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The development of cognitive flexibility beyond the preschool period: An investigation using a modified Flexible Item Selection Task

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A B S T R A C T

We explored the development of cognitive flexibility in typically developing 6-, 8-, and 10-year-olds and adults by modifying a common cognitive flexibility task, the Flexible Item Selection Task (FIST). Although performance on the standard FIST reached ceiling by 8 years, FIST performance on other variations continued to improve until 10 years of age. Within a detailed task analysis, we also explored working memory storage and processing components of executive function and how these contribute to the development of cognitive flexibility. The findings reinforce the notion that cognitive flexibility is a multifaceted construct but that the development of working memory contributes in part to age-related change in this ability.

Introduction

Cognitive flexibility describes the ability to begin solving a problem in one way and to then shift to solving the same problem in a different way. Despite this simple description, a more precise characterization of the principal cognitive processes that comprise cognitive flexibility has remained elusive (Cragg & Chevalier, 2012; Deak, 2004; Dick & Overton, 2010). This is because the standard tasks proposed to assess cognitive flexibility are likely simultaneously assessing multiple component executive functions (Hughes & Graham, 2002; Miyake et al., 2000), and it has been difficult to define and parse

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each of these components. In addition, there has been a renewed interest in characterizing the development of cognitive flexibility and other executive functions beyond the preschool period (Cragg & Chevalier, 2012), a period that has to date received the most attention (Best, Miller, & Jones, 2009; Garon, Bryson, & Smith, 2008). Here we addressed both issues. We conducted a focused analysis of cognitive flexibility development with an emphasis on the contributions of working memory, and we did so by adapting a Flexible Item Selection Task (FIST) developed by Jacques and Zelazo (2001) so that it remains sensitive to development in cognitive flexibility beyond the preschool period.

Classic investigations of cognitive flexibility have made use of several tasks, the most prominent of which is the Wisconsin Card Sorting Test (WCST; Berg, 1948; Grant & Berg, 1948). In this task, participants must sort picture cards by one dimension (e.g., color) and then switch to sort the cards by a different dimension that is guessed from experimenter feedback. The WCST has also been modified for preschool children (i.e., as the Dimensional Change Card Sort [DCCS]; Frye, Zelazo, & Palfai, 1995) by using fewer cards and by making the sorting rule explicit. Developmental investigations of the WCST and DCCS have revealed some surprising results. Despite success on the DCCS at around 4½ years of age, children have difficulty in performing the basic task requirements of the WCST until around 6 years of age, and when they do meet these requirements they make perseverative errors on a level identical to that of adults with prefrontal lesions, failing to perform at a normal adult level until around 10 years of age (Chelune & Baer, 1986; Chelune & Thompson, 1987; Crone, Ridderinkhof, Worm, Somsen, & van der Molen, 2004; Kirk & Kelly, 1986; Paniak, Miller, Murphy, & Patterson, 1996; Rosselli & Ardila, 1993; Welsh, Pennington, & Groisser, 1991). In addition, rather than the rapid change in success found between 3 and 4½ years of age on the DCCS (i.e., children tend to either pass or fail the task), improvement on the WCST is gradual (Chelune & Baer, 1986; Crone et al., 2004). More difficult variations of the DCCS also show age-related improvement across childhood, but these are not appropriate for preschool children (Zelazo, Craik, & Booth, 2004).

Another addition to this family of sorting tasks, and the focus of the current study, appears to measure cognitive processes similar to those of the WCST and DCCS. This task, called the Flexible Item Selection Task (Blair, Peters, & Granger, 2004; Blair & Razza, 2007; Jacques & Zelazo, 2001), requires participants to abstract a relevant matching dimension and to switch flexibly to a new matching dimension. In the standard FIST (referred to here as a 2-Match FIST), a child is presented with three objects, and they must select two objects that match in one way (i.e., the first selection). Thus, the child must abstract out a relevant dimension on which two objects are alike. For example, the child might be shown the following cards: one large red rabbit (Card 1), one large blue rabbit (Card 2), and one large blue boat (Card 3). The first abstraction could be accomplished by considering two cards in relation to a third card (e.g., Cards 1 and 2 are the same shape, which is different from Card 3). Next the child must flexibly abstract and switch to a second dimension. For example, for the second selection, the child must select two other objects that match in a way that is not like the third object (e.g., Cards 2 and 3 are the same color, which is different from Card 1).

Jacques and Zelazo (2001) conducted the first developmental investigation of the FIST. In their study, the authors assessed children on tasks containing two relevant dimensions (i.e., a 2-Match FIST) and reported the following pattern of development. First, 2-year-olds are unable to pass the criterial measures of the task. Second, relative to their older peers, most 3-year-olds show poor performance on both the first selection and the second selection. Third, 4-year-olds show good performance on the first selection but have difficulty in switching to the second selection. Fourth, 5-year-olds can flexibly abstract the relevant dimension of the first selection and perform better at the second selection than their younger peers. However, 5-year-olds are still performing only at 50% on the second selection and do not approach ceiling performance until 6 years of age (Yerys, Wolff, Moody, Pennington, & Hepburn, 2012).

The DCCS, WCST, and FIST share surface similarities (i.e., they all require sorting cards by perceptual dimensions), but it is unclear which specific skills are necessary for success on these tasks. Although children are able to successfully navigate the DCCS by 4½ years of age, they have considerable difficulty on the WCST for quite some time afterward. No extensive investigation of the FIST has been conducted beyond the preschool and early school-age period; thus, the developmental pattern beyond these years is unknown. This developmental question was explored in the current study. The existing literature investigating developing cognitive flexibility beyond the preschool period suggests that children will continue to perseverate on more difficult manipulations of the FIST until at least 10 years of age (Cepeda, Kramer, & Gonzalez de Sather, 2001; Cragg & Nation, 2009; Crone, Bunge, van der Molen, & Ridderinkhof, 2006; Davidson, Amso, Anderson, & Diamond, 2006; Huizinga, Dolan, & van der Molen, 2006; Zelazo et al., 2004).

In addition to characterizing age-related improvements on these shifting tasks, researchers have attempted to identify what these tasks measure. The WCST has been proposed to measure a number of abilities, including set shifting/mental flexibility (Ashendorf & McCaffrey, 2008), working memory (Gamboz, Borella, & Brandimonte, 2009), inhibition (Gamboz et al., 2009; Salthouse, Atkinson, & Berish, 2003), and problem solving (Greve et al., 2002). For tasks like the DCCS and FIST, researchers have presented several theoretical accounts (Kirkham, Cruess, & Diamond, 2003; Kloo & Perner, 2005; Morton & Munakata, 2002; Munakata, Morton, & Yerys, 2003; Müller, Dick, Gela, Overton, & Zelazo, 2006; Ramscar, Dye, Gustafson, & Klein, 2013; Zelazo, Müller, Frye, & Marcovitch, 2003), many of them focusing on the roles of inhibition and working memory (see Garon et al., 2008, for a review). The FIST is particularly suitable for manipulating working memory demands, and for this reason we focused on the contribution of working memory to developing cognitive flexibility.

Improvements in working memory, typically defined as processes involved in the active maintenance and manipulation of information over brief time periods (Miyake & Shah, 1999), have been offered as an explanation for improvements in cognitive flexibility (Blackwell, Cepeda, & Munakata, 2009; Demetriou, Christou, Spanoudis, & Platisidou, 2002; Gordon & Olson, 1998; Halford, Wilson, & Phillips, 1998; Marcovitch & Zelazo, 2009; Munakata, 2001, 2002; Zelazo et al., 2003). This construct can be further parsed into maintenance and manipulation components or, more commonly, "storage" and "processing" components. As children become increasingly capable of holding information in mind over a temporal delay, they can be said to improve *working memory storage capacity*, which is often measured by tasks like Forward Digit Span (i.e., repeating a series of digits in the order they were given). More complex tasks require holding in mind and updating/manipulating the information, such as during Backward Digit Span (i.e., repeating a series of digits in reverse order), and this is termed *working memory processing capacity* (Gathercole & Pickering, 2000; Gathercole, Pickering, Ambridge, & Wearing, 2004).

In addition to providing a potential task for assessing executive function development beyond the preschool period, the FIST can be manipulated to affect working memory storage demand by adding potential matching dimensions, which requires the child to remember which selections were made in previous trials and to hold these items in mind over a short period of time (Miyake & Shah, 1999). When conditions of conflict are present, because the child must consider the relations between competing representations, working memory processing demands are also increased (Halford et al., 1998). In this study, we assessed whether these latter two components, working memory processing and storage, make a significant contribution to the development of cognitive flexibility.

