Evaluation of visuospatial short-term and working memory from the first to second year of life: a novel task

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Abstract

The prototypical tasks for assess visuospatial memory in infancy are based on the search for a hidden object in two locations. Fewer studies include more locations, delayed responses nor changes in the object's position. Our aim was to assess the visuospatial short-term and working memory in 12, 15, 18 and 22-month-old children (N=65). Assessment included our experimental task, a working memory task and a cognitive developmental scale. Short-term and working memory abilities increased markedly at 22 months compared to younger ages and the performance of the children in our experimental task is related to other tasks previously used.

Keywords: visuospatial memory; short-term; working; infants; behavior; development

Introduction

Visuospatial memory refers to the ability to store and retrieve visual and spatial information (Baddeley, 1997). Short-term memory refers to a temporary store with a limited amount of visual which lasts a short period of time, while long-term memory involves the retrieval of visual and spatial information months or even years later (Baddeley, 1997). Another function is the visuospatial working memory, based on the ability to maintain visuospatial information and manipulate or update it (Baddeley, 1997). This memory relies directly on the visual perception or the generation of a previously stored visual image, and it oversees the maintenance and visuospatial manipulation of these images. Such visuospatial memory has been found impaired in neurological pediatric populations, for instance, Down syndrome (Godfrey & Lee, 2018), Williams syndrome (Bostelmann et al., 2017), cerebral palsy (Critten et al., 2018), prematurity (Cimadevilla et al., 2014; Fernandez-Baizan et al., 2020) or fetal alcohol syndrome (Uecker & Nadel, 1998). Nevertheless, a deep knowledge about how spatial memory develops at early ages in typical development would be required to examine such at risk populations.

In typical development, one of the first signs of visuospatial short-term memory is found on A-not-B tasks. In its classic paradigm (Piaget, 1954), an object is hidden under a location (A) and the child must retrieve it. Then, the object is hidden in a second location (B) and the child is asked to look for it. A modified version of this task, named delayed response task, introduces periods of time where the child is not allowed to retrieve the object. According to Piaget studies (Piaget, 1954), 12-month-olds stop committing errors on this type of task - that is, to search into location A despite having seen how the stimulus was hidden in B -, although later authors verified that a delayed A-not-B paradigm could be overcome at 6 months (Reznick et al., 2004) and 9 months (Diamond & Goldman-Rakic, 1989). Regarding delay response, children begin to tolerate short delays that seem to increase with age, from 1 or 2 seconds at 5.5 months (Reznick et al., 2004) to 10 seconds at 12 months (Diamond & Goldman-Rakic, 1989; Diamond & Doar, 1989), being that improvement probably associated with the maturation of the dorsolateral prefrontal cortex (Diamond & Goldman-Rakic, 1989; Diamond et al., 1997). Furthermore, the ability to update information held in short-term memory appears later and it can be assessed with invisible displacements based-tasks (Piaget, 1954) (similar to A-not-B tasks, but the child cannot directly observe how the stimulus is hidden in the target location, but rather the examiner hides the toy in some sort of cloth or screen). Previous studies show that this task progressively improves from 15 to at least 30 months of age (Diamond et al., 1997), although it can be performed with relative success after 2 years of age (Call, 2001).

Therefore, a searching-task with two possible spatial locations could be solved throughout the first year of life, including also short waiting periods, while the update of previously learnt information could be tackled during the second year of life. However, some authors have increased the difficulty of these search tasks by introducing more than two locations in earlier ages: children at 8 months are able to locate the object from 3 and 4 possible locations (Pelphrey et al., 2004), while from 18 months, a task based on 4 locations, delay period and position changes starts to be applied (Garon et al., 2014). Other researchers used 5 possible hiding places, surprisingly obtaining better results than on the classic A-not-B (Cummings & Bjork, 1983b), although later studies have shown that performance is not better if all the possible hiding places are covered during delay periods (Diamond et al., 1994).

Hence, these previous literature points out that, in order to fully evaluate visuospatial memory before the age of two, seems vital to consider: including more than two possible locations (Cummings & Bjork, 1983a; Garon et al., 2014; Pelphrey et al., 2004), introducing a delay period (Baillargeon et al., 1989; Diamond & Goldman-Rakic, 1989; Diamond & Doar, 1989; Reznick et al., 2004; Ropeter & Pauen, 2013) and including tasks based on updating the memory contents (Call, 2001; Diamond et al., 1997; Garon et al., 2014), being also important not to allow the child to visualize the hiding places during the delay period (Diamond et al., 1994). Although many of the tasks outlined above cover some of these aspects, few covers all of them during a long developmental period (Garon et al., 2014; Pelphrey et al., 2004; Reznick et al., 2004).

Our main aim was to analyze the typical visuospatial memory development in infants (12, 15, 18 and 22 months of age), using an experimental device and protocol for the evaluation of short term and working visuospatial memory (the Baby-mnemo task). We hypothesize that there will be differences between the age groups in the parameters measured, with 22-month-old children obtaining the best performance. We also aimed to compare the performance on our experimental task with other tests proposed for the evaluation of working memory (the Hide and Seek task). We hypothesize that both tasks will be moderately related to each other.

