



Published in final edited form as:

J Exp Child Psychol. 2009 June ; 103(2): 241–249. doi:10.1016/j.jecp.2009.01.002.

When Simple Things Are Meaningful: Working Memory Strength Predicts Children's Cognitive Flexibility

Katharine A. Blackwell*

Department of Psychology, University of Colorado at Boulder

Nicholas J. Cepeda

Department of Psychology, York University and Department of Psychology, University of California, San Diego

Yuko Munakata

Department of Psychology, University of Colorado at Boulder

Abstract

People often persevere, repeating outdated behaviors, despite correctly answering questions about rules they should be following. Children who persevere are slower to respond to such questions than children who successfully switch to new rules, even controlling for age and processing speed. Thus, switchers may have stronger working memory strength than perseverators, with stronger rule representations supporting both flexible switching and faster responses to questions (Cepeda & Munakata, 2007). Alternatively, better inhibitory abilities may support switchers' faster responses by helping to resolve conflict. The current study tested these accounts using a new one-dimensional card sort. Even with all possible sources of conflict removed, switchers still responded faster to questions about rules than perseverators, supporting the graded working memory account.

Keywords

cognitive flexibility; task switching; working memory; inhibition; processing speed; children

People are generally able to behave flexibly, breaking habits to deal with novel situations. However, sometimes we repeat old behaviors that are no longer appropriate. Such perseveration is apparent in older adults, children, prefrontal patients, and schizophrenics (Dunbar & Sussman, 1995; Zelazo, 2004; Rossell & David, 1997; Ashendorf & McCaffrey, 2007). For example, when three-year-olds are presented with cards depicting blue trucks and red flowers, they will continue to sort them by the first rule they are given, color or shape, despite being instructed to sort them by the other rule (Kirkham & Diamond, 2003; Perner & Lang, 2002; Zelazo & Frye, 1998). However, they can answer simple queries about the rule they are failing to use: When asked, "Where do trucks go in the shape game?" they correctly point to the red truck, but when given a blue truck they put it with the blue flower (Zelazo, Frye & Rapus, 1996). Six-year-olds show similar behavior when asked to switch from deciding

© 2009 Elsevier Inc. All rights reserved.

*Corresponding Author Address: 345 UCB, University of Colorado at Boulder, Boulder, CO 80309 katharine.blackwell@colorado.edu
Telephone: 303-492-6389 Fax: 303-492-2967.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

whether a speaker is happy or sad based on sentence content to deciding based on intonation, perseverating on content despite correctly answering queries about the rules for happy and sad intonation (Morton & Munakata, 2002b).

Why do perseverators succeed at answering simple queries about the rules of a game but fail to respond according to those rules? The problem appears to reflect a difficulty in resolving conflict. When queries contain information about the two conflicting dimensions (e.g., “Where do blue trucks go in the shape game?”), children persevere just as they do when sorting cards (Morton & Munakata, 2002b; Munakata & Yerys, 2001). We contrast two explanations for this difficulty. The graded working memory account posits that the critical factor is the strength of working memory representations (Munakata, 2001). Children persevere because their memories for the current rule are not strong enough to overcome the conflict in multidimensional questions and cards, but can answer simple queries because weaker working memory suffices when there is no conflict (as simulated in Morton & Munakata, 2002a). The directed inhibition account, in contrast, posits that the critical factor is inhibitory ability (Kirkham & Diamond, 2003; Zacks & Hasher, 1994). Children persevere because they cannot inhibit information about the first dimension in multidimensional questions and cards, but can answer simple queries because there is no information to inhibit.

