Annals of
Medical & Surgical Case Reports

Research Article

Giuliani F and Schenk F Ann Med & Surg Case Rep: AMSCR-100035

The Parallel Map Theory: Ontogeny of Flexible Spatial Strategies in Young Children

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Citation: Giuliani F and Schenk F (2020) The Parallel Map Theory: Ontogeny of Flexible Spatial Strategies in Young Children. Ann Med & Surg Case Rep: AMSCR-100035

Received date: 26 December 2019; **Accepted date:** 04 January 2020; **Published date:** 10 January 2020

Abstract

Background: The ontogeny of flexible spatial strategies with the parallel map theory hasn't yet been documented in detail.

Methods: We recorded the fixation points and studied the qualitative analysis of visual scanning of children between the ages of 4 and 14 in 3 experiments: 1) drawing a square, 2) image matching, and 3) reading aloud. 97 children between the ages of 4 and 14 participated in the experiment. The children came from classrooms of varying academic levels. None of the children had developmental or psychological disorders.

Results: Using parallel map theory, we can assume that experiment 1 was under the control of the efferent copy belongings to the bearing map, which functions as the permanent frame or scaffold for the integrated map. For experiment 2 the children used the sketch map because the sketch map uses positional cues. During the development and acquisition of visual exploratory strategies, our results show that by the age of 7, children have begun to use flexible, integrated strategies.

Conclusions: Our results shed new light on the stages of the ontogeny of visuo-motor skill; all while nourishing a hypothesis that looks at the development of the cerebral systems involved in cognitive and motor control.

Keywords: Children; Eye-tracking; Flexible spatial strategies; Ontogeny; Parallel map theory; Reading

Introduction

There are few studies focusing on the ontogeny of flexible spatial strategies and traditionally, developmental studies of spatial cognition have focused on when children begin to use landmarks [1-4]; at the very most there are a few studies on the development of reading. Mickael Land has published numerous articles on the visual perception of adults in natural contexts such as preparing tea, reading, playing music [5-10] and his research inspired our work. We also relied upon the theory of the parallel map to study the ontogeny of visual strategies using three tasks: drawing, image matching, and reading aloud.

Drawing mainly employs processes related to the efferent copy: Sensory-motor activities facilitate body control within its environment as a function of the targets determined by the individual. Behavioral adaptations include postural control as well as following external objects with the eyes and the hand. This type of behavior can be compared to that of a controller [11].

The movement depends on sensory-motor integration. This mode of data integration facilitates a comparison between the planning stage of the movement and the efferent copy of the accomplished movement. The difference between the two images (the planning image and the copy image) is used for corrections until an optimal balance is achieved [12, 10] highlight that the gaze necessarily precedes the action because the aim of vision is to provide the motor system with the data necessary for action. All actions follow the same pattern: the gaze identifies the necessary data, localizes a target, and guides the hand or the body. The object is then seized, or the task is carried out. To evaluate this action, we chose a simple task: drawing a square. The visual fixation length would allow us to study the ontogeny of processes related to the efferent copy.

Image matching draws upon parallel map theory: The proposal made here is that image matching follows upon the process described above (efferent copy) and is necessarily associated with working memory [13]. This operation uses two associative circuits (parietal and temporal pathways) for processing visual information [14], The first, the parietal pathway, passes by the lateral geniculate nucleus and reaches the visual cortex. The second, older system, the temporal pathway, works from the retina to the upper colliculus and contributes to coding localization. Various authors [15-18] have focused on object recognition and have shown that individuals retain the general idea of visual scenes as well as, more specific to identity, the presence (or absence) of objects, their position and their color. We hypothesize that the cognitive map is constructed from two parallel maps that, when integrated, allow the child to calculate cognitive map shortcuts.

These parallel maps developed by [1] differ in how they represent space, what cues are used to represent space, and what hippocampal structures are involved in creating the representation. According to this theory, the bearing map is created from-directional cues and stimulus gradients; and the sketch map is constructed from-positional cues. The integrated map combines the two mapping systems. To evaluate this action, we chose a simple task: image matching. To measure the evolution of these processes we hypothesized that we could infer whether the child's strategies were coming either from the efferent copy or from working memory. To do this, we conjectured that visual fixation length would inform us on the use of the efferent copy; performance was an indicator of working memory and the qualitative analysis of visual scanning would inform us about the use of parallel map theory.