In summary, this study had two aims. The first was to adapt the FIST to be useful for assessing developing cognitive flexibility beyond the preschool period using a single task paradigm. The second aim was to conduct a focused task analysis of the FIST, with specific emphasis on working memory processing and storage demands. We predicted that (a) performance on the standard 2-Match version of the FIST would approach ceiling by 6 years of age (Yerys et al., 2012); (b) adding dimensions in a manner to increase conflict would increase working memory storage and processing demands, and these increased demands would elicit below-ceiling performance even in older children; and (c) children would begin to perform at adult levels by 10 years of age.

Method

Participants

Participants were 77 predominately Caucasian children from private schools in the Philadelphia, Pennsylvania, area in the eastern United States. Participants were divided into three age groups: 28 6-year-olds (M_{age} = 78.68 months, SD = 3.32, range = 72–84; 14 girls and 14 boys), 28 8-year-olds (M_{age} = 102.64 months, SD = 3.51, range = 96–107; 14 girls and 14 boys), and 21 10-year-olds

(M_{age} = 126.67 months, SD = 3.38, range = 120–131; 12 girls and 9 boys). Children received a small prize for participating. To represent the adult sample, we recruited 28 Temple University undergraduates (M_{age} = 273.61 months, SD = 70.55, range = 217–546; 16 women and 12 men). The Temple University institutional review board approved the study, and informed consent was obtained for all participants. Participants under 18 years of age had parental informed consent and gave assent.

Materials and task design

We used five different manipulations of the FIST: a 2-Match version, two 3-Match versions, a 4-Match version, and a 6-Match version. All age groups received all versions. The stimuli were based on Jacques and Zelazo (2001) and presented on a laptop computer. Stimulus objects were contained in "cards" on a white background, with three or four stimulus cards being presented vertically on a screen at one time. Each set of cards was derived from the combination of four dimensions (color, number, size, and shape), and these varied along three attributes (shape = rabbit, flower, boat; color = red, green, blue; number = one, two, three). Size varied from large (rectangular dimensions = 3.30 × 2.40 cm), to medium (rectangular dimensions = 1.65 × 1.20 cm), to small (rectangular dimensions = 0.83 × 0.60 cm).

Procedure

All participants received the same order of presentation, beginning with the demonstration and criterial trials and proceeding through the test trials with the order 2-Match, 3-Match A, 3-Match B, 4-Match, and 6-Match FIST versions. Demonstration and criterial trials preceded the first test trials (for the 2-Match version), and one additional demonstration trial preceded each version.

Demonstration and criterial trials

Participants were told that they would see some cards with pictures on them. On the demonstration, four cards were presented on the computer screen. Two of the cards were identical on all four dimensions, whereas the other two cards were also identical on all dimensions but differed from the first two cards. For example, two cards with one small green boat and two cards with two medium blue rabbits were presented. Thus, there was no "pivot" card (i.e., Cards 1 and 4 match and Cards 2 and 3 match with no overlap). Participants saw all possible stimulus attributes (total of 12) before the series of test trials.

Participants were told the instructions from Jacques and Zelazo (2001), which described how to pick two cards that were the same and two cards that were the same but in a different way. After the demonstration trial, participants were given two criterial trials and were given the following instructions:

> "Now this one is a little different. Here I am going to point to two cards that are the same in some way that is not like the other card(s), but the way the two cards are the same has to be different from the other card(s)—so, two cards that are the same but different from the other card(s) (Selection 1). [For Selection 2:] Now, show me two cards that are the same in another way that is different from the other card(s)—so, two cards that are the same but different from the other card(s)."

All participants displayed evidence of understanding the concept of *same* and the concept of *same but in a different way.* To further ensure that participants completely understood the instructions, a demonstration containing conflict was given prior to each variation of the FIST. These demonstrations were identical in structure to the test trials and used the same stimulus attributes, but they were not identical to any of the test trial combinations. In these demonstrations, the experimenter explained each match and the reason for each match. If participants were clear on the instructions, the test trials were administered.

Test trials

For test trials, three cards (for the 2- and 3-Match versions) or four cards (for the 4- and 6-Match versions) were shown on each screen. The instructions were identical to those given in the criterial trials. Relevant dimensions are those that are potential matching dimensions. Constant or irrelevant dimensions are those that cannot be matched. We selected stimulus attributes to represent many different combinations across all 30 test trials across the five versions of the FIST. Placement of the pivot card was counterbalanced from its appearance at the top, middle, or bottom of the card presentation. Participants were told why they made incorrect responses.

The specific presentation of each FIST version is described below, and examples are provided in Fig. 1.

2-Match FIST. The 2-Match FIST was a replication of the Jacques and Zelazo (2001) study with the exception that only six test trials were used instead of 12. Cards were identical on two irrelevant dimensions (e.g., size and number) and varied on two relevant dimensions (e.g., shape and color). Two of the three cards matched on one relevant dimension (e.g., shape), and a different pair matched on the other relevant dimension (e.g., color). Thus, one of the three cards (i.e., the pivot card) matched on two relevant dimensions. The placement of a pivot card creates a condition of conflict because the same card can be matched on two dimensions.

3-Match A, 3-Match B, 4-Match, and 6-Match FIST versions. Four additional versions of the FIST were constructed in the same manner as above. Because of the large number of possible combinations of the stimulus dimensions, partial counterbalancing was used. Within each test trial, the number of possible matching selections varied with the manipulation, but all 12 stimulus attributes were presented at least once for each manipulation. Two versions of the 3-Match FIST were constructed.

3-Match A version. In this manipulation, three matching selections were possible, but for each selection there was only one pivot card per selection. For example, Cards 1 and 3 may match on shape, Cards 2 and 3 may match on size, and Cards 1 and 2 may match on number (with color as the irrelevant stimulus dimension).

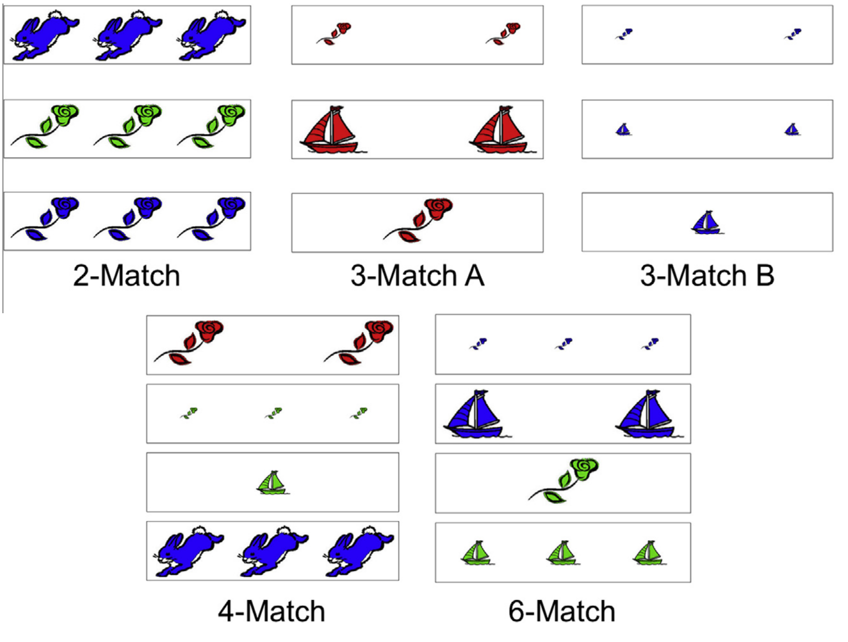

Fig. 1. Examples of the five FIST manipulations. The name of each example indicates the number of nonrepeating matches that can be made from the single stimulus. Correct matches are described in the text.

3-Match B version. In this manipulation, two of the selections involved the exact same stimulus cards but for different reasons. For example, Cards 1 and 2 may match on both size and number, and Cards 2 and 3 may match on shape (with color as the irrelevant dimension).

4-Match FIST. In this version, matching selections of all four dimensions (i.e., color, number, size, and shape) were possible without repeating a selection. Thus, four cards were used in this manipulation, and there were four possible matches.

6-Match FIST. In this version, matching selections of all four dimensions (i.e., color, number, size, and shape) were possible, but two dimensions were repeated. The repetitions involved the same dimension (e.g., shape) but different stimulus values (e.g., rabbits and boats). Thus, six matching selections were possible from an array of four cards.

