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Memory for complex visual objects but not for allocentric locations during the first year of life

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Abstract

Although human infants demonstrate early competence to retain visual information, memory capacities during infancy remain largely undocumented. In three experiments, we used a Visual Paired Comparison (VPC) task to examine abilities to encode identity (Experiment 1) and spatial properties (Experiments 2a and 2b) of unfamiliar complex visual patterns during the first year of life. In the first experiment, 6- and 9-month-old infants were familiarized with visual arrays composed of four abstract patterns arranged in a square configuration. Recognition memory was evaluated by presenting infants with the familiarized array paired with a novel array composed of four new patterns. The second couple of experiments aimed to examine infant ability to encode the spatial relationships between each pattern of the array (e.g., where is A in the square configuration). The 6-, 9- and 12-month-old infants were tested on a spatial version of the VPC task, in which the novel array was composed of the same patterns than the familiarized array but arranged differently within the square configuration. Results indicated that infants retained the identity of the patterns but not their specific spatial relationships within the square configuration (i.e., allocentric location of the patterns), suggesting either an immaturity of the processes involved in object-to-location binding, or the inappropriateness of unfamiliar complex objects to reveal such early allocentric abilities.

Keywords

infant, visuospatial memory, spatial relational memory, allocentric coding, object–location binding

Most developmental studies on infant memory have focused on investigating the emergence of the memory systems, as what kind of objects infants are able to memorize, and for how long they can be hold in memory. For instance, infants demonstrated evidence of recognition memory as early as 3 days after birth (Pascalis & de Schonen, 1994), even 2 weeks after exposure at 6 months of age (Fagan, 1973), and for various stimuli, including abstract patterns (e.g., Cassia, Simion, Milani, & Umilta, 2002; Fagan, 1970, 1971, 1973; Farroni, Valenza, Simion, & Umilta, 2000), object motion (Bahrick, Hernandez-Reif, & Pickens, 1997; Bahrick & Pickens, 1995), and faces (Fagan, 1972; Pascalis, de Haan, Nelson, & de Schonen, 1998; Pascalis & de Schonen, 1994). In contrast, there are few data on capacity limits in memory, and on how and which information about stimuli is encoded, that is, for example, whether the relation between elements is encoded and, if so, which kind of relationships. In the present studies, we addressed two specific questions: (1) is infant memory limited by the amount of information (number and complexity) to learn from their environment? and (2) are spatial relations between elements of the outside world encoded? It is of particular interest since infants' visual world is composed of numerous complex objects that possess spatial relationships between them.

Most research on infant's memory is based on familiar objects (e.g., faces), or at least objects that infants may have previously encountered (e.g., cats, mountains), making the contribution of pre-existing representations possible. In order to determine if the infant's brain is able to encode complex objects, it is important to use unfamiliar abstract stimuli, which necessarily involve the formation of new memory traces. Some studies used unfamiliar abstract stimuli but their complexity was relatively limited. For example, in his studies, Fagan (1970, 1971, 1973) used single-shape black and white patterns (e.g., an array of several black lines of different orientation and length on a white background). To the best of our knowledge, no study has tested whether infants are able to memorize complex multi-feature stimuli (i.e., composed of different colours, shapes, and orientations).

In the same vein, our knowledge about spatial relational representations during the first year of life is scarce. Coding the spatial relationships between elements refers to an allocentric spatial coding of the objects, according to which space is coded independently of our body's position and orientation, locations of elements being coded in terms of their relation between each other and/or relative to the surrounding environment (O'Keefe & Nadel, 1978). The existence of very basic spatial memory from 3 days of life can be inferred from neonates' ability to distinguish and remember global spatial arrangement of elements (e.g., cross vs. diamond shape

