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More than a matter of getting 'unstuck': Flexible thinkers use more abstract representations than perseverators

Maria Kharitonova, **Sarina Chien**, **Eliana Colunga**, and **Yuko Munakata**
University of Colorado, Boulder

Abstract

Why do people perseverate, repeating prior behaviors that are no longer appropriate? Many accounts point to isolated deficits in processes like inhibition or attention. We instead posit a fundamental difference in rule representations: Flexible switchers use active representations that rely on later-developing prefrontal cortical areas and are more abstract, while perseverators use latent representations that rely on earlier-developing posterior cortical and subcortical areas and are more stimulus-specific. Thus, although switchers and perseverators should apply the rules they use to familiar stimuli equally reliably, perseverators should show unique limitations in generalizing their rules to novel stimuli, which require abstract representations. Two behavioral experiments confirmed this counterintuitive prediction early in development. Three-year-old children sorted cards by one rule, were asked to switch to another rule, and then were asked to simply continue their behavior, with novel cards. Perseverators applied the rule they were using (the first rule) just as reliably as switchers applied the rule they were using (the second rule) with familiar cards; however, only switchers generalized their rule to novel cards. This finding supports an early link between active representations that support switching and abstract representations that support generalization. We interpret this synergy in terms of prefrontal cortical development.

Even as adults, we sometimes fail to think flexibly and instead repeat behaviors that worked in the past but are no longer applicable (e.g., failing to make a planned detour from a practiced driving route or repeatedly searching for keys in the same pocket). Children are even more robust perseverators: infants tend to search for a toy in its previous hiding location even after observing it being hidden in a new place (Diamond, 1985; Piaget, 1954). Three-year-olds continue sorting cards by the first rule they are exposed to (e.g., color) even when explicitly and repeatedly told that the rule has changed (e.g., to shape) (Perner & Lang, 2002; Zelazo, Frye, & Rapus, 1996).

What processes lead to perseveration versus flexible switching? According to prominent explanations (e.g., Dempster, 1992; Diamond & Kirkham, 2005; Milner, 1963; Norman & Shallice, 1986; Zelazo et al., 1996), perseverators and switchers do not necessarily differ in how they represent the basic rules they use (e.g., to sort cards by color or by shape), but rather in separate processes like inhibition or attention that operate on these rules. For example, according to the Attentional Inertia account, switchers are better than perseverators at overcoming attentional inertia toward continuing to see stimuli according to one dimension, so that they can switch to another dimension (Kirkham, Cruess, & Diamond, 2003). Or, according to the Cognitive Complexity & Control (CCC) account, switchers are better at representing higher order rules that relate the lower order rules of color and shape to one another (Zelazo et al., 1996). However, according to an alternative active-latent account, switchers and

Correspondence concerning this article should be addressed to Maria Kharitonova, Department of Psychology, 345 UCB, University of Colorado, Boulder, Boulder, CO 80309, Phone: (303) 492-9771, Fax: (303) 492-6389, Email: maria.kharitonova@colorado.edu.

perseverators use distinct types of competing rule representations (Cohen & Servan-Schreiber, 1992; Munakata, 1998). Specifically, switchers rely more on “active” representations, which take the form of sustained neuronal firing and serve to maintain and provide top-down support for currently relevant task information, thus leading to flexible switching to a new task. Perseverators rely more on “latent” representations, which take the form of changes in neuronal connections and build through repeated experiences, leading to biases to repeat prior behaviors, which may lead to perseveration under insufficiently strong competition from active representations.

Active representations are thought to rely on prefrontal cortical regions and develop relatively late, whereas latent representations are thought to rely more on posterior cortical and subcortical regions and develop relatively early (Casey, Durston, & Fossella, 2001; Frank, 2005; Jog, Kubota & Graybiel, 1999; Miller, Erickson, & Desimone, 1996; Miller & Desimone, 1994; Morton & Munakata, 2002). In addition, active and latent memory systems differ in the type of information they represent: prefrontal active representations are thought to code for more abstract information, while posterior latent representations code for more stimulus-specific information (Ashby & Maddox, 2005; Bunge, Kahn, Wallis, Miller, & Wagner, 2003; Bunge & Zelazo, 2006; Patalano, Smith, Jonides & Koeppe, 2001; Rougier, Noelle, Braver, Cohen, & O'Reilly, 2005; Wallis, Anderson, & Miller, 2001). For example, prefrontal representations can code for whether any two objects or relationships between any two words are the same or different, regardless of the specific features of the objects or words (Bunge et al., 2003; Bunge, Wendelken, Badre, & Wagner, 2005; Wallis et al., 2001). Prefrontal representations support generalization to novel exemplars based on more abstract rules, while posterior representations are more tied to the specifics of previously-seen exemplars (Patalano et al., 2001).

