Factors underlying cognitive giftedness: Mental versus perceptual attention

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Factors Underlying Cognitive Giftedness: Mental Versus Perceptual Attention

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Abstract

Children identified as cognitively gifted, in comparison with age-matched mainstream samples, are advantaged in numerous areas, including mathematics, speed and efficiency in cognitive processing, and resistance to interfering stimuli. Although working memory (WM) has been implicated as a factor mediating these advantages, evidence suggests that gifted children may not be advantaged in all aspects of WM function. We hypothesized that this difference is related to the contrast between mental (related to prefrontal dopamine circuits) and perceptual attention (likely related to prefrontal acetylcholine circuits). Specifically, it was expected that cognitively gifted children would excel in WM tasks taxing mental but not perceptual attention. Ninety-one children from grades 4 and 8, in the gifted and mainstream academic streams, received WM tasks requiring primarily perceptual attention (SOPT) and mental attention (n-back), as well as measures of mental-attentional capacity, shifting, and inhibition. Gifted children outperformed their mainstream peers on all tasks, except SOPT (even when mental demand was matched). Results demonstrate a necessary distinction between mental and perceptual attention in the measurement of WM.

Factors Underlying Cognitive Giftedness: Mental Versus Perceptual Attention

Conceptualisations of cognitive giftedness often entail an element of intellectual precocity (e.g., intelligence significantly exceeding the average for a given chronological age), as commonly measured by standardized intelligence tests. In fact, identification of gifted children for subsequent inclusion in gifted education programs is often still determined, at least in part, by performance on these standardized measures. Children identified as gifted, in comparison with age-matched mainstream samples, are advantaged in numerous areas, including mathematics (Hoard, Geary, Byrd-Craven, & Nugent, 2008), speed and efficiency in cognitive processing (Johnson, Im-Bolter, & Pascual-Leone, 2003; Saccuzzo, Johnson, & Guertin, 1994), and resistance to interfering stimuli (Johnson et al., 2003).

Working memory (WM) has been implicated as a factor mediating the demonstrated cognitive advantages of gifted children. That is, gifted children, in addition to superior performance on standardized intelligence tests, also tend to demonstrate an increased WM capacity in comparison with their mainstream peers (Johnson et al., 2003; Pascual-Leone & Johnson, 2010; Saccuzzo et al., 1994; Segalowitz, Unsal, & Dywan, 1992). This is consistent with research showing a strong association between performance on working memory and general ability measures in children and adults (e.g., Cowan et al., 2005; Cowan, Fristoe, Elliott, Brunner, & Saults, 2006; Engle, Kane, & Tuholski, 1999; Heitz, Unsworth, & Engle, 2005; Kaufman, DeYoung, Gray, Brown, & Mackintosh, 2009).

Complicating this relationship, however, is Segalowitz et al.'s (1992) finding that gifted children outperformed their mainstream counterparts on tasks of central executive function, but not on two visual-spatial WM tasks (for findings indicating a gifted advantage on visual-spatial WM tasks, see Hoard et al., 2008). A possible explanation for this dissociation among WM tasks is suggested by the Theory of Constructive Operators (TCO) (Pascual-Leone & Goodman, 1979), in its contrast between effortless perceptual (externally-driven) attention versus effortful mental attention - a distinction that is not readily available in contemporary WM theory. Gifted children, thus, may be advantaged on tasks requiring primarily mental attention (the domain-free aspects of WM or general executive strategies), but not on tasks that can be solved primarily with perceptual attention.

Attentional Processes Subserving Working Memory: Mental Versus Perceptual Attention