The graded working memory account makes a unique prediction: Switchers should answer simple queries faster than perseverators. Stronger representations of the current rule (e.g., shape) provide top-down support for task-relevant representations (e.g., truck, flower); the greater this support, the faster those task-relevant representations can reach threshold for driving a response. This prediction has been confirmed (Cepeda & Munakata, 2007). Six-year-olds completed a computerized three-dimensional card sort (“3D card sort”; Figure 1a) with stimuli varying along three dimensions (shape, color, and size; Deák, 2003). Children who flexibly switched between the rules and children who perseverated were equally accurate in answering simple queries (e.g., “In the shape game, what do you press when you see a cat?”), but switchers responded faster than perseverators, even when controlling for age and processing speed. Thus, stronger representations of the current rule may support both flexible switching with conflicting stimuli and faster responses with non-conflicting stimuli. This result appears to challenge directed inhibition accounts.

Directed inhibition may nonetheless have helped switchers respond faster to simple queries, as two potential sources of conflict might have been resolved through inhibition. First, targets varied along all three dimensions (e.g., large blue cat), so ability to inhibit other dimensions of the target (e.g., to ignore that a blue cat is blue and focus on the fact that it is a cat) may have speeded reaction times. Second, responding to simple queries could require switching between modalities, as simple queries were auditory but the targets were visual¹, so ability to inhibit the previous modality (i.e., to stop focusing on the auditory query and respond to visual stimuli) may have speeded reaction times. In addition, switchers' faster responses might reflect greater motivation or general cognitive abilities that aid performance on all tasks, rather than working memory specifically.

The goal of the current study was to address the potential roles of inhibition, motivation, and general cognitive ability in Cepeda & Munakata's (2007) findings, to more directly test the role of working memory strength in children's flexibility. We utilized the 3D card sort to classify children as switchers and perseverators, introduced a one-dimensional card sort (“1D card sort”) with no information to inhibit to test our prediction about working memory strength, and adapted a probabilistic selection task (Frank, Woroach, & Curran, 2005) to distinguish benefits

¹Visual simple queries (e.g., a white bird of a size that did not exactly match any of the targets) were also presented, but were not analyzed for the paper due to concerns about whether visual stimuli could truly be size-neutral.

of greater working memory strength from greater motivation and general cognitive ability. The 1D card sort reduces each target to a single dimension of pattern (stripes or dots) that matches stimuli exactly, removing any benefit of inhibiting irrelevant target dimensions (Figure 1b). Responses should still be speeded by stronger working memory, because children are instructed to respond as quickly as possible and maintenance of the current rule should provide beneficial top-down support. The 1D card sort contrasts with standard measures of working memory, such as span tasks, which focus on capacity rather than working memory strength and likely tap multiple other processes, such as updating. The 1D card sort also presents simple queries in both auditory and visual modalities, to test switchers' advantage when not switching between modalities (i.e., on visual queries). The probabilistic selection task relies on incremental, long-term learning about the reward values of stimuli, and thus should not show particular benefits from greater working memory strength.

The graded working memory account predicts that switchers should respond more quickly than perseverators to queries in the 1D task, whereas the directed inhibition account predicts that switchers and perseverators should be equally fast because there is no conflicting information that could be inhibited. The graded working memory account further predicts that switchers and perseverators should be equally fast in incremental learning on the probabilistic selection task, whereas accounts based on greater motivation or general cognitive ability predict that switchers should learn more quickly.

Method

Participants

Forty-two five- to six-year-olds ($M = 72.2$ months, range 69.1 – 75.4 months, 23 female) participated in this study. An additional 19 participants were excluded: 10 did not meet the preswitch accuracy criterion of 70%, four had mixed switching performance (perseverating on one postswitch block but switching on the other), two did not complete both processing speed tasks, and reaction time data for three were lost. Children were categorized by performance on the color and size blocks, as “switcher” (83% to 100% correct, $M = 97.0\%$ of color and 94.1% of size trials correct) or “perseverator” (0% to 25% correct, $M = 3.0\%$ of color and 1.9% of size trials correct). Thirty participants (71%, 16 female) perseverated and 12 participants (29%, 7 female) switched. Mean age was 72.2 months for both perseverators ($SD = 1.5$) and switchers ($SD = 2.1$).

Materials and Procedure

All participants completed tasks in the same order: box completion, offset reaction time, 3D card sort, 1D card sort, probabilistic selection.

