Working Memory in 3½ , 4-, and 4½ -year-old Children and Increasing Specificity of Task-Related 6-10Hz EEG Power

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INTRODUCTION

Working memory (WM) plays a crucial role in a young child's interaction with the environment and is important for both cognitive and social development.

One popular oganizational framework of WM (Engle, Kane, & Tuholski, 1999; Kane & Engle, 2002) includes the following components:

- Domain specific components (e.g., phonological loop)
- A domain-free, limited capacity controlled attention component
- Dorsolateral prefrontal cortex (DL-PFC) functioning
- Individual differences in the functioning of the aforementioned components are associated with individual differences in WM

Research supports the applicability of this model to young children.

- Young children (ages 3½-to-7) can perform cognitive tasks that require working memory **and** inhibitory control (Diamond, Prevor, Callender, & Druin, 1997; Diamond & Taylor, 1996; Gerstadt, Hong, & Diamond, 1994; Wolfe & Bell, 2004).
- There are substantial increases in WM – in accuracy and speed – across these early childhood years (Diamond & Taylor, 1996).
- An increase in 6-9Hz EEG power from baseline-to-WMIC task for the medial frontal region ***only*** has been found for 4½-year-olds (Wolfe & Bell, 2004)…a notably different activation pattern than seen for infants in which an increase in EEG power from baseline-to-WMIC task for frontal ***and*** posterior regions has been found for high performing infants (Bell, 2001, 2002, 2004). This frontal specificity is comparable to *f*MRI work done with 7- and 8-year-olds, Casey et al., 1995; Casey et al., 1997).

The main goal of this study was to extend our research with 4½-year-olds to include ages 3½- and 4-years to assess age-related changes in WM and associated physiological functioning and to answer the question: *When does the medial frontal region begin to display an increase in activation – relative to the other brain regions – during this type of cognitive task?*

PARTICIPANTS

	3½	4	4½
n	20	20	21
Males	8	10	12
Age	41-43 mo	47-49 mo	51-53 mo

Percentage of males	**49.2**
Percentage of children with 1 or 2 siblings	**80.4**
Percentage of European Caucasian children	**85.2**
Percentage of children with right-handed parents	**84.5**
Percentage who attended preschool	**90.2**
Mean age of parents (yrs)	**34.55**
Mean education level of parents (yrs)	**16.26**

PROCEDURE

Warm-up Exercises. The first two tasks were played without physiological recordings and served as "warm-up" or "ice-breaker" exercises: The pig-bull task (Reed, Pien, & Rothbart, 1984) and the tongue task (Kochanska, Murray, & Harlan, 2000). Both of these tasks required the children to pay attention to a given set of rules, remember these rules throughout the task, and to inhibit a dominant response tendency.

Physiological Measure. EEG measures were accomplished during a 2-minute eyes-open baseline period and during two WM tasks. EEG electrodes were applied as the child was entertained by a research assistant and an age appropriate computer game. EEG was recorded using an Electro-Cap from eight left and eight right scalp locations: Frontal pole (fp1/fp2), medial frontal (f3/f4), lateral frontal (f7/f8), central (c3/c4), anterior temporal (t3/t4), posterior temporal (t5/t6), parietal (p3/p4), and occipital (o1/o2).

Working Memory Tasks. Two tasks were used to investigate the children's WM abilities. Each of these tasks required the child to pay attention to a set of rules, remember the rules throughout the task, and to inhibit a dominant response. These tasks were accomplished during the EEG recording: The Stroop-like day-night task (e.g., Gerstadt, Hong, & Diamond, 1994) and the yes-no task (Wolfe & Bell, 2004).

Day-Night Task

RESULTS

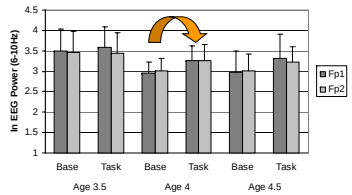
The results of a repeated measures MANOVA revealed, for the entire group of children, an increase in baseline-to-task EEG power for the frontal pole, medial frontal, and posterior temporal scalp locations and an age x hemisphere effect for the anterior temporal region.

