

Quantitative Analyses of Schooling Effects on Executive Function in Young Children*

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ABSTRACT

Developmental studies have demonstrated the utility of select executive function (EF) tasks for the early diagnosis of specific learning-related problems (e.g., Snow, 1998). However, previous data demonstrating schooling effects on EF measures suggests potential pitfalls in clinical interpretation. In the present study three common EF measures, (Wisconsin Card Sort, Thurstone Word Fluency, and a mazes task) in addition to a VIQ estimating task, were administered to a cross-section of 115 children aged 7 to 9. Using a *school-entrance cut-off design* the unique contributions of formal schooling versus age-related changes to performance on the EF measures were examined. Schooling effects were both *task* and *age-dependent* supporting the conclusion that the proper use of EF measures with children in this age range depends upon consideration of factors beyond that usually depicted in net-effect models.

In addition to the lack of a conceptualization of an age-related developmental hierarchy within the executive function domain it is contended that many developmental studies neglect to adequately address the issue of schooling effects. In this paper Welsh, Pennington and Grossier's (1991, p. 132) definition that "executive function facilitates future-oriented behavior by allowing for planning, flexible strategy employment, impulse control, and organized search" is adopted. Moreover what role particular experiences, such as those associated with schooling, play in the development of executive functions has not been widely studied beyond the nonspecific age effects, until recently.

Two different methodologies examining the effect of *schooling* on the development of executive function are relevant. First are the studies that examine the effect of schooling on perfor-

mance of adult populations on executive function tasks (e.g., net-effect studies). Studies of this kind use years of formal education as the independent variable. Focusing on the type of executive function measures used in the current study, Heaton, Grant and Matthews (1991) and Yeudall, Fromm, Reddon and Stefanyk (1986) reported small education effects on the Wisconsin Card Sorting Task performance; and Daigneault, Braun, Gilbert and Proulx (1988) reported similar effects on the Porteus Maze tasks. Education by age interaction effects – such that those individuals with 13+ years of education maintain optimal performance levels longer than those with less education – have been suggested by Lezak (1995) on the basis of normative data presented by Spreen and Strauss (1991). Furthermore education effects are frequently found on fluency measures (Benton, Hamsner, Varney

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& Spreen, 1983; Wertz, 1979) but it has been speculated that these effects could be mediated by individual differences in general ability (Crawford, Moore & Cameron, 1992).

The second type of study of interest are those that either assess the effect of specific schooling experiences on executive function task performance or compare the performance of schooled and nonschooled participants. On the first line of research, Dreher and Oerter (1987) found that subjects who completed a course which was designed to facilitate the development of skills associated with activities of daily living (e.g., home economics) did better in a route-planning task than would have been expected on the basis of their age and general educational level. Using a natural experimental design Morrison, Smith and Dow-Ehrensberger (1995) found that one extra year of schooling at the grade one level enhanced the use of active memory strategies. These two studies suggest that specific schooling experiences foster the development of executive function, with some evidence of generalization across knowledge or content domains.

On the second line of research Tanon (1991) compared the influence of formal education to that of informal education (skilled employment as a weaver) on the development of planning competency. The results demonstrated that schooled individuals generally outperformed the other groups in the planning tasks. In contrast unschooled skilled-employed and schooled individuals performed at approximately the same levels, with unschooled individuals obtaining the lowest scores. Das and Dash (1990) found that 10 to 12 year old children that were schooled performed significantly better on a modified Trail Making test than their same age unschooled peers, whereas inter-group differences in Piagetian conservation tasks were not significant. Collectively, these studies suggest that formal schooling exert small to medium-sized effects on executive function development.

The purpose of this study was to examine the independent effects of two classes of experiences (those related to formal schooling and those related to age) on executive function using a variant of the school entrance cutoff design (Bentin, Hammer & Cahan, 1991; Bisanz, Mor-

risson & Dunn, 1995; Cahan & Cohen, 1989; Morrison, Smith, & Dow-Ehrensberger 1995; Varnhagen, Morrison & Everall, 1994). In the cutoff design, participants are selected from both sides of the cutoff date so that their age differences are minimal, yet they have received different levels of schooling. For example, comparisons between the oldest children in Grade 1 and the youngest children in Grade 2 would produce information on the effect of one additional year of formal schooling when age is held constant: whereas the comparison between the youngest and the oldest children in Grade 1 would produce information on the effect of one year of age-related experiences when schooling is held constant.