Processing speed—Two measures of processing speed were collected to provide a covariate for working memory strength. Both processing speed measures have low task set and cognitive demands, which we believe makes them relatively pure speed measures. Children were instructed to complete both tasks “as fast as you can.” The first was a box completion task in which participants drew the fourth side of each box in an array of three-sided boxes (Salthouse, 1994). They practiced on a sheet containing 12 three-sided boxes, and then completed as many boxes of a 5×7 array as possible in 30 seconds. The second was a computerized task in which participants placed one finger on a star in the corner of the screen and attempted to “pop” blue circles that appeared on the screen by pressing them. Reaction time to remove their finger from the star (finger-offset or finger-lift RT) was recorded across 10 trials.

3D card sort—The 3D card sort task was adapted from Cepeda and Munakata (2007) and based on Deák (2003). The top half of the screen contained three target images that were present throughout the task: a large blue cat, a small yellow fish, and a medium red bird (Figure 1a). The task was divided into three blocks (shape, color, and size) in which participants were asked to match pictures by the current rule. Pre-recorded video clips relayed instructions. For each block, participants were asked to identify all stimuli by the current dimension (e.g., “Can you press the cat?”), informed of the current rules (e.g., “In the color game, when you see a red one, press the red one.”), asked three simple queries about the rules of the game in the absence of any visual stimuli (e.g., “In the size game, what do you press when you see a small one?”), and presented with 12 individual stimuli that matched each target on one dimension (e.g., a large yellow bird).

No feedback or reminders were provided. Stimuli were always presented in a predetermined order that participants could not predict. All responses were made by pressing one of the targets; reaction time was recorded upon target press. Individual participants usually responded with the same hand and returned that hand to the same starting position between trials, but starting position differed across participants².

1D card sort—The 1D card sort consisted of 20 trials of simple queries, 10 auditory and 10 visual, about the rules for a pattern game. Children were encouraged to respond “as fast as you can,” to encourage goal maintenance. The top half of the screen contained two target images that were present throughout the task: stripes and dots (Figure 1b). Pre-recorded auditory clips relayed instructions. First, children were instructed to follow auditory requests in the absence of visual stimuli: “In the pattern game, when I say tap the stripes/dots, tap the stripes/dots.” Trials were presented in random order, with the verbal prompt, “In the pattern game, which do you tap for the stripes/dots?” Next, children were instructed to respond to visual stimuli exactly matching one target presented on the bottom half of the screen: “In the pattern game, when you see stripes/dots, tap the stripes/dots at the top.” Trials were presented in random order, with images appearing at the end of the verbal prompt, “In the pattern game, which do you tap for this one?” All responses were made by pressing one of the targets; reaction time was recorded upon target press.

Probabilistic selection task—This 2-alternative forced choice task was presented as a game of “hide-and-seek” in which children tried to find animals behind one of two rocks on the computer monitor. One rock was correct on 90% of trials. The game ended when children selected the correct response on 7 of 10 consecutive trials, or after 76 trials.

Data trimming and scores—Simple query reaction times were trimmed as in Cepeda and Munakata (2007), following a modified version of Friedman and Miyake's (2004) trimming procedure, to remove skewness caused by the small number of trials contributing to each mean. This procedure builds on prior work in this area and yields more easily interpretable results, but results were comparable with other skewness reduction procedures, such as log transform. Participant means were trimmed by block (shape, color, size) or modality (auditory, visual). Cases where participants responded correctly to only one query (2% of 3D card sort and 1% of 1D card sort trials) or responded in less than 200 ms (1% of 3D card sort and 0% of 1D card sort trials) were excluded without replacement; cases more than 3 *SDs* from the mean of the remaining participants were removed and replaced with a value exactly 3 *SDs* from the new mean (9% of 3D card sort and 7% of 1D card sort trials). One box completion score and two offset reaction times greater than 3 *SDs* from the mean of remaining scores were replaced with values exactly 3 *SDs* from the new mean. A composite processing speed score was calculated

²Results were reliable despite any error added to the RT measurement from variations in starting position and hand used.

from the z-scores of each processing speed measure³. Switchers and perseverators did not differ in processing speed ($F < 1$).