Materials and methods

Participants

Sixty-five infants (32 boys and 33 girls) from 12 (N=16), 15 (N=16) and 18 (N=18) and 22 (N=15) months of age made up the final sample (Mean=16.71, SD=3.647). From an initial sample of 74 participants, 9 infants were excluded, due to lack of collaboration during the assessment, which caused the evaluation protocol to not be fully administered (e.g., tantrums or inattention and distractibility during the whole evaluation), or due to a lower cognitive development level (<1 SD standard deviation) assessed with the Merrill-Palmer R scales (Roid & Sampers, 2011). Participants were recruited from pre-schools. Inclusion criteria included having been born after 37 weeks of gestation, absence of neurological illnesses or traumatic events, and no visual or hearing impairments. Parents were provided with information about the purpose of this study, and they gave their written informed consent before the study began. This study was approved by a local Research Ethics Committee and conducted following the Helsinki Declaration for biomedical research involving humans.

Visuospatial short-term and working memory assessment

Two tasks were used to measure memory in infants: our experimental task, Baby-Mnemo, and an adapted version of the Hide and Seek task, previously published by Garon et al. (2014).

Baby-mnemo (BM) is a task designed for the evaluation of different aspects of visuospatial memory in children under 2 years of age. The device consists of a mobile drawer made of wood (Figure 1). Six pushbuttons with light and six platforms were on the front, while on the back of the apparatus, the examiner has access to six switches for turning on the light and six levers to rise up the platforms. A blanket is employed to partially cover the device and reduce the amount of visuospatial information the child has to process. The decision to use 4 possible locations instead of 6 is based on findings from previous literature (Garon et al., 2014; Pelphrey et al., 2004).

The Baby-mnemo task included three phases: Recall of Location, focused on short-term memory, Delay, focused on tolerance of delayed response, and Update, focused on working memory. This three were preceded by a selection of the stimulus to be used during memory tasks, as well as by a familiarization with the device.

First, the examiner showed four small toys and encouraged the child to play with them during approximately 2 minutes. The preferred toy (which the child sighted, pointed, touched and played during more time) was the item selected to use in the following tasks. After this, the examiner showed the Baby-mnemo drawer to the child, encouraging her/im to explore it. The child stood in front of the buttons and s/he could explore and press them, while the examiner stood at the back. Then, when the child touched a particular button, the examiner turned on the corresponding light. After that, the examiner picked up the selected toy, placed it in the chosen platform and took it down. The platform selected was that equivalent to the button that the child used the most (the most sighted, pressed, pointed, etc., by the child). A sequence of three steps, called *Examiner examples* (Figure 2A), was repeated three times: the examiner pressed the correspondent button, turned on its light, and raised up the lever showing the hidden toy again. After that, the examiner pointed the correct button and asked: "Where is the (name of the toy)?". It was taken as the correct answer that the child touched the right button, when then the examiner turned on the light, raised the toy and reinforced her/is performance. They were taken as incorrect responses that the child touched another button or did not touch any other button. When this happened, the examiner pointed at the right button and asked him/er again: “Where is the (name of the toy)? Try here”. If after this opportunity the child continued to fail, other additional three Examiner Examples were applied, and if s/he failed again, the last three Examiner Examples were repeated (Figure 3). Therefore, this familiarization could end either when the child responded correctly twice, starting then with Baby-mnemo evaluation, or when all examples were exhausted, in which case Baby-Mnemo was not applied.

In the first phase, Recall of Location (I) (Appendix A), administered following the familiarization, the examiner asked for the toy on four more occasions, but without pointing to the correct pusher (Figure 2B). The child received one point for each correct answer emitted, and zero points for no answer or a wrong answer. If the child obtained at least two of the four possible points, this phase ended, and the Delay phase was administered. If the child received one or zero points, the examiner went back to the three Examiner Examples, followed by two attempts by the child and then try another Recall of Localization (II) (Figure 3). It could be applied up to a maximum of 3 Location phases. If the child did not respond correctly in at least two trials in any of the Recall of Location (I, II or III), the task was stopped. BM Location measure was obtained, where the child received a point for each correct response, varying in a range from 0 (the child has not emitted any correct answer) to 12 (the child has done four correct answers in the first Recall of Location).

In the Delay phase (Appendix B), an increasing delay was introduced where the child was not allowed to execute the response. Keeping the toy in the same hiding place, the examiner covered the entire device with fabric for two seconds in the first trial (2”), then uncovered it, and the child was asked about the location of the toy (Figure 4A). If the child responded correctly, the next rehearsal was increased by an additional two seconds (4"). Thus, after a correct trial, the delay time was increased in intervals of two seconds in each new rehearsal (4", 6", 8", etc.), until reaching a maximum of 30 seconds. If the child did not respond correctly, the examiner applied another trial with the same delay time on which the child had failed. If the child responded correctly, the examiner added two seconds extra in the next trial. If the child failed again this second time, this phase ended. BM Delay measure was obtained, which records the number of seconds the child was able to give the correct response, varying between 0 (the delay tolerated was null) and 30 (the maximum time established for this task).