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organizations, Cassia et al., 2002; Easterbrook, Kisilevsky, Muir, & Laplante, 1999; Farroni et al., 2000). These data suggest early abilities to encode spatial relations between elements (e.g., A, B and C are spatially arranged in the form of a triangle; here, we called these abilities "*basic* spatial relational memory"), but it does not provide any insight on infants' ability to encode the spatial relations specific to each element within a global configuration (e.g., where is A in the triangle configuration, which we called here "spatial relational memory" or allocentric memory). This later ability requires not only encoding object identities (e.g., A, B and C identities) and object locations, or "*basic* spatial relational memory" (e.g., the elements are spatially arranged in the form of a triangle), but also associating or binding this information together in order to encode object-to-location relations (e.g., A is above B and C, etc.). Binding refers to representations which contain contextual features that are tightly bound, or fused together with an item. We can distinguish between "intrinsic" contextual features that are inherent to the studied item (e.g., the colour or spatial location of the item) as opposed to "extrinsic" contextual features for which processing is optional (e.g, identity of the test room, Baddeley, 1982). Infants from 6 months of age have been shown to encode a range of "extrinsic" contextual information into their memory representations, such as the background upon which an object was presented (Haaf, Lundy, & Coldren, 1996; Richmond & Nelson, 2009; Richmond & Power, 2014; Robinson & Pascalis, 2004), or the room in which learning occurred (Bushnell, Mccutcheon, Sinclair, & Tweedlie, 1984; Hayne, Boniface, & Barr, 2000; Jones, Pascalis, Eacott, & Herbert, 2011). Concerning "intrinsic" contextual features, Kaldy and Leslie (2003) reported that 9-month-old infants were able to memorize spatial positions of objects based on their shapes, showing object shape-to-location binding abilities. When presented with two distinct objects that were independently moved behind spatially separated screens, infants looked longer toward the removed screens that revealed a swap in object locations. However, it is not clear from this study whether infants memorized the spatial relation between objects (i.e., A in relation to B; *allocentric* coordinates), or the location of the objects in relation to their own location (i.e., A and B in relation to their body; *egocentric* coordinates). To date, no study has examined purely allocentric memory during the first year of life. Such memory has only been investigated in older infants from 18 months of age (Ribordy, Jabès, Lavenex, & Lavenex, 2013; Sluzenski, Newcombe, & Satlow, 2004). In these studies, infants were encouraged to search hidden objects that could be found based on the location of another object or environmental cues. Only 24-month-olds were able to perform the task, suggesting that allocentric memory emerges around 2 years of age. However, the task demand, that is, to learn spatial relations between objects and to use this knowledge in order to find hidden objects, could have precluded younger infants to demonstrate evidence of allocentric memory. Therefore, such search tasks might not be appropriate to examine spatial relational (or allocentric) memory in early infancy; younger infants might not be able to *use* allocentric memory to solve the task, even if they were able to *encode* allocentric information.

Task demands can be minimized using the Visual Paired Comparison (VPC) task (Fagan, 1970, 1971, 1972, 1973; Fantz, 1964; for a review see Pascalis & de Haan, 2003). The VPC procedure indexes the participant's level of interest for one stimulus in a pair after one of these stimuli has been learned during a prior familiarization or habituation period. Recognition memory is inferred from the participant's tendency to fixate toward the novel stimulus. Forgetting or lack of encoding of the original stimulus is inferred when the fixation times for the familiarized and the novel test stimuli are equal. This procedure makes possible the examination of allocentric memory by manipulating the object arrangements during the test phase (spatial version of the VPC task). So far, the spatial VPC task has been used in Monkeys (Bachevalier & Nemanic, 2008; Blue, Kazama, & Bachevalier, 2013) and rats (Wan, Aggleton, & Brown, 1999), and has shown recognition memory for familiarized arrangements in adult animals, but not earlier in development.

In the present study, we tested human infants from 6 to 12 months of age on both classical and spatial versions of the VPC task. The first experiment aimed to address whether complex visual abstract patterns can be learned and remembered by changing the identity of the patterns during the test phase. In the second set of, experiments we changed the arrangement of the patterns during the test phase to determine whether spatial relationships between patterns were stored in memory. If spatial relationships are encoded in memory, then infants should show a novelty preference when both identity (Experiment 1) and arrangement of patterns are changed (Experiments 2a and 2b). On the contrary, if infants encode pattern identities without encoding their spatial relationships, then a novelty preference should be observe only for a change in identity, but not a change in the arrangement of patterns.

Experiment 1

In the first experiment, we used a classical VPC task to examine whether 6- and 9-month-old infants were able to encode unfamiliar complex visual abstract patterns.

