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Accounting for individual differences in the development of verbal and visual short term memory processes in children

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ABSTRACT

In developmental research on memory, the model of working memory of Baddeley and Hitch (1974, Baddeley, 1986) is the theory most often referred to. This theory has played an important role in studies on human learning in general. However, it is not clear how the verbal and visual short term memory systems develop. In order to investigate this development, we argue that some important issues should be taken into account; a longitudinal research design and individual differences between children. The current study is a follow-up study in which we investigated the transitions that a subsample of 30 children made between verbal and visual processing during the course of one year. Our results showed that the children showed large variation in STM processes and did not move from one type of processing to another in a consistent manner. This implies that the development of the verbal and visual STM systems may be less predictable than expected based on the literature, stressing the importance to be cautious when individual differences between children are not taken into account.

1. Introduction

In memory research, the most robust and frequently used theory on memory processes is the model of working memory of Baddeley and Hitch (1974) and Baddeley (1986), proposing that working memory (WM) consists of three systems. The phonological loop and the visuospatial sketchpad are modality-specific short term memory (STM) systems, which are part of the central executive, a modality-independent WM system. The phonological loop is a system for storage and processing of verbal information and the visuospatial sketchpad is a system for storage and processing of visual and spatial information. More recently the episodic buffer has been added to the model; a fourth system to store information from the STM systems and long term memory in one episodic representation (Baddeley, 2000). Studies on the model of WM typically investigate the use of the phonological loop and the visuospatial sketchpad with different types of memory tasks and relate performance on these tasks to different types of outcomes such as language development, mathematical and reading ability, and more complex higher order cognitive functions (for an overview, see Baddeley, 2003; Jarrold & Towse, 2006; Zimmer, 2008). As such, the model of WM lies at the heart of many studies on learning in children.

Although the model of WM was initially developed based on adult studies (see Baddeley, 2003), developmental studies have shown that the same structure of memory systems can be assumed to exist in children from four years of age onward (Alloway, Gathercole, & Pickering, 2006; Bayliss, Jarrold, Gunn, & Baddeley, 2003; Gathercole, Pickering, Ambridge, & Wearing, 2004). Developmental researchers have extensively applied this model to investigate the verbal and visual memory systems in children. However, the actual developmental pathway of the verbal and visual memory systems remains uncovered. Clarifying and understanding this developmental pathway would be beneficial for, among others, the design of educational methods focusing on children of different ages. It may be expected for example, that younger children benefit more from visual methods than verbal methods. However, if visual memory develops further as children grow older, and as such, continues to play a significant role in learning, visual educational methods should still be available for older children instead of being replaced by verbal methods. Whether this is the case can only be concluded after the actual development of the memory systems has been studied further.

Despite the similarities of memory systems in children and adults, there is a peculiar gap between findings of developmental studies and those of adult studies with respect to STM processes. Adult studies have shown that some participants use verbal and visual processing interchangeably depending on the type of task and that there are large individual differences with respect to the use of verbal and visual processing (Daneman & Carpenter, 1980; Della Sala, Logie, Marchetti, & Wynn, 1991; Logie, Della Sala, Wynn, & Baddeley, 2000). For instance,

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some adults use visual processing when memorizing verbal material such as words, while others do not (Logie, Della Sala, Laiacona, Chalmers, & Wynn, 1996). Developmental studies on children, however, seem to conclude that development 'ends' with the use of verbal STM. This idea can also be seen in educational settings where different teaching materials are used for young children (mostly visual) than for older children (mostly verbal). If verbal processing would indeed be 'the final stage' of STM development in children, then adults should also show predominantly verbal processing. However, studies like the ones described above, which take individual differences between adults into consideration, have shown otherwise.

We argue that more insights about the development of verbal and visual processes can be gained, provided that the limitations of the most common developmental approaches are highlighted and taken into account. Two of these limitations concern the use of cross-sectional research designs and the way of dealing with individual differences in memory processes between children. The aim of the current study is therefore, to account for these two limitations while investigating the development of the verbal and visual STM systems according to the model of Baddeley and Hitch (1974).

First of all, the developmental pathways of STM processes on its own right have barely been studied. As Ornstein and Haden (2001, p. 202) wrote strikingly: "*[…] it is as if researchers have focused on memory development and have not been concerned with the development of memory*." Indeed, when reviewing the literature, it becomes clear that many theories on memory have been developed until now (e.g., Anderson, 1976; Baddeley & Hitch, 1974; Henson, 1998; Luck & Vogel, 1997; Nairne, 1990; Oberauer, 2009; Page & Norris, 1998; Paivio, 1991; Yonelinas, 2002), but very few studies have focused on how memory processes develop in children. Moreover, most of these developmental studies use cross-sectional research designs (e.g., Baddeley, Gathercole, & Papagno, 1998; Camos & Barrouillet, 2011; Chuah & Mayberry, 1999; Conrad, 1971; Gathercole et al., 2004; Hitch, Woodin, & Baker, 1989; Kemps, De Rammelaere, & Desmet, 2000). However, when research questions concern the developmental changes in memory processes within individual children, cross-sectional studies fall short of providing an accurate answer.