The active-latent account thus leads to a unique and counterintuitive prediction. Despite the fact that switchers and perseverators are equally reliable in applying the sorting rules they are using to familiar cards (with switchers applying the new rule and perseverators applying the old rule), they should differ in their ability to apply their rules to novel cards. Specifically, switchers should generalize their behavior to novel stimuli more reliably than perseverators. If perseverators sort cards using stimulus-specific rules (red cards in one pile, blue cards in another), they should consistently apply these rules to familiar red and blue cards, but not to new exemplars (e.g., a yellow card).[1] In contrast, if switchers sort cards using more abstract rules (e.g., according to *color*), they should use these abstract rules in sorting new exemplars. Our prediction is unique, because other accounts posit that switchers and perseverators do not differ in how they represent the basic sorting rules, such that once they are using any given rule, switchers and perseverators should apply it in the same way. Our prediction is also counterintuitive, given that generalization to novel cards requires perseverators to simply extend the single rule they have been using all along. Two experiments test this prediction by comparing switchers (who are reliably using a new rule) and perseverators (who are equally reliably using an old rule) in their ability to apply the rule they are using to sorting novel stimuli.

[1]Some existing results are consistent with this prediction but do not test it directly. For example, children are less likely to perseverate when the features on cards change between the first rule (e.g., to sort red boats and blue rabbits by shape) and the second rule (e.g., to sort yellow cars and green flowers by color) (Total Change condition of Zelazo et al., 2003). This suggests that perseveration is at least in part stimulus-specific. However, it is not clear how this compares to switching. Moreover, children in these studies were not asked to generalize their behavior to the novel stimuli (and were in fact asked to switch to a new rule). Thus, it remains to be seen whether switchers and perseverators differ in their abilities to generalize when instructed.

Experiment 1

To assess whether switchers and perseverators differ in applying their equally-reliable sorting rules to novel cards, children were asked to sort familiar cards by one rule, then switch to sorting the same cards by a new rule, and finally apply the rule they were using to novel cards.

Method

Participants—Forty-one 39-month olds (*M* = 39.0 months; range: 38.6 - 39.3 months; 23 boys) participated. Eighteen participants were in the color-to-shape condition (first asked to sort cards by color and then switch to shape), and 23 were in the shape-to-color condition.[2] Additional children were excluded from analyses due to fussiness (4), mixed behavior in postswitch (4), failing preswitch (1), and experimental error (1). All participants were recruited through a departmental participant pool. Informed consent was obtained for all children. Children received a small prize and their parents were paid $5 for travel expenses.

Design and Procedure—The experiment consisted of four phases (Figure 1). In the *preswitch* phase, children sorted cards by one rule - either color or shape, counterbalanced. In the *postswitch* phase, children were asked to sort the same cards by the other rule. In the *novel* phase, generalization ability was assessed by asking children to sort new cards by the same rule they had been using (postswitch rule for switchers; preswitch rule for perseverators). In the final *familiar* phase, children were again presented with and asked to sort the original cards used in preswitch and postswitch. This phase served to assess whether children still remembered their sorting rule, in which case any differences observed in the novel phase could be attributed to generalization abilities, and not to extraneous factors such as forgetting the rule or unwillingness to continue playing the game.

All children were tested individually in a session that lasted approximately five minutes. Each child sat across a table from the experimenter. Two trays were on the table, each with a target card affixed to it. The target cards remained constant throughout the experiment and depicted a red truck and a blue flower. The cards-to-be-sorted included the standard cards (used in preswitch, postswitch, and familiar phases) and the novel cards (used in the novel phase). The standard cards depicted blue trucks and red flowers (thus exactly matching each target card on one dimension). The novel cards depicted a turquoise TV, an orange ball, an orange-yellow mirror, a teal refrigerator, a green house, and a yellow apple. Thus the novel cards only approximately matched each dimension of the target cards. These stimuli were designed so that the novel stimuli became increasingly dissimilar to the standard stimuli across trials, and generalization would be difficult without an abstract representation of the appropriate rule.

Only one condition (shape-to-color) is described here for simplicity. The preswitch phase started with the experimenter first naming the game and explaining the rule (“Today we are going to play a game called the shape game. In the shape game, trucks go here and flowers go here.”). The experimenter then demonstrated the game by sorting two cards facedown into the appropriate trays. The child was then invited to participate (“Now it's your turn to play!”) and for each of the subsequent six preswitch trials, the rule was reiterated (“Remember, in the shape game, trucks go here and flowers go here.”) and feedback was given (“Good job!” if correct or “No, trucks go here in the shape game” if incorrect).