Although the 1D card sort used 10 trials of each modality, continued maintenance of the rule should not be required with additional trials and performance should reflect habit memory more than active working memory. To maximize contributions from working memory, only the first half of each modality (five trials) was analyzed. Results are the same with cutoffs at any point within the first six trials of each modality, after which reaction times tended to plateau.

Results

Switchers responded to 1D simple queries faster than perseverators, controlling for age and processing speed (Figure 2a; $F(1, 37) = 7.6, p < .01, \eta^2 = .17$), and simple query reaction time predicted whether children switched or perseverated, better than age or processing speed (Table 1). There was no effect of modality ($F < 1$) and no interaction of modality and switching ($F < 1.5$). Switchers and perseverators did not differ in the time to learn the correct response on the probabilistic selection task (19.8 vs. 18.3 trials, $F < 1$). In addition, the main findings of Cepeda and Munakata (2007) were replicated: Switchers responded to 3D simple queries faster ($M = 1229$ ms, $SD = 495.6$) than perseverators ($M = 1678$ ms, $SD = 813.2$), controlling for age and processing speed ($F(1, 36) = 4.6, p < .05, \eta^2 = .11$)⁴, and 3D simple query reaction time predicted whether children switched or perseverated, better than age or processing speed (Table 2).

Discussion

Switchers responded to simple queries about the rule they should be using faster than perseverators, even after controlling for age and processing speed, and even with attempts to remove all conflict from the queries. These results confirm a unique prediction from the graded working memory account of perseveration: Switchers have stronger working memory representations than perseverators, which provide greater top-down support for answering simple queries and thus speed reaction times. Inhibitory abilities, motivation, or general cognitive ability cannot explain these differences, because both the stimuli and the targets in the 1D card sort contained no information to inhibit, and switchers and perseverators learned the probabilistic selection task equally quickly.

Follow-up analyses suggest that revised inhibitory explanations are also unlikely. One argument is that switchers might benefit from inhibiting information that is no longer relevant (e.g., to switch from a task with three targets to a task with two targets, or from a task involving size to a task involving pattern). If this were the case, the link between switching and reaction times should be most prominent on the first trial. Another argument is that the 1D card sort involved switching between targets (i.e., stripes vs. dots), which conferred a reaction time advantage for switchers. If this were the case, switchers should show an advantage on target-switch trials (e.g., dots after stripes) but not on target-repeat trials (e.g., dots after dots). Neither inhibitory prediction was corroborated: There was no effect of trial type (first trial, target-switch trial, or target-repeat trial) on switchers' advantage (Figure 2b; $F < 2$). The profile of

³The measures were mildly but not significantly correlated ($r = .14$), as one might expect given the many methodological differences between these tasks (paper-and-pencil vs. computerized, motor demand differences, etc.). Results did not differ if processing speed measures were entered individually.

⁴There was an interaction between switch status and block ($F(2, 72) = 3.6, p < .05$), such that the switcher advantage decreased across blocks. No such interaction was found in Cepeda and Munakata (2007), but the interaction of block and status is not different between the two studies ($F < 3$). There was an interaction between block and study ($F(2, 118) = 4.7, p = .01$) such that reactions times on the shape block were slower in the current study, likely because children were younger and needed more time to get comfortable with the task.

switchers' reaction time advantage is instead more consistent with greater working memory strength that benefits all trial types.

Our results do not rule out inhibitory explanations for all aspects of perseveration. However, some of the evidence used to argue for inhibition may be more consistent with graded working memory. For example, knowledge-action dissociations cannot simply reflect problems inhibiting prior actions, because dissociations disappear when knowledge and action measures are equated for conflict (Morton & Munakata, 2002a; Munakata & Yerys, 2001). Dissociations could reflect inhibitory problems at a more representational level (e.g., a difficulty inhibiting attention to the first dimension; Kirkham & Diamond, 2003), but graded working memory is sufficient to account for such dissociations (Morton & Munakata, 2002a). Furthermore, only graded working memory accounts predict switchers' advantage on tasks with nothing to inhibit. Thus, although inhibition may play some yet-to-be-discovered role in flexible behavior, graded working memory can explain many existing findings.