Although WM processing is intrinsically variable due to the variability in modality (e.g., visual, auditory) and domain (e.g., spatial, quantitative) across WM tasks, neuroscientific evidence has implicated distinct brain structures and processes consistently involved in WM. Foremost among these are the contributions of the dorsolateral prefrontal cortex and prefrontal dopamine to the activation, inhibition, and coordination of cortical pathways (routinely bundled as attentional and executive functions; Diamond, Briand, Fossella, & Gehlbach, 2004; Diamond, Prevor, Callender, & Druin, 1997; Petrides & Milner, 1982; Wiegersma, van der Scheer, & Hijman, 1990). Despite evidence for these common mechanisms, however, recent findings have shown that even these domain-general components of WM are insufficient to explain the entire range of WM function. For instance, Diamond et al. (2004) reported that whereas success on the self-ordered pointing task (SOPT; a WM task commonly used to assess prefrontal executive function) is reliant upon the dorsolateral prefrontal cortex (Diamond et al., 2004; Petrides & Milner, 1982; Wiegersma et al., 1990), performance was unaffected by depleting prefrontal dopamine (DA; Diamond et al., 1997, 2004; Petrides & Milner, 1982). These findings appear particularly problematic for frameworks that envision a singular attentional mechanism subserving WM, as the recruitment of differential brain resources across tasks that are purportedly homogenous (at least insofar as they commonly engage WM) suggests the mobilization of a discrepant set of cognitive processes toward task completion.

In resolving the inability of prefrontal DA to account for the broad range of WM functions, the Theory of Constructive Operators (TCO) distinguishes between effortless perceptual (externally-driven) attention and effortful mental attention – a distinction that is not readily available in contemporary WM theory (Pascual-Leone & Goodman, 1979). The TCO further hypothesizes that these distinct forms of attention are mediated by different neurotransmitters according to the functional characteristics of the task (Pascual-Leone & Johnson, 2006). Perceptual attention, believed to be mediated by the acetylcholinergic neurotransmitter, refers to cognitive processing of external (perceptually available) information (Pascual-Leone & Johnson, 2006). In contrast, mental attention, believed to be mediated by the dopaminergic neurotransmitter, entails the voluntary, often effortful cognitive processing of internal (mental) information, which functions with relative autonomy from perceptual input (Pascual-Leone & Johnson, 2006). These hypotheses receive support from findings that prefrontal functioning in strongly misleading situations (e.g., as in the n-back task) is supported by the DA-system (Braver & Barch, 2002; Luciana, Hanson, & Whitley, 2004; Mehta, Manes, Magnolfi, Sahakian, & Robbins, 2004; Mollion, Ventre-Dominey, Dominey, & Brousolle, 2003), whereas facilitating situations, as in the SOPT, are thought to be supported by prefrontal acetylcholine (ACh) (Foldi, White, & Schaefer, 2005; for a review of ACh function see Sarter & Bruno, 1997).

Linking Mental Attention, Perceptual Attention, Working Memory, and Giftedness

Although previous evidence has shown gifted children tend to outperform their mainstream peers on measures of WM capacity, mental-attentional (*M*-) capacity, and executive function (Johnson et al., 2003; Johnson, Pascual-Leone, Im-Bolter, & Verrilli, 2004), it is not clear to what extent, as a group, higher gifted performance on WM and *M*-measures is due to advanced capacity versus superior executive skills. This lack of clarity stems from the fact that heightened performance on *M*-measures may result from a heightened *M*-capacity, superior executive processes, or both, due to the concurrent requirement for activation and inhibition in these tasks. Further sources of activation exist in WM measures (e.g., overlearning, affect), whereby mental attention is but one of these possible sources of high activation. From this perspective, *M*-capacity can be seen as the causal factor underlying developmental growth in WM (Pascual-Leone & Johnson, 2005). Further, in conjunction with learning, the maturation of *M*-capacity (from one symbolic unit at 3-4 years of age to seven symbolic units at 15+ years, increasing one unit approximately every two years) leads to increasingly complex cognition and performance across development. In contrast, perceptual attention (controlled by the brain's default network) is believed to develop earlier and more rapidly than mental attention.

In the present study we sought to investigate the factors underlying cognitive giftedness by examining the TCO's contrast between mental and perceptual attention in gifted and mainstream children. It was predicted that gifted children can be distinguished by a superior executive repertoire, such that they should perform better than mainstream peers on a high-executive-demand task requiring mental attention (i.e., n-back updating task). However, they should not show superior performance on a lower-executive-demand task that involves primarily perceptual attention (i.e., SOPT), even when the updating element and mental demand of the tasks are equated. Conversely, if gifted children are found to score higher on both tasks (i.e., both metal and perceptual attention), then *M*-capacity alone (which can also be used in perceptual tasks) may be sufficient, without regard to executive repertoire, to distinguish gifted children from mainstream ones. On the premise that gifted children possess a sophisticated executive repertoire, it was further hypothesized that gifted children would outperform their mainstream peers on executive function tasks. As executive strategies can be learned, such a result would suggest that the demonstrated advantages of gifted children are, at least in part, learned. If so, there exists the possibility that appropriate educational initiatives could narrow the demonstrated performance gap between gifted and mainstream students.