Contribution of parvo and magnocellular circuits in reading: Research on reading processes has confirmed the essential role of a sufficiently precise control of the ocular motor system, especially the saccades, convergence, and fixations [19-24] have shown the limits of the ventral system of reading, and the conditions in which it must be supplemented by the mechanisms of the dorsal system to guarantee reading in a series ("letter by letter"). To evaluate this action, we chose a simple task: reading aloud a simple word. The third experiment is the sum of the previous processes reference copy, working memory-to add to the linguistic capabilities. The fixation length indicates the precision of the ocular motor system, the performance indicates the working memory, and the qualitative analysis of visual scanning indicates the linguistic and semantic capacities.

In summary, the aim of our study using eye-tracking was to evaluate the evolution of visual scanning with simple tasks in a qualitative and quantitative way in order to: 1) determine whether it is possible to link this evolution to the maturation of the neurophysical mechanisms involved in the control of visual movement and; 2) to understand if this evolution could be explained by parallel map theory. Based on Land's experiments, we chose three tasks ranging from the simplest action of "drawing a square" to the intermediate stage of "image matching" (use of simple action but this time supported by the recognition process based on working memory) and finally, to the most complex task of "reading aloud".

Materials and Methods

Subjects: The 97 schoolchildren who participated in this experiment came from multicentric classrooms in Switzerland. These multicentric classes were a part of the public-school system in the canton of Vaud. **Table 1** summarizes this information. None of the children were affected by developmental or psychiatric disorders. The Department of Education, the school directors, the classroom teachers, and the students' parents all agreed to the experiment. The parents gave consent for their children to participate in the study and the study complied with the code of ethics of the World Medical Association (Declaration of Helsinki) for experiments involving human subjects in research.

Descriptive statistics of the schoolchildren to be evaluated in the study						
Age	Number of girls	Number of boys	Number of right-handed children	Number of left-handed children	Children wearing glasses	Total
4-5 years old	12	8	20	0	2	20
7-8 years old	11	9	16	4	5	20
9-10 years old	11	11	21	1	3	22
12-14 years old	20	15	30	5	5	35
Total	54	43	87	10	15	97

Table 1: Summary of the number of girls and boys by age.

1.1 **Apparatus:** We used a "Mobile Eye" to conduct our experiment. Our device was from Applied Science Laboratories in Bedford, USA. The "Mobile Eye" is an eye-tracking system that is free and without constraints, since the system is mobile and

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ISSN 2652-4414

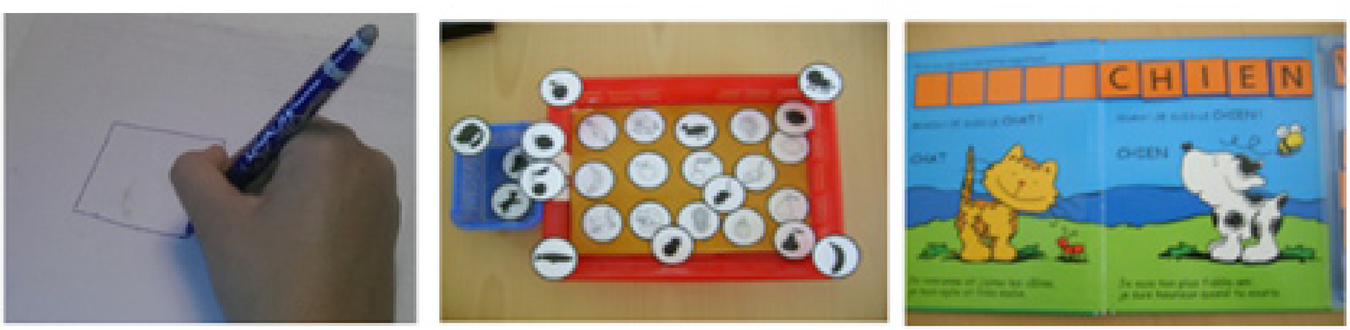
does not have to be used in a laboratory. It can be used anywhere because the optical system is extremely light (76 g) and discreet, worn like a pair of glasses, and its recording device is fairly small and can be worn at the waist in a small pack.

An 880-nanometer infrared light beam is projected onto the fovea of the right eye. This beam size corresponds to the requirements outlined by [25] for a light beam that is not a risk to the eye. The three-point corneal reflection is 0.50 mW/cm^2 and makes it possible to transmit the direction and the fixation points without having to hold the head steady. The system also detects blinking. The distance can be calibrated to reduce the parallax. Also, a second camera is integrated onto the glasses to record the visual scene in color as well as the sound. Note that the visual field recorded is smaller than the eye's visual field. Indeed, the camera's field is 50 degrees horizontally by 40 degrees vertically, while the eye's visual field is 180 degrees horizontally by 150 degrees vertically.