Our results provide a similar challenge for other theories of perseveration. The redescription account posits that children perseverate because they cannot describe stimuli in terms of a second dimension (Perner & Lang, 2002). The cognitive complexity and control theory (Zelazo & Frye, 1998) posits that children perseverate because they cannot represent a higher-order rule structure necessary for switching between two sets of rules. These accounts seem unable to explain why switchers are faster than perseverators when there is nothing to redescribe and only one set of rules. Instead, working memory strength may support redescription and higher-order rule representations, because actively maintaining both dimensions may allow redescribing stimuli or switching between the rules for those dimensions. Thus, working memory strength should correlate with redescription and use of higher-order rules, and may link these factors to flexibility.

It may seem surprising that children bother to maintain a goal in answering non-conflict queries, when three-year-olds show decreased maintenance of task set after sorting cards that match targets exactly (Marcovitch, Boseovski, & Knapp, 2007). Our tasks may encourage more goal maintenance because the 3D card sort requires following a rule focused on one of three possible sorting dimensions, and the 1D card sort includes the instruction for children to respond "as fast as you can." In addition, six-year-olds may have a greater tendency to actively maintain information than three-year-olds. It also may seem surprising that more than half of six-year-olds in this study perseverated on the 3D card sort, given previous reports that four-year-olds perform well on this task (Deák, 2003; Narasimham, Deák, & Cepeda, 2008). Key differences in the procedure include the lack of physical target boxes and stimulus cards, more preswitch trials, and single-dimension trials introducing the preswitch rule, all of which could have made the computerized task more difficult.

An additional test of the role of working memory in flexibility could come from direct manipulations of working memory strength, if this could be manipulated independent of other working memory processes, such as updating. Previous findings are suggestive. For example, six-year-olds are more likely to perseverate when working memory demands are increased by reducing the frequency of rule reminders (Morton, Trehub & Zelazo, 2003; see also Deák, Ray & Pick, 2004).

Our results demonstrate that speed to answer non-conflict queries about the rules of a game predicts ability to behave flexibly, suggesting that that inhibition, redescription, and higher-order representations cannot be solely responsible for flexibility. This finding supports the graded working memory account of perseveration, indicating that strength of working memory for a current rule is a significant contributor to cognitive flexibility that should be factored out before assessing the contributions of other factors. This is consistent with observations about

the relationship between working memory and seemingly inhibitory abilities, such as controlling intrusive thoughts (e.g., Brewin & Beaton, 2002); resolving conflict among stimulus features (Egner & Hirsch, 2005); and overcoming prepotent responses in an anti-saccade task (Unsworth, Schrock, & Engle, 2004), in the Stroop task (Kane & Engle, 2003), and in the absence of obvious memory demands (Stedron, Sahni, & Munakata, 2005). The fact that working memory may do more explanatory work than other factors in understanding cognitive flexibility also has implications for training and remediation; cognitive effort might be better applied to improving maintenance of the task at hand (e.g., focusing on skiing through a narrow path) rather than inhibition of unwanted information (e.g., focusing on the trees you don't want to hit). The graded working memory framework should prove useful for understanding these facets of cognitive flexibility.

Acknowledgments

This work was supported by grants from the National Institutes of Health (RO1 HD37163 and P50-MH079485). We thank Sara McQuiston, Joedy Hulings, and other members of the Cognitive Development Center for useful discussions and assistance with this study.