Method

Participants. The final analysis included 46 healthy full-term 6- and 9-month-old infants. They were recruited from the maternity ward of the Centre Hospitalier Universitaire (CHU), Grenoble, France. Parents were naive to the purpose of the study. This experiment was approved by an ethic committee (Comité d'Ethique des Centres d'Investigation Clinique de l'inter-région Rhône-Alpes-Auvergne, Institutional Review Board (IRB), protocol number: 2010-21), and was conducted with the understanding and written consent of each parent. There were 25 participants in the group of 6-month-olds (Mean age $=$ 192 days, $SD = 6.1$ days, range from 183 to 209 days; 16 females), and 21 participants in the group of 9-month-olds (Mean age $=$ 283 days, $SD = 6.9$ days, range from 275 to 298 days; 11 females). A further 16 infants were eliminated from the analysis due to technical problems ($n = 3$ for 9-month-olds), changing state during the test (i.e., infant started to cry, $n = 2$ for 6-month-olds), strong position bias (i.e., the infant looked in one direction for more than 95% of the time, $n = 6$ for 6-month-olds, $n = 2$ for 9-month-olds), insufficient looking time toward the stimuli during the familiarization phase ($n = 1$ for 6-month-olds, $n = 1$ for 9-month-olds), or null looking time toward the stimuli during the test phase ($n = 1$ for 6-month-olds).

Stimuli. Coloured unfamiliar arrays were used in the experiment (see examples in Figure 1). They were created by combining four abstract patterns varying on multiple dimensions (i.e., shape, texture and colour). The four patterns were spatially arranged to form a global square shape. A total of 10 abstract patterns were used to

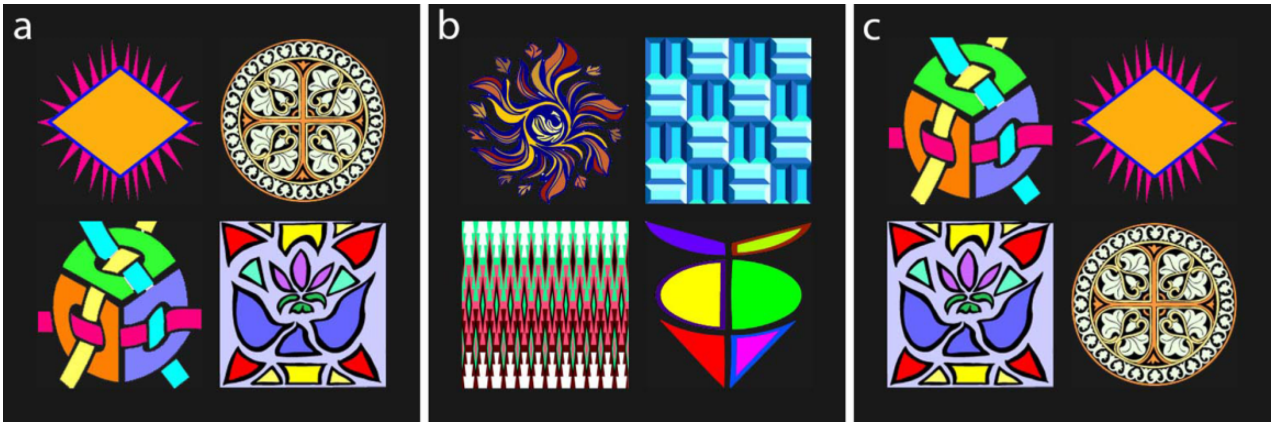

Figure 1. Example of one set of arrays used in Experiments 1 and 2a and b: (a) represents the familiarization array, (b) represents the novel array paired with (a) in Experiment 1; each pattern was new, and (c) represents the novel array paired with (a) in Experiment 2a and b; the spatial arrangement of patterns was modified.

create the arrays. Abstract patterns were combined so that colour-, shape- and texture-complexity were kept as equivalent as possible between arrays. The arrays were approximately 18 cm high and 18 cm wide (with a visual angle of approximately 17° × 17°, each abstract pattern was 6 cm high × 6 cm wide). Four different arrays were created for the familiarization phase. For each of them, four test pairs were created, representing the familiarized and the novel arrays. The novel array of each pair was composed of abstract patterns all different from the abstract patterns of the familiarization array. This yielded a total of 16 different sets of arrays (4 familiarization arrays × 4 test pairs).

Procedure. The infants were tested in a quiet room and seated on their parent's lap. They were approximately 60 cm away from the 22-inch monitor screen onto which the images were projected. Parents were instructed to fixate centrally above the screen and to remain quiet during testing.

