The Development of the Child’s Working Memory.
Abdellah El Idrissi

Abstract
This article focuses on the child's working memory as the most important pillar of human cognition. This topic is approached based on a psycho-developmental approach. It also relies on many empirical studies and research that attempted to explore the developmental processes of the child's memory structures and especially the phonological loop, the visuo-spatial sketchpad and the central executive.

Keywords: Working Memory; Phonological Loop; Visuo-spatial Sketchpad; Central Executive.

نمو الذاكرة العاملة لدى الطفل.
عبد الله الإدريسي

ملخص
يتناول هذا المقال الذاكرة العاملة لدى الطفل باعتبارها تشكل أهم ركائز المعرفية الإنسانية. وستكون معالجتنا لهذا الموضوع وفق مقاربة سيكولوجية، بحيث سنستحضر العديد من الأبحاث والدراسات الأمريكية التي حاولت استكشاف سيرورات نمو بنيات الذاكرة العاملة لدى الطفل وخصوصا الحلقة الفونولوجية والمذكرة البصرية-المكانية ومركز التنفيذ.

الكلمات المفتاحية: الذاكرة العاملة؛ الحلقة الفونولوجية؛ المذكرة البصرية-المكانية؛ مركز التنفيذ.

22 Faculty of Letters and Human Sciences - Dhar El Mehraz - University Sidi Mohamed Ben Abdellah, Fes, Morocco.
Introduction
According to Baddeley (2002), the working memory constitutes the core of the human cognition since it is considered responsible for all processes and cognitive activities. It also strengthens “the process of human thinking by providing mediation between perception and long-term memory and action” (Zarhbouch, 2013, p. 105). Baddeley and Hitch (1974) assumed that it is composed of the central executive that monitors two slave systems which are the phonological loop and the visuo spatial sketchpad (Figure 1). Moreover, Baddeley (2000) added a fourth component in his new model which he called the Episodic buffer. Thus, this article tackles the processes and the structures of the child’s working memory according to Hitch and Baddeley’s (1974) model.

Figure 1: Baddeley’s updated model (2000, p. 421)

1- The development of the phonological loop
The phonological loop is considered as a sub-component of the working memory (Baddeley & Hitch, 1974; Baddeley, 2000, 2002) excessing the short-term unilateral memory model that endures multiple deficiencies (Atkinson & Schiffrin, 1986). It intervenes in storing and repeating verbal- audio and visual-information. It plays a key role in the acquisition of the mother tongue and foreign languages (Baddeley, 1992). It also constitutes a revolution in our understanding of the processes of language production (Baddeley, 1995: 559) and its disorders (Gaonac’h & Fradet, 2003; Gillet, et al, 1996; Vallar & Shalice, 1990). Consequently, the verbal tests in general and the verbal span tests in particular constitute an essential component of the IQ tests. To measure the capacity and development of the phonological loop, verbal span tests are usually used. These tests reveal “the maximum of units that an individual can temporarily store, whether these units are words, sentences, numbers and retrieve them immediately after submission” (Fayol & Gaonac’h,
The Development of the Child’s Working Memory

2007, p. 146). Furthermore, psychologists use also the articulation tasks which require the pronunciation of the largest number of units in a limited period of time in order to measure the verbal repetition; a sub-component of the phonological loop. This is also along with the tasks that aim at evaluating the decrease in the effect of the phonological store as it is shown in the Paradigm of Brown Peterson- Peterson adapted (Gaonac'h & Larigauderie, 2000, p. 143).

In this context, there are those who work on measuring each component of the working memory apart (the phonological loop, the visuo spatial Sketchpad, the central executive) (Hitch & Baddeley, 1974; Baddeley, 2000; Beddeley, 2002; Alloway et al, 2006; Gathercole et al, 2004; Pross, et al, 2008). And there is another trend that considers working memory as a general capacity (Daneman & Carpenter, 1980; Engle, et al, 1990; Aschraft, 1989).

It is obvious that the span of the phonological loop develops exponentially with age. This is confirmed by many studies who focused on working memory development in general. Since 1964, both Woodworth and Schlosberg have presented a table concerning the development of the working memory based on the age.