Design and procedures: Taking inspiration from Land [8], we studied three visual skills for each child. Land briefly summarizes how an action is executed by loops interacting between three systems (orientation, motor, and visual) working under the supervision of a fourth system (executive control) which activates an internal representation of the task. Capturing through gaze involves a specific ocular movement, or a combined movement of the head or the body (orientation system). Next, the motor system ensures the object is seized, or the task is accomplished. Each task has a specific protocol and there was no time imposed to accomplish the tasks:

- **Experiment 1:** The "drawing a square" is, according Land, an alternating step-based storing-action task in which the efference copy is used to anticipate the kinesthetic and somatosensory consequences caused by the movement itself. The difference between the real and expected sensory effects will calibrate the following movement. The efference copy belongs to the bearing map, which functions as the permanent frame or scaffold for the integrated map according the parallel map theory.
- **Experiment 2:** The "image matching" task is made up of a succession of multiple action sequences described at Experiment 1 and coupled to working memory. We can assume that according to the parallel map theory this task involves primitive working memory that is reset at the start of every action. The working memory vector might then acquire more dimensions when it is associated with external points, one that cannot be computed without the path integration process.
- **Experiment 3:** the "reading aloud" task is, according Land, a loop of continuous production of superior cognitive processes integrating multiple operations such as sensory perception, ocular movements, working memory and linguistic and semantic capacities The information is fed in a loop in a semi-continuous way to produce a continuous output.

In Experiment 1, we asked the children to freehand draw a square on a sheet of paper, using their preferred hand, and then again with their other hand **(Figure 1a)**. This corresponds to the execution of a simple movement. In Experiment 2, a display board and a small basket were placed before them. The display included black and white images of fruits and animals inside circles. The same images on separate cards were inside the basket. The schoolchildren had to place the card inside the circle, on the board, when the two images corresponded **(Figure 1b)**; this task involved perception, as well as making a motor gesture and working memory to place the card on the corresponding image. In Experiment 3, we gave a picture book to the 4-10-year-olds, who were then asked to try to read the words "cat" and "dog" out loud **(Figure 1c)**. The 12- 14-year-old schoolchildren had to read a sentence of newspaper aloud.



A B C

Figure 1abc: Three experiments given to the schoolchildren. a) draw a square; b) match fruits from the basket with fruits on the display; c) read the words cat and dog aloud.

Measures: The parameters studied were the fixation points and their duration during the entirety of each of the three tasks. The performance was measured with the time taken to complete the task. These tasks each lasted several minutes. The data gathered by the “Mobile Eye” were analyzed using the software GazeTracker in order to give us an average length of the fixation points in seconds, with its standard deviation. This device conducts a measurement every 3 milliseconds. For all the children, we calculated the length of each task (in seconds +/- standard deviation), which we describe in **Table 2**.

Length in seconds of each task of the protocol			
Age	**Drawing Experiment 1**	**Matching Experiment 2**	**Reading Experiment 3**
4-5	11.9 ± 3.3	77±31.2	94.1± 22.9
7-8	5.2 ± 2.8	66.7±21.1	68.7± 20.3
9-10	3.9 ± 1.9	45.1±13.9	43.04±10
12-14	6.6 ± 2.1	23.5±7.6	18±7.3

Table 2: Length in seconds of each experiment.

Statistical Analyses: The analyses were done on a computer using Statview 5.0. A p value of <0.05 was considered significant. ANOVAs were carried out to investigate gender differences in Experiment 1 with gender as between-factor and age as the covariate variance analyses with repeated measurements on the three tasks as a function of age and gender. The same analyses were conducted in Experiment 2 and Experiment 3. Then, we conducted a T-test to compare the results according to age, independently of gender and according to the gender but independent of age. All analyses are presented in the appendix.

- **Experiment 1:** Drawing a square We asked the children to draw a square on a sheet of paper.
- **Results**: Results were analyzed separately for the preferred and the non-preferred hand. There were significant differences between age groups: between the 4-5-year-olds and the 7- 10-year-olds, there was a decrease in fixation times. At the age of 12-14 years old, the fixation time was significantly prolonged.

In this task, there was no gender effect but an age effect for the average length of fixation **(Figure 2)**. We detected three stages during development: a first strategy of visual scanning that was not functionally mature. The children had trouble calibrating data integration between the planning stage of the movement and the efferent copy of the accomplished movement. The second stage was an optimal balance because the children used the difference between the two images (the planning image and the copy image) to adapt their sensory-motor behavior. The last stage showed a change of strategy. Beginning at the age of 12 years and older, the fixation length became longer which may reflect a change in visual strategy. Drawing a square was henceforth under the control of procedural memory (it’s easy) and visual scanning was then an action of peripheral vision which explains the increased fixation length.