Familiarization trials. Infants were first presented with the familiarization array displayed in the centre of the screen for four 5-second trials. The four different familiarization arrays were counterbalanced across participants. Before each trial, an attention-getter screen was presented until the infant looked at the middle of the screen. Each trial started when the infant looked at the array in the centre and ended after 5 seconds had elapsed, yielding to a 20-second familiarization phase.

Test trials. Immediately after the 4-familiarization trials, the familiarized and a novel array were displayed side-by-side for two 5-second test trials. The novel arrays associated to each familiarized stimulus were counterbalanced across participants. The left/right position of the novel array during the first test trial was counterbalanced across infants and was reversed for the second test trial. The arrays were separated by a 21-cm gap on the monitor, and displayed at the same size than during the familiarization phase. An attention-getter screen was presented before each trial until the infant looked at the middle of the screen (i.e., for approximately 2 seconds). The trial started when the infant looked at one of the two arrays and ended after 5 seconds had elapsed.

Infant's eye movements were recorded during stimulus presentation by a video camera specialized for low light conditions. The film was then digitized to be analysed offline, frame by frame, by two independent observers, blind to the screen positions of the novel and familiarized arrays. Inter-observer agreement was calculated on 33% of the participant videos from the final sample and showed high agreement (Pearson $r > .96$, calculated for the familiarization and test phases, on the whole data set from all three Experiments).

Analysis. Three scores were calculated for each participant and averaged across each age group: The total looking time during the familiarization (familiarization looking time) and test (test looking time) phases, and the novelty preference during the test as a measure of recognition memory (novelty preference percentage). This later score corresponded to the total amount of time spent looking at the novel stimulus divided by the total amount of time spent looking at both the novel and the familiarized stimuli, converted then to a percentage value.

Analyses were performed using R v3.0.2 with an alpha threshold defined at .05. Novelty preference was tested in each age group by performing one sample Student *t* tests against chance (i.e., *t* test against 50%). Bonferroni a priori correction was applied on the alpha threshold for multiple comparisons ($\alpha_{\text{Bonferoni-adjusted}} = \alpha / c = .025$ with c = 2 groups [6- and 9-month-olds]). Age group difference was tested with a Student *t* test for independent groups.

Results and discussion

The 6- and 9-month-olds spent in average 18.0 ($SD = 2.1$ s) and 18.1 ($SD = 1.8$ s) seconds looking at the array during familiarization, respectively. During the test phase, the mean total looking time toward the stimuli reached 8.8 seconds ($SD = 1.0$ s) for 6-month-olds and 8.9 seconds ($SD = 1.1$ s) for 9-month-olds.

Mean novelty preference for each age group is given in Table 1 (see also Figure 2 for individual data). On average, 6- and 9-month-olds spent 58.4% and 58.5% of the time looking at the novel stimulus, respectively. Age group difference was not significant, $t(42) < 1$, $p = .970$. Student *t* tests against chance (i.e., 50%) revealed that infants in both age groups looked significantly longer at the novel stimuli than the familiarized one, $t(24) = 2.87$, $p = .008$ for 6-month-olds, $t(20) = 2.64$, $p = .016$ for 9-month-olds, showing clear evidence of recognition of the familiarized array. These data

Table 1. Percentage of looking time to the novel array by 6- and 9-month-olds in Experiment 1 where pattern identities were changed, and by 6-, 9- and 12-month-olds in Experiments 2a and 2b where the arrangement of patterns was changed.

	Change in identity (Experiment 1)		Change in arrangement (Experiments 2a and 2b)	
Age	% looking time to the novel array (SE, 95% CI)	*t* test	% looking time to the novel array (SE, 95% CI)	*t* test
6-month-olds	58.36 (2.92, 52.34–64.38)	$p = .008$	50.97 (1.95, 46.95–54.99)	*ns*
9-month-olds	58.53 (3.23, 51.79–65.27)	$p = .016$	49.89 (3.11, 43.50–56.29)	*ns*
12-month-olds			51.95 (2.04, 47.82–56.08)	*ns*

Note. For Experiment 1, $n = 25$ for 6-month-olds and $n = 21$ for 9-month-olds; For Experiments 2a and 2b, $n = 26$ for 6-month-olds, $n = 27$ for 9-month-olds, and $n = 37$ for 12-month-olds; Standard errors (SE) and 95% confidence intervals (95% CI) are shown in brackets.