<table>
<thead>
<tr>
<th>Age</th>
<th>2.5 years</th>
<th>3 years</th>
<th>4-6 years</th>
<th>7 years</th>
<th>10 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Units</td>
<td>2 units</td>
<td>3 units</td>
<td>4 units</td>
<td>5 units</td>
<td>6 units</td>
</tr>
</tbody>
</table>

Table 2 Development of working memory (Gaonac'h & Larigauderie, 2000, p. 198).

In the same respect, Dempster (1981) argues –as the data he provided indicates- that working memory capacity (span) develops with age, which is shown in table 2. Moreover, when the child reaches the age of of 11-12, only at this time, he can reach the performance of adults by storing approximately 7 units to fit its storage capacity with the magic number 7+2 (Miller, 1956). However, there are those who believe that the verbal span develops between the age of 3 and 13 through storing 2 units to 7 units and this is the average performance of adults (Dégeilh et al, 2015, p. 250). Moreover, Baddeley (2002) divided the phonological loop into two main components: the phonological store and the articulatory rehearsal system that performs its functions through the subvocal rehearsal. This leads to the emergence of some strategies of mental repetition in tasks of the short-term recall, which leads to the separation between the phonological store and the articulatory rehearsal system.

The phonological store functions in a systematic way once the child reaches three years old, while the articulatory rehearsal system appears only starting from 7 years old and matures when the child reaches 12 years old (Gaonac'h & Fayol, 2007: 148). According to Gathercole (1995) we can see individual differences in the phonological loop span starting from 3 years old, but the
development of the phonological loop and working memory in general couldn’t be highly quantified till 6 years old and does not grow qualitatively until after this age (Gathercole, 1999; Gathercole & Baddeley, 1993). This qualitative development is reflected in the emergence of many storage strategies, such as the subvocal rehearsal strategy which does not appear until about 7 years old. More than that, there is the Chunking strategy and the use of symbolic links between the items to be stored and the use of mental images, in addition to the double coding. Therefore, "memory development reflects the acquisition of new strategies and the completion of strategies available to the person and generalizing them to new situations” (Seigler, 2001, p. 215).

In line with this developmental profile of the various components of working memory, the span of the phonological loop can be increased through cognitive training on many effective memory strategies (Fayol, Montel, 1994; Lemaire, 2012; Khalfan al Fouri, et al., 2016). The pilot study of Omar Haroun al-Khalifa et al (2012) which intends to verify the effectiveness of the program (UCMAS) in increasing STM span by training children between 7-12 years to recall digits directly and inversely demonstrated that those children outmatch the classic magical number 7+2. This training leads to a new magical number of of about 12+2. The results of this study are consistent with the results of the Japanese study of Tanaka and his assistants completed in 2002, in which the average number of figures for the experimental group is 12,2+1,55, while the average of the control group is 8.5+1,13. There are several studies that support this conclusion, such us the Indian study conducted by Bashkaran and his colleagues in 2006, the Chinese studies carried out by Lizhu and others in 2010, and the study of Zhiping and Jimin in 2010.

All these studies highlight statistically significant differences in favor of the trained groups on UCMAS program, which plays an effective role in enhancing the abilities of phonological memory, the visuo spatial memory and the memory in general. This is positively reflected in solving mathematical problems, IQ tests, and problem solving compared to control groups (Haroun Al Khalifa et al., 2012, pp. 32-53).

The study of Dunning et al. (2013) has shown the effectiveness of training the various components of working memory in improving its performance for children who suffer from memory deficits. By using a training program that consisted of the use of remembering strategies to improve children’s working memory, the study of Khalfan al Fouri, et al (2016) founds that there are statistically significant differences in the averages of the different components of the working memory between the experimental and the control groups in the post-tests. The results showed that there were statistically significant
differences in the average performance of children in the experimental group on the tests of working memory through (prior, post and sequential) measurements for each component of working memory. The performance of children in the post-test was better than their pre-test performance, and their performance on sequential testing was also better than their performance on the post-test (Khalfan al Fouri, et al., 2016, p. 73).