An example of each version of the FIST is given in Fig. 1.

Scoring

Within each trial, a correct response consisted of both the correct selection (e.g., Cards 1 and 2) and the correct reason for the selection (e.g., "same shape," "both are rabbits"). Incorrect selections were categorized into three response types. First, "Match Irrelevant" indicated a match by an irrelevant dimension (e.g., same color if all objects were the same color) (note that this could not occur in the 4- and 6-Match versions). Second, "Match Same" indicated a repeated selection of the same reason for matching the same two cards from a previous selection (note that this could not occur on the first selection). Third, "No Response" indicated no response to a question regarding the existence of further possible matches (e.g., participants were given a "No Response" if they answered "no" to the question "Do you see any more cards that match?").

Additional measures

After completing the FIST, all participants received, in the following order, the Wisconsin Card Sort Test-64 (WCST-64; Heaton, 2000), the Peabody Picture Vocabulary Test–Revised (PPVT-R; Dunn, 1981), and the Backward Digit Span and Backward Word Span tasks.

Wisconsin Card Sort Test-64

All participants performed the task on a laptop computer using the *WCST-64: Computer Version for Windows* software from Psychological Assessment Resources (Heaton, 2000). The task has been normed for several age groups (Kongs, Thompson, Iverson, & Heaton, 2000) and has been shown to be comparable to the standard version of the WCST (Axelrod, 2002; Sherer, Nick, Millis, & Novack, 2003). Performance was scored using the scoring software.

Peabody Picture Vocabulary Test–Revised

The PPVT-R is a measure of verbal ability in which children must select from a set of four pictures the one best illustrating the meaning of a word. It is a nonverbal measure, making it appropriate for children, and it correlates significantly with standard measures of intelligence (Carvajal, Parks, Logan, & Page, 1992; Hodapp, 1993).

Backward Digit Span and Backward Word Span

The Backward Digit Span and Backward Word Span tasks were administered following Gathercole and colleagues (Gathercole & Pickering, 2000; Gathercole et al., 2004). The total testing time for all tasks was approximately 45 min.

Results

This section is organized as follows: (a) preliminary correlational analyses concerning the convergent validity of the FIST with other measures of cognitive functioning (i.e., the PPVT-R, Backward Digit Span, Backward Word Span, and WCST measures), (b) Rasch item analysis of the FIST, (c) parametric analyses of the different versions of the FIST, and (d) error analysis of the FIST.

Preliminary analyses concerning convergent validity

To establish the convergent validity with other measures of cognitive flexibility, verbal ability, and working memory, the versions of the FIST were compared with the WCST-64, PPVT-R, Backward Digit Span, and Backward Word Span measures. Descriptive statistics for these measures are presented in Table 1. Descriptive statistics for the FIST measures are presented later in the parametric analyses. Only the submeasures of the WCST-64 that have been the focus of prior developmental research (Chelune & Baer, 1986) are reported in Table 1, with the descriptive statistics for other WCST-64 measures being reported in the online supplementary material.

Developmental improvements in performance were revealed for all measures. In all analyses, sex was included to conduct an exploratory analysis. For the six non-FIST measures in Table 1, separate Sex (2) × Age (4) analyses of variance (ANOVAs) were computed, with planned polynomial contrasts computed for the age effects. For the PPVT-R, the dependent variable was the PPVT-R raw score. There was a significant linear effect of age, $F(1, 97) = 23.73$, $p < .001$ ($r_{contrast} = .44$), which was qualified by a significant quadratic effect, $F(1, 97) = 4.30$, $p = .04$ ($r_{contrast} = .21$). This linear quadratic pattern is the result of a considerable increase between the 10-year-olds and adults. There was no effect of sex ($p = .43$) and no interactions ($p = .42$).

For the backward span measures, the dependent measure was the total number of correct recalls. For the Backward Digit Span, there was a significant linear effect of age, $F(1, 96) = 11.30$, $p < .001$ ($r_{contrast} = .32$), no effect of sex ($p = .35$), and no interactions ($p = .59$). A similar trend was found for the Backward Word Span. There was a significant linear effect of age, $F(1, 96) = 11.88$, $p < .001$ ($r_{contrast} = .33$), no effect of sex ($p = .70$), and no interactions ($p = .19$).

Three ANOVAs were computed for the WCST measures, and the major findings were consistent with Chelune and Baer (1986). The linear age effect was significant for Categories Achieved, $F(1, 97) = 4.59$, $p < .05$ ($r_{contrast} = .21$), and for Perseverative Errors, $F(1, 97) = 6.03$, $p < .05$ ($r_{contrast} = .24$), but not for Failures to Maintain Set, $F(1, 97) = 0.50$, $p > .05$ ($r_{contrast} = 0.07$). This latter finding replicates Chelune and Baer (1986), who found only a trend toward significance for age for the Failures to Maintain Set measure. However, although Chelune and Baer found a significant sex by age interaction for Perseverative Errors, in the current study we found no significant effects of sex, nor any significant interactions, for WCST measures (smallest $p = .10$ for sex; $p = .19$ for interaction).

Correlations among tasks

To establish the convergent validity of the FIST with other measures of cognitive flexibility and working memory, we calculated correlations and partial correlations (controlling for age in months, PPVT-R, Backward Digit Span, and Backward Word Span). For this analysis, the dependent measure for the FIST was the percentage of correct responses for each version. With one exception, all measures were significantly correlated in the expected direction (Table 2). The exception to this was the relation

Table 1
Summary of developmental data by age.

Variables	Age			
	6 Years	8 Years	10 Years	Adult
General				
Participants (*n*)	28	28[a]	21	28
Age in months	78.68 (3.32)	102.64 (3.51)	126.67 (3.38)	273.61 (70.55)
PPVT-R	82.57 (10.59)	99.68 (11.19)	117.10 (14.65)	153.46 (9.06)
BDS[a]	5.82 (1.44)	7.74 (1.89)	9.24 (2.28)	12.57 (2.94)
BWS[a]	4.71 (1.27)	6.30 (2.20)	8.05 (1.72)	10.64 (2.36)
WCST-64				
Categories Achieved	1.71 (1.24)	2.71 (1.27)	2.81 (1.44)	3.46 (1.37)
Perseverative Errors	14.68 (5.66)	10.86 (5.09)	8.43 (3.11)	7.61 (3.62)
Failures to Maintain Set	0.64 (1.16)	0.71 (1.05)	0.81 (1.29)	0.32 (0.38)

Note. All values in parentheses represent standard deviations. PPVT-R: Peabody Picture Vocabulary Test–Revised; BDS: Backward Digit Span; BWS: Backward Word Span; WCST-64: Wisconsin Card Sort Test-64.
[a] $n = 27$ for BDS and BWS measures.

Table 2
Intercorrelations and partial correlations among measures for all age groups.

	1	2	3	4	5[a]	6[a]	7	8	9	10	11
1. Perseverative Errors	–	−0.61*** (−0.53***)	−0.11 (−0.21*)	−0.46*** {−0.20*}	−0.45*** [−0.15]	−0.36*** [−0.01]	−0.37*** (−0.25*)	−0.42*** (−0.20*)	−0.44*** (−0.25*)	−0.52*** (−0.29**)	−0.50*** (−0.27**)
2. Categories Achieved		–	−0.40*** (−.37***)	0.40*** {0.17}	0.35*** [0.07]	0.29** [−0.03]	0.24* (0.10)	0.26** (0.05)	0.24* (0.04)	0.40*** (0.20*)	0.37*** (0.16)
3. Failure to Maintain Set			–	−0.17 {−0.04}	−0.12 [0.02]	−0.14 [−0.03]	−0.02 (0.06)	0.05 (0.16)	0.01 (0.10)	−0.08 (0.03)	0.0 (0.15)
4. PPVT-R raw score				–	0.80*** |0.59***|	0.78*** |0.61***|	0.44*** {0.16}	0.52*** {0.13}	0.53*** {0.22*}	0.66*** {0.33***}	0.65*** {0.26**}
5. Total BDS[a]					–	0.82*** [0.53***]	0.34** [−0.03]	0.58*** [0.31**]	0.50*** [0.16]	0.63*** [0.24*]	0.63*** [0.24*]
6. Total BWS[a]						–	0.44*** [0.16]	0.50*** [0.16]	0.49*** [0.15]	0.56*** [0.10]	0.56*** [0.11]
7. 2-Match %							–	0.44*** (0.30**)	0.43*** (0.29**)	0.44*** (0.26**)	0.43*** (0.25*)
8. 3-Match A %								–	0.64*** (0.49***)	0.76*** (0.63***)	0.76*** (0.63***)
9. 3-Match B %									–	0.70*** (0.54***)	0.75*** (0.62***)
10. 4-Match %										–	0.85*** (0.73***)
11. 6-Match %											–

Note. PPVT-R: Peabody Picture Vocabulary Test–Revised; BDS: Backward Digit Span; BWS: Backward Word Span; (): partial correlations controlled for age in months; []: partial correlations controlled for age in months and PPVT-R; {}: partial correlations controlled for age in months, BDS, and BWS; ||: partial correlations controlled for age in months.