The last phase, Update (Appendix C), involved presenting the toy on the three platforms that had not been used so far. The examiner picked up the toy from its previous platform, placed the toy on a different platform chosen randomly, lowered the platform, and asked the child for the toy (Figure 4B). It was considered a correct answer if the child pressed the button corresponding to the new location, receiving three points in this case. After that, the toy was again moved from its platform, following the procedure described above, until it had passed through the three platforms not previously employed. If the child emitted an incorrect answer, s/he received zero points, and the examiner carried out a correct example, that is, the examiner performed the push-button-light-toy combination in this new location and asked the child again. If the child now responded correctly, s/he received two points, and the toy was moved to another platform, following the procedure described above. In the case of an incorrect answer, the examiner performed two examiner examples and asked again. If the child gave a correct answer, s/he received 1 point; otherwise, s/he received no points for that location. The task ended when the examiner had presented the toy on each of the platforms not used in the last phases. BM Update measure were collected with a score range between 0 (s/he was not able to press any new buttons) and 9 (s/he managed to do so in the first trials and on all platforms).

The Hide and Seek (HS) adapted task is based on Garon and colleagues (2014), proposed for the evaluation of visuospatial working memory in children between 1.5 and 5 years of age. Two large boxes with lids (24 x 34 x 11 cm for the largest box, and 22 x 26 x 11 for the medium box) containing smaller boxes, also with lids, are used (each 11 x 11 x 10 cm). One of the large boxes contains only one small box inside, centrally located, whereas the other large box contains four small boxes, equidistant from each other. For this task, we employed the preferred toy of the child as we described above. In the training phase, the child was shown a cardboard box containing a smaller box where the toy was hidden. After enduring a brief delay period (4 seconds for 12-month-olds, 6 seconds for 15-month-olds, and 10 seconds for 18- and 22-month-olds) during which the stimulus remained hidden from view, the child had to find it. After performing this procedure twice, the second box, containing four smaller boxes, was used for the test phase. Once again, the toy was hidden in one of the boxes, and the child was asked to find it after the delay period. This procedure is done four times, so that the toy is hidden in each of the small boxes. This task allows us to obtain a score of HS Retention (score obtained on the first two trials), focused on short-term memory evaluation, and HS Update (score obtained on the last two trials), focused on working memory, each ranging between 0 (no correct answer) and 8 points (all correct answers). We also obtained a total score for HS Errors (0 to 16 points) and HS Correct answers (0 to 16 points).

General cognitive development and behavior assessment

The Merrill-Palmer Revised Scales of Development (MP-R) cognitive battery, used to measure the cognitive development of children from 0:0 to 6:5, was employed to assess the overall cognitive development of infants. This scale was used as an inclusion/exclusion measure, establishing a minimum score of 85 (mean=100, standard deviation=15) on the general cognitive index of this scale. All the children included in the final analysis passed this criterion.

In addition, Behavior during the evaluation scale from the MP-R was also used. This questionnaire, completed by the examiner at the end of the assessment, measured the behavioral characteristics the child manifests during the assessment session. It collects different types of behavior that the child may have exhibited during the assessment, and it is composed of the following indices: for children aged 12 and 15 months, Irritability, Attention, and Fear and caution (MP-R Irritability, MP-R Attention, and MP-R Fearful, respectively); and for children aged 18 and 22 months, Organization and cooperation, Activity and diligence, and Anger and poor collaboration (MP-R Organized, MP-R Active, and MP-R Angry, respectively).

Procedure

Parents were informed of the purpose and procedure of the study in a meeting. After the parents signed the informed consent, the evaluation was carried out in a single session lasting approximately one hour. Assessments took place from 9:30 a.m. to 12:00 p.m., when the infants normally went to their pre-schools. It started with the application of the Hide and Seek task, then the Baby-Mnemo task, and ending with the MP-R scale. At the end of the session, the evaluator completed the Behavior during the Evaluation scale. Afterwards, parents completed a sociodemographic questionnaire, as well as the Temperamental Style scale.

Statistical analysis

Analyses were performed with SPSS Version 24. Sociodemographic data were analyzed descriptively, in terms of means, standard deviations, and percentages, as well as statistically with Chi-square. Shapiro-Wilk was used to test normality, and Levene was employed to check homogeneity. After verifying the non-compliance, we proceeded to apply non-parametric statistics. Friedman's statistic was used to analyze Age groups, employing Wilcoxon corrected by Bonferroni in post-hoc comparisons. Spearman correlations were used to relate the Baby-mnemo performance with Hide and Seek, and behavioral and temperamental measurements.

Results

First, sociodemographic characteristics of the sample were analyzed. We found no significant differences between age groups in terms of parental age and level of education or presence of disease in the parents, or the number of siblings, type of breastfeeding, or the presence of more than one language normally spoken at home ($p>0.05$) Sociodemographic descriptive data and Baby-Mnemo direct scores for each age group are shown in Table 1.

First, analyzing Age groups (12 vs 15 vs 18 vs 22) in Baby-Mnemo task (BM), we found significant differences on BM Location ($H_3=10.806$, $p=0.013$), BM Delay ($H_3=14.816$, p=0.002), and BM Update (H_3=15.680, p=0.001). Post-hoc analyses showed that differences in BM Location are found between 12 and 22 months (U=56; p=0.004; r=-0.519), between 15 and 22 months (U=58; p=0.005; r=-0.502), and between 18 and 22 months (U=67; p=0.005; r=-0.487). Similarly, on BM Delay, differences were found between 12 and 22 months (U=30.500, p<0.001, r=-0.650), 15 and 22 months (U=61; p=0.001; r=-0.515), and 18 and 22 months (U=57.5; p=0.004; r=-0.499). These same age differences were observed for BM Update, with significant results found between 12 and 22 months (U=45.500, p=0.003, r=-0.537), 15 and 22 months (U=58, p=0.005, r=-0.502), and 18 and 22 months (U=46.500, p=0.001, r=-0.577). In all these previous comparisons, the best scores were obtained by the 22-month-old group (Figure 5A).