In the current study, three common executive function measures were used: Thurstone Word Fluency Test (TWFT), Wisconsin Card Sorting Test (WCST), and a test similar to Porteus Mazes, that is, the Mazes subtest from WISC-III Revised (Heaton, Chelune, Talley, Kay & Curtiss, 1993; Thurstone & Thurstone, 1962; Wechsler, 1991). TWFT examines the ability of individuals to systematically search the internal semantic network and to hold those words that they have already said in mind so as not to make perseverative errors (Welsh et al., 1991). The WCST has a strong relationship with measures sensitive to mental flexibility, planning/programming, and monitoring functions (Snow, 1998, p. 90). Maze tests also assess the ability of individuals to engage in forward planning and ongoing monitoring of their performance (Gardner & Rogoff, 1990). The WISC-III-R Mazes are often substituted for the lengthier Porteus Mazes and each test contains items graded for similar level of difficulty to one another (Lezak, 1995, p. 657).

All three tasks assess a component of executive function that has been shown to develop in the age ranges targeted in this study. That is, children's performance begins to peak on mazes approximately at age 8 (Gardner & Rogoff, 1990); on WCST tasks by aged 10 (Kirk & Kelly, 1986; Levin et al., 1991; Welsh et al., 1991; Snow, 1998); while measures of performance on TWFT tasks may increase steadily into late adolescence (Heaton, Grant & Matthews, 1991).

While previous studies have generally used combined age groups and not examined differences on a year-by-year basis, it is plausible that such differences could be detected given that performance on these tasks has been shown to improve across the targeted age range of 7 to 9. Moreover, the effect of schooling is contrasted directly with the effect of age-related experiences, allowing assessment of the relative magnitude of both sources of change independently of each other.

METHOD

Participants were 115 (50 males and 65 females) volunteers from three age groups (7, 8, and 9) and four grade levels (1 to 4). Students were recruited from 14 elementary schools within the Calgary Public School System in Canada. Students with a history of neurological, psychiatric or learning difficulties were excluded from the study based upon school counselor review of student's files. Within each of the age groups, only students with birthdays in either January/February, or March/April were asked to participate in relation to March 1 school entrance cutoff date. On the basis of age and grade level, students were divided further into 6 subgroups as displayed in Table 1.

Consequently within each age group it is possible to assess schooling effects when age is held constant by comparing early and late school entrance subgroups. The two groups in each column

in Table 1 differ in age on average by 71, 64, and 70 days in age groups 7, 8, and 9, respectively; yet differed by almost a full year in their formal schooling experiences. Similarly, in grades 2 and 3 the effect of age was assessed while schooling was held constant by comparing the two groups (e.g., grade 2 and 3 rows) that had the same schooling experience but differed in age by 10 months and 9 months, respectively.

That age and schooling effects can be interpreted unambiguously in this study rests on the assumption that (1) allocation of children to birth dates is random, and that (2) grade level is determined by age only (Cahan & Cohen, 1989). Only the second assumption is potentially problematic, as noted by Bentin, Hammer and Cahan (1991), because the cutoff is not necessarily imposed and exceptions are not random: children who are grade accelerated are often intellectually advanced whereas those who are held back are intellectually less advanced. Both processes would lead to confusion in the interpretation of the results of this study. This is a potential difficulty particularly with older students that have had more chances of being left behind. However, (1) grade retention and acceleration were very infrequent practices for the school district from which students were recruited, and (2) exclusion of prospective participant atypical age/grade matching was limited to only a few instances. Table 1 also reports verbal intelligence estimates (VIQ) for each group obtained from the Peabody Picture Vocabulary Test-Revised (Dunn, 1981).

Table 1. Sample Size, Average Age and VIQ by Age by Grade.