[a] $N = 105$ for full correlations except that one 8-year-old did not complete the backward span measures.

* $p < .05$.

** $p < .01$.

*** $p < .001$.

between Failures to Maintain Set and all other measures. Partial correlations were reduced in size but remained significant. The only exception to this pattern was between Categories Completed and other measures. All measures of the FIST were significantly related to each other, which provides initial verification that all versions of the FIST are measuring the same underlying construct. The significant relation between the FIST and the WCST provides additional evidence for the FIST as a measure of cognitive flexibility. All FIST measures were strongly related to the Perseverative Errors and Categories Achieved measures of the WCST. Importantly, the relation of all FIST measures to Perseverative Errors remained significant even after controlling for age, PPVT-R scores, and both backward span measures. This suggests that the FIST and WCST performance reflects a similar ability to shift cognitive set, a finding that replicates the general pattern reported by Levine, Stuss, and Milberg (1995) examining a similar concept generation task and the WCST in older adults.

The significant relations among the backward span measures and the FIST and WCST measures also indicate an important working memory processing component for these tasks. This finding is consistent with other investigations of WCST performance and its relation to working memory (Fristoe, Salthouse, & Woodard, 1997; Parkin, Walter, & Hunkin, 1995). However, two findings indicate that working memory processing does not constitute the singular component of cognitive flexibility. First, the relations between FIST and WCST performance remain significant even after controlling for the backward span measures (and PPVT-R and age), suggesting that there are additional sources contributing to the shared variance of the two measures. Second, when partial correlations controlling for age and PPVT-R scores are conducted between the backward span measures and the FIST and WCST, several correlations reduce to nonsignificance; only the correlations between Backward Digit Span and the 3-Match A, 4-Match, and 6-Match FIST versions remain significant. This may be due to the shared variance between PPVT-R scores and the backward span measures; both remain highly correlated even after controlling for age (.59 and .61 for Backward Digit Span and Backward Word Span, respectively), and so it is possible that partialling out PPVT-R scores masks the contribution of working memory processing to success on the FIST. However, the overall pattern of results still suggests that whereas working memory processing makes some contribution to developing cognitive flexibility, other processes also seem to contribute to its development.

These preliminary correlational analyses establish the relation of the FIST to other measures of cognitive functioning, including those previously reported to measure cognitive flexibility (the WCST), verbal ability (the PPVT-R), and working memory processing (backward span measures). Additional analyses, however, are needed to establish the pattern of development of FIST performance and to further investigate component processes related to cognitive flexibility. These additional analyses (Rasch analysis, parametric analysis, and error analysis of the FIST) are presented below.

Rasch analysis

The Rasch model was used to assess whether the five versions of the FIST reflected the measurement of a theoretically uniform latent dimension (i.e., cognitive flexibility). Although all versions of the FIST were expected to fit the model, it was also expected that they would vary in difficulty along this uniform latent dimension. That is, the Rasch model assumes that the data will be ordered along a hierarchy of difficulty on a single continuum of interest (Bond & Fox, 2001; Wright & Masters, 1982; Wright & Stone, 1979). The output provides (a) reliability estimates for person and item estimates, (b) estimates for how well each of the items fit the model, and (c) item difficulty and person ability along a logit scale.

Reliability of the FIST

Person reliability (which indicates the replicability of person ordering one could expect if the sample were given another set of items measuring the same construct) was high (R_P = .91), as was item reliability (which indicates the replicability of item placements if these items were given to a different sample with the same general ability; R_I = .91). From high item reliability, one can have confidence in the consistency of the measure (Bond & Fox, 2001).

Infit and outfit statistics

Rasch analysis also reports two measures of *misfit,* that is, the extent to which items and persons statistically deviate from the assumptions of the Rasch model. Thus, the concept of fit describes the degree of match between the pattern of observed responses and the model's expectations. Items that are passed or failed by all people, as well as people who pass or fail all items, are removed from the analysis (indicated by the notation minimum (or maximum) estimated measure).

To be regarded as fitting the Rasch model, fitting t values must fall between the accepted range of $-2.0 < t < +2.0$ (although an exception for developmental data is discussed below). The fit statistics are determined by the pattern of responses on the items. People who solve difficult items but do not solve easy items will produce positive misfit. Response patterns that are too ordered (i.e., Guttman or deterministic) will produce negative misfit. However, for developmental data, extremely negative fit statistics are theoretically expected. This deterministic pattern, known as *overfit* (i.e., $t < -2.0$), would be consistent with the idea of the development of a cognitive ability or skill of interest. Thus, in developmental studies that use Rasch analysis, overfit is generally not considered a form of misfit (Dawson, 2002a, 2002b). For the purposes of this analysis, to be considered as fitting the Rasch model, all items must show standardized infit scores of $t < +2.0$.

Exact fit statistics and item difficulty estimates for all items are reported in the supplementary material. Of the 30 trials of the FIST, 27 fit the expectations of the Rasch model. Thus, the theoretical prediction that all variations of the FIST were assessing the same underlying dimension was broadly supported. It is unclear why 3 items did not fit the Rasch model, but to maintain consistent means across versions of the FIST, these items were *not* removed from the analyses. However, the results indicate that future uses of these FIST variations should remove these items.

Item difficulty and person ability

Under the assumption of the unidimensionality of the measure, we can continue on to the analysis of item difficulty and person ability. Fig. 2 presents the output summarizing item difficulty and person ability along a logit scale where zero is arbitrarily set as the mean of the item difficulty estimates. Items with positive logits are progressively more difficult, and items with negative logits are progressively easier. Person ability is presented alongside estimates of item difficulty, with more capable people placed higher on the scale than less capable people.

An examination of the left side of the figure and the person ability mean (M) shows that the majority of the sample did not have difficulty with many of the variations of the FIST ($M = 2.91$ logits, $SD = 1.47$). However, the distribution of ages shows the expected developmental pattern of increasing ability with age, with 6-year-olds, and to some extent 8-year-olds, having considerable difficulty with several variations of the FIST. This supports the prediction that the development of cognitive flexibility as measured by the FIST continues beyond the preschool period, a conclusion that is examined in more detail in the parametric analysis presented in a later section. Finally, although 8-year-olds showed some difficulty on the task, many 10-year-olds and adults approached ceiling performance. However, only one participant, a 10-year-old, was removed from the analysis for passing all items, indicating that even adults failed to successfully make some of the FIST selections.

An examination of the right side of Fig. 2, for items, also shows the predicted pattern. The notation for each item in Fig. 1 contains information about the specific FIST variation (i.e., 2, 3A, 3B, 4, or 6), the specific trial (i.e., 1, 2, 3, 4, 5, or 6), and the specific selection within that trial (i.e., A = first selection, B = second selection, . . . , F = sixth selection). For example, Item 62F represents 6-Match, Trial 2, sixth selection. The more difficult items were later selections of the 6-Match version, the 4-Match version, and both 3-Match versions. In contrast, easier items were the early selections (the first and second selections) of all versions. Thus, the expected difficulty of shifting to further selections is apparent. This pattern of performance, however, does raise questions about why certain versions of the FIST are more difficult than others.