References

- Ashendorf L, McCaffrey RJ. Exploring age-related decline on the Wisconsin Card Sorting Test. *The Clinical Neuropsychologist* 2007;1–11. [PubMed: 17366273]
- Brewin CR, Beaton A. Thought suppression, intelligence, and working memory capacity. *Behaviour Research and Therapy* 2002;40:923–930. [PubMed: 12186355]
- Cepeda NJ, Munakata Y. Why do children persevere when they seem to know better: Graded working memory, or directed inhibition? *Psychonomic Bulletin & Review* 2007;14:1058–1065. [PubMed: 18229475]
- Deák, GO. The development of cognitive flexibility and language abilities. In: Kail, R., editor. *Advances in child development and behavior*. Vol. 31. Academic Press; San Diego: 2003. p. 271–327.
- Deák GO, Ray SD, Pick AD. Effects of age, reminders, and task difficulty on young children's rule-switching flexibility. *Cognitive Development* 2004;19:385–400.
- Dunbar K, Sussman, D. Toward a cognitive account of frontal lobe function: Simulating frontal lobe deficits in normal subjects. *Annals of the New York Academy of Sciences* 1995;769:289–304. [PubMed: 8595033]
- Egner T, Hirsch J. Cognitive control mechanisms resolve conflict through cortical amplification of task-relevant information. *Nature Neuroscience* 2005;8:1784–1790.
- Frank MJ, Worocho BS, Curran T. Error-related negativity predicts reinforcement learning and conflict biases. *Neuron* 2005;47:495–501. [PubMed: 16102533]
- Friedman NP, Miyake A. The relations among inhibition and interference control functions: A latent-variable analysis. *Journal of Experimental Psychology: General* 2004;133:101–135. [PubMed: 14979754]
- Kane MJ, Engle RW. Working-memory capacity and the control of attention: The contributions of goal neglect, response competition, and task set to Stroop interference. *Journal of Experimental Psychology: General* 2003;132:47–70. [PubMed: 12656297]
- Kirkham NZ, Diamond A. Sorting between theories of perseveration: performance in conflict tasks requires memory, attention and inhibition. *Developmental Science* 2003;6:474–476.
- Marcovitch S, Boseovski JJ, Knapp RJ. Use it or lose it: examining preschoolers' difficulty in maintaining and executing a goal. *Developmental Science* 2007;10:559–564. [PubMed: 17683342]
- Morton JB, Munakata Y. Active versus latent representations: A neural network model of perseveration, dissociation, and decalage. *Developmental Psychobiology* 2002a;40:255–265. [PubMed: 11891637]
- Morton JB, Munakata Y. Are you listening? Exploring a developmental knowledge-action dissociation in a speech interpretation task. *Developmental Science* 2002b;5:435–440.
- Morton JB, Trehub SE, Zelazo PD. Sources of inflexibility in 6-year-olds' understanding of emotion in speech. *Child Development* 2003;74:1857–1868. [PubMed: 14669900]

- Munakata Y. Infant perseveration and implication for object permanence theories: A PDP model of the AB task. *Developmental Science* 1998;1:161–184.
- Munakata Y. Graded representations in behavioral dissociations. *Trends in Cognitive Science* 2001;5:309–315.
- Munakata Y, Yerys BE. All together now: when dissociations between knowledge and action disappear. *Psychological Science* 2001;12:335–337. [PubMed: 11476102]
- Narasimham G, Deák GO, Cepeda NJ. Does development of rule-switching flexibility “scale up?” Evidence from a test of card sorting by three competing dimensions (the 3DCCS). 2008 Manuscript in preparation
- Perner J, Lang B. What causes 3-year-olds' difficulty on the dimensional change card sorting task? *Infant and Child Development* 2002;11:93–105.
- Rossell SL, David AS. Improving performance on the WCST: Variations on the original procedure. *Schizophrenia Research* 1997;28:63–76. [PubMed: 9428065]
- Salthouse TA. The nature of the influence of speed on adult age differences in cognition. *Developmental Psychology* 1994;30:240–259.
- Stedron JM, Sahni SD, Munakata Y. Common mechanisms for working memory and attention: The case of a perseveration with visible solutions. *Journal of Cognitive Neuroscience* 2005;17:623–631. [PubMed: 15829082]
- Unsworth N, Schrock JC, Engle RW. Working memory capacity and the antisaccade task: Individual differences in voluntary saccade control. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 2004;30:1302–1321.
- Zacks, RT.; Hasher, L. Directed ignoring: Inhibitory regulation of working memory. In: Dagenbach, D.; Carr, TH., editors. *Inhibitory mechanisms in attention, memory, and language*. Academic Press; New York: 1994. p. 241-264.
- Zelazo PD. The development of conscious control in childhood. *Trends in Cognitive Science* 2004;8:12–17.
- Zelazo PD, Frye D. Cognitive complexity and control II: The development of executive function in childhood. *Current Directions in Psychological Science* 1998;7:121–126.
- Zelazo PD, Frye D, Rapus T. An age-related dissociation between knowing rules and using them. *Cognitive Development* 1996;11:37–63.