Method

Participants

Participants were 91 children from an elementary school in the Greater Toronto Area. They were from grades 4 and 8 and from gifted and mainstream academic programmes. The four groups were: grade 4 mainstream (n=22), grade 4 gifted (n=28), grade 8 mainstream (n=22), and grade 8 gifted (n=19). Students categorized as gifted were in congregated classrooms for children identified as gifted. Identification required a minimum achievement of 97th percentile on Board-approved standardized intelligence or ability tests. Children categorized as mainstream in the current study were in regular classrooms. The sample was comprised of 45 girls and 46 boys. Age ranged from 9.28 to 14.23 years (grade 4: M=9.81, SD=0.33; grade 8: M=13.72, SD=0.31).

Measures

All computer-based measures were presented on a Dell Latitude D820 laptop computer and were programmed in E-Prime 1.2 (Psychology Software Tools, Pittsburgh, PA). Responses to the SOPT were made via a KTMT-1700W Magic Touch add-on touch screen (Keytec Inc., Garland, TX) using a stylus.

Higher executive-demand measure, primarily requiring mental attention: N-back. The n-back requires subjects to mentally update the set of relevant stimuli at the expense of those that are no longer task-relevant (Cohen et al., 1997; Friedman et al., 2006; Im-Bolter, Johnson, & Pascual-Leone, 2006; Nystrom et al., 2000). Subjects must evaluate whether the currently presented stimulus matches a stimulus presented *n* items earlier, which is no longer perceptually available. It carries high executive demand and requires mobilization of mental attention. We predicted that gifted children would score higher on updating trials.

This computer-based task had three conditions, presented in ascending order of difficulty. Stimuli were three-dot patterns that were presented serially on a computer screen. In the 0-back condition, subjects identified whether or not each new stimulus matched a particular 3-dot target pattern. In the 1-back condition, they identified whether or not each new pattern matched the immediately preceding one (i.e., 1 item back). This condition required subjects to update the contents of WM after each presentation. The 2-back condition required subjects to match the current pattern to the one presented two items earlier in the sequence (i.e., 2 items back). This condition required the continual and serial updating of the two most recent patterns.

There were nine distinct three-dot patterns, presented in a semi-random order. For each condition children received verbal training, 15 paper-based practice trials on 5x8 inch cue cards, 14 computer-based practice trials, and 54 task trials (4 non-scored preparation trials, 30 non-match test trials, and 20 match test trials). The paper-based practice trials were repeated a maximum of three times, if the child did not understand the instructions (evidenced by one or more incorrect responses). Participants indicated with a key press whether or not the current pattern matched the target pattern (0-back) or the pattern seen one or two trials earlier. Each stimulus was presented for 500 ms, followed by a 2500 ms gap, during which the subject could respond. A tone signalled responses that were incorrect or made beyond the trial time limit. We report data on the proportion of correct target identifications (i.e., match trials).

Lower executive-demand measures, primarily requiring perceptual attention: SOPT. The self-ordered pointing task (SOPT; originally developed by Petrides & Milner, 1982) is a WM task of prefrontal executive function. Subjects repeatedly see the same set of stimuli (rearranged on each trial) and must point to a new stimulus on each trial. The SOPT is facilitating, because the relevant stimuli are always perceptually available, and it carries minimal executive demand (i.e., little need for inhibition, shifting, or updating). We predicted that gifted children would score equivalently to mainstream children on the SOPT.