In addition to the developmental factor and the training factor, the span of the phonological loop is affected by various linguistic phenomena such as phonological similarity, length of words, speed of pronunciation, verbal suppression. Therefore, its span is not stable; it changes according to the age and tasks.

2- The development of visuo spatial Sketchpad:
It is noticed that the visuo spatial sketchpad did not receive the same amount of research and investigation like both the phonological loop and central executive. However, there are many neuro-anatomical data confirming the existence of this memory structure (Nichelli & De Renzi, 1975; Hanley, et al., 1991; Baddeley & Vallar, 1984) So, in addition to the experimental data that was collected through many tasks like Brooks’ Paradigm (Brooks, 1968), the task of the pattern (Wilson, et al., 1987) and the Corsi-Blocks (Corsi, 1972; Milner, 1971).

The last test is considered as one of the most important tests used in the measurement of the visuo spatial Sketchpad and especially the spatial store. This is despite the difficulty of the separation between the visual and spatial components in particular (Baddeley, 2002, p. 88). However, there are researches who try to isolate these components from each other through using different approaches and paradigms, such as interrelated tasks and the experimental manipulation of independent variables, the developmental approach and then the neuropsychological approach (Gaonac'h & Larigauderie, 2000, p. 76).

If it is well known that all the components of working memory develop with age, then "the available data on the development of the Visuo- spatial span is dramatically different, given the diversity of tasks used in its assessment" (Gaonac'h & Fayol, 2007: 149). Wilson, Scott and Power have worked on the evaluation of the visuo spatial sketchpad for children by using the "missing cube" test. They concluded that the storage capacity ranges from 4 cubes for children aged 5 and 14 cubes for 11 years old children, while the storage of the spatial positioning emerges at around the age of 6 months (Dégeilh, et al., 2015, pp. 250-251). According to Fournier & Albaret (2013, p. 89), the visuo spatial span grows slowly for children. In their study, which relied on Corsi-blocks tapping task, the average span of the visuo spatial test in the normal order (the
The Development of the Child’s Working Memory

visuo spatial sketchpad) among schooled children who contributed to this study (456 children) reaches the following averages.

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>6 years</td>
<td>7 years</td>
<td>8 years</td>
<td>9 years</td>
<td>10 years</td>
<td>11 years</td>
<td>12 years</td>
</tr>
<tr>
<td>4.33</td>
<td>4.80</td>
<td>5.02</td>
<td>5.36</td>
<td>5.46</td>
<td>5.58</td>
<td>5.67</td>
</tr>
</tbody>
</table>

Table 2 averages of the visuo-spatial test in the normal order.

The children of this study also obtained the following averages in the visuo spatial span in reverse order (the visuo spatial working memory).

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>6 years</td>
<td>7 years</td>
<td>8 years</td>
<td>9 years</td>
<td>10 years</td>
<td>11 years</td>
<td>12 years</td>
</tr>
<tr>
<td>3.17</td>
<td>4.05</td>
<td>4.56</td>
<td>5.01</td>
<td>5.03</td>
<td>5.64</td>
<td>5.89</td>
</tr>
</tbody>
</table>

Table 3 averages of the visuo spatial working memory span.

These values obtained in the normal visuo spatial span (the visuo spatial sketchpad) or in reverse order (the visuo spatial working memory) concord with results from several of studies. Particularly the study of De Agostini and colleagues (1994) conducted on children between 6 and 8 years old, and the study of Anderson and his colleagues (1995) on an Australian sample of 376 children between the age of 7 and 13 years (Fournier, Albaret, 2013, p. 89). The scientific debate among researchers about the early development of the visuo spatial sketchpad appears to be moving in the direction of this proposition. According to Hitch, et al. (1989), the visual spatial sketchpad shows an ascending development between the age of 4 and 11. In the same context, the study of Alloway, et al. conducted on children between 4 and 11 years old shows that all the components of the working memory in the model of Hitch and Baddeley (1974) have a real presence once the child reaches 4 years old. This was also demonstrated by the study conducted by Roebers and Zoelch (2005) through the usage of the separate formulas for all components of the model of Hitch and Baddeley (1974) for the working memory of children of 4 years old. Meanwhile, the research of both Logie and Pearson (1997) and Miles, et al. (1996) concluded that the development of the visuo spatial sketchpad is late since it does not appear until 5-6 years old. The child reaches the level of the adults’ performance in visuo spatial span in about 11 years (Dégeilh, et al., 2015, p. 251).