			Age		
			7	8	9
Grade	1	N	24		
		Age ¹	6-11-17		
		VIQ (SD)	104.6 (13.5)		
	2	N	16	20	
		Age	7-01-29	7-12-06	
		VIQ (SD)	101.6 (11.6)	105.4 (8.9)	
	3	N		10	24
		Age		8-02-11	8-11-14
		VIQ (SD)		106.7 (20.3)	108.4 (11.0)
	4	N			21
		Age			9-01-25
		VIQ (SD)			112.7 (13.2)

Note. ¹ Mean age displayed as years-months-days.

RESULTS

Independent sample *t* tests indicated no significant differences in VIQ between any two groups that are compared in the analyses below. The largest VIQ difference for schooling comparisons is in the oldest group, and this may reflect nonrandom selection processes of small magnitude occurring over time. Homogeneity of variance assumptions was checked for violation for all multivariate and univariate comparisons since there was some sample cell size deviation. No significant sex differences were found in the children's IQ, $t(113) = 1.15, p > .1$, or on executive measures, Wilk's $\lambda = .984, F(3, 102) = .540, p > .1$; and sex was collapsed across for the remaining analyses. Table 2 depicts the descriptive statistics for the effects of schooling across the age ranges from 7 to 9 on the 3 executive function measures used in this study. These data may be useful for interpretation of children's neuropsychological test scores by clinicians.

Supplementary WCST measures, categories achieved and failures to maintain set were non-significant on any schooling or age-related comparisons and were dropped from further analyses. The *specific effects of schooling-related experiences* were examined by calculating three MANOVAs, one for each age level (7, 8 and 9), with the three executive measures as dependent

variables and schooling as an independent variable. ANOVAs assessing the same relationships separately for each task followed significant MANOVA.

MANOVA comparing 7-year-olds in grade 1 to their same age peers in grade 2 indicated no significant overall effect of an additional year of schooling at this level: Wilk's $\lambda = .973, F(3, 36) = .335, p > .1$. At age 8, MANOVA was significant, Wilk's $\lambda = .770, F(3, 26) = 2.58, p = .075$. ANOVAs indicated a significant schooling effect at this level (grade 2/grade 3) on TWFT ($F(1, 28) = 8.19, p < .01$), but not on Mazes or WCST (both $F_s < 1$). Finally, at age 9, MANOVA demonstrated no significant overall differences in executive function as a result of one extra year of schooling in grades 3 and 4, Wilk's $\lambda = .896, F(3, 41) = 1.59, p > .1$. Due to some initial differences in the VIQ estimate (e.g., see Table 1), age 9 comparisons were replicated with VIQ as a covariate. MANCOVA indicated that VIQ significantly predicted variance (albeit a small proportion) associated with executive function at this level (Wilk's $\lambda = .675, F(3, 40) = 6.41, p < .01$). ANCOVAs revealed that this effect was limited to the Mazes and WCST.

The *specific effects of age-related experiences* were examined by calculating two MANOVAs, one in grade 2 comparing 7 and 8 year-

Table 2. Means and Standard Deviations on the Executive Function Tasks (Raw Scores).

		Age					
		7		8		9	
		Grade 1	Grade 2	Grade 2	Grade 3	Grade 3	Grade 4
TWFT	<i>X</i>	13.33	15.25	19.00	25.90	33.04	32.29
	<i>SD</i>	(7.52)	(9.53)	(6.13)	(6.42)	(11.16)	(9.40)
WCST							
	Perseverative Errors	<i>X</i>	37.71	38.31	34.75	27.50	20.54
	<i>SD</i>	(24.10)	(22.79)	(23.84)	(18.84)	(7.49)	(14.15)
Categories Achieved	<i>X</i>	3.21	3.75	3.90	4.20	4.71	5.24
	<i>SD</i>	(2.06)	(1.88)	(2.07)	(1.87)	(1.37)	(1.14)
Failure to Maintain Set	<i>X</i>	1.54	.75	1.75	1.60	1.62	1.48
	<i>SD</i>	(2.00)	(.93)	(2.53)	(1.07)	(1.93)	(1.44)
WISC-III-R Mazes	<i>X</i>	16.08	17.13	19.65	19.40	19.75	21.62
	<i>SD</i>	(5.87)	(3.83)	(3.56)	(3.69)	(4.07)	(4.11)