We used the abstract stimuli condition of the SOPT version developed by Cragg and Nation (2007). Subjects were shown a set of abstract designs (4, 6, 8, or 10 designs) on a laptop screen, and could select (i.e., touch) any design to begin. Upon making a selection, the next screen appeared with the same designs in different locations. With each screen, subjects had to select a new design, without duplicating a selection, thus attempting to select each design exactly once. Each set was repeated three times successively, separated by a screen indicating the "game" number, differing only in stimuli locations. The designs within the three presentations of each set size remained constant; however, novel abstract designs were adopted for each set size. Designs measured 43 x 43 mm and were black and white presented on a blue background (for examples see Cragg & Nation, 2007). Task levels were presented in order of ascending set size, with the first (4 design) level used as training. Abstract designs were chosen due to the difficulty of encoding them verbally, thereby minimizing the possible influence of differential linguistic ability between groups. We report data for a span score (mean number of correct touches until the first error, not including the first touch for which an error is not possible). Results were similar when data were analyzed in terms of accuracy (proportion correct selections).

In order to complexify the SOPT we developed a version that required updating; we call this the U-SOPT. The updating component was introduced in order to match the mental demand (in terms of *M*-capacity) and updating requirement of the n-back, yet preserve the task's demand primarily for perceptual attention. Only the 4, 6, and 8 design levels were administered in the U-SOPT, and again, the 4-design level was used for training. In addition to selecting a new design on each screen, subjects had to indicate their just-previous selection. For example, upon reaching the second screen, they were required to choose a previously unselected ('new') design, followed by indicating the ('old') selection that immediately preceded this. After subjects indicated their selections, the stimuli would rearrange (via the experimenter's press of the spacebar on an external keyboard). The stimuli remained the same as for each corresponding level of the standard SOPT. As with the SOPT, we report data on mean span until the first error of any sort (mean number of correct screens until the first error, not including the first screen for which an error is not possible).

***M*-capacity measures.** The Figural Intersections Task (FIT; Pascual-Leone & Baillargeon, 1994; Pascual-Leone & Ijaz, 1989; Pascual-Leone & Johnson, 2010) is a paper-based measure of *M*-capacity. Each item is comprised of a set of two to eight discrete shapes on the right-hand side of the page, and the same set of shapes in an overlapping configuration on the left-hand side (in some items there is an additional irrelevant shape, to be ignored, on the left). Subjects must locate the one area of common intersection of the relevant overlapping shapes on the left. Item level is defined as the number of relevant shapes to be held in mind in order to find the intersection. Item level also corresponds to the demand of items in terms of need for *M*-capacity (i.e., *M*-demand; Pascual-Leone & Baillargeon, 1994; Pascual-Leone & Johnson, 2010).

The FIT was administered in one group session for each class, with each subject independently completing his or her own booklet. FIT booklets consisted of 36 randomly ordered items (ranging from difficulty levels 2 to 8). There were 5 items at each difficulty level 2 through 8, with the exception of level 4 which had 6 items. Training was provided to the group in the context of 8 practice items. FIT *M*-score corresponded to the highest item level with at least 80% of items solved correctly, provided all lower levels also reached the 80% threshold with one lower level permitted to fall to 60%.

The Direction Following Task (DFT) is a linguistic measure of *M*-capacity (Agostino, Johnson, & Pascual-Leone, 2010; Cunning, 2003; Im-Bolter et al., 2006; Pascual-Leone & Johnson, 2010). Subjects use cut-outs that vary in shape (circle or square), colour (white, blue, green, red, or yellow), and size (small or large) in order to carry out verbal directions of increasing complexity. The directions require placing a cut-out onto a space on a wooden board (i.e., "place X on Y"). Spaces vary in size and color.

The task consisted of 35 graded items (5 items at each of seven levels of complexity), preceded by verbal training and 5 practice items. Complexity was a function of the number of objects, spaces, and characteristics in the direction (e.g., "Place a white square on a small blue space," "Place a red square and a white circle on a small yellow space"). Directions referring to two objects had to be carried out in the specified order. The shapes and board were covered while each instruction (item) was read aloud, after which the stimuli were made available to the subject to carry out the instruction.

