbergh, G.J., & van der Kamp, J. (1994). The effect of body orientation to gravity on
670 early infant reaching. *Journal of Experimental Child Psychology*, 58(3), 510-
671 528.Sainburg, R. L., (2002). Evidence for a dynamic-dominance hypothesis of
672 handedness, *Experimental Brain Research*: 142., (2), 241–258.

673 Schuler, N.D., Rushworth, M. F., Passingham, R.E., & Mills, K.R. (1998). Temporary
674 interference in human lateral premotor cortex suggest dominance for the selection of
675 movements. A study using transcranial magnetic stimulation, *Brain*, 121, 785–799.

676 Smith, L.B., & Thelen, E. (1993). A dynamic systems approach to development. Cambridge,
677 MA : MIT Press.

678 Starkes, J., Helsen, W., & Elliott, D. (2002). A menage a trois: the eye, the hand and on-line
679 processing, *J. Sports Sci.* 20, 217–224.

680 Tanné-Gariépy, J., Rouiller, E.M., & Boussaoud, D. (2002). Parietal inputs to dorsal versus
681 ventral premotor are as in the macaque monkey: evidence for largely segregated
682 visuomotor pathways, *Experimental Brain Research*, 145, 91–103.

683 Thelen, E., Corbetta, D., Kamm, K., Spencer, J.P., Schneider, K., & Zernicke, R. (1993). The
684 transition to reaching: Mapping in attention to intrinsic dynamics, *Child Development*, 64,
685 1058–1098.

686 Todor, J. I., & Cisneros, J. (1985). Accommodation to increased accuracy demands by the
687 right and left hands, *Journal of motor behavior*, 17(3), 355-372.

688 Verstynen, T.D., Diedrichsen, J., Albert, N., Aparicio, P., & Ivry, R.B. (2005). Ipsilateral
689 motor cortex activity during unimanual hand movements relates to task complexity,
690 *Journal of Neurophysiology*, 93, 1209–1222.

691 White, B.L., Castle, P., & Held, R. (1964). Observations on the development of visually
692 directed reaching, *Child Development*, 35, 349–364.

693 Witherington, D. C. (2005). The development of prospective grasping control between 5 and
694 7 months: A longitudinal study, *Infancy*, 7, 143–161

695

696 **List of Figures**

697

698 **Figure 1:** Experimental design. Eye-tracking system was configured to record looks on a horizontal
699 plan. 1A: Scene plane recorded by the scene camera. Live recording of the table was synchronized on
700 line with the remote optics eye camera by computer which calculated the superimposition of specific
701 looks (symbolized by two crossing lines) and the fixated plan of the table. 1B: view of front webcam
702 synchronized to the two other cameras to record infants' behavior, facial expressions and head
703 orientation (infant with a Mini Bird Head tracker). 1C: infant's line of gaze was measured by computing
704 the pupil-corneal reflection at a sampling rate of 50 Hz.

705 **Figure 2:** Examples of images recorded by scene camera allowing to record infant's hands activity
706 useful for the coding of hands activity. The superimposition of the fixed plane with the looks
707 (intersection of horizontal and vertical black lines) on video recording scene plane gave indication of
708 when infants looked at the hands.

709 **Figure. 3:** Calibration phase: 9 calibrations points were used. This most frequently used method
710 provides robust and accurate data under most circumstances (a). A Flashing Ball was used to visually
711 attract the subject: for each nine points, the flashing ball was put on a calibration point (examples in b
712 and c). For each calibration point, when the infant looked at the ball and we had simultaneously a
713 cross given by the eye-tracker indicating a gaze, another experimenter approved the calibration point
714 and manually confirmed it on the computer. The target-object was placed on the table, on the right or
715 on the left of the baby, inside the scene plane.