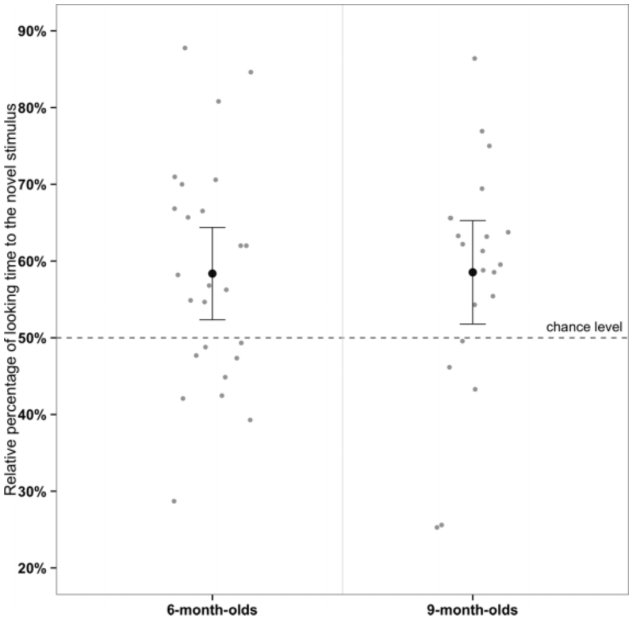

Figure 2. Percentage of time spent looking at the novel array for each age group in Experiment 1. Light grey dots represent individual scores whereas black dots represent mean scores (vertical bars denote 0.95 confidence intervals). Percentage scores above 50% mean that infants looked longer toward the novel array than the familiarized one.
Note. $n = 25$ for 6-month-olds, $n = 21$ for 9-month-olds.

demonstrate 6- and 9-month-old infant abilities to memorize and retrieve identity of complex abstract stimuli made of four elements.

Experiment 2a

In the second experiment, we presented 6- and 9-month-olds with a spatial version of the VPC task to examine whether spatial relationships between elements of visual stimuli can be memorized in the first year of life. We used the same stimuli as in the familiarization phase of Experiment 1, for which infants of similar ages have shown memorization and retrieval abilities.

Method

Participants. A total of 53 healthy full-term 6- and 9-month-old infants recruited from the maternity ward of the Centre Hospitalier Universitaire (CHU, Grenoble, France) were included in the final analysis. As in Experiment 1, parents were kept naive to the purpose of the study. The experiment was approved by an ethic committee and was conducted with the understanding and written consent of each parent. There were 26 participants in the group of 6-month-olds (Mean age = 190 days, *SD* = 6.0 days, range from 180 to 207 days; 9 females) and 27 participants in the group of 9-month-olds (Mean age = 280 days, *SD* = 5.4 days, range from 266 to 291 days; 17 females). A further 32 infants were eliminated from the analysis due to technical problems ($n = 2$ for 6-month-olds, $n = 5$ for 9-month-olds), changing state during the test (i.e., infant became too tired and/or started to cry or to be restless, $n = 1$ for 6-month-olds, $n = 2$ for 9-month-olds), strong position bias (i.e., infant looked in one direction for more than 95% of the time; $n = 5$ for 6-month-olds, $n = 10$ for 9-month-olds), or insufficient looking time toward the stimuli ($n = 3$ for 6-month-olds, $n = 4$ for 9-month-olds).

Stimuli. The stimuli were identical to the ones used in Experiment 1 except that only two test pairs were created for each of the 4-familiarization arrays. The novel arrays were composed of the same abstract patterns used for the familiarization array but arranged differently: The four abstract patterns were permuted by translating each of them to their neighbour location in a clockwise or counter-clockwise fashion (without applying any rotation transformation to each pattern, see Figure 1). This yielded a total of eight different sets of arrays (4 familiarization arrays × 2 test pairs).

Procedure. The procedure was identical to the one used in Experiment 1.

Analysis. Three scores were calculated as in Experiment 1: The familiarization looking time, the test looking time and the novelty preference percentage.

