Cognitive Development 43 (2017) 224–234

Contents lists available at ScienceDirect

Cognitive Development

journal homepage: www.elsevier.com/locate/cogdev

The effects of working memory training on improving fluid intelligence of children during early childhood

Jun Peng[1], Lei Mo[*,1], Ping Huang, Ying Zhou

Center for Studies of Psychological Application & School of Psychology, South China Normal University, Guangzhou, China

ARTICLE INFO

Keywords:
Working memory
Intervention
Fluid intelligence
Early childhood

ABSTRACT

Early childhood is a phase of rapid development in many aspects, and early interventions can be more effective than interventions provided later on. In prior research, working memory training has demonstrated the possibility to improve the fluid intelligence of both adults and school-aged children. This study examined the training effects of enhancing the development of fluid intelligence in the long-term for preschoolers. Seventy-four preschoolers participated in the experiment. Participants in the experimental group were trained for 14 days using n-back program. Fluid intelligence tests were administered four times: pretest, post-test, 6-month follow-up, and 12-month follow-up. Results indicated that, the experimental group significantly enhanced their working memory performance. The experimental group also significantly outperformed the two control groups on the fluid intelligence post test and maintained their superior performance for up to 12 months. Implications are discussed within the context of providing effective early childhood interventions to improve fluid intelligence.

1. Introduction

From birth to 6 years old, children experience a critical period of development in multiple domains (Piaget, 1981). Important cognitive functions such as language, perceptual processing, emotional control, and social skills yield rapid development during this period. For example, Fenson et al. (1994) reported a period of rapid language acquisition between 2 and 4 years. Besides, children rapidly improve their verbal memory during this period: between the age of 3 and 5 years, children are able to verbally report events using their developing memory ability (Simcock & Hayne, 2003). Development of communication skills and self-discipline is also significant during early childhood (Man, 2013). Many evidences from neuroscience researches illustrate that early childhood is the important period of brain development. The brain develops rapidly in early childhood and reaches approximately 95% of the size of an adult brain by age 6 (Lenroot & Giedd, 2006). The developmental trajectory of the brain is influenced by both genetic and environmental factors (Lenroot & Giedd, 2006). If children suffer from severe sensory deprivation, their brains may be significantly smaller than average and demonstrate abnormal development of the cortex (Perry & Pollard, 1997).

The development of intelligence during early childhood is rapid. Intelligence is defined as a general mental ability that mainly involves comprehending, reasoning, problem solving, and efficient learning. Individual intelligence is associated with the lateral prefrontal cortex and parietal association cortex (Deary, Penke, & Johnson, 2010). These brain areas are highly malleable during early childhood (Lenroot et al., 2009). For children with normal intelligence, the thickness of their cortex reaches its maximum when they are about 5.6 years old (Shaw et al., 2006), suggesting the rapid brain growth during this critical stage of development.

* Corresponding author at: South China Normal University, Guangzhou 510631, China.
E-mail address: molei@scnu.edu.cn (L. Mo).
[1] These authors contributed equally to the work.

http://dx.doi.org/10.1016/j.cogdev.2017.05.006
Received 3 June 2015; Received in revised form 27 March 2017; Accepted 17 May 2017
Available online 07 June 2017

Special attention should be given to children's development of fluid intelligence at this stage. According to Cattell, fluid intelligence is an important dimension of general intelligence. It refers to the ability to solve abstract relational problems and has been considered to be free of cultural influences (Carpenter, Just, & Shell, 1990). Unlike crystallized intelligence, which is shaped by past experiences, fluid intelligence is considered partly hereditary and independent of acquired knowledge (Cattell, 1971). Fluid intelligence improves steadily during childhood, typically peaks during adolescence, and exhibits an early and regular aging loss (Baltes & Kliegl, 1986; Horn & Cattell, 1967), which indicates that fluid intelligence is primarily associated with biological functioning and brain status (Aizpurua & Koutstaal, 2010; Manard, Carabin, Jaspar, & Collette, 2014; Schretlen et al., 2000). Fluid intelligence is highly predictive for academic achievement and future accomplishments (Deary, Strand, Smith, & Fernandes, 2007; Neisser et al., 1996; Rohde & Thompson, 2007; te Nijenhuis, van Vianen, & van der Flier, 2007).

Experience and environmental factors play essential roles in shaping intelligence during early childhood (Bruer, 1997; Viadero, 1996). A substantial body of research (Barnett, 1995; Batty, Deary, & Gottfredson, 2007) has established the importance of providing intervention programs during early childhood to improve intelligence over the long term. Barnett (1995) reported that programs designed for disadvantaged children can yield immediate boosts of about eight IQ points. Nisbett et al. (2012) suggested that early childhood interventions aimed at improving IQ can lead to significant effects for later academic and life achievements. Therefore, it is possible that effective early interventions can produce long-term effects in individuals' intelligence.