The results of the Rasch analysis suggest at least one reason for difficulty in shifting, that of working memory storage. From this perspective, later selections, especially of the 6- and 4-Match versions, were predicted to be the most difficult, a prediction that was borne out. The Rasch analysis reveals that the last selections are the most difficult on the 4- and 6-Match versions. In addition, later selections of the 2- and 3-Match versions were generally more difficult than earlier selections. However,

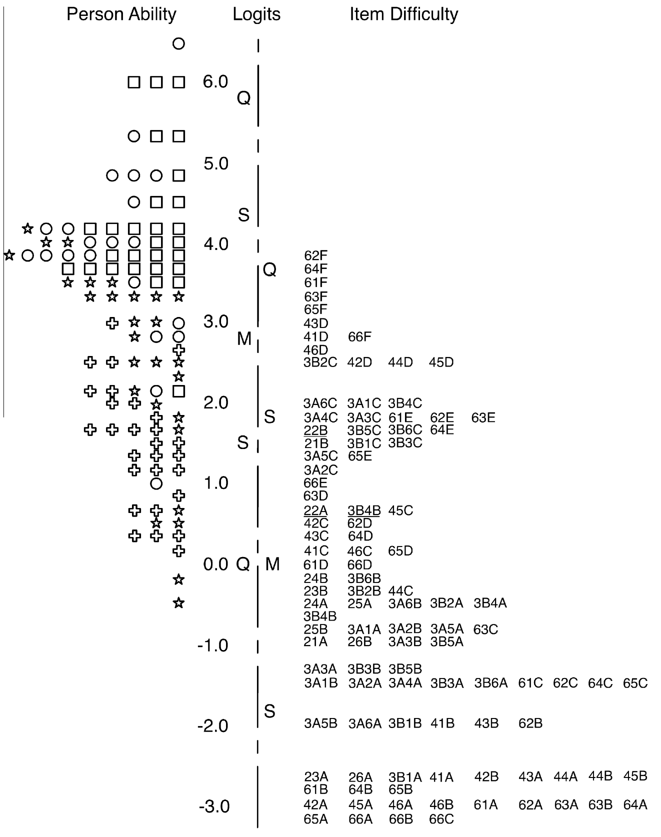

Fig. 2. Person difficulty and item difficulty estimates for the FIST. Squares: adults; crosses: 6-year-olds; stars: 8-year-olds; circles: 10-year-olds; M: mean; S: 1 standard deviation from mean; Q: 2 standard deviations from mean. The notation for each item contains information about the specific FIST variation (i.e., 2, 3A, 3B, 4, or 6), the specific trial (i.e., 1, 2, 3, 4, 5, or 6), and the specific selection within that trial (i.e., A = first selection, B = second selection, . . . , F = sixth selection). For example, Item 62F item represents 6-Match, Trial 2, sixth selection. The underlined items (22A, 22B, and 3B4B) did not fit the Rasch model.

selection number was not the best predictor of item difficulty. For example, referring to Fig. 2, Item 66C is one of the easiest, with a minimum estimated measure (i.e., passed by all participants). In contrast, 3B2C is a relatively difficult item (2.45 logits). Thus, the Rasch findings suggest that working memory storage demands cannot in and of themselves explain difficulty.

Parametric analyses of the FIST

The Rasch analysis established the overall reliability of the several versions of the FIST and that these variations measure the same underlying construct and a general developmental function. However, parametric analyses will provide a more detailed perspective on the development of cognitive flexibility. Unless stated otherwise, the analyses that follow used separate repeated measures Selection × Age (4) × Sex (2) ANOVAs for each of the five versions of the FIST. Interactions were decomposed with post hoc analyses, which were corrected for multiple comparisons (Bonferroni *p* values reported). For clarity, only relevant main and simple main effects results are discussed. As noted above, we did conduct an exploratory analysis of sex, but because these effects were not predicted we report only a brief summary of these here. Thus, we found that 6-year-old girls outperformed boys for the 2-Match version. For the 3-Match A version, 6-year-old boys outperformed girls on the third selection, and 8-year-old boys outperformed girls on the second selection. For the 4- and 6-Match

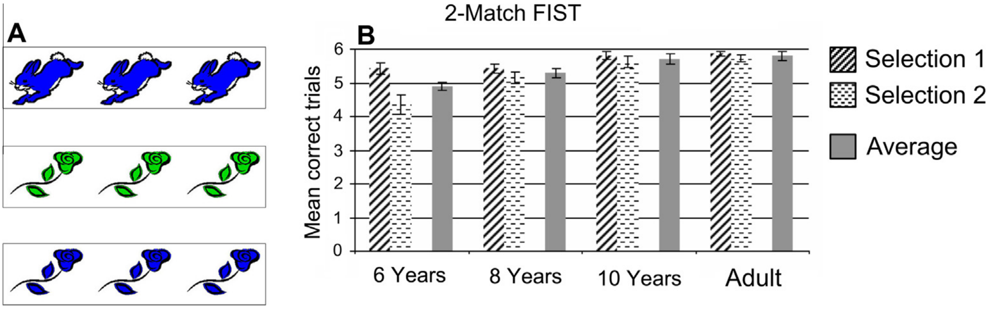

Fig. 3. 2-Match FIST. (A) In this example, Cards 1 and 3 (top and bottom) match because of color, and Cards 2 and 3 (middle and bottom) match because of shape. Size and number are the constant dimensions. (B) Mean correct for each age for the 2-Match FIST. Error bars represent ±1 standard error.

versions, on average 6-year-old boys outperformed girls. Omnibus statistics, including those associated with the sex effects, are presented in the ANOVA tables in the supplementary material.

2-Match FIST

The main effect of selection provides additional support for the hypothesis that the second selection is more difficult than the first (Fig. 3). The interaction effects, however, qualified this finding. For the Age × Selection interaction, the first and second selections differed significantly only in the 6-year-old group ($p < .001$). The result suggests that the second selection was difficult only for 6-year-olds. Successful shifting on the 2-Match version was achieved by 8 years of age.

3-Match A FIST

For the Age × Selection interaction, within both 6- and 8-year-olds, the first and second selections differed from the third selection (highest $p < .001$). Selections did not differ significantly for 10-year-olds and adults. These results suggest that the 3-Match A version was difficult for 6-year-olds, and even 8-year-olds showed some difficulty in shifting to the third selection (Fig. 4, upper panels). However, by 10 years of age, children were performing similar to adults.

3-Match B FIST

The significant Age × Selection interaction was due to the fact that within 6-, 8-, and 10-year-olds, the first and second selections differed from the third selection (highest $p = .02$). Selections did not differ significantly for adults. This result suggests that the 3-Match B version was difficult for 6-year-olds, and even 8- and 10-year-olds showed some difficulty in shifting to the third selection (Fig. 4, lower panels).

4-Match FIST

For the Age × Selection interaction, within 6-year-olds, all selections differed from each other (highest $p < .01$). Within 8-year-olds, only the first and second selections did not differ (highest $p < .01$). Within 10-year-olds and adults, the only differences were between the fourth selections and all other selections (highest $p < .01$). These results suggest that performance on the 4-Match version improved with age, but shifting to multiple selections appeared to be difficult. Even 10-year-olds and adults had difficulty in shifting to the fourth selection, albeit to a lesser extent than 6- and 8-year-olds (Fig. 5, upper panels).

6-Match FIST

For the Age × Selection interaction, within 6-year-olds, all selections differed from each other with the exception that the first selection did not differ from the second or third selection (highest $p < .02$). Within 8-year-olds, only the second and third selections did not differ (highest $p < .04$). Within

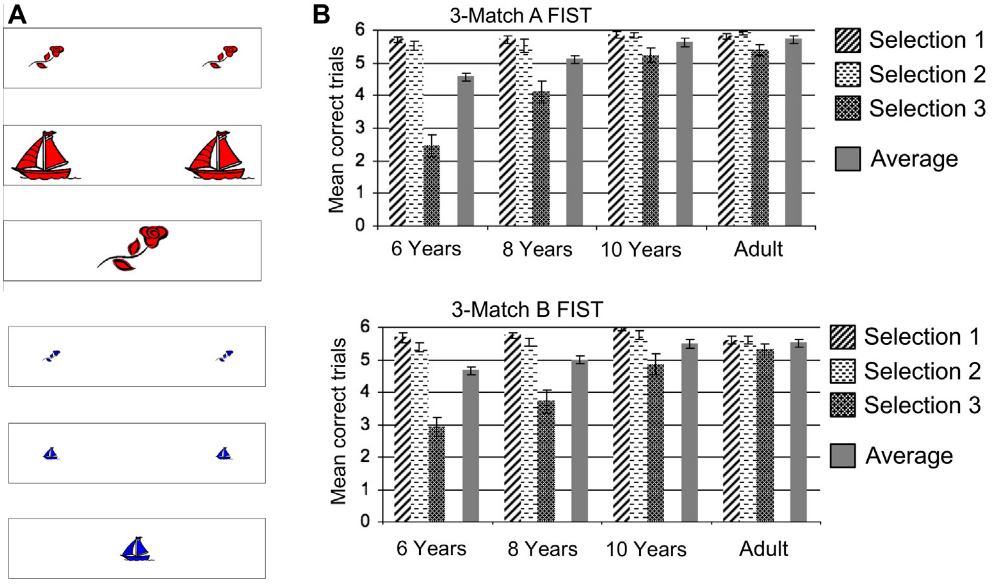

Fig. 4. Upper panels: 3-Match A FIST. (A) In this example, Cards 1 and 3 (top and bottom) match because of shape, Cards 2 and 3 (middle and bottom) match because of size, and Cards 1 and 2 (top and middle) match because of number. Color is the constant dimension. (B) Mean correct for each age for the 3-Match A FIST. Error bars represent ±1 standard error. Lower panels: 3-Match B FIST. (A) In this example, Cards 2 and 3 (middle and bottom) match because of shape, and Cards 1 and 2 (top and middle) match because of size and number. Color is the constant dimension. (B) Mean correct for each age for the 3-Match B FIST. Error bars represent ±1 standard error.