By age groups in Hide and Seek (HS), we found significant differences in HS Retention (H_3=10.785, p=0.013), HS Errors (H_3=11.704, p=0.008), and HS Correct answers (H_3=11.704, p=0.008). No significant results were found for HS Update (p=0.335). Bonferroni post-hoc tests showed that these differences were found when comparing the 12 and 22 month groups: HS Retention (U=44.500, p=0.002, r=-0.558), HS Errors (U=41.500, p=0.002, r=--0.560), and HS Correct answers (U=41.500, p=0.002, r=-0.560) (Figure 5B).

Association between the visuospatial memory tasks were analyzed. BM Location was significantly associated with HS Retention (r=0.291, p=0.019). BM Delay was positively and significantly related to HS Retention (r=0.348, p=0.004) and to HS Correct answers (r=0.268, p=0.031), but negatively and significantly associated with HS Errors (r=-0.268, p=0.031). Finally, BM Update correlated significantly and directly with HS Retention (r=0.338, p=0.006) and HS Accuracy (r=0.310, p=0.012), but inversely with HS Errors (r=-0.310, p=0.012). HS Update was not significantly related to any of the Baby-Mnemo variables.

Finally, we considered whether the behavior shown during the session had any association with the results obtained on the Baby-Mnemo test. On this occasion, given that the behavior and temperament questionnaires offer different measures for children depending on their age, a separate analysis was carried out for each age group. Analyzing correlations found in the 12-month group, we found statistically significant associations between BM Location and MP-R Irritability ($r=-0.714$; $p<0.001$) and MP-R Attention ($r=0.784$; $p<0.001$). At this age, BM Update also correlated significantly with MP-R Irritability ($r=-0.786$; $p<0.001$) and with MP-R Attention ($r=0.697$; $p=0.003$). At 18 months, we observed statistically significant correlations between BM Delay and MP-R Angry ($r=-0.502$; $p=0.034$), while BM Update showed statistically significant correlations with MP-R Organized ($r=-0.517$; $p=0.028$) and with MP-R Active ($r=-0.705$; $p=0.001$). We did not find any significant correlations in the 15-month and 18-month groups between behavior and Baby-mnemo scores ($p>0.05$).

Discussion

We assessed different aspects of visuospatial short-term and working memory in children below 2 years of age through an experimental task, in order to obtain more knowledge about the regular development of this ability in early childhood with the future purpose of being able to examine child populations vulnerable to memory impairment, focusing on an early detection that allow to a promptly intervention.

We observe important improvements between the first and second year of life in visuospatial short-term and working memory abilities. With the Baby-Mnemo assessment, we find that the ability to memorize one spatial location among four possible places (Location) seems to develop markedly at 22 months of age, compared to 12, 15, and 18 months. This pattern of development shows that the improvement in visuospatial location memory at these early ages does not occur linearly, as it is found by Pelphrey and colleagues (2004), with a notable increase in the visuospatial memory capacity towards the end of the first year of life. However, others authors find that from 18 months onwards, short-term and working memory seem to increase very progressively, unlike other executive functions (Garon et al., 2014). Although we already know that 12-month-old children can remember one location out of two possible positions (Diamond & Goldman-Rakic, 1989; Piaget, 1954), children of this age can perform these tasks if four locations are used according to our results.

Both the ability to keep information in memory (Delay) and the ability to update it through working memory (Update) follow the same pattern of development, where the best performance is achieved at 22 months, compared to 12, 15, and 18 months. Therefore, at 22 months, children have a longer delay tolerance time and can update information previously learned more easily. The data found at 18 months would be comparable with Garon's outcomes (2014), employing a delay of 10 seconds. Although an average 10 seconds of delay is found at 12 months (Diamond & Goldman-Rakic, 1989; Pelphrey et al., 2004), they are obtained with 2 locations, and so it is possible that when introducing 4, the mean delay would be drastically reduced. Whereas Pelphrey's study (2004) shows that from 6-to-12 months of age, the delay increases progressively, our study points to a marked improvement just at the end of the second year. Results for the Update phase show again that the 22-month group achieve a better performance, as observed in previous phases, while the performance at 12, 15, and 18 months is very similar. These data indicate, again, a notably development of such capacity at the end of the second year of life. Therefore, it could be interesting both to examine ages between 18 and 22 months in order objectify when this markedly improvement emerges, and to evaluate ages above 22, in order to verify when these mnesic abilities reach a ceiling effect.