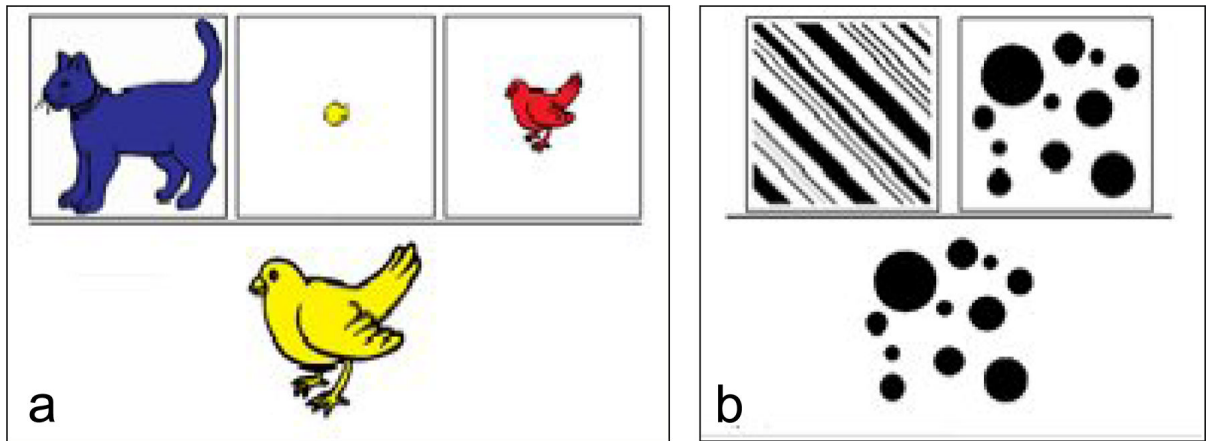


Figure 1.

a) 3D card sort (adapted from Cepeda & Munakata, 2007). Participants selected one of the three target cards along the top row on each trial. Conflict stimuli matched each target on one dimension. No stimuli appeared on the lower half of the screen during simple query trials. b) 1D card sort. Participants selected one of the two target cards on each trial. Stimuli exactly matched one of the two targets, so no inhibition of an irrelevant dimension was necessary to complete the task. No stimuli appeared on the lower half of the screen during auditory trials.