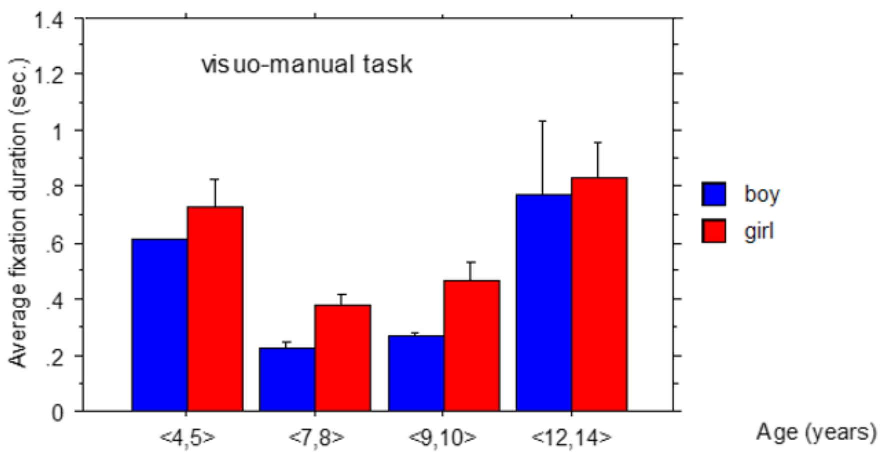


Figure 2: Experiment 1.

In relation to their visual-motor coordination, we found that the 4- 5-year-old children showed a non-differentiated use of the right or left hand. This was probably because children of this age are not yet clearly lateralized [26] explain that action and perception evolve with age.

Ann Med & Surg Case Rep, an open access journal
ISSN 2652-4414

Action is linked to egocentric strategies and to the dorsal regions of the brain, while perception is linked to allocentric strategies and more ventral pathways. According to these authors, before the age of 7, children use both strategies indiscriminately for perceptual activities and visual-motor activities. Before that age, there isn't any functional separation between the two strategies. This can explain why the fixation lengths were longer in this youngest group of children. For the oldest group, the visual-motor coordination of the12- 14-year-old schoolchildren is mature at this stage, and a mature, adultlike visual system might require a new adaptation strategy of their capacities, with an increase in fixation durations because their adaptation isn't under the supervision of the efferent copy [27] add interesting and complementary information that would enlighten changes in matching tasks. According to these authors, children under 7-are not able to use a two-dimensional reference system when they are faced with a localization problem. These children struggle in processing spatial relationships between model and copy (mismatch between expected and perceived). This could explain why the fixation lengths of the 4- 5-years-old children was longer than the 7- 10-years-old children: for them, achieving the task might imply hesitation and slowness. They had to look more often and longer at the drawing in order to reproduce it. From our observations, we believe that the lack of difference between the two hands during development doesn't come from children's high practical capacity. Indeed, the drawings they produced with the left and right hand were not precisely identical, while the fixation lengths were the same. In this way the drawing was different depending on which hand was used, but the visual scanning remains unchanged because it was relayed by the efferent copy.

- **Experiment 2:** Image matching.

We asked the children to match fruits from the basket with fruits on the display.

- **Results:** Fixation duration significantly reduced from age 4, with a stabilization between the ages of 7 and 12. We found five significant differences between the age classes. There was a gender effect for the average length of fixation in this experiment, as presented in **Figure 3**.

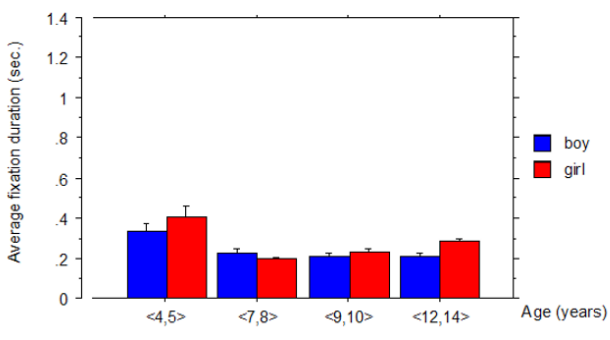


Figure 3: Experiment 2.

The fixation lengths of the girls were significantly longer than those of the boys. For the girls, the fixation points were significantly different between 4 years old and the other ages, and also between 7 and 12. For the boys, there were differences in the average length of fixations, which was longest at 4 years old compared to all other ages. For the school-aged children between 7-10 years old, the results were very homogenous, as shown in **Figure 3**. There was a gender effect for the average length of fixation at 12-14 years old.