Furthermore, we observe that on the Hide and Seek test, the results obtained are partially comparable with the Baby-mnemo outcomes. At 22 months of age compared to 12 months, better scores are obtained in the Retention and Correct answers, while fewer Errors are committed. Thus, this task again points out that short-term location memory seems to develop markedly at 22 months. There are, however, no differences in the age groups based on the Updating variable; nor do differences appear between 15 and 18 months compared to 22 months. Although our task do reveal differences in its Update phase, we have to consider important methodological differences: whereas on the Hide and Seek task, the act of searching in the same place where the object is hidden allows the children to get the toy, on our Baby-Mnemo task, it is required a more complex learning where the memorized location (pushbutton) leads the child to access the object's hiding place (platform). According to spatial cognition's terminology (Fernandez-Baizan et al., 2019), we could say that Hide and Seek uses coincident cues (the stimulus is directly associated with the particular characteristics of its location or hiding place) while Baby-Mnemo uses non-coincident cues (the stimulus must be found following relative positions related to the target place). Previous studies shows that when the spatial location is not clearly indicated by coincident cues, children mistake until two years of age (Spencer et al., 2001). Although on our Baby-mnemo task the spatial locations are defined (platforms and pushbuttons), they are not coincident cues either. Thus, the difference in procedures between the tasks may be a reason that the Update phases of the two tests reveal different results.

In addition, we find that both tasks, Baby-Mnemo and Hide and Seek, are related on some of their measures. Retention in Hide and Seek is associated with all the variables of Baby-Mnemo. Methodologically, the Baby-mnemo phase most similar to Hide and Seek Retention would be Recall of Location, but we observe that Retention maintains a stronger relationship with the Delay and Update phases. This absence of association between Baby-mnemo Delay and Update and the Update measure of Hide and Seek is surprising, but the methodological differences between these variables, as discussed previously, may be the reason for this lack of association.

These early mnesic abilities seem to depend on the prefrontal lobe maturation, which is linked to process novel information (Wiebe et al., 2006), working memory (Cuevas et al., 2013), and keep information in memory (Baird et al., 2002). An increasing neuronal density is detected at 2 years of age in these areas (Teffer & Semendeferi, 2012). Although the prefrontal lobe is the last one to finish its maturation (Li et al., 2013), before 2 years of age the prefrontal cortex undergoes important changes. Furthermore, although the literature in this regard is still scarce, these changes may occur differently according to the different areas and the age of the child, which could explain why the improvement in visuospatial memory capacities between the first and second year of life would not be progressive.

Finally, in order to properly understand the results obtained on Baby-Mnemo, it seems important to consider the behavior during the cognitive evaluation. We observed that the presence of adaptive and proactive behaviors, such as paying attention and being collaborative and proactive during the evaluation, was associated with better performance on Baby-mnemo. By contrast, the presence of disruptive behaviors, such as irritability or angriness, was associated with worse results. Regarding the relationship between behavior and neuropsychological performance, in older children, studies have shown that the presence of behavioral problems, as opposed to their absence, is related to worse cognitive performance, although the relationship between these variables has less magnitude than others, such as socioeconomic or child care variables (Melhuish et al., 2001).

This research shows several limitations. The sample size of the groups is small, making it difficult to draw definitive conclusions. Given the number of participants, we did not carry out covariance analyses, which would have allowed us to establish possible causal relationships between certain behavioral manifestations and cognitive performance. In addition, the experimental task, Baby-mnemo, was designed considering the growing difficulty of skills related to visuospatial memory, although this structure can result in an excessive attentional span for children, especially those who show greater difficulty in operate with the device. Trying to simplify the administration of this task could be an issue for future research.

Conclusions

Our study has shown that the visuospatial short-term memory capacity would already be relatively present at the beginning of the first year of life (12 months), but the end of this year (22 months) seems to be a key developmental age when all the functions, short-term and visuospatial working memory, develop in a more noteworthy way, probably related to the maturation of the prefrontal lobe. Thus, we have seen that the development of visuospatial memory is not progressive between the first and second year of life, but there seems to be a peak of development right at the end of the second year, although more research analyzing the development period between 18 and 22 would be necessary to specify how and when this progress occurs. This experimental procedure, which should ideally be accompanied by a behavioral evaluation, could be used to determine the standardized developmental course of mnesic functions, and then to be used as a diagnostic tool for children who have difficulties in this capacity.

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Declaration of interest statement

The authors declare that there is no conflict of interest.

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Figure 1. Front (A) and back (B) view of the Baby-Mnemo device.

Front view sows infant's view during the assessment: four push buttons are available with their 4 corresponding platforms. A blanket is employed to partially cover the device. In the back view, the position of the examiner is shown, the examiner has access to several elements: an on/off switch that activates the electrical system of the apparatus, six LEDs that are illuminated when the child has pressed the respective button, six switches that the examiner can flip to activate a light on the equivalent button and six platforms that the examiner can lift vertically by using the levers located at the back of the apparatus.

Figure 2. Examples of Baby-mnemo administration: Examiner Examples (A) and Recall of Location (B)

Figure 3. Decision diagram in the application of Baby-mnemo phases

Figure 4. Examples of Baby-mnemo administration: Delay (A) and Update (B)

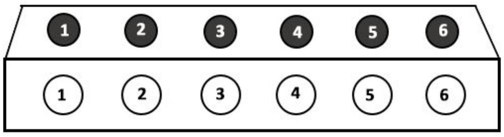
Figure 5. Mean scores and SEM of age groups in the Baby-Mnemo (A) and Hide and Seek (B) tasks.

(A) We found significant differences between age groups in Location, Delay and Update (**$p<0.01$). (B) We found significant differences in Retention, Correct answers and Errors between 12 months and 22 months (**$p=0.002$).