1.1. Enhancing development of fluid intelligence through working memory training

Although it is commonly agreed upon that academic interventions can improve academic achievements, it is still controversial whether cognitive interventions can improve the fluid intelligence. Recent studies have found that through cognitive training, especially working memory training, it is possible to enhance individuals' performances in tasks measuring fluid intelligence (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Jaeggi, Buschkuehl, Jonides, & Shah, 2011; Jausovec & Jausovec, 2012; Klingberg et al., 2005; Klingberg, Forssberg, & Westerberg, 2002; Stephenson & Halpern, 2013). Working memory is a memory system with limited capacity. It temporarily maintains and manipulates important information while simultaneously inhibiting irrelevant information (Baddeley, 2003; Baddeley & Hitch, 1974; Baddeley & Hitch, 1994). Working memory capacity is predictive of multiple cognitive abilities such as reading (Baddeley, 1992; Daneman & Carpenter, 1980), writing (McCutchen, 1996; Swanson & Berninger, 1996), learning English as a second language (Abu-Rabia, 2003), and arithmetic (De Smedt et al., 2009; Destefano & Lefevre, 2004; Gathercole et al., 2004). Children with learning disabilities in reading or mathematics were found to have small working memory capacity (Chiappe, Hasher, & Siegel, 2000; Swanson, 1993, 1994; Swanson & Beebefrankenberger, 2004).

A strong correlation between working memory and fluid intelligence has been documented in prior research (Colom, Abad, Quiroga, Shih, & Flores-Mendoza, 2008; Colom, Rebollo, Palacios, Juan-Espinosa, & Kyllonen, 2004; Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Conway, Kane, & Engle, 2003; Engel de Abreu, Conway, & Gathercole, 2010; Kane, Hambrick, & Conway, 2005). For instance, a confirmatory factor analysis by Kyllonen and Christal (1990) reported high correlations between working memory capacity and factors contributing to reasoning ability. Neuropsychological studies have indicated that working memory and fluid intelligence share similar neural networks, which are mainly located in the dorsolateral prefrontal and parietal cortex (Gray, 2002; Gray, Chabris, & Braver, 2003; Gray & Thompson, 2004; Kane & Engle, 2002), which may explain the mechanism underlying the relation between working memory and fluid intelligence.

An increasing number of studies have emerged during the last decade reporting that working memory training can enhance cognitive abilities, including fluid intelligence (Klingberg, 2010). A recent meta-analysis (Weicker, Villringer, & Th & ne-Otto, 2016) analyzed 103 studies of working memory training and found that training lead to long-lasting improvements on reasoning/intelligence and cognitive control functions. They suggested that the working memory training had a long-lasting beneficial effect on cognitive function of brain injured patients. Besides, Au et al. (2015) put forward that there was a small but significant positive effect of a specific training program (n-back training) on improving fluid intelligence among healthy adults in their meta-analysis. Similarly, another meta-analysis (Karbach & Verhaeghen, 2014) suggested that the working memory trainings were effective on near- and far-transfer (i.e., measuring the same and different task constructs, respectively). Another meta-analysis (Melby-Lervåg & Hulme, 2013) and two systematic reviews (Morrison & Chein, 2011; Shipstead, Redick, & Engle, 2012) synthesized empirical studies examining the effects of working memory training on related cognitive skills and reported consistent and positive immediate improvements but mixed transfer effects. There are multiple types of training programs, including Cogmed training (RoboMemo© from Cogmed Cognitive Medical Systems AB, Stockholm, Sweden; Beck, Hanson, Puffenberger, Benninger, & Benninger, 2010; Bergman Nutley et al., 2011; Dahlin, 2011), Jungle memory (Alloway & Alloway, 2009), n-back training (Jaeggi et al., 2008, 2010; Li et al., 2008; Seidler et al., 2010), and running span training (Dahlin, Neely, Larsson, Bäckman, & Nyberg, 2008; Dahlin, Nyberg, Bäckman, & Neely, 2008; Zhao, Wang, Zhou, Wang, & Tan, 2011). Among the various training methods, the *n*-back training was found to be more effective than training using simple/complex tasks (Shipstead et al., 2012).

While positive effects of working memory training were reported, researchers also expressed concerns about the effects of the training (Melby-Lervåg & Hulme, 2013; Shipstead et al., 2012). Firstly, some studies reported that participants were unable to transfer the improved working memory abilities to enhance their performance on other tasks, including academic achievement tests (Holmes, Gathercole, & Dunning, 2009; Horowitz-Kraus & Breznitz, 2009; Van Der Molen et al., 2010), intelligence tests (Bergman Nutley et al., 2011; Redick et al., 2013; Westerberg et al., 2008), and attention tasks (Dahlin, Nyberg et al., 2008; Van Der Molen et al., 2010; Westerberg et al., 2007). Secondly, the sources of these changes are still unclear; further research is necessary to show that the improvement represents a true growth of cognitive abilities instead of a test-retest effect (Colom et al., 2010).

Some researchers suspected that the improvement is only temporary and that the maintenance effects are questionable. In