From their experiences in image matching [28] assert that it is only from the age of 12 that children are able to discriminate several visual signals presented simultaneously and to ensure the reliability of the discriminated elements. Children 12 and over are challenged by two pieces of information that are complementary: attention and emotion. Before 12 the pairing of images is considered a game and after 12, children want to have the best performance. This may explain the slightly increased number of fixations in the 12- 14-year-old girls for this task, with respect to the 7- 10-year-old girls. Girls want to have the best performance and they are meticulous.

- **Experiment 3:** Reading

We asked the children to read aloud.

- **Results:** A significant difference appeared between young children just learning how to read (4-5 years old) and all the other schoolchildren. The length of the fixations of the youngest children was significantly longer than that of the older children until the age of 10 years. Between 7 and 10 years old, fixation length remained stable in boys and girls. At 12, there was again a marked increase in fixation length, as indicated by a significant difference from the younger children.

There was a significant difference between girls and boys at 12-14 years old. The comparisons between the different ages of the girls showed more fluctuation in development; we found seven significant differences. For the boys, only two comparisons were significantly different. These results are presented in **Figure 4** for the average length of fixation.

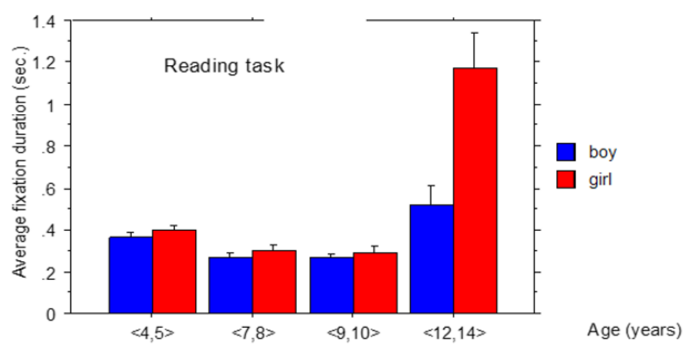


Figure 4: Experiment 3.

For this task, our results show a decrease in fixation length during development between the ages of 4 and 10. The 4-year-old children must look longer to detect the letters and so their average fixation length is quite long. Visual fixations are similar between 7 and 10 years old. Indeed, at 7 the task is carried out in 68.7 ± 20.3 whereas at 10, the schoolchildren completed the task in 43.04 ± 10. Simultaneous word processing (use of overall reading) appears at around the age of 12, thus prolonging the fixation length. These extended fixation lengths are particularly found in "good" readers, which would explain the difference between good and bad readers in the 12- 14-year-old age bracket and confirms [29]. As we see it, "good" readers use overall reading which increases fixation length, while bad readers of the same age are still processing the letters of the word simultaneously, hence reduced fixation lengths requiring a greater number of ocular saccades. All of the 12- 14-year-old schoolchildren had longer fixation lengths than those aged 7-10 years [30] add that the difference between 4- 5-year-olds vs 7- 10-year-olds can also be explained by a progressive habituation to the shapes of letters in the words and to words in phrases, something which makes reading easier. This leads to a decrease in the length and number of fixations. These authors also note that readers with the best capacities can recognize most of the words with a single fixation, while beginners need several fixations.

Qualitative analysis of visual scanning

Through an analysis of the video recordings of the tasks, we found that the gaze of the younger children (4-5 years old) moved readily away from the task at hand as if more easily distracted by the environment. For the three tasks-drawing, image matching, and reading-the children between 4-7 years old poorly anticipated the action to be performed.

At 12 years old, the visual strategy was transformed. The average length of the fixations of the 12-14-year-old schoolchildren was again lengthened. Their gaze was fixed in a more localized way on the task at hand. **Figure 5** shows an example of a schoolchild performing the visual-motor coordination task (Experiment 1), using a preferred hand, for 1 second. The image shows that the 4-5-year-old child has one single fixation, while the 9-10-year-old child has four fixation points in the same length of time (1 sec.). The eye of the 4-5-year-old child rested on a static target when he used his preferred hand, but the 9-10 -year-old accomplished the task without remaining completely under the visual control.

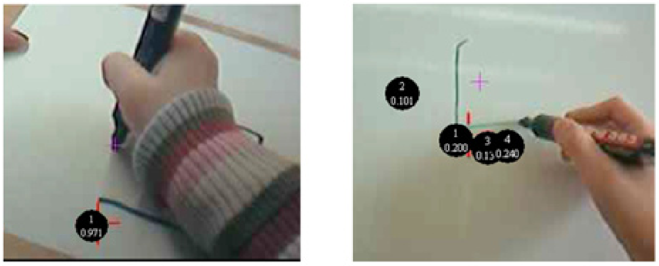


Figure 5: Visualization of the number of fixations during 1 second while drawing a square (Experiment 1) with the preferred hand. 4-5-year-old schoolchild (left) compared to a 9- 10-year-old schoolchild (right).