Appendix A. Record sheet of Baby-mnemo Recall of Location

Circle the location used and cross out the covered part.

Child



Examiner

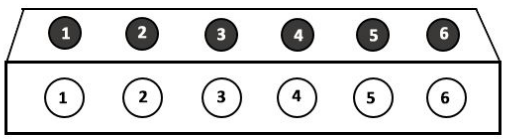
Apply Examiner Examples if the child scores 0 or 1

	Recall of Location I	Recall of Location II	Recall of Location III
	Scores	Scores	Scores
Trial 1	0 1	0 1	0 1
Trial 2	0 1	0 1	0 1
Trial 3	0 1	0 1	0 1
Trial 4	0 1	0 1	0 1
Score	/4	/4	/4
Total score	Score x 3= / 12	Score x 2= / 12	Score x 1= / 12

Appendix B. Record sheet of Baby-mnemo Delay

Circle the location used and cross out the covered part.

Child



Examiner

Apply Second trial with the same delay period if the child scores 0 in the First trial

	First trial	Second trial		First trial	Second trial		First trial	Second trial
2”	0 1	0 1	12”	0 1	0 1	22”	0 1	0 1
4”	0 1	0 1	14”	0 1	0 1	24”	0 1	0 1
6”	0 1	0 1	16”	0 1	0 1	26”	0 1	0 1
8”	0 1	0 1	18”	0 1	0 1	28”	0 1	0 1
10”	0 1	0 1	20”	0 1	0 1	30”	0 1	0 1
Maximum delay achieved (in seconds)					/30			

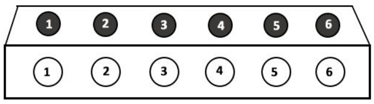
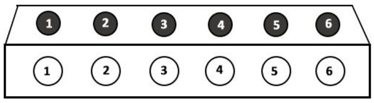
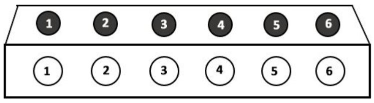
Stop criteria
0 points in 2 consecutive trials with the same seconds of delay

Appendix C. Record sheet of Baby-mnemo Update

If the child scores 0 in the First trial, make 1 Examiner Example and apply the Second trial

If the child scores 0 in the Second trial, make 2 additional Examiner Examples and apply the Third trial

Use each non-previously used location and circle in its corresponding trial

		First trial	Second trial	Third trial
1.		0 3	0 2	0 1
2.		0 3	0 2	0 1
3.		0 3	0 2	0 1
Scores		/9	/6	/3
Total scores		/9		