10-year-olds and adults, the only differences were between the sixth selection and all other selections (all *ps* < .001). These results suggest that performance on the 6-Match version followed the same pattern as the 4-Match version. Performance improved with age, but shifting to multiple selections was difficult. Even 10-year-olds and adults had difficulty in shifting to the last selection, 6-year-olds had difficulty in switching to selections beyond two, and 8-year-olds had difficulty in switching to selections beyond three (Fig. 5, lower panels).

The role of stimulus conflict

We expected that FIST versions in which there was a clear conflict between possible selections would be more difficult for early selections than those in which there was low conflict. That is, the early selections of the 4- and 6-Match versions can be accomplished without using a pivot card that can be matched on more than one dimension. We compared high-conflict early selections of the 3-Match version with low-conflict early selections of the 4- and 6-Match versions. Thus, for the following analyses, the average of the first three selections for the 3-Match A, 3-Match B, 4-Match, and 6-Match versions yielded a single dependent variable for each version. Then three orthogonal contrasts were computed to assess the differences between both 3-Match versions and the 4- and 6-Match versions together.

As expected, performance on the first three selections improved with age (Fig. 6). In addition, the contrasts examined were consistent with the findings of the Rasch analysis. When compared with the 3-Match versions, for the first three selections the 4- and 6-Match versions were actually easier. The 6-Match version was also easier than the 4-Match version, although this finding was qualified by a significant interaction with age. Simple effects analyses revealed that the 4-Match version differed from the 6-Match version for 6-year-olds but not for the other age groups ($p < .001$). The results suggest that even though the working memory storage demands of the first three selections are identical, the high-conflict 3-Match versions are more difficult. Thus, conflict appears to be a primary determinant of difficulty in the 2- and 3-Match versions, whereas working memory storage demands appear to become more important sources of difficulty in the later selections of the 4- and 6-Match versions.

Error analysis of the FIST

Investigation of the pattern of errors also provides insight into the potential working memory processing and storage demands of the FIST. Three kinds of errors were possible in the FIST: No Response, Match Irrelevant, and Match Same. A summary of the errors by age is presented in Table 3, and each provides a different piece of information about the development of cognitive flexibility.

If participants failed to make a response and took a considerable amount of time to respond, they were asked whether they could select any more objects that matched. If the answer was “no,” they were coded as a No Response. Younger children were more likely to make this kind of error than 10-year-olds and adults (68% and 50%, respectively), $\chi^2(1, N = 1636) = 37.64$, $p < .001$.

Match Irrelevant errors occurred when participants matched two cards based on an attribute that was shared by all objects (a violation of task instructions). This could occur because the integration of representational elements into a single cognitive representation requires effortful manipulation of these elements in working memory. However, analyses revealed a surprising pattern. As a percentage of total errors, younger children (6- and 8-year-olds) were actually less likely to make this kind of error than 10-year-olds and adults (37% and 60%, respectively), $\chi^2(1, N = 634) = 687.34$, $p < .001$. This is potentially due to the fact that when younger children could not bring to mind a response, they were more likely to indicate this than to search for a potential answer. Thus, they would be coded as a No Response, whereas older children and adults would make the effort to respond but may have made one of the two other kinds of errors.

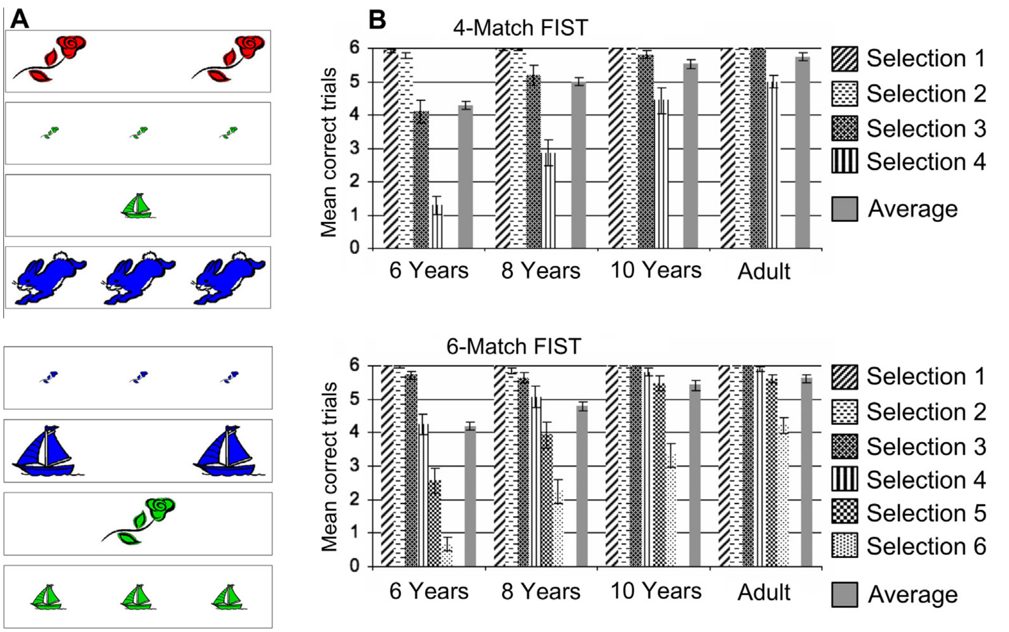

Fig. 5. Upper panels: 4-Match FIST. (A) In this example, Cards 1 and 2 (top and second from top) match because of shape, Cards 2 and 3 (second from top and third from top) match because of color, Cards 2 and 4 (second from top and bottom) match because of number, and Cards 1 and 4 (top and bottom) match because of size. (B) Mean correct for each age for the 4-Match FIST. Error bars represent ±1 standard error. Lower panels: 6-Match FIST. (A) In this example, Cards 1 and 2 (top and second from top) match because of color, Cards 1 and 3 (top and third from top) match because of shape, Cards 1 and 4 (top and bottom) match because of number, Cards 2 and 3 (second from top and third from top) match because of size, Cards 2 and 4 (second from top and bottom) match because of shape, and Cards 3 and 4 (third from top and bottom) match because of color. (B) Mean correct for each age for the 6-Match FIST. Error bars represent ±1 standard error.

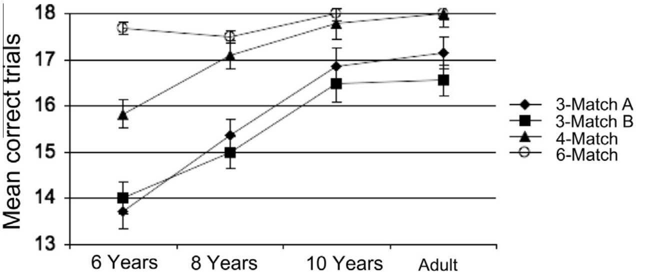

Fig. 6. Mean correct for each age for the first three selections on the 3-Match A, 3-Match B, 4-Match, and 6-Match FIST versions. Error bars represent ±1 standard error.

Table 3
Analysis of errors by age and each version of the FIST.