In cross-sectional designs, developmental patterns in the use of memory processes between children are mostly described in terms of rough age boundaries. For example, until five years of age children have been found to rely on visual STM and hardly on verbal STM; from six years onward children have been found to start using additional verbal processing; and from 10 years onward children start showing performance levels on STM tasks resembling that of adults (Baddeley et al., 1998; Conrad, 1971; Gathercole, 1998; Gathercole, Adams, & Hitch, 1994; Gathercole et al., 2004; Hitch et al., 1989). The problem with such a description of development is that it does not give an explanation of *how* the verbal and visual systems develop. Especially the role of the visual STM system in the development of memory remains unclear. It seems that there are two possible explanations; either the development of visual STM stagnates around the age of six to become supplemented with the use of verbal STM (Hitch et al., 1989) or visual STM continues to develop after the age of six, but this development is difficult to detect because at the same time, children become more inclined to use verbal STM (Henry, Messer, Luger-Klein, & Crane, 2012; Riggs, McTaggard, Simpson, & Freeman, 2006). The latter implies that children are able to use visual processing at a higher level when they are older and therefore, older children may use visual processing in learning in a qualitatively different way than younger children.

We assign the difficulties with addressing these developmental issues both to the widely used cross-sectional designs, as well as to the focus on average scores. Because younger children not only rely more on visual STM but also show worse overall performance compared to older children, the cross-sectional approach using average scores leads to the intuitively logical conclusion that visual processing reflects a point in memory development that is inferior to verbal processing. However, adult studies provide strong evidence against this conclusion. Adult studies show that participants who use visual STM to process verbal stimuli do not perform worse than participants who use verbal STM (Logie et al., 2000; Saito, Logie, Morita, & Law, 2008). To put it differently, adults who process stimuli of memory tasks visually are not considered to be 'less developed' in terms of memory than adults who process the same stimuli verbally. Then why should we assume this is the case in children?

The next point is an important assumption underlying conclusions about the developmental pathway of children of a certain age based on average scores obtained from cross-sectional research designs. This is the rather strong assumption that the average score of children in a certain age group is a good representation of the performance of all the individuals in that age group, that is, the age groups are assumed to be homogenous. Subsequently, it is assumed that changes in average scores from one age group to another represents developmental changes of all the individual children. However, we argue that this assumption is questionable at the least. Children vary greatly in their memory performance (Henry et al., 2012; Koppenol-Gonzalez, Bouwmeester, & Vermunt, 2012; Palmer, 2000) and therefore, they may also vary greatly in the developmental pathways they follow.

In order to keep a priori assumptions about development to a minimum, we need a research design to meet two important criteria; it should account for individual differences and it should be longitudinal. Therefore, the research design should enable the identification of differences between children in terms of verbal/visual processing and performance, and it should detect how their STM use changes over time. Unfortunately studies that meet these criteria hardly exist. The few longitudinal studies on memory are mainly focused on specific memory skills as predictors of the development of other cognitive skills, such as reading acquisition (de Jong & van der Leij, 1999; Lervåg, Bråten, & Hulme, 2009; Perez, Majerus, & Poncelet, 2012), vocabulary development (Leclercq & Majerus, 2010), and academic achievement (Bull, Espy, & Wiebe, 2008). The general aim of the current study is to contribute to the literature on the development of memory processes according to the model of Baddeley and Hitch (1974) on the one hand, and to contribute to the literature on learning by accounting for individual differences between children in the use of verbal and visual STM, on the other hand.

2. Measuring the use of verbal and visual STM and individual differences

Assuming the model of WM of Baddeley and Hitch (1974), a very insightful method to distinguish between the use of verbal and visual STM processes is by manipulating the similarity of stimuli that are visual in nature (i.e., concrete pictures) but can easily be labeled verbally (i.e., existing words) (see e.g., Hitch et al., 1989; Logie et al., 2000; Poirier, Saint-Aubin, Musselwhite, Mohanadas, & Mahammed, 2007). When the visuospatial sketchpad is used to memorize pictures in a certain serial order (i.e., based on their visual features) and the pictures are visually similar, this similarity causes confusion leading to worse performance compared to the same situation with visually dissimilar pictures (Logie, 1995). Therefore, when pictures that are visually similar are recalled worse than pictures that are visually dissimilar, this can be assumed to indicate the use of visual STM. The same principle holds for pictures with labels that are phonologically similar (i.e., rhyme words). In this case, the phonological loop is used to verbally memorize the labels of the pictures. When the labels have to be recalled in a certain serial order and are phonologically similar, this will lead to confusion resulting in worse performance compared to the same situation with phonologically dissimilar pictures (Baddeley, 2003). Therefore, when pictures with phonologically similar labels are recalled worse than pictures with phonologically dissimilar labels, this can be assumed to indicate the use of verbal STM. This is specifically the case when memory for serial order is being called upon and, therefore, the