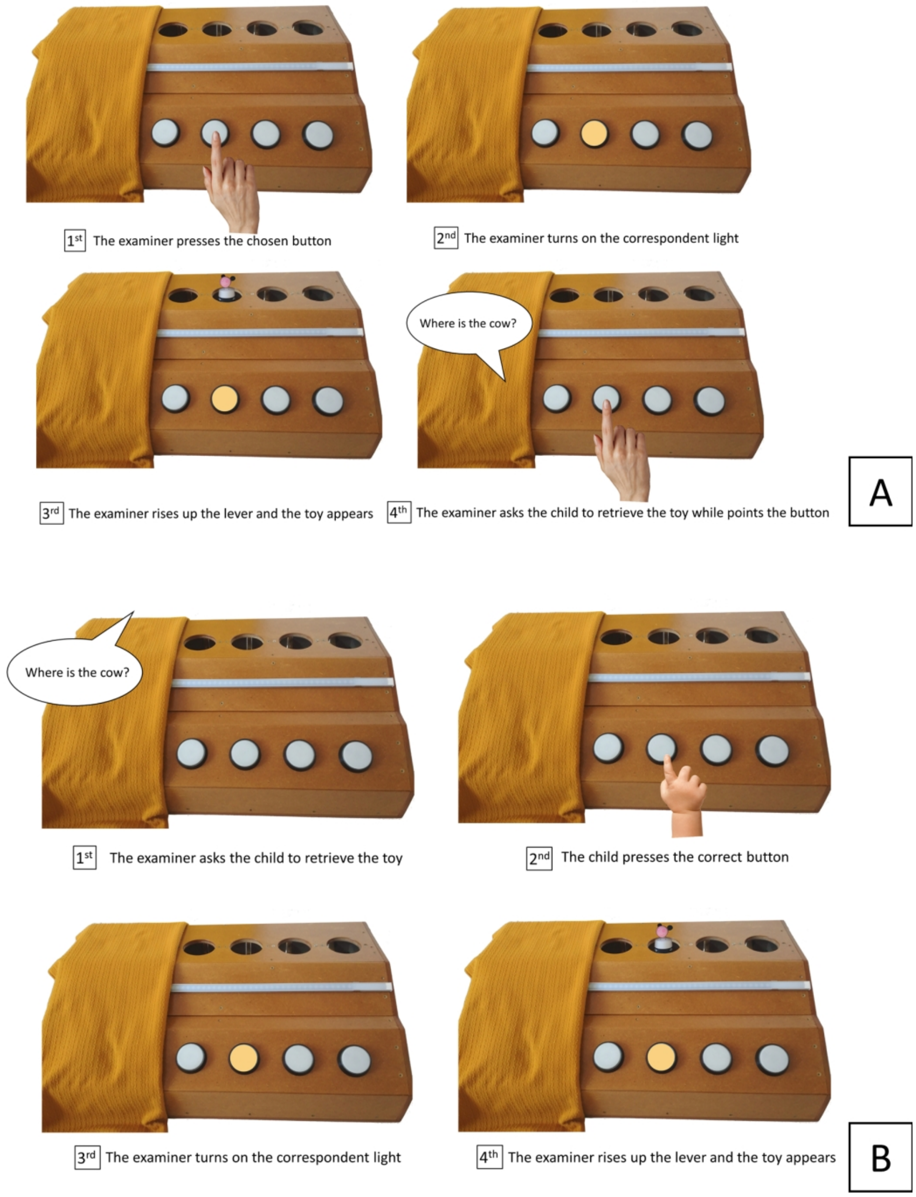


Figure 2. Examples of Baby-mnemo administration: Examiner Examples (A) and Recall of Location (B)

458x600mm (96 x 96 DPI)

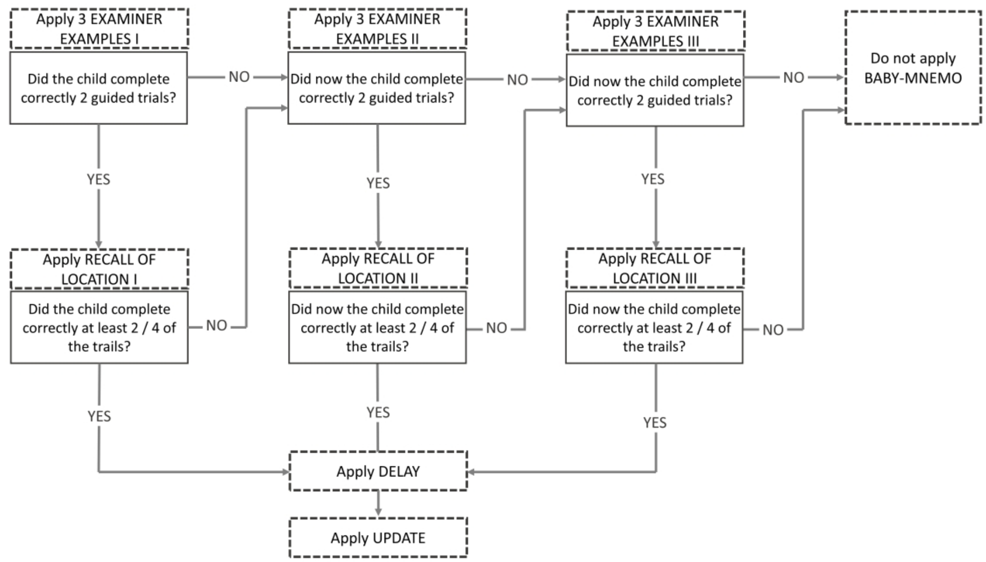


Figure 3. Decision diagram in the application of Baby-mnemo phases

1408x800mm (96 x 96 DPI)