The *M*-demand of DFT levels is a function of the number of elements within the instruction that must be activated simultaneously with mental attention. Theoretical *M*-demand estimates have been validated empirically (Cunning, 2003; Im-Bolter et al., 2006; Pascual-Leone & Johnson, 2005, 2010). DFT *M*-score corresponded to the *M*-demand of the most complex level with at least 60% of items solved correctly, provided all lower levels also reached the 60% threshold with one lower level permitted to fall to 40%. Consistent with previous findings, we expected gifted students to score higher than mainstream students on the *M*-tasks.

Executive function tasks. The Contingency Naming Task (CNT) was designed by Taylor, Albo, Phebus, Sachs, and Bierl (1987) as a cognitive flexibility measure (see also, Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001; Anderson, Anderson, Northam, & Taylor, 2000). It has since been used as a measure of shifting or task switching (e.g., Agostino et al., 2010; Mazzocco & Kover, 2007). The task involves two simple naming trials, as well as a one-dimensional and a two-dimensional shifting trial. These trials are presented in order of increasing difficulty.

The stimulus card contained three rows of nine coloured (blue, green, and pink) shapes (square, circle, and triangle), each enclosing an inner shape (square, circle, and triangle). Above three of the stimuli in each row there was a backward pointing arrow. Subjects named aloud the color or outer shape of each stimulus, based on a set of rules. In the first trial, they named the colour of each design, and in the second trial named the outer shapes. The one-dimensional shifting trial required them to name the color of the design when the inner and outer shapes matched, but to name the outer shape when there was no match. The two-dimensional shifting trial involved switching between two rules: 1) maintain the rule from the previous one-dimensional switching task; but 2) reverse this rule when a backward arrow appeared above a design. Instructions emphasized both speed and accuracy.

Before each trial condition, children were introduced to the relevant rule and practiced it on a seven-design practice card. Practice was repeated until all seven responses were correct or a maximum of five practice trials had been administered. For each trial condition, the tester noted errors and used a hand-held stopwatch to record the time taken to respond to all 27 stimuli. We report data for an efficiency score that reflects both accuracy and speed. It is calculated by the following formula: [(1/ time to complete the sub-task) / SQRT (errors + 1)] x 100, and a higher score represents better ability to shift (Anderson et al., 2000).

The Antisaccade task (adapted from Miyake, Friedman, Emerson, Witzki, & Howerter, 2000) indexes inhibitory control (Agostino et al., 2010; Im-Bolter et al., 2006; Miyake et al., 2000). The prepotent response in this task is to perform a saccade in the direction of a visual cue that suddenly enters the visual field. For successful performance, however, subjects must inhibit this saccade. While focusing on a fixation point, subjects are faced with a visual cue (a solid black square) on one side of a computer screen, promptly followed by a target stimulus (an arrow pointing up, right, or left inside a box) on the opposite side of the screen. They must inhibit their reflexive saccade toward the visual cue, instead looking toward the target stimulus on the opposite side of the screen, in order to identify the target before it is masked. Failure to inhibit this saccade results in subjects' being unable to accurately identify the direction the target stimulus was pointing (indicated by pressing the '←', '↑', or '→' key on the laptop keyboard). The timing of stimuli presentation was as follows: a fixation cross for a variable time (1500-3500 ms); a blank screen for 50 ms; a cue for 225 ms; a target for 100 ms, followed by a mask that remained on screen until a response was made.

Twenty-two practice trials and 90 target trials were administered. The order of stimuli (arrow direction and left vs. right side of screen) was determined randomly for each subject. Scores were proportion correct target identifications and latency for correct responses.

Procedure

Tasks were administered in three sessions, two individual (in a separate, quiet classroom) and one group (in the students' homeroom), each about 40 minutes long. Order of task administration was held constant as follows: Individual Session 1 – Self-Ordered Pointing Task, Updating Self-Ordered Pointing Task, Contingency Naming Task, Direction Following Task; Individual Session 2 – n-back, Antisaccade; and Group Session – Figural Intersections Task.

Results

Data Screening

Data first were screened for normality and sphericity. Because sphericity consistently was violated, an adjusted degrees of freedom analysis (Greenhouse-Geisser) was conducted for all within-subjects effects. For all task scores in which outliers were present (i.e., n-back, DFT, antisaccade accuracy, and antisaccade latency) analyses were run with and without extreme observations. Because the pattern of results did not differ for any variable, we retained these observations in all reported analyses.