We used identical analyses as in Experiment 1 except that three additional analyses were conducted to compare results between both experiments. We first conducted two ANOVAs with Age (6- vs. 9-month-olds) and Experiment (1 vs. 2a) as between-subject factors on both the familiarization looking time and the test looking time. These analyses aimed to ensure that memory performance was not affected by differences in the time infants allocated looking at the stimuli during the familiarization or the test phases between the two experiments. Then, we conducted an ANOVA with Age (6- vs. 9-month-olds) and Experiment (1 vs. 2a) as between-subject factors on the novelty preference scores in order to assess any difference in memory performance between the two experiments.

Results and discussion

The 6- and 9-month-olds spent in average 17.8 (*SD* = 2.4s) and 18.4 (*SD* = 1.2 s) seconds looking at the stimuli during the entire familiarization phase, respectively. During the test phase, the mean total looking time toward the array reached 9.0 seconds ($SD = 1.4$ s) for 6-month-olds and 8.6 seconds ($SD = 1.6$ s) for 9-month-olds, respectively. The ANOVAs conducted to compare mean looking times between Experiments 1 and 2a, in both experimental phases, failed to reveal any significant effect (all $ps > .25$), suggesting similar looking time through both experiments.

Analyses on the mean novelty preference percentages, revealed that infants did not prefer neither the novel nor the familiarized arrays in this second experiment: On average, 6- and 9-month-olds respectively spent 51%, $t(25) < 1$, and 49.9%, $t(26) < 1$, of the time looking at the novel stimulus. Furthermore, the ANOVA conducted to compare the novelty preference scores between Experiments 1 and 2a, revealed a significant main effect of the Experiment, $F(1, 95) = 7.94$, $p < .01$, with no main effect of Age nor Experiment × Age interaction, $Fs(1, 95) < 1$.

Overall, the analyses showed that, whereas infants demonstrated a significant novelty preference when pattern identities were changed (Experiment 1), they did not look longer at the novel spatial arrangement of patterns which identity was preserved (Experiment 2a), despite similar exploration times during the familiarization and the test phase in both Experiments (1 and 2a). These findings demonstrate that 6- and 9-month-olds were able to memorize and retrieve visual complex abstract patterns (Experiment 1) without encoding and/or remembering their spatial relationships (Experiment 2a).

Experiment 2b

In the Experiment 2b, we presented 12-month-olds with the spatial version of the VPC task to examine whether spatial relationships memory abilities emerge later at the end of the first year of life.

Method

Participants. Thirty-seven 12-month-old infants (Mean age = 374 days, $SD = 4.5$ days, range from 365 to 382 days; 16 females) were included in the final analysis. They were full-term and recruited from the maternity ward of the Centre Hospitalier Universitaire (CHU, Grenoble, France). Parents were kept naive to the purpose of the study. The experiment was approved by an ethic committee and was conducted with the understanding and written consent of each parent. A further seven infants were eliminated from the analysis due to technical problems ($n = 3$), changing state during the test ($n = 1$), and strong position bias ($n = 3$).

Stimuli and procedure. We used identical stimuli and procedure as in Experiment 2a.

Analysis. Three scores were calculated as in Experiments 1 and 2a: The familiarization looking time, the test looking time and the novelty preference percentage. We performed one-sample Student *t* test against chance level on the later mean score to test for novelty preference.

Results and discussion

The 12-month-olds spent in average 18 seconds ($SD = 2.1$ s) looking at the stimuli during the entire familiarization phase and 8.8 seconds ($SD = 1.2$ s) during the test phase. Critically, they did not look significantly longer to either stimuli during the test phase (novelty preference = 51.9%, $t[36] < 1$). Taken together, data from Experiments 2a and 2b indicated that infants from 6 to 12 months of age did not encode the allocentric location of the patterns that composed our arrays.

General discussion

The VPC task was used in three experiments to examine whether infants are able to remember abstract complex visual stimuli, and to investigate the nature of this memory, that is, whether or not spatial relationships between elements are encoded in memory along with their identities. The first experiment showed clear evidence of visual recognition of the familiarized array, in 6- and 9-month-olds, when paired with a novel array composed of new patterns. It demonstrates infant abilities to memorize a complex array of patterns, or at least one complex multi-feature pattern. Indeed, encoding only one pattern over four could have been enough to induce a novelty preference during the test phase.[1] In contrast, Experiments 2a and 2b failed to demonstrate visual recognition of the same complex array, by 6- and 9-month-olds, and even by older 12-month-old infants, when paired with a novel spatial arrangement of the patterns. Importantly, the absence of novelty preference in Experiments 2a and 2b cannot be explained by differences in exploration times during the familiarization or the test phases, between the two experiments, since analyses revealed similar amount of looking times to stimuli. Moreover, we can certainly rule out explanations in terms of inability to memorize such complex patterns and/or immaturity of the visual system, which would make infants unable to code fine visual features of complex objects. Such alternative seems indeed unlikely given that, in the first experiment, that require similar visual processing abilities, 6- and 9-month-old infants clearly demonstrated visual recognition memory. Thus, the absence of novelty preference in Experiments 2a and 2b is likely to reflect how visual information is actually coded by the perceptual system, and/or encoded in memory, during the first year of life.