Age	Kind of error	2-Match	3-Match A	3-Match B	4-Match	6-Match
6 Years						
	Irrelevant	32 (52)	33 (28)	32 (29)	–	–
	Same	2 (3)	16 (13)	7 (6)	34 (18)	48 (16)
	No Response	28 (45)	71 (59)	73 (65)	158 (82)	255 (84)
8 Years						
	Irrelevant	31 (78)	31 (41)	21 (25)	–	–
	Same	0 (0)	13 (18)	13 (15)	27 (24)	66 (33)
	No Response	9 (22)	31 (41)	50 (60)	86 (76)	137 (67)
10 Years						
	Irrelevant	7 (58)	15 (68)	9 (30)	–	–
	Same	0 (0)	1 (5)	3 (10)	6 (16)	19 (27)
	No Response	5 (42)	6 (27)	18 (60)	31 (84)	52 (73)
Adult						
	Irrelevant	11 (92)	13 (54)	32 (78)	–	–
	Same	0 (0)	3 (13)	3 (7)	8 (42)	33 (52)
	No Response	1 (8)	8 (33)	6 (15)	11 (58)	31 (48)

Note. Values in parentheses represent percentages.

Match Same errors occurred when participants repeated a prior match (note that these could also be termed *perseverative errors*). For example, if a participant chose two cards that matched by color on the first selection and repeated the same two cards by the same criteria in a later selection, this would be coded as a Match Same error. This error might suggest a problem with recall of prior selections (i.e., with working memory storage). In both cases, it would be expected to occur more often as more selections are necessary (i.e., in the 3-, 4-, and 6-Match versions). The data in Table 3 support this prediction. Match Same errors increased as a function of the number of potential selections, $\chi^2(4, N = 1636) = 65.80$, $p < .001$. There is also a relation between age and Match Same errors, $\chi^2(3, N = 1636) = 32.92$, $p < .001$. However, like Match Irrelevant errors, younger children (6- and 8-year-olds) were less likely to make this kind of error than 10-year-olds and adults (as a percentage of total errors, 18% and 23%, respectively), $\chi^2(1, N = 1636) = 5.44$, $p < .02$. The source of this is the same as the explanation presented above for Match Irrelevant errors, that is, that younger children make more No Response errors.

Discussion

The study reported here had two aims. The first was to develop and extend the FIST to make it appropriate for investigating the development of cognitive flexibility beyond the preschool period. The current literature has few tasks that are applicable for investigating, using the same task paradigm, the development of cognitive flexibility from preschool into later childhood. In the current work with 6-, 8-, and 10-year-olds, we supported and extended the findings of prior research. For example, consistent with earlier work, performance on the WCST (Chelune & Baer, 1986; Chelune & Thompson, 1987; Crone et al., 2004; Kirk & Kelly, 1986; Paniak et al., 1996; Welsh et al., 1991) and on other task-switching paradigms continues to show age-related change beyond the preschool period (Cepeda et al., 2001; Cragg & Nation, 2009; Crone et al., 2004, 2006; Huizinga et al., 2006; Zelazo et al., 2004), at least until 10 years of age. But as we mentioned in the Introduction, these tasks are generally not appropriate for use with children under 6 years of age. The FIST has been used in the past with preschool children (Blair & Razza, 2007; Blair et al., 2004; Jacques & Zelazo, 2001; Yerys et al., 2012). Here we showed that it can be modified to be used with older children and, crucially, we provided evidence (using Rasch analysis) that the modifications do not fundamentally change the structure of the task.

Specifically, in the current study, we modified the standard FIST to elicit age-related change in 6-, 8-, and 10-year-olds. We first established the convergent validity of the FIST with another measure of cognitive flexibility, the WCST. Next we showed that although all versions of the FIST were highly correlated and load on a single latent variable—which we term *cognitive flexibility*—performance on the standard 2-Match FIST clearly reaches ceiling between 6 and 8 years of age. In contrast, the 3-, 4-, and 6-Match FIST versions provide sufficient difficulty to detect further development and did not reach adult levels until 10 years of age. This underscores the notion that the FIST manipulations developed here are useful for assessing developing cognitive flexibility from preschool through later childhood using the same task paradigm across those age ranges, which is potentially very useful for studying both typical and atypical development.

The second aim of this study was to investigate potential component cognitive processes associated with development in cognitive flexibility, specifically as measured by the FIST. In a recent study, Dick (2012) made some progress toward this goal by examining processes that contribute to difficulty on the 2-Match FIST. In that study with adult participants, it was shown that impaired responding on the FIST (as measured by slower response time) was attributable to two complementary attentional processes. The first was the suppression of the representation of the ignored dimension. This was shown by an experimental manipulation such that response times to select an object in an oddity task immediately following the first selection on the FIST were slower if the oddity target was the previously ignored stimulus of the FIST. However, the experimental manipulation also suggested that a second attentional process, proactive interference from the previously relevant stimulus, contributed to impaired responding. These results suggested that difficulty on the FIST could be attributed to both the need to shift away from the previously attended representation (consistent with an attentional inertia account of developing cognitive flexibility; Diamond & Kirkham, 2005; Kirkham et al., 2003) and the need to shift to a previously ignored representation (consistent with negative priming explanations; Müller et al., 2006; Zelazo et al., 2003). Research with other similar card sorting paradigms also suggests that these processes contribute to cognitive inflexibility in task switching situations (Chevalier & Blaye, 2008; Maes, Damen, & Eling, 2004).

Although the study by Dick (2012) addressed "bottom-up" attentional processes that contribute to cognitive inflexibility on the 2-Match FIST, it was not able to answer how successful shifting was accomplished in spite of slowed responding. In other words, the question of what "top-down" processes contribute to *passing* the task remained unanswered. In attempting to answer this question, the current study focused on the role of working memory storage and processing and provided evidence that both processes contribute to developing cognitive flexibility. However, we also found that working memory could not account for all of the variance in FIST performance, suggesting that additional processes contribute to developing cognitive flexibility. In the next section, we discuss the potential working memory contributions and then discuss alternatives.

Working memory contributions to developing cognitive flexibility

We found that some errors were attributable to an inability to recall prior selections, suggesting a problem with working memory storage. Demands on working memory storage have been cited as a source of difficulty for other tasks that assess cognitive flexibility such as the WCST (Fristoe et al., 1997; Parkin et al., 1995) and the A-not-B task (Diamond, Cruttenden, & Neiderman, 1994). Barceló and colleagues conducted extensive task analysis of the WCST and showed that some kinds of errors on this test are due to "set loss" or failure of task set maintenance (Barceló, 1999; Barceló & Knight, 2002; Nyhus & Barceló, 2009). Perhaps not surprising, these kinds of errors are made with increasing frequency on the FIST as the number of potential matching dimensions increases. This would also be predicted based on the findings of Cowan, Morey, AuBuchon, Zwilling, and Gilchrist (2010), who showed that the number of items in memory is a significant contributor to children's performance on visual tasks that require filtering irrelevant information. In that study, 7-year-olds recalled fewer items than 10-year-olds and adults, but for displays with a small number of items the age effect did not depend on the attention condition. For larger displays, older children and adults were far superior to younger children. This was interpreted to suggest that when there is an obligation to do an additional attention-demanding task, working memory storage load affects younger children more than older children and adults. Applied to the FIST, this would suggest that working memory storage load is a more significant contributor to performance for younger children, but only if the number of items sufficiently taxes working memory storage.

We also found, however, that there are differences in the difficulty of the FIST even when the number of previous matches was the same, which controls for working memory storage demands. For example, for the first three selections, the high-conflict 3-Match versions were more difficult than the 4- and 6-Match versions. Furthermore, the backward span measures of working memory processing were correlated with FIST performance, and in the case of the Backward Digit Span several correlations remained significant after controlling for PPVT-R and age (none of the Backward Word Span measures remained significant, although this may be due to the considerable variance shared between working memory and vocabulary; Engel de Abreu, Gathercole, & Martin, 2011). Taken together, these findings suggest that the additional demand to manipulate the contents of working memory contributes at least partially to task performance, a possibility that is incorporated in several theoretical accounts of developing cognitive flexibility. For example, application of a higher order rule (Müller et al., 2006; Zelazo et al., 2003), or considering the relations between rules (Andrews, Halford, Bunch, Bowden, & Jones, 2003; Halford et al., 1998) places demands on working memory processing and has been proposed to explain how children successfully navigate card sorting tasks. Computational models of working memory processing also explain the suppression of prepotent responses under conditions of stimulus conflict (Blackwell et al., 2009; Cepeda & Munakata, 2007; Cohen, Dunbar, & McClelland, 1990; Kimberg & Farah, 1993; Marcovitch & Zelazo, 2009; Morton & Munakata, 2002; Munakata et al., 2003).