N-back. Due to demand for mental attention, we predicted that gifted students would score higher than mainstream peers on updating conditions of the n-back task. We conducted a Greenhouse-Geisser (G-G) 2 (stream) x 2 (grade) x 3 (condition) ANOVA on proportion of correct responses on trials in which there was a match between stimulus and target (i.e., correct target identification). There were main effects for stream, $F(1, 87) = 8.81$, $p = .004$, partial $\eta^2 = .09$; grade, $F(1, 87) = 7.86$, $p = .006$, partial $\eta^2 = .08$; and n-back condition, $F(1.771, 154.071) = 238.02$, $p < .001$, partial $\eta^2 = .73$. Overall, gifted students scored higher than mainstream peers, grade 8s scored higher than grade 4s, and contrasts showed that scores decreased with each increase in n-back level.

There were Stream x Condition, $F(1.771, 154.071) = 6.16$, $p = .004$, partial $\eta^2 = .07$; and Grade x Condition interactions, $F(1.771, 154.071) = 3.84$, $p = .028$, partial $\eta^2 = .04$. These were conditioned by a Stream x Grade x Condition interaction, $F(1.771, 154.071) = 6.46$, $p = .003$, $\eta^2 = .07$. This interaction can be understood as follows: 1) There was no gifted advantage on the simple 0-back task; 2) gifted children in both grades showed an advantage on the moderately difficult 1-back task; and 3) on the difficult 2-back task, there was a gifted advantage only for the older children—indeed, mainstream grade 8s and both groups of grade 4s performed at chance level on this task.

Self-ordered pointing task (SOPT). If giftedness in childhood is characterized by high performance in tasks with high demand for both mental attention and executive processing, then we would not expect a gifted advantage on a task such as SOPT, which is facilitated by perceptual attention. We examined mean span (i.e., mean number of correct touches till an error) with a G-G 2 (stream) x 2 (grade) x 3 (condition) ANOVA. Grade 8s had longer spans than grade 4s, $F(1, 88) = 8.50$, $p = .004$, partial $\eta^2 = .09$; and span increased as number of designs increased, $F(1.762, 155.081) = 36.72$, $p < .001$, partial $\eta^2 = .29$. Gifted and mainstream children did not, however, differ in terms of span score on any of the task conditions, $F(1, 88) = 0.70$, $p = .407$, partial $\eta^2 = .01$. We examined two other scores derived from the SOPT and found no difference between gifted and mainstream students in mean number of correct responses, $F(1, 88) = 1.31$, $p = .256$, partial $\eta^2 = .02$; or median latency for correct responses, $F(1, 77) = 2.54$, $p = .115$, partial $\eta^2 = .03$. These results could be due, however, to factors other than SOPT performance being facilitated by perceptual attention. SOPT differs from the n-back both in terms of executive demand and demand for mental attention (or working memory).

Updating self-ordered pointing task (U-SOPT). We thus modified the SOPT by adding an updating component that should increase the mental demand of the task, while maintaining its primary reliance on perceptual attention. We report data for mean span (i.e., mean number of correct screens) before an error of any kind. A G-G 2 (stream) x 2 (grade) x 2 (condition) ANOVA was conducted. Similar to results with the SOPT, grade 8s outperformed grade 4s, $F(1, 88) = 21.20$, $p < .001$, partial $\eta^2 = .19$; and span increased with the number of designs, $F(1, 88) = 52.14$, $p < .001$, partial $\eta^2 = .37$. However, gifted and mainstream children did not differ in terms of span score in any of the U-SOPT task conditions, $F(1, 88) = 1.33$, $p = .253$, partial $\eta^2 = .02$. This pattern of results held even when span scores were analyzed separately for 'new' and 'old' touches. Similarly, there were no effects involving academic stream when data were analyzed in terms of mean number of correct old or new touches. Thus, consistent with predictions, gifted children scored higher on the n-back but not on SOPT or U-SOPT.