In the example below, we conducted the same task (Experiment 1) using the non-preferred hand for 1 second **(Figure 6)**. The 4- 5-year-old child needed to adjust his gaze to his movement and so we see the gaze moving along as the pencil moves along. The 9- 10-year-old child used the same strategy no matter which hand was used.

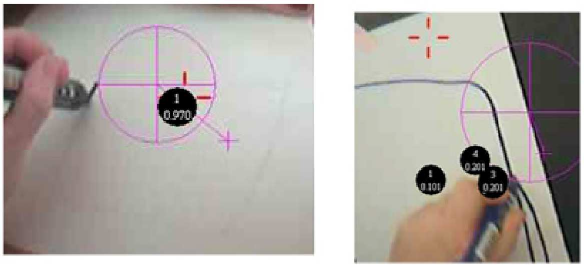


Figure 6: Average length of fixation during 1 second in the visual-motor coordination task with the other hand. 4- 5-year-old schoolchild (left) compared to a 9- 10-year-old schoolchild (right).

5-year-old schoolchild (left) compared to a 9- 10-year-old schoolchild (right).

In terms of image matching-Experiment 2 - **(Figure 7)**, the two examples show that the child became more reactive with age. Indeed, in 1 second, the 12- 14-year-old schoolchild had significantly more fixations than the 7- 8-year-old schoolchild.

Figure 7: Average fixation length in 1 second in the image-matching task (Experiment 2). 7-8-year-old schoolchild (left) compared to a 12-14-year-old schoolchild.

Finally, for the reading Task-Experiment 3-**(Figure 8)**, the example shows that the 7- 8-year-old child had a shorter fixation length compared to the 12- 14-year-old schoolchild.

Figure 8: Average length of fixation during 1 second in the reading task (experiment 3). 7- 8-year-old schoolchild (left) compared to a 12- 14-year-old schoolchild (right).

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General Discussion

Our goal in this study was to evaluate the evolution of visual scanning to determine whether children would use a flexible spatial strategy. Performance in the three tasks revealed a change between the ages of 4 and 7 years old, evident as a regular decrease in the average length of the fixations. The optimal balance of their visual strategy appears between the ages of 7 and 10. At 12 and older, the schoolchildren show a change of visual strategy.

Here are the results which seem most relevant

A. Figures 2-3-4 indicate that performance changes with age in all experiments: drawing a square (Experiment 1), image matching (Experiment 2), and reading aloud (Experiment 3). First, the 4- 5-year olds were set apart from the others by a significantly longer fixation length. The length of the fixations then decreased at the age of 7, and there was a similar visual calibration between the age of 7 and 10. Finally, fixation lengths significantly lengthened around 12 years old when drawing a square and reading aloud. In the image matching task, the length of the fixations remained stable from the age of 7 and onward.

B. From a qualitative point of view (Figures 5 to 8), the long fixation points of the schoolchildren were accompanied by movements beyond the field of the task. There was more heterogeneity in the results for girls compared to boys. This is particularly noticeable in the reading task for 12-year-old girls.

C. The visual scanning in schoolchildren aged 4 to 14 enable us to link results to the maturation of neurophysiological mechanisms: the use of the efferent copy is optimal at age 7. At the age of 12, schoolchildren preferentially use procedural memory. The recognition process based on working memory becomes the most effective at the age of 7 and this process remains stable from 7 to 14. Regarding the most complex task of reading aloud, the results were similar for schoolchildren between the ages of 7 and 10. At 12, a change in visual strategy appears, showing a greater heterogeneity of fixation length. At this point onward, some schoolchildren use global vision that is perceived by greater fixation lengths.

Drawing employs processes related to the efferent copy that itself belongs to the bearing map: The task of drawing a square is monitored by primitive processes based on the efferent copy [1, 8, 17, 29, 31, 32]. This system is further modified as the child develops. At 4-5 years-old, the efferent copy process is not completely operational and requires sensory-motor control. The program of the movement to be accomplished is slow-as confirmed by the long fixation length-and is supervised by a system called "low level nodes" [29]. These adjustments throughout the body correspond to the embodied mind formalized by [33]. Although the efferent copy is a primitive system, it also responds to Neisser's definition of the cognitive map [34] and it is under the control of the bearing map according to the parallel map theory [1].

This representation links actions with expectations [35]. It is thought that any implementation of an action is based on the serial activation of various intermediary relays on nerve paths that are said to be top-down or motor. But each relay also receives bottom-up or sensory information. These display the status in progress: the interpretation of this information is influenced by the top-down messages that bear the imprint of the expected consequences. These intermediate activations obviously impose many mini-delays on the planned execution.

