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The trajectory of mathematics skills and working memory thresholds in girls with fragile X syndrome

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ABSTRACT

Fragile X syndrome is a common genetic disorder associated with executive function deficits and poor mathematics achievement. In the present study, we examined changes in math performance during the elementary and middle school years in girls with fragile X syndrome, changes in the working memory loads under which children could complete a cognitive switching task, and the association between these two areas of function, in girls with fragile X syndrome relative to their peers. Our findings indicate that the trajectory of math and executive function skills of girls with fragile X differs from that of their peers and that these skills contribute to predicting math achievement and growth in math performance over time. Also, changes in math performance were associated with incremental increases in working memory demands, suggesting that girls with fragile X have a lower threshold for being able to perform under increasing task demands. Still, we found improvement in executive function performance between 10 and 12 years in girls with fragile X rather than a performance plateau as has been reported in other studies. The findings implicate the importance of early

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intervention in mathematics for girls with fragile X that addresses poor calculation skills, the supporting numerical skills, and deficits in executive functions, including working memory.

The roles of executive functions and working memory in mathematical performance have received both theoretical and empirical support (Bull, Johnston, & Roy, 1999; Bull & Scerif, 2001; Mazzocco & Kover, 2007). Moreover, learning disabilities in mathematics have been linked to working memory deficits specifically (Andersson & Lyxell, 2007; Swanson & Beebe-Frankenberger, 2004), even if not exclusively. Collectively, studies of the cognitive characteristics of children with mathematical difficulties implicate a wide range of executive skills as underlying their performance deficits and support different theoretical constructs of working memory (as reviewed by Berch, 2008). Children with fragile X syndrome, an X-linked genetic condition, have a biologically predisposed increased risk for mathematical learning disability (MLD; Mazzocco, 2001; Murphy & Mazzocco, 2008) and select executive dysfunction (e.g., Mazzocco, Hagerman, Cronister-Silverman, & Pennington, 1992). Thus, the present paper builds upon findings across studies of fragile X syndrome by exploring the link between poor math achievement and these select deficits reported for children with fragile X syndrome, including deficits in executive functions and working memory.

If we define working memory as the ability to maintain and access stored information while engaged in cognitive tasks, its relevance to math ability is evident for both higher mathematics and basic math skills such as counting and specific strategy use (e.g., finger counting and verbal counting; Geary, 2004). Implicit in this definition is the need to successfully inhibit competing responses, a deliberate executive function that can serve to either prevent a proponent response from occurring or to both prevent the response and substitute an alternative less automatic one. The working memory demands (or load) of a task may influence whether attempts to inhibit a prepotent response are successful; more effortful tasks may diminish the availability of cognitive resources needed, relative to those available for tasks with fewer cognitive demands. Individual differences in the "threshold" level that impedes a person's efficient executive functions may partially underlie individual differences in mathematics achievement levels. In our earlier work, we reported lower thresholds among girls with fragile X syndrome, but that study did not include a parallel evaluation of math performance (Kirk, Mazzocco, & Kover, 2005). Studying specific etiologies of MLD, such as fragile X syndrome, may reveal aspects of the association between executive functions, working memory, and math achievement.

In studies of working memory influences on math performance, researchers often rely on Baddeley's model of working memory (Baddeley, 1996, 2003), although other models have been proposed as highly relevant (see Berch, 2008 for a discussion). Summarized briefly, Baddeley conceptualizes working memory as a central executive, with deliberate control of two core "slave systems;" these slave systems, the phonological loop and visuospatial sketchpad, store linguistic or visually represented information, respectively. Both storage systems are subject to the limitations of storage capacity and processing efficiency. Several recent studies have explored components of working memory deficits in children with MLD. Geary, Hoard, Byrd-Craven, Nugent, and Numtee (2007) demonstrated that the central executive, phonological loop, and visuospatial sketchpad were each associated with math performance, but the precise association depended on the math task being assessed. Still, these researchers identified the central executive as the "core component" underlying performance deficiencies in children with MLD, as did Andersson and Lyxell (2007), who also showed correlations between working memory and math achievement among children of all math achievement levels.

Working memory deficits differentiated children with versus without MLD in both of these studies. However, in Geary's study, working memory did not differentiate children with low average math achievement from those with age appropriate math outcomes. Instead, processing speed differentiated both those with MLD or low achievement from their typically achieving peers. The findings of Geary et al. (2007) are similar to those we reported earlier (Murphy, Mazzocco, Hanich, & Early, 2007),