Taken together, our data first show that infants did not learn only a snapshot of the array, without encoding at least some of its constituent parts. A snapshot representation of the array would have been sufficient to elicit a novelty preference, not only in Experiment 1, but also in Experiments 2a and 2b: Indeed, the changes in spatial relationships between patterns, in Experiments 2a and 2b, created differences in the overall stimuli. Given that infants did not present a novelty preference in Experiments 2a and 2b, we can conclude that they somehow encoded the components of the arrays. This explanation is in line with Haaf and colleagues' (1996) data which support that infants encode stimuli in terms of their components rather than holistically.

Secondly, our data reveal that information stored in memory is not necessarily represented in terms of spatial properties specific to each element of the outside world, at least during the first year of life. Infants have likely encoded the identity of the patterns of the array, without encoding their specific spatial relations (i.e., the allocentric location of each pattern). This can be explained (1) by the immaturity of the allocentric memory system and (2) by the nature of our stimuli, and/or by the experimental context that might not encourage infants to encode the allocentric location of patterns that composed our arrays.

Looking at the first explanation, allocentric memory might not yet be operational at 12 months of age. The current findings, taken together with previous data showing that newborns were able to learn *basic* spatial relation between elements (e.g., A, B, C, D are in a square configuration, Cassia, et al., 2002; Easterbrook, et al., 1999; Farroni, et al., 2000), suggest that failure in the allocentric memory is likely caused by the inability to bind objects to their locations within the array, rather than by the inability to learn object identities per se, or objects' *basic* spatial relationships per se. This explanation is consistent with data showing a late emergence (24 months of age) of allocentric memory (Ribordy, et al., 2013; Sluzenski, et al., 2004), and with Jabès and Nelson's hypothesis linking immaturity of the hippocampal formation during the first year of life with allocentric memory limitations (Jabès & Nelson, 2015; see also Ribordy, et al., 2013). Finally, our findings mirror recent data on patients with medial temporal lobe lesions, which demonstrated normal memory for isolated properties of items, such as their location or their identity, but impairment at binding together these properties (Pertzov et al., 2013).

For our second explanation (2), we suppose that if the allocentric memory system is operational during the first year of life, it might not be systematically involved in the processing of all kind of stimuli. Our data show that infants encoded the arrays in terms of their components, which might not be appropriate to code the spatial relationships between them. In other words, the allocentric information in the present stimuli might be not sufficiently salient to motivate infants to encode the spatial relations among the patterns. Spatial relationships between separate elements of a stimulus might be processed in infants provided that it is processed at a global level or holistically, and not only at the element level. As an example, Quinn and Tanaka (2009) reported data suggesting that 3- to 7-month-olds were able to encode configural information present in faces (i.e., spatial relations between facial features). As discussed by Uncapher, Otten, and Rugg (2006), successful binding of separate features of an object might require to allocate attention at the object level, so all the features can be attended simultaneously, as a whole. Similarly, a successful binding of the identity of an object to its relative position among other objects is more likely to occur when the separate objects can be perceived as a whole, as it is the case for facial features embedded in a face (Quinn and Tanaka, 2009). This later interpretation offers new avenues for future research, which might test whether patterns presented in a way that would encourage infants to code the visual information globally (e.g., by embedding patterns in a global shape) is a better approach to demonstrate allocentric memory abilities during the first year of life.

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Note

1. This point should be further investigated to make sure that infants are able to memorize more than one complex pattern at the same time. Crucially, our interpretation of Experiments 2a and 2b is not jeopardized: whatever the number of encoded patterns is (e.g., one to four), infants should exhibit a novelty preference for the novel spatial arrangement if they have encoded the allocentric position of the pattern(s).

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