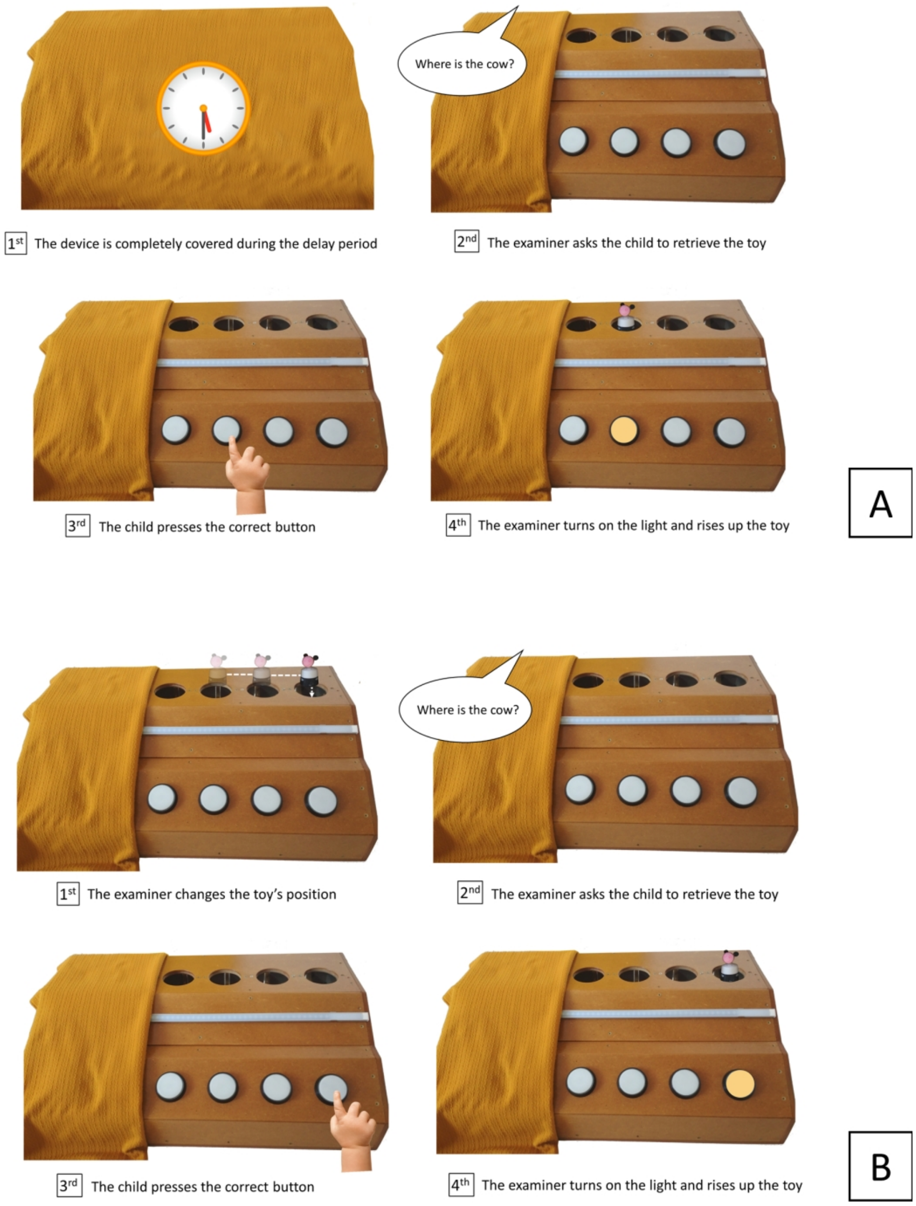


Figure 4. Examples of Baby-mnemo administration: Delay (A) and Update (B)

458x600mm (96 x 96 DPI)

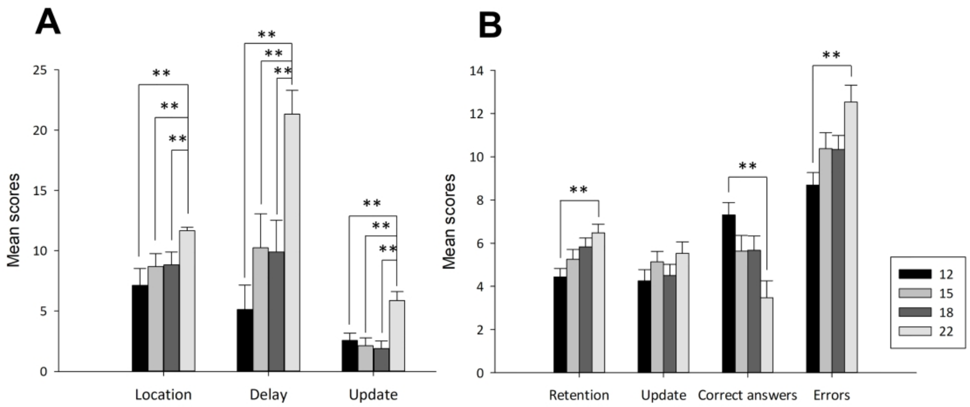


Figure 5. Mean scores and SEM of age groups in the Baby-Mnemo (A) and Hide and Seek (B) tasks. (A) We found significant differences between age groups in Location, Delay and Update (**p<0.01). (B) We found significant differences in Retention, Correct answers and Errors between 12 months and 22 months (**p=0.002).

1999x851mm (96 x 96 DPI)

Table 1. Sociodemographic and Baby-mnemo (BM) descriptive data of the sample

		12	15	18	22
		Baby-mnemo outcomes			
		Mean (Standard Deviation)			
BM Location (Score)		7.13 (5.53)	8.69 (4.30)	8.83 (4.48)	11.67 (1.04)
BM Delay (Seconds)		5.13 (8.06)	10.25 (11.21)	9.89 (11.13)	21.33 (11.60)
BM Update (Score)		2.56 (2.47)	2.13 (2.57)	1.89 (2.65)	5.87 (2.85)
		N (%) above chance			
BM Location (Score)		10 (45.5%)	14 (81.8%)	15 (72.7%)	15 (100%)
BM Update (Score)		6 (73%)	4 (67.6%)	5 (64.9%)	13 (94.6%)
		Sociodemographic data			
		N (%)			
Girls		8 (50%)	8 (50%)	9 (50%)	8 (53.3%)
Boys		8 (50%)	8 (50%)	9 (50%)	7 (46.7%)
Mother's level of education	Primary	0 (0%)	0 (0%)	1 (6.3%)	0 (0%)
	Secondary	0 (0%)	1 (7.1%)	3 (18.8%)	4 (28.6%)
	Technical	4 (25%)	5 (35.7%)	6 (37.5%)	4 (28.6%)
	Bachelor's degree	12 (75%)	8 (57.1%)	6 (37.5%)	6 (40%)
Father's level of education	Primary	0 (0%)	0 (0%)	0 (0%)	0 (0%)
	Secondary	4 (28.6%)	2 (16.7%)	5 (33.3%)	5 (41.7%)
	Technical	3 (21.4%)	3 (25%)	5 (33.3%)	4 (33.3%)
	Bachelor's degree	7 (50%)	12 (58.3%)	5 (33.3%)	3 (25%)
		Mean (Standard deviation)			
	Mother's age	37.06 (3.71)	37.53 (4.20)	36.94 (3.36)	36.79 (4.83)
	Father's age	37. 86 (4.81)	38 (3.10)	38.75 (4.13)	38.67 (2.67)