Therefore, in 4-year-old children, this delay is clearly visible by slow visual scanning coupled with a slowness in executing the design of the square. In addition, from age 7, this fringe of delay and anticipation will be almost non-existent. Indeed, the system stabilizes at the age of 7 and remains the same until the age of 10. At the age of 12, the system is again modified, seen through an increase in fixation length. Note that the notion of efferent copy is a concept based on the neurophysiological description rooted in proprioception and that all sensory data informs changes in the state of the moving body-in our case, the hand. These data are mostly dynamic, which indicates their ability to translate movements in progress. In addition to confronting these movements with the intentions that animate them, the reflexive nature of proprioception assures the schoolchild that he is performing this action [35]. Activation of this copy at the age of 12 thus becomes more of a proprioceptive reflex associated with procedural memory. This abduction can be seen through the modification of visual fixation length. In fact, the latter have a mature, adultlike visual system requiring that their strategies adapt once more to their capacities, with a modification in the length of the fixations.

We could hypothesize, moreover, that action is linked to egocentric strategies and to the dorsal regions of the brain, while perception is linked to allocentric strategies and more ventral pathways. According to these authors [3,36], before the age of 7, there isn't any functional separation and the children use both strategies indiscriminately for perceptual activities and visual-motor activities. This can explain why the fixation lengths were higher in the younger children [27] add interesting and complementary information. According to them, children younger than seven are not able to use a two-dimensional reference system when they are faced with a localization problem. These children struggle in processing spatial relationships between model and copy (a mismatch between expected and perceived).

This could explain why the fixation lengths of the 4-5-year-old children were higher than those of the 7-10 year-olds: for them, achieving the task might involve hesitation and slowness. They had to look more often and longer at the drawing in order to reproduce it. From our observations, we believe beyond reasonable doubt that the lack of difference between the two hands during development doesn't come from children's high practical capacity. Indeed, the drawings they produced with the left and right hand were not precisely identical, while the number of fixations during 1 second while drawing the square was the same for each child. We deduce this by the fact that the mental representation in our

Ann Med & Surg Case Rep, an open access journal
ISSN 2652-4414

case, the image of the square, is a multidimensional structure [35] most probably attached to a kind of mirror image of the drawing progress. Even if the drawing does not correspond exactly to the mental representation, the number of visual fixations does not need adjusting, which is why we did not find a difference in the fixation points between the two different hands even if the drawing was not the same. Schoolchildren activated the same (visual fixation) to get a different result (the drawing).

Image matching draws upon parallel map theory: For the image matching, our results show a decrease in fixation length during development between the ages of 4 to 7 and a stabilization of fixation length between the ages of 7 and 14. In this task, however, we can attempt to extrapolate from the results obtained in the simple drawing of the square. It can be inferred that the visual sensory modality is dominant between 4 and 7 years. Around age 7, it also relies on a spontaneous tendency (which can be related to ontogenesis) of complex activity that requires assistance from so-called top-down processes based on memory and anticipation, two components of abduction. Image matching makes it possible to conjecture the entanglement between perception and memory.

[28] assert that it is only from the age of 12 that children demonstrate a capacity for mature integration. From that age on they are able to discriminate several visual signals presented simultaneously and to ensure the reliability of the discriminated elements. Their attention is thus brought toward several visual signals coming from the same object simultaneously, which promotes sensory fusion. Children older than 12 are challenged by two pieces of complementary information because this requires an increased attention to then select the pertinent information. This may explain the slightly increased number of fixations in the 12-14-year-old girls for this task, with respect to those between the ages of 7 to 10. For them, we can assume that an emotional-type adaptive strategy dimension is added. This qualifier is not opposed to that rational strategy. Emotion expresses the evaluation of the relevance of oneself in a situation. The speech one spoken in parallel to the execution of a task amplifies this evaluation.

For this group, there is a relevance in designating a "meaning ", that is to say a set of somatic and psychic processes by which the girl responds to the environmental pressure, according to a balance between her expectations, intentions, and understanding of the situation in which is occurs. It can thus be inferred that in a 12-year-old girl, the desire to do well amplifies the minutia of her action. The indication of this is a slight increase in visual fixation length. For the boy, it's a matter of doing quickly regardless of the meaning.

Contribution of parvo and magnocellular circuits in reading: For the reading task, our results show a decrease in fixation time during development between the ages of 4-10, which is in line with the position of various authors [3, 36-39]. At the age of 4, children must look longer to detect the letters and so their average length of fixation is quite long.