Hypotheses-driven post-hoc analyses revealed increases in baseline-to-task EEG power for four regions in the 4-year-olds (i.e., frontal pole, medial frontal, anterior temporal, and posterior temporal) and increases in baseline-to-task power for two regions in the 4½-year-olds (i.e., medial frontal and posterior temporal). No condition effects were found for the age 3½ group likely due to the incomplete EEG data for this group of children and the subsequent reduction in sample size.

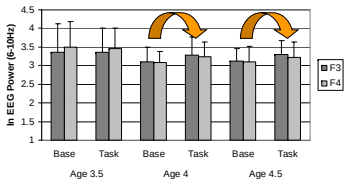
	df	*Fp1/Fp2*	*F3/F4*	*T3/T4*	*T5/T6*
AGE 3½					
Condition	*1,10*				
Hemisphere	*1,10*				
Condition x Hemisphere	*1,10*				
AGE 4					
Condition	*1,16*	13.85	12.25	20.48	21.65
Hemisphere	*1,16*				
Condition x Hemisphere	*1,16*				
AGE 4½					
Condition	*1,18*		12.06		10.82
Hemisphere	*1,18*				
Condition x Hemisphere	*1,18*				

Adjusted $p \leq .004$ (4 regions x 3 age groups = 12 analyses; $p = .05/12 = .004$); only values significant at $p \leq .004$ are shown.

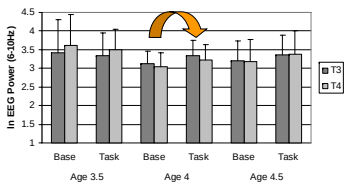
RESULTS



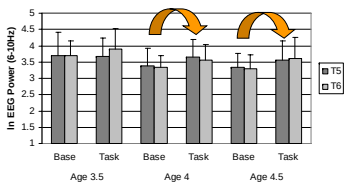
Frontal pole (fp1/fp2)
There was a main effect for condition at age 4 only with greater power values during the tasks than during baseline for this age group, $t(16) = 3.722$, $p = .002$.



Medial frontal (f3/f4)
There were main effects for condition at age 4 and age 4½ with greater power values during the tasks than during baseline for these age groups, age 4 $t(17) = -3.50$, $p = .003$ and age 4½ $t(18) = -3.472$, $p = .003$.



Anterior temporal (t3/t4)
There was a main effect for condition at age 4 only as there were greater power values during the tasks than during baseline for this age group, $t(17) = 2.184$, $p < .001$.



Posterior temporal (t5/t6)
There was a main effect for condition at age 4 and age 4½ with greater power values during the tasks than during baseline for these age groups, age 4 $t(17) = -4.653$, $p < .001$ and age 4½ $t(18) = -3.289$, $p = .004$.

EEG power at age 3½ appears to be consistently higher than that of the two older age groups. This pattern is characteristic of the 6-10Hz frequency band which shows a developmental increase and then a decrease in power for some scalp locations from infancy to early childhood (Marshall, Bar-Haim, & Fox, 2002).

EEG power at age 3½ did not follow the activation pattern seen age 4 or 4½ or even of that seen with infants. Preliminary analyses indicate that those high performing 3½-year-olds – compared to those low performing 3½-year-olds – do show baseline-to-task activation patterns similar to the older children.

CONCLUSION

This project demonstrates an increasing specificity of baseline-to-task 6-10Hz EEG power across the early childhood years and lends support to the applicability of a WM model (with an emphasis on DL-PFC functioning) to this young population. This is an exciting finding and suggests that the reorganization of the brain, specifically the specialization of function, is occurring during the early childhood years at the same time many higher order cognitive advances are being made – and further can be captured through electroencephalographic measures.

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