***M*-measures.** We predicted that gifted students would out-score mainstream peers on measures of *M*-capacity. A 2 (stream) x 2 (grade) ANOVA on the FIT *M*-score yielded main effects for stream, $F(1, 86) = 10.70$, $p = .002$, partial $\eta^2 = .11$; and grade, $F(1, 86) = 34.13$, $p < .001$, partial $\eta^2 = .28$. Gifted students scored higher than their mainstream peers, and grade 8s scored higher than grade 4s. Further, performance levels corresponded closely to theoretically predicted values (Pascual-Leone & Johnson, 2010). That is, grade 4 mainstream children (aged 9-10) obtained mean *M*-scores close to four, and grade 8 mainstream children (aged 13-14) obtained mean *M*-scores close to six. Gifted children, in contrast, scored approximately one level higher than their mainstream counterparts (i.e., about 5 for grade 4s and about 7 for grade 8s).

A 2 (stream) x 2 (grade) ANOVA run on the Direction Following Task (DFT) *M*-score yielded main effects for stream, $F(1, 88) = 13.25$, $p < .001$, partial $\eta^2 = .13$; and grade, $F(1, 88) = 20.45$, $p < .001$, partial $\eta^2 = .19$. Gifted students scored higher than their mainstream peers, and grade 8s scored higher than grade 4s. Performance level mirrored theoretical prediction for grade 4 mainstream students, but grade 8 mainstream students tended to underperform on the DFT relative to FIT and theoretical predictions. Still, gifted students in both grades scored about one unit higher than their mainstream peers.

Shifting measure. The Contingency Naming Task (CNT) efficiency score conjointly reflects speed and accuracy. A G-G 2 (stream) x 2 (grade) x 4 (condition) ANOVA yielded main effects for condition, $F(2.26, 198.92) = 515.94$, $p < .001$, partial $\eta^2 = .85$; grade, $F(1, 88) = 66.97$, $p < .001$, partial $\eta^2 = .43$; and stream, $F(1, 88) = 10.89$, $p = .001$, partial $\eta^2 = .11$. Efficiency scores were higher for grade 8s than grade 4s, higher for gifted over mainstream students, and higher for naming (i.e., trials one and two) than for shifting trials (i.e., trials three and four). These main effects were conditioned by a Grade x Condition interaction, $F(2.26, 198.92) = 8.47$, $p < .001$, partial $\eta^2 = .09$, indicating a significant difference between grade 8s and grade 4s at all task levels, although this difference decreased as task difficulty increased. These effects were further conditioned by a Grade x Stream x Condition interaction, $F(2.26, 198.92) = 3.02$, $p = .045$, partial η2 = .03. This interaction suggests a gifted advantage on the shifting trials but not on simple speed of naming trials; this advantage held only for grade 8 gifted students on trial four, possibly due to the high *M*-demand of the two-dimensional shifting task. This gifted advantage on shifting trials, but not on speeded naming trials, was maintained in separate analyses of accuracy, $F(1, 88) = 23.40$, $p < .001$, partial $\eta^2 = .21$; and latency, $F(1, 82) = 7.58$, $p = .007$, partial $\eta^2 = .09$ (although the gifted advantage was found only in grade 8 for latency).

Inhibition measure. Proportion correct target identifications on the antisaccade task was examined with a 2 (stream) x 2 (grade) ANOVA. It yielded main effects for grade, $F(1, 87) = 18.93$, $p < .001$, partial $\eta^2 = .18$; and stream, $F(1, 87) = 7.11$, $p = .009$, partial $\eta^2 = .08$. Gifted children were more accurate than mainstream children, and grade 8s were more accurate than grade 4s. Analysis of median response times demonstrated a main effect for grade, $F(1, 87) =$

49.69, $p < .001$, partial $\eta^2 = .36$; but not for stream, $F(1, 87) = 0.51$, $p = .479$, partial $\eta^2 = .01$. Grade 8s responded faster than grade 4s did. In sum, grade 8 students performed better than grade 4's on all tasks. As predicted, gifted students scored higher than mainstream on all tasks, except the two SOPT versions.