If we have already pointed out that the visuo spatial sketchpad is subject to quantitative development reflected in the growth of visuo spatial span, it is also subject to quantitative development reflected in the improvement of visuo spatial processing strategies, which are limited by Pickering (2004) to five mechanisms related to the visuo spatial memory. These strategies are the phonological re-coding, knowledge development, the strategic processes,
especially the organization and replication processes, as well as the speed of visuo spatial mechanism and the development of attention capacity that plays an important role in focusing relevant information or inhibiting irrelevant information.

3- The development of the central executive

In the model of Hitch and Baddeley (1974) and Baddeley (2000; 2002), the central executive is responsible for higher cognitive functions and for the control processes called in neuropsychology- executive functions, which include processes such as cognitive inhibition, updating and mental flexibility. These processes controlled by working memory are localized in frontal lobes, which are responsible of functioning of the central executive. These functions develop from childhood to adolescence in parallel with the development of working memory. The three processes mentioned earlier doesn't seem to exist by the age of three, but they gradually become independent of one another. Until the age of 11 years old, the inhibition process and the mental flexibility are not clearly separate, but the period between 11 and 14 years is a crucial period during which the three processes gradually become specific and function fully at the age 15 years (Dégeilh et al., 2015, p. 251).

The central executive performs many functions; such as supervising the functioning of memory systems, planning activities and monitoring attention, coordinating information from different sources, inhibiting inappropriate and confusing information, and continuously interacting and activating with long-term memory.

The activity of this central executive, whether in cognitive psychology or developmental psychology or neuropsychology, is evaluated using a series of tests that rely on complex tasks, such as the execution of two tasks at the same time. Another example of these complex tasks is Corsi block-tapping test in reverse classification (Corsi, 1972; Milner, 1971), which measures the visuo-spatial working memory requiring the storage of the visuo spatial positioning and the cognitive treatment that is reflected in the resetting of the series in reverse classification.

The backward digit span is considered a good tool to evaluate central executive, and 4 or 5 items in this test are considered normal for adults. The normal difference between the span of the phonological loop (remembering in normal order) and the phonological working memory (remembering in reverse order) is limited to one unit (Gaonac'h & Larigauderie, 2000, p. 141). This is in addition to many other tests such as Stroop test, London Tour test, Hanoi tour test, Toronto tour test, the task of random generation, and the missing number test (Gaonac'h & Larigauderie, 2000).
Like the rest of the components of the working memory model, the central executive develops as the child grows up. However, its development compared to other components (phonological loop and visual-spatial sketchpad) is slow because it requires neurological maturity, especially at the level of the prefrontal cortex, which is reflected positively on the development of attention abilities and the effectiveness of the cognitive processing.

The Hughes’ (1998) study showed that the central executive begins to develop earlier for the child from the age of three and four. In the same context, the study of Alloway et al. (2006), which was conducted on children between 4 and 11 years old, indicates that the central executive exists since the age of four and its capacity increases like the other components. According to Gathercole et al. (2004), the central executive grows exponentially between the age of 4 and 15.

Using simple and complex span tasks and executive tasks in a verbal and visual way, Pross et al. (2008) - in their study conducted on children aged between 8 and 10 - found that the various components of the working memory, including the central executive, develop with age. By using the correlation analysis and the exploratory global analysis, the subsystems gradually become specialized and the operations of the central executive become subordinate to this specialization. This study indicates that the central executive is not a single device but a multidimensional and functional one.

Consistent with previous findings, Al-Ansari and Sulaiman (2013) found in a study in which participated 891 children that the central executive is undergoing a development process since the age of four, along with other components (phonological loop and visuo-spatial sketchpad) that have a real presence in Kuwaiti children between the age of 4 and 12 years.

In addition to that, we used the results of Fournier and Albaret (2013) which examined the central executive in a visuo-spatial format using a Corsi-blocks tapping test in reverse classification as a model illustrating the developmental process of the central executive.