Furthermore, the sufficiently precise control of the ocular motor system, in particular the saccades and the fixations, allowed the schoolchildren to have an equivalence of visual fixations lengths between the ages of 7 and 10 years old. In these schoolchildren, we found a similar fixation length coupled to an increased execution speed (the visual fixations were identical but the reading speed was different). Indeed, the 7-year-olds used 68.7 ± 20.3 seconds to perform the reading task aloud while the 10-year-olds used 43.04 ± 10 seconds.

In the study by [22] younger children had longer fixation points compared to 10-12 year-olds, something which we also found. Rayner has also shown that bad readers and beginner readers make longer and more numerous fixations.

Overall, we can infer that the increase in visual fixation for the 12-14 year-olds is related to the results obtained by Rayner. He has broadly documented the interaction between cognitive and oculomotor control during the processing of written language [40-42]. He showed that the saccade makes it possible to bring a new region into foveal vision, so much so that the longer the word, the longer the fixation. Moreover, he also completes his explanation by reporting that when reading aloud, the fixations are longer than during a silent reading.

Finally, using the hypothetico-deductive method, we conjecture that simultaneous word processing (use of overall reading) appears at around the age of 12, thus prolonging the fixation length. These extended fixation lengths are particularly found in "good" readers, which would explain the difference between good and bad readers in the 12-14-year-old group and which is consistent with Ashby et al.'s theory [29]. As we see it, "good" readers use overall reading which increases fixation length, while bad readers of the same age are still processing the letters of the word simultaneously. This would involve reduced fixation lengths requiring a greater number of ocular saccades. All the 12-14 year-olds had longer fixation lengths than the 7-10-year-olds.

Conclusion

The development of flexible spatial strategies occurs at around 4-5 years old, when children are not yet lateralized and indiscriminately rely on allocentric and egocentric strategies. Our study is confirmed by [3,36] who show that 3- and 4-year-old children differ considerably in their motion abilities. Moreover, these authors show that the children use sketch maps according to the parallel map theory [1,43]. The second phase occurs in 7-10 year-old children, with very few changes. The visual system is beginning to mature in these schoolchildren. They are lateralized and begin to use allocentric strategies in a specific way for perception and egocentric strategies for action. Beyond facilitating the acquisition of skills and knowledge, these changes enable them to reduce the length and quantity of fixations while accomplishing requested tasks in a shorter time. The third phase occurs in children who are 12-14 years old. This group has an operational visual system, which pushes them to re-adapt their strategies.

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This multi-level modeling can account for our results and is in line with the hypothesis given by [20,35] insists that mental representation remains a delicate concept because we must avoid the temptation to limit it to a (re)creation in the brain of sensory-organ based reflections of reality. Instead, it is always incorporated in possibilities of action. This epistemological bias, which we must work to counteract, is however strengthened because the dominant sensory modality in many adaptive strategies is vision. Indeed, it also relies on a trend that occurs spontaneously during ontogeny and favors topological or spatial hypotheses in the broad sense. Yet, our experiments have shown that a mental representation goes beyond the "simple copy in the head". If it is based on a topological organization typical of the sensory pathways that maintain the idea of a symmetrical image (efferent copy), it transcends it by its relation to the behaviors and expectations it assists.

In sum, we think that children used the bearing map for Experiment 1 and the sketch map for Experiment 2 because the sketch map uses positional cues. They may be stored outside the hippocampus as spatial objects, possibly chunked to one another and this is the efferent copy. Moreover, the children integrate information to update their current position relative to their starting point. Path integration is the outcome of the process that regularly updates a directional vector. The vector is generated by the children's movement during an exploratory bout and is based on this dynamic sensory flow and the efferent copy of the intended action. During the development and acquisition of visual exploratory strategies, our results show that by the age of 7, children have begun to use flexible, integrated strategies. Like the study by [4], our study demonstrates the girls' advantage in flexible spatial strategies by their constant results.

There were several limitations to our study. First, there were less boys than girls (43 boys for 54 girls). Second, we did not distinguish between left-handed schoolchildren and right-handed schoolchildren. Furthermore, our study cannot be compared to existing studies because of its singular nature, which is why the protocol should be replicated on a larger scale.

Declarations

Ethics approval and consent to participate: The research was conducted after participants provided written informed consent and in accordance with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Availability of data and materials: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests: The authors declare that they have no competing interests in this section.

Authors' contributions: All authors contributed equally to this article. Fabienne Giuliani collaborated on creating the Test Series, conducted the trials with the children, writing the article and developing the theorical overview. Françoise Schenk conducted developing the overview and the supervision of writing the article.

Acknowledgements

We are grateful to all the schoolchildren who participated in the study, as well as the schools and the parents who gave their consent. A special thank you is given to Morgane Jacquemettaz who collaborated on data analyzed and Michelle Bailat-Jones for editing.

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