Correlations. Because correlations computed across the entire sample would conflate age and stream differences, making interpretation difficult, we present correlations computed within stream and with age partialled out (correlations thus reflect individual differences). There were few significant correlations for the gifted sample. Theoretically, most of the shared variance between FIT and DFT should be due to age; thus, a low correlation is expected when age variance is removed. The general absence of correlations between *M*-scores and other tasks suggests that rather than relying on an advanced endogenous mental-attentional capacity or general executive know-how, gifted children may rely on more specialized (task-specific) executive skills. This is in accordance with the hypothesis that gifted (but not mainstream) children will have already acquired a sophisticated executive repertoire.

In contrast, there were numerous inter-task correlations in the mainstream sample. The *M*-tasks correlated with the 2-back (FIT only), SOPT, U-SOPT, and CNT. Switching efficiency in the CNT correlated with all other tasks. The antisaccade correlated with 2-back and switching. This pattern suggests that mainstream children may be relying more on general capacity or general executive know-how. That is, in line with predictions, the mainstream children, unlike their gifted peers, may have fewer specific executive schemes that selectively apply in particular tasks. Instead, mainstream students may rely on general executives and *M*-capacity, as is demonstrated by the significant correlation between the average *M*-capacity score (the mean of FIT and DFT *M*-scores) and all other measures.

Discussion

Consistent with past research (Johnson et al., 2003; Johnson et al., 2004; Navarro et al., 2006; Pascual-Leone & Johnson, 2010), and as predicted, gifted children demonstrated an advantage over their mainstream peers on tasks mobilizing primarily mental attention, but not those involving primarily perceptual attention (even when it was made more complex by adding an updating component). That is, gifted children scored higher than mainstream peers on the n-back WM task, as well as measures of *M*-capacity, inhibition, and task switching. Gifted children did not score higher on the SOPT, however, even when it was made more complex by adding an updating component.

These results suggest why a construal of WM as the significant factor underlying cognitive giftedness fails to adequately explain the gifted advantage. However, characterizing giftedness in terms of heightened *M*-capacity can be similarly problematic. Indeed, performance on measures of *M*-capacity is co-determined by an individual's organismic *M*-capacity and their 'executive know-how' (e.g., problem solving strategies), thereby raising the question of whether this mental attentional advantage is related to a heightened endogenous *M*-capacity or a superior repertoire of executive strategies.

In support of a disparate executive know-how between the educational streams (i.e., gifted vs. mainstream), and as predicted, gifted children demonstrated superior performance on tasks of higher executive demand (i.e., 1-back, 2-back, *M*-measures, antisaccade, contingency naming task). This advantage did not appear, however, on tasks of lower executive demand (i.e., SOPT, U-SOPT, 0-back, and speeded naming trials of the contingency naming task). In fact, if the gifted advantage were attributable solely to an advanced organismic *M*-capacity, superior performance should be expected across all tasks because mental attention could be recruited in support of perceptual attentional resources, thereby boosting gifted performance on the SOPT and U-SOPT as well. Conversely, and in line with the current results, if the gifted advantage is attributable to superior executive repertoires, this would provide little advantage on the lower-in-executive-demand (in relation to the n-back) SOPT and U-SOPT.

As children's executive know-how is largely influenced by learning, these findings open an interesting avenue towards educational programs that, equipped with these distinctions, may provide a means for active academic enrichment applicable to all children. This possibility was supported by the suggestion that the gifted advantage appears, in *M*-normal children, to be related to a superior repertoire of executive schemes, thereby emphasizing learned advantages and training programs rather than focusing on inherent organismic differences. One potentially viable educational direction for bridging the performance gap between identified gifted and mainstream children might involve increasing the exposure to novel problem situations and other executive-enhancing situations. That is, rather than constructing higher-order, subject-specific concepts by way of facilitating construction of lower-order requisite knowledge structures, executive know-how might be better developed by supplying children with suitable problem situations in which children can explore (with suitable cognitive guidance) the relations and invariances across situations. Through repeated exposure to this mode of learning, it could be expected that children develop an enhanced repertoire of executive schemes (e.g., strategies) that foster increased success in transferring specific knowledge to novel situations or novel applications (a common requirement within educational assessment). Although this study provides clear support for these claims, further study is required to strengthen and develop these possibilities.

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