Table 1. The average visuo-spatial span in reverse classification for children studied between 6 and 12 years old (Fournier & Albaret, 2013, p. 189).

<table>
<thead>
<tr>
<th>The average visuo-spatial span in reverse classification</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.17</td>
<td>6 Years</td>
</tr>
<tr>
<td>4.05</td>
<td>7 Years</td>
</tr>
<tr>
<td>4.56</td>
<td>8 Years</td>
</tr>
<tr>
<td>5.01</td>
<td>9 Years</td>
</tr>
<tr>
<td>5.03</td>
<td>10 Years</td>
</tr>
<tr>
<td>5.64</td>
<td>11 Years</td>
</tr>
</tbody>
</table>
It can therefore be said that the processing abilities that appear in performances that require reorganization, such as repeating numbers in reverse order "or re-tapping the cube series in reverse order" are continuously growing up till the second stage of adolescence (Dégeilh et al., 2015, p. 251).

Finally, we conclude from our study (El Idrissi, 2018) which deals with the development of the processes and the structures of working memory (the phonological loop, the visual-spatial sketchpad, the central executive in a phonological form: the phonological working memory, the central executive in visuo-spatial form) for children from 4 years to 11 years in the Moroccan context.

Table 2. Development of the children's memory span in the Moroccan context (EL Idrissi, 2018).

<table>
<thead>
<tr>
<th>Age categories</th>
<th>Grade levels</th>
<th>Development of the average phonological loop span</th>
<th>Development of the average visuo-spatial sketchpad</th>
<th>Development of the average phonological working memory</th>
<th>Development of the average span of the phonological working memory</th>
<th>Average development of visuo-spatial working memory</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-5 Years old children</td>
<td>First and second year at the Kindergarten</td>
<td>3.40</td>
<td>3.87</td>
<td>2.30</td>
<td>2.60</td>
<td></td>
</tr>
<tr>
<td>6-7 years old children</td>
<td>First and second primary grades</td>
<td>3.67</td>
<td>4.57</td>
<td>2.80</td>
<td>2.97</td>
<td></td>
</tr>
<tr>
<td>8-9 years old children</td>
<td>Thrid and fourth primary grades</td>
<td>4.32</td>
<td>5.17</td>
<td>3.22</td>
<td>3.87</td>
<td></td>
</tr>
<tr>
<td>10-11 years old children</td>
<td>Fifth and sixth primary grades</td>
<td>4.50</td>
<td>5.70</td>
<td>3.77</td>
<td>4.42</td>
<td></td>
</tr>
</tbody>
</table>

One of the most important findings of this study is the variation in the processes of development in the span of memory structures of the children who participated in this study (aged 4 to 11 years). This is either on the level of the span of each memory structure separately or when compared, as well as at the
level of variation in the processes of span development of these structures in each category.

Conclusion
Both cognitive developmental psychology and neurodevelopment psychology try to collect scientific data related to the child's working memory, either in terms of neural-anatomical basis, or in terms of its developmental and functional strategies, or in relation to the cognitive and psychological phenomena associated with it. This is with the aim of moving forward to explore its mysterious aspects and to identify the actual factors governing its neurological and psychological development processes and its functioning in different cognitive situations. It also aims at achieving a manifest scientific understanding that allows the specialists to engage in studying it in the infant. All in all, this will contribute to the elaboration of a neuro-cognitive developmental and functional approaches which reflect the mental work in different life stages.
The Development of the Child’s Working Memory

References
- EL Idrissi, Abdellah. (2018). Noumouw Dhakirat Al A’amal wa Ta’aloum al Anchita al A’adadiya lada al Tifl. [The Development of Working Memory and
The Development of the Child’s Working Memory

Learning of Numerical Activities in Children]. Phd Dissertation. Faculty of Letters and Human Sciences- Dhar el Mehraz, Fes.
- Khalfan al Fouri, Fatema; Mahmoud Abd Al Fattah, Sabri; Mehdi Kadem, Ali; Salim Al Zabidi, Abd Al Qawi. (2016). Fa’aliyat Barnamaj Tadribi bi-stikhdami
The Development of the Child’s Working Memory

The Development of the Child’s Working Memory