Note. TWFT = Thurstone Word Fluency Test (verbal responding); WCST = Wisconsin Card Sorting Test.

olds and the other in grade 3 comparing 8 and 9-year-olds, with the three executive measures as dependent variables and age as an independent variable. Neither MANOVA comparing younger and older grade 2 students (Wilk's $\lambda = .840$, $F(3, 32) = 2.04$, $p > .1$), nor MANOVA comparing younger and older grade 3 students (Wilk's $\lambda = .879$, $F(3, 30) = 1.38$, $p > .1$) demonstrated significant overall effects of age-related experiences on executive function. Although the overall age MANOVAs were nonsignificant, exploratory ANOVAs were undertaken in order to calculate effect sizes (e.g., see below). ANOVAs in grade 2 were not significant for TWFT or WCST (F values 2.04 and .38, respectively, both $ps > .1$); whereas the opposite was true for Mazes ($F(1, 34) = 4.19$, $p < .05$). In grade 3, age-related differences in TWFT approached significance: $F(1, 32) = 3.56$, $p = .068$.

Since there was some sample size deviation, an examination of the strength of these relationships with effect sizes that do not depend on the sample size was undertaken. Each executive function task was used in five comparisons, three of which assessed the effect of schooling (in ages 7, 8, and 9) and two of which assessed the effect of age (in grades 2 and 3). Figure 1

displays the effect sizes (Cohen's d with pooled error variance) for each of these comparisons as a function of the task (Cohen, 1988). Effect sizes from schooling comparisons are displayed in open patterns and effect sizes for age comparisons in solid patterns.

On average, effect sizes for age-related comparisons were slightly larger than that of schooling-related comparisons. Mean effect sizes were .13, .47, and .21 for the three schooling comparisons, and .43 and .44 for the two age-related comparisons. Figure 1 shows no general task, schooling, or age-related patterns. Both the effects of schooling and age-related experiences demonstrate task and age-dependency, with the possible exception of generally negligible schooling effects in the youngest group (age 7).

The results indicate that schooling has small to moderate-sized effects on the development of executive function across age-matched groups. Specific schooling experiences associated with grade 2 and 3 appear to have largely contributed to the development of semantic search fluency, as measured by the TWFT. Age-related experiences seem to contribute slightly more, as indicated by the larger effect sizes, than formal schooling. The nonsignificant multivariate anal-