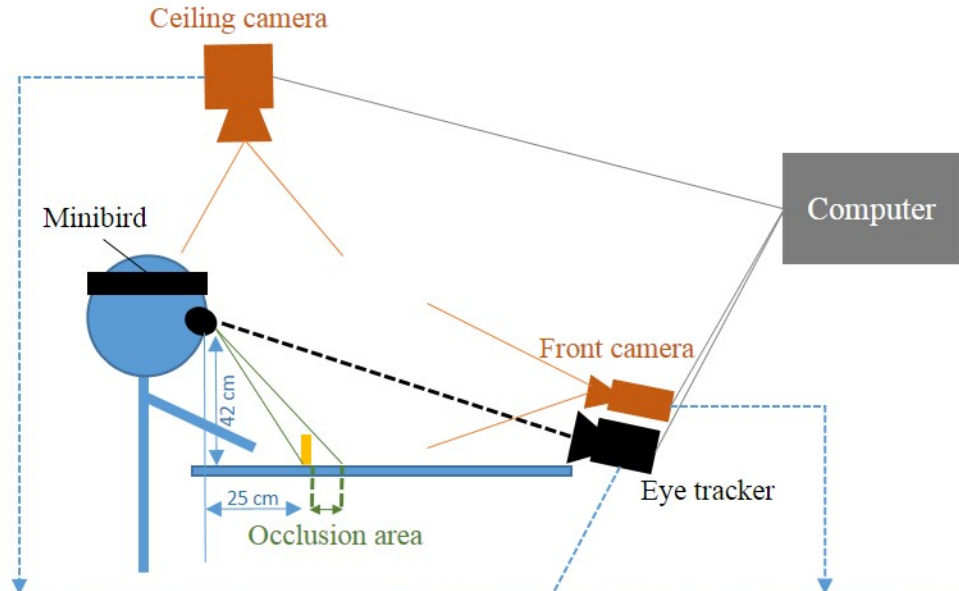
716 **Figure 4.** Proportion of time the left- and the right-hand remained stationary

717 **Figure 5:** Distribution of gazes (in %) according to the hand tested.

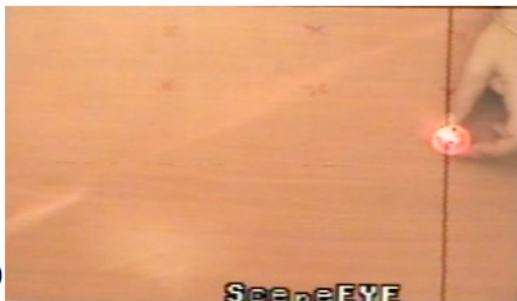
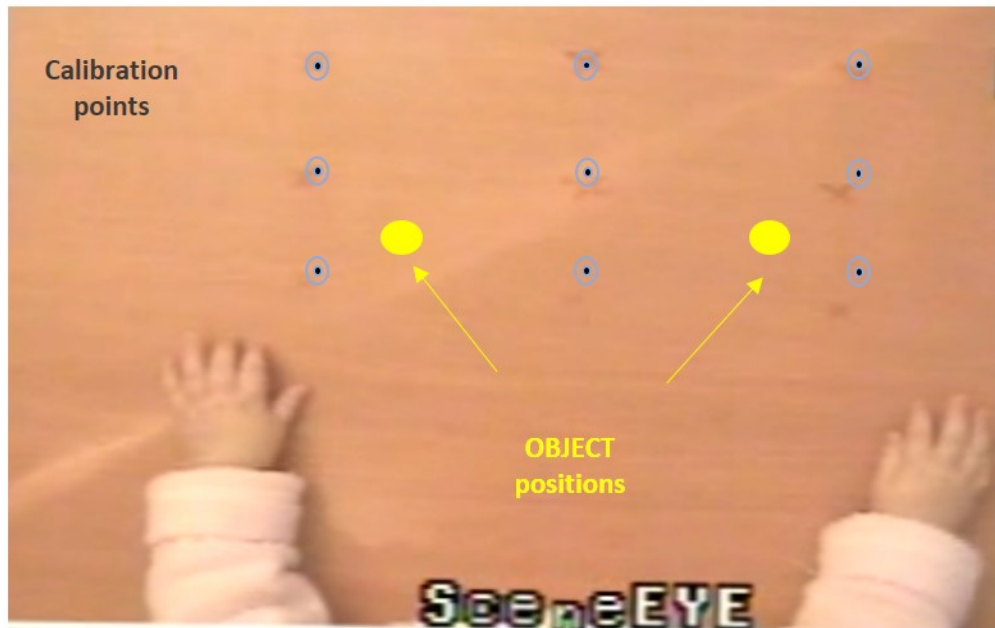
718 **Figure 6:** Distribution of gazes (in %) when the hand tested remained stationary according to the hand
719 tested.

720 **Figure 7:** Distribution of gazes (in %) when the hand tested is moving according to the hand tested.

721







Proportion of time the hand was
unmoving