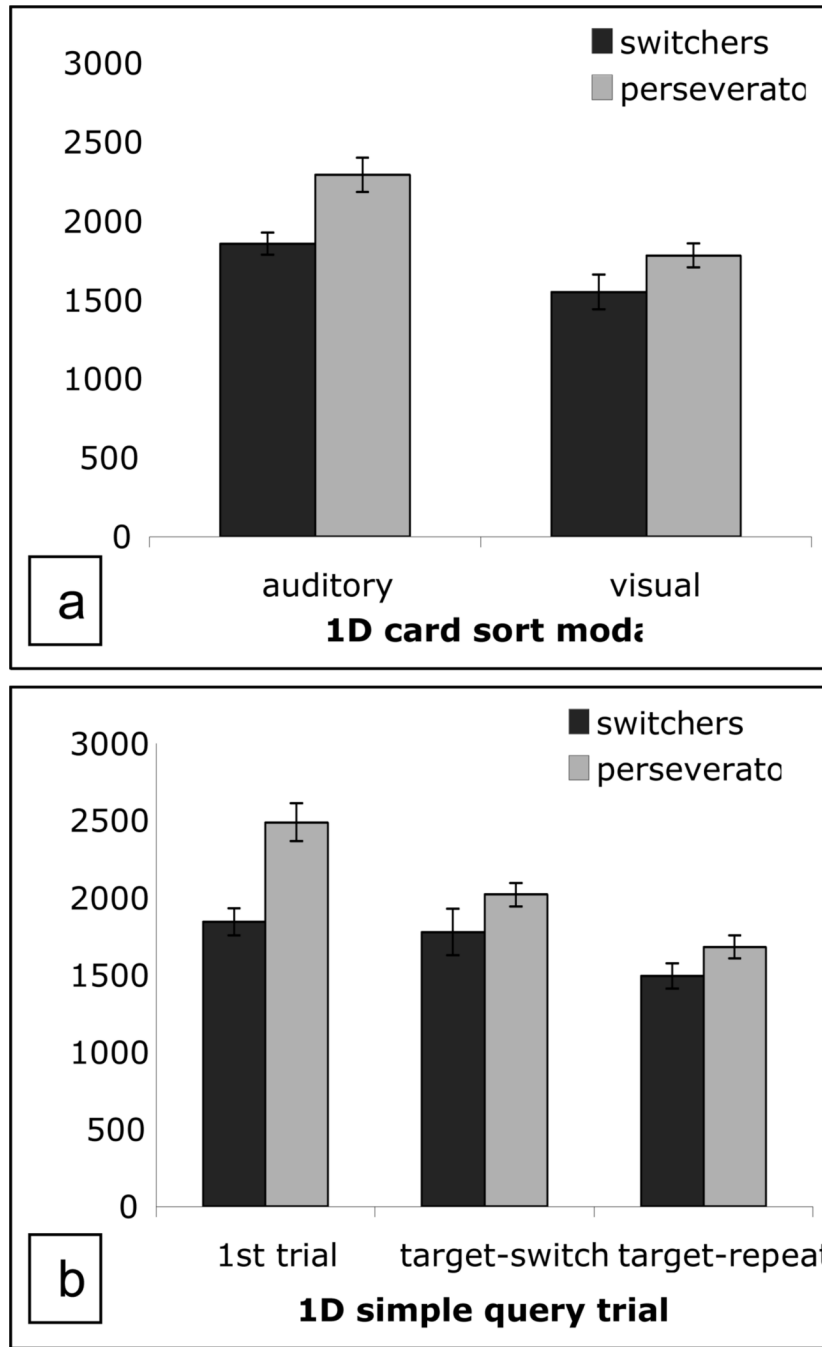


Figure 2. a) Switchers responded faster than perseverators to 1D simple queries, even after controlling for age and processing speed. b) Switchers responded faster than perseverators to 1D simple queries across the first trial and target-switch and target-repeat trials.

Table 1
Hierarchical Regression of Card Sort Status on ID Simple Query Reaction Time

Independent Variable	B	Exp(B)	Wald	p	R ²	R ² Change
age	-.022	.979	.01	.93	.00	
processing speed	.519	1.68	.95	.33		.012
ID simple query reaction time	-.004	.996	6.14	.01		.299

ID simple query reaction time – hierarchical regression with Nagelkerke R². ID simple query reaction time was predictive of ability to switch even after controlling for age and processing speed, and was more predictive than processing speed.

Table 2
Hierarchical Regression of Card Sort Status on 3D Simple Query Reaction Time

Independent Variable	B	Exp(B)	Wald	p	R ²	R ² Change
age	.045	1.05	.04	.84	.00	
processing speed	.933	2.54	2.47	.12		.012
3D simple query reaction time	-.002	.998	3.88	.05		.191

3D simple query reaction time – hierarchical regression with Nagelkerke R². 3D simple query reaction time was predictive of ability to switch even after controlling for age and processing speed, and was more predictive than processing speed.