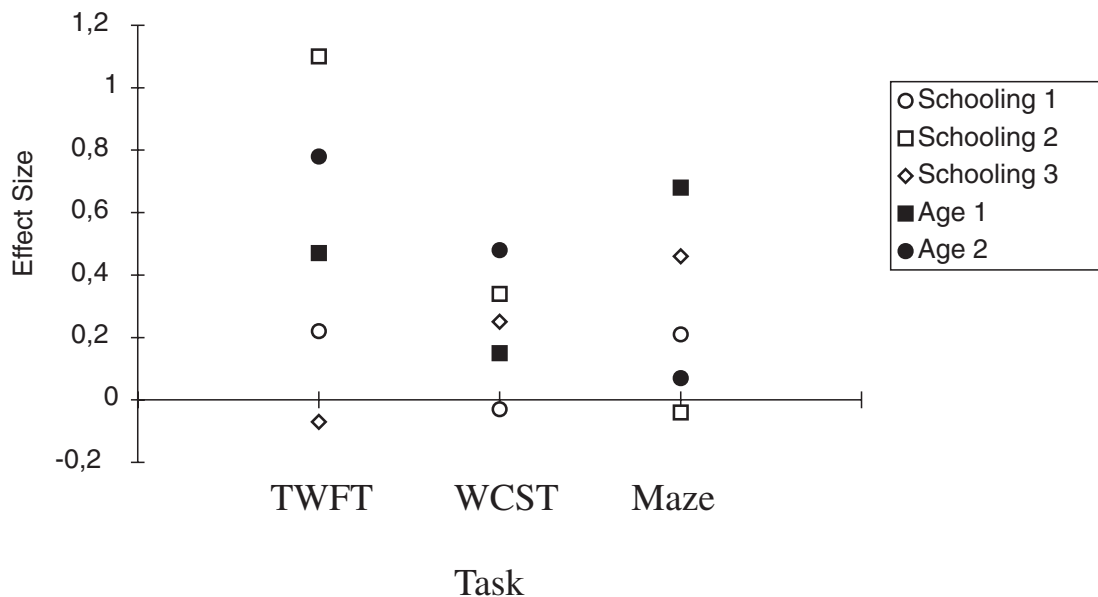


Fig. 1. Small (0.2σ), medium (0.5σ), and large effects (0.8σ), respectively.

yses suggest that age-effects on specific executive function tasks were dependent on the task parameters. Specific age-related development was observed on two occasions: 8-year-olds did better than 7-year-olds with comparable schooling experiences on the Mazes task that requires simple forward planning; and 9-year-olds performed better than 8-year-olds in TWFT.

DISCUSSION

The results demonstrate that formal schooling exerts small to moderately sized effects on the development of executive function during the early elementary grades and that this effect is highly dependent upon the nature of the task. A large schooling effect on the verbal fluency measure at age 8 was detected, suggesting that schooling may directly improve performance on executive measures, as opposed to indirectly through the selection effects of general ability as suggested in prior net-effect studies. Such schooling effects could conceivably arise from several factors, including an increased knowledge-base, learning of general problem-solving strategies, or the learning of domain-specific strategies (Morrison, Smith & Dow-Ehrensberger, 1995; Varnhagen, Morrison & Overall, 1994).

The link between level of education and Wisconsin Card Sort Test performance is established in adults and demographically corrected normative data has been provided (Boone et al., 1993; Heaton et al., 1993; Heinrichs, 1990). A recent Canadian study of developmental norms for children aged 9–14 on the Wisconsin Card Sort Test is the largest to date (Paniak, Miller, Murphy, Patterson & Keizer, 1996); and Spreen and Strauss (1998, pp. 225–226) recommended substituting these norms for Heaton and colleagues' (1993) norms tabled in the WCST manual. Although these later norms are more representative of North American children, such net-effect studies are incapable of examining the independent effects of age and schooling. Mazes tasks have also demonstrated small to moderate effects of education (Lezak, 1995), effects

which were found to be similar in magnitude to those found for the Wisconsin Card Sort Test in this study.

Of theoretical interest, previous investigators have also demonstrated moderately sized effects of schooling on the development of performance on a range of fluid intelligence measures (Ingeborg, Ferdinand, Ehlers & Remer, 1995). This aspect of intelligence, important in finding relationships, problem solving and in learning unfamiliar material has often been associated with processing speed-related parameters (Horn & Cattell, 1967). Moreover executive function and fluid intelligence share similarities in that with both normal child development and adult aging there are reliable life-span increments and decrements, respectively, in performance on tasks measuring these two classes of cognitive processes (Lezak, 1995). It should be emphasized that although executive function shares similarities with fluid intelligence these constructs are conceptually distinct. For example, planning (an important constituent of executive function) is inextricably linked within a social and cultural environment, with these intervening variables influencing under what conditions planning will take place in children (Friedman & Scholnick, 1997). Future research should further examine the potential relationship between the effects of social-motivational factors on context/task interactions for performance on classic EF tasks such as the WCST (e.g., Ozonoff, 1995).

The evidence suggests that formal schooling exerts small to moderate effects on the development of performance on the Wisconsin Card Sort Test, Thurstone Word Fluency Test, and Mazes tests. Since executive processes are essential for the control of distributed functional systems often associated with the frontal lobes but not exclusively with these structures (Stuss, Alexander & Benson, 1997), it seems probable that changing patterns of functional connectivity within these regions underlie at least in part the developmental age effects manifested on EF. Specifics of the mechanisms of these age-related neurophysiological changes associated with the prefrontal cortex are discussed in detail elsewhere (e.g., see Spreen, Risser & Edgell, 1995).