Empirical evidence supports these claims. In a study with preschoolers, Espy and Bull (2005) showed that higher working memory span is correlated with performance on tasks that require disengagement from an internally represented rule or response set. They suggested that better memory facilitates activation of one rule or response in one context and shifting to engage a conflicting rule in another context. However, some evidence suggests that working memory is associated more with task set maintenance than with switching. For example, using a novel task switch paradigm with preschoolers, Chevalier and Blaye (2008) found that some kinds of errors on the task could be attributed to the inability to maintain the task representation in the face of distraction. Indeed, in preschoolers, working memory capacity is associated with performance on a goal neglect version of the DCCS designed to assess task set maintenance (Marcovitch, Boseovski, Knapp, & Kane, 2010). Other studies also suggest a contribution of working memory processing and storage to developing cognitive flexibility, with later maturation of rule maintenance (which taxes working memory) than rule switching (Chelune & Baer, 1986; Crone et al., 2004). Notably, we replicated Chelune and Baer's (1986) findings with the WCST in our sample. Thus, our findings are consistent with the idea that maintenance of the task set, which relies on working memory, is a significant contributor to developing cognitive flexibility (Cragg & Chevalier, 2012).

Inhibitory control contributions to developing cognitive flexibility

Although we focused on working memory, an alternative process—namely, inhibition—might also explain our findings. For example, instead of reflecting a failure to recall prior selections, Match Same errors might reflect perseveration, or the failure to inhibit previous selections, which would become more frequent in later selections due to the fact that there are more opportunities to make these kinds of errors. In support of this possibility, it is important to note that the correlation between FIST and WCST performance remained significant after partialling out the variance contributed by age, working memory, and verbal ability. This suggests that additional cognitive processes, possibly including inhibition, contribute to performance on these tasks. Indeed, tasks that are similar to the FIST (e.g., the DCCS and variants) are sometimes proposed to assess inhibitory control and are correlated with other tasks proposed to assess inhibitory control (Carlson & Moses, 2001).

It has been difficult, in past investigations of developing cognitive flexibility, to tease apart the different subcomponents that contribute to its development. Part of the difficulty is attributable to the fact that, in many situations, the notion of an inhibition "mechanism" does not go very far beyond the description of the outcome of the task; that is, children display evidence of inhibition when they inhibit the response to the now irrelevant task demand. However, this same outcome can be predicted without appealing to a separate mechanism of inhibition (Blackwell et al., 2009; Munakata et al., 2003). The difficulty in teasing apart working memory and inhibition can also be attributed to the fact that inhibition can potentially occur at the cognitive level or at the response level. Carlson and Moses (2001) made this distinction explicit by showing that working memory is related to tasks proposed to tap the former ability ("conflict" tasks) but not the latter ability ("delay" or response suppression tasks). Notably, in that study the card sorting task the authors used loaded most strongly on the conflict dimension proposed to require working memory to hold additional conflicting representations in mind. Indeed, when inhibition is assessed with a delay task, it is not found to correlate with task switching in preschool children (although it was associated with the ability to maintain the goal representation; Chevalier et al., 2012). A limitation of our study is that we did not include an independent measure of inhibition; thus, we must constrain our discussion to the contributions of working memory, which we did measure.

One of the enduring challenges to executive function researchers is how to reconcile the fact that the same outcomes can often be attributed to more than one cognitive process, and it has been historically difficult to tease apart the independent contributions of component cognitive processes such as inhibition and working memory. The now well-known study by Miyake and colleagues (2000) applied some clarity to the issue. In that framework, common executive function measures can be conceptualized as tapping three main executive functions of *shifting, updating,* and *inhibitory control.* Again, on its face, the FIST appears to draw on all three functions. Children must Inhibit perseverating on the previous selection, shift from the first selection to future selections, and update their working memory to reflect the fact that they have made a previous selection. The question, then, is whether the FIST truly draws on these several subfunctions or whether it can be more parsimoniously understood as tapping one particular subfunction of executive function.

Miyake and colleagues (2000) provided a clue in their assessment of the WCST. Using a confirmatory factor analysis approach, they reported that the WCST loaded most strongly on the shifting factor and that adding additional factors did not significantly improve the model fit. Given the significant relations found in the current study between the WCST and the FIST, and the fact that all FIST versions load on the same factor in the current study, we might expect a similar pattern of results if the FIST were included in a factor analysis of executive function measures. But Miyake and colleagues also showed that there were moderate to high correlations among the three factors of shifting, updating, and inhibitory control. They attributed this "unity" of executive function to common task requirements, one of which was the maintenance of task goals and context information in working memory. Our findings are consistent with those of Miyake and colleagues. That is, we found that all measures of the FIST load on a single latent construct, which we term *cognitive flexibility* but which could easily be termed *shifting* as described by Miyake and colleagues. However, by analyzing the source of errors on the various FIST manipulations, and by comparing performance on these with the span measures of working memory, we find evidence that each manipulation makes a demand on working memory. Thus, our results are also compatible with those models of executive function development that emphasize the development of working memory and its contribution to improved cognitive flexibility (Blackwell et al., 2009; Halford et al., 1998; Marcovitch & Zelazo, 2009; Morton & Munakata, 2002; Zelazo et al., 2003).

A second limitation of the study is that we are unable to rule out the effects of dimension saliency. It has been shown that switch costs in children can be asymmetric (Ellefson, Shapiro, & Chater, 2006), which means that it is more difficult to switch to a rule or dimension that is consistent with a prepotent tendency than to switch to a rule or dimension that requires inhibition of that tendency. For example, Ellefson and colleagues (2006) found that children are faster and more accurate to categorize by color compared with shape and also incur greater switch costs for shifting from color compared with shape. In the FIST, the fact that some dimensions are more salient/easier to conceptualize than others means that those dimensions that are easier might be more likely to be abstracted for earlier selections. This in turn means that children need to shift to harder to abstract dimensions for later selections, which would also have the effect of inducing greater switch costs. We tried to equalize dimension saliency; for example, in pilot testing we determined that the size dimension was less salient and made an adjustment to the saliency of this dimension (see Levine et al., 1995, for a similar approach). However, because a major component of this task is to abstract the relevant dimension, individual differences in perceptual biases make it difficult to completely rule out this alternative explanation for difficulty in later selections.

Utility of the modified flexible item selection task for assessing developing cognitive flexibility in typical and atypical populations

The expanded FIST that we developed here is potentially useful for the assessment of children with developmental disabilities and delays. The major advantage of the task is that it is simple in its instruction, and the 2-Match version can be used with children from 3 years of age to adulthood. We did not test a preschool cohort on the more difficult versions, but the task instructions do not change with the addition of dimensions. Indeed, the Rasch model suggests high reliability of the items within the battery, which suggests that adding dimensions increases difficulty of the task but not of the task structure. Furthermore, although this needs to be verified empirically, the task appears to be resistant to practice effects. Therefore, it could potentially be used on multiple occasions to quantify improvement over time.

Some work with the 2-Match FIST has been conducted to suggest that the task can be used with both typical and atypical populations. Yerys and colleagues (2012) already showed that the 2-Match FIST is appropriate for use with children with autism spectrum disorder and found that it is sensitive to differences in cognitive flexibility relative to typical controls. However, they also encountered ceiling effects that would be mitigated by the more difficult versions we developed here. The FIST modifications might also be useful for assessing improvement in attention deficit/hyperactivity disorder (ADHD), but this remains to be validated. Willoughby and colleagues (Willoughby, Blair, Wirth, & Greenberg, 2010; Willoughby, Pek, & Blair, 2013) included a modification of the 2-Match FIST as part of a battery of executive function measures. This battery was a significant predictor of risk for ADHD, but the effect size was modest with poor sensitivity; strong performance on the battery predicted low risk for ADHD, but poor performance on the battery was a less informative predictor of high risk for ADHD. Furthermore, when the FIST was isolated as a predictor of ADHD risk, it was only modestly associated (highest effect size $r = -.40$; Willoughby et al., 2010). These findings suggest caution when using this assessment with ADHD until further studies of the validity can be conducted.

Summary

The analyses of the FIST modifications used in this study indicate a multifaceted picture for cognitive flexibility and its development. The evidence suggests that cognitive flexibility develops considerably beyond the preschool period, at least until 10 years of age when assessed on the more difficult FIST manipulations. Furthermore, the analyses of the FIST, WCST, Backward Digit and Word Span tasks point to some role for working memory storage and processing as fundamental components of the construct of cognitive flexibility. Although more research is needed to pinpoint more precisely the component cognitive processes that contribute to developing cognitive flexibility, the FIST battery developed here is a promising tool for assessing typical development of cognitive flexibility and may also be useful for atypical populations.

Appendix Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jecp.2014.01.021.

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