Quantitative analysis of schooling effects via the cutoff design has only recently been used as an effective methodology for exploring the effects of formal schooling on cognitive processes. Bisanz, Morrison and Dunn (1995) found that in the domain of mathematical skills the influence of formal schooling was specific, but that age-related variables other than schooling were implicated in more general elementary quantitative precursor skills such as conservation of number. A similarly designed study by Varnhagen, Morrison and Everall (1994) examining reading skill suggested that such age effects were attributable to general development in memory capacity and deployment of cognitive resources; while schooling effects were related to the acquisition of domain specific strategies.

The findings of schooling effects on executive function are not limited to theoretical discussion or to issues pertaining to the validity of clinical interpretation. Also relevant is Snow's (1992) analysis of a subgroup of children and adolescents with learning difficulties who performed poorly on the Wisconsin Card Sort Test and other measures of executive processes. These children were also found to have depressed mathematical calculation abilities, a domain that requires visual-spatial analysis, planning and sequencing. Applying these and other findings in an instructional context Naglieri and Gottling (1997) demonstrated that children with specific difficulties in strategy deployment as measured by standard planning tasks differentially benefited from an instructional intervention which involved graduated prompting, an inductive problem-solving approach and the overt verbalization of on-task strategies. Students enrolled in the instructional intervention later performed significantly better than a control group on a mathematics computation worksheet exercise, suggesting positive transfer of the intervention from the specialized instructional context to the classroom. Further research should focus on what *qualitative* and *quantitative* factors associated with formal education facilitate the development of executive processes. Such studies would have implications for the reliable interpretation of child neuropsychological assessment data in neurological and psy-

chiatric settings, and for educators interested in developing empirically based instructional interventions for students with planning problems.

The present study's results attest to the heterogeneity of executive function. No overall pattern of effects is evident across the three tasks hypothesized to assess different facets of executive function; and the preceding discussions suggest that executive processes exhibit complex task/age, and domain/context interaction effects. This conclusion is supported by a recent meta-analysis of the role of executive functions in some common developmental psychopathologies (Pennington & Ozonoff, 1996). These authors examined the efficacy of various executive tasks in discriminating children with attention-deficit-hyperactivity disorder (ADHD) from controls. Their results showed that the effect sizes for simpler tasks (WCST, mazes and letter fluency tests) possibly tapping only one or two aspects of executive function were considerably smaller than those for the Tower of Hanoi task: the latter could reasonably be expected to recruit multiple components of a distributed executive processing system. Moreover, different components of executive function were found to be impaired in two developmental psychopathologies often associated with dysexecutive spectrum syndromes, autism (e.g., verbal working memory problems) and ADHD (e.g., motor inhibition problems).

Table 2 depicts data which may be especially useful for interpreting the results of an assessment of a child who has either: (i) a birth date close to the school entrance cutoff date; and/or (ii) has been referred for the purposes of assessment of a learning problem and there are concerns about the amount/quality of the child's previous formal schooling experiences. Although many school districts in North America adhere to the March 1 (spring) cutoff many do not. It is perhaps more important that clinicians take note of the relative magnitude of age and schooling effects at these grade levels when making diagnostic interpretations for these executive function tasks (Table 3).

Executive function (EF) and planning tasks are increasingly being used as effective tools for the diagnosis and subtyping of learning prob-

lems of children (Snow, 1998). Proper interpretation of performance on these tasks will require an understanding that schooling effects on EF do not exert simple net-effect relationships. The results suggest that schooling effects are highly task-dependent, exhibit complex task/age and domain/context interactions. The problems of methods variance and issues of non-linearity of schooling effects are formidable conceptual difficulties unique to the assessment of EF. Future studies might attempt to address these problems by using dynamic assessment techniques with common executive function tasks, computational modeling techniques, or longitudinal designs with age, initial EF, and neurophysiological indicators as predictors so that the effects of school experience could be judged against the baseline per individual.

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