The postswitch phase started with the experimenter strongly emphasizing the change of the game: “Now we are going to switch and play a new game, called the color game. We are not going to play the shape game anymore. No way! We are going to play the color game and the

[2]More children were run in the shape-to-color condition to obtain a reasonable number of switchers in this condition: fewer children switched in shape-to-color (22%) than in color-to-shape (44%), although this difference was not significant, Yates $\chi^2(1) = 1.5$, $p = 0.22$.

color game is different. In the color game, red ones go here and blue ones go here." During the postswitch phase, the rule was repeated for each of the six trials ("Remember, in the color game, red ones go here and blue ones go here."). However, in postswitch no feedback was given – the experimenter neutrally said "OK" after the child placed each card into a tray.

In the novel phase, the experimenter simply asked the children to continue their behavior: "You are doing great! Just keep doing what you are doing!" Children were presented with six novel cards and asked, "Where do you think this goes?"

The familiar phase started with the experimenter stating, "You are almost done!" Children were presented with six standard cards again (blue trucks and red flowers) and asked, "Where do you think this goes?" The rule was not repeated and feedback was not provided for either the novel or the familiar phases.

Results

Initial descriptive analyses indicated that the data were non-normal in the preswitch, postswitch, and familiar phases.[3] Thus, as in previous studies (Kirkham et al., 2003), children were classified within each of these phases based on whether they sorted at least 5 out of 6 cards according to a consistent rule. Because the contrast of interest concerned switchers versus perseverators, children had to pass preswitch, and then either clearly switch (sort at least 5/6 cards correctly, $N = 13$) or clearly perseverate (sort at least 5/6 cards incorrectly, $N = 28$) in postswitch to be included in the study. Reliability during postswitch and generalization phases was measured as the number of consecutive cards, starting with the first card, sorted according to the rule used in postswitch (the new rule for switchers and the old rule for perseverators).[4] Chance performance for generalization was 0.98 cards. This number was computed across all 64 permutations of how the 6 novel cards could be sorted, and represents the average number of consecutive novel cards sorted according to the rule used in postswitch across these permutations.

The key prediction for this study was confirmed: Switchers applied their postswitch sorting rule to more consecutive novel cards ($M = 3.1$, $SD = 2.4$) than perseverators ($M = 1.4$, $SD = 1.6$), $F(1, 40) = 10.3$, $p = 0.003$ (Figure 2), controlling for age and postswitch reliability. (During postswitch, perseverators were actually marginally more reliable than switchers in applying the rule they were using (perseverators: $M = 5.9$, $SD = 0.4$ vs. switchers: $M = 5.1$, $SD = 2.3$, $t(39) = 1.9$, $p = 0.07$). Switchers generalized their rule to novel cards better than expected by chance ($t(12) = 3.2$, $p = 0.008$), while perseverators' generalization did not differ from chance ($t(27) = 1.4$, $p = 0.2$). Similar results were obtained when the rule children were told to use in postswitch was included as a factor instead of the rule they actually used. Additionally, color ($M = 2.7$, $SD = 2.1$) was marginally easier to generalize than shape ($M =1.5$, $SD = 1.8$), $F(1,40) = 3.2$, $p = 0.08$.

Finally, performance in the familiar phase was highly consistent with the rule used in postswitch, with no significant difference between the percentage of perseverators (96%) and switchers (77%) passing the familiar phase (Yates $\chi^2(1) = 1.9$, $p = 0.2$). Perseverators' excellent performance with familiar cards indicates that their poor performance with novel cards reflected difficulty generalizing their sorting rule, rather than extraneous factors, such as an inability to remember the rule or unwillingness to continue with the task.

[3]Prior to excluding data from children who failed preswitch or showed mixed behavior in postswitch, 80% of children sorted all six preswitch cards correctly, 80% sorted all 6 cards correctly or all 6 cards incorrectly in postswitch, and 83% sorted all 6 familiar cards consistently with the rule they used in postswitch.

[4]Results are similar across other measures of reliability (e.g., overall number of cards sorted consistently with the rule used in postswitch), but number-of-consecutive-cards is used as a potentially more sensitive measure, due to its greater differentiability from chance and the increasing difficulty of cards across the generalization phase.

Discussion

Despite switchers and perseverators both showing highly reliable performance in applying the rule they were using to familiar cards, the groups differed strikingly in applying their rule to novel cards. Specifically, children who flexibly switched from one sorting rule to second sorting rule with familiar cards consistently applied that second rule to sorting novel cards. In contrast, children who reliably sorted familiar cards by the first rule throughout were unable to apply this rule to novel stimuli. This counterintuitive finding suggests an early synergy between two abilities supported by prefrontal cortical regions in adults: flexibility and generalization.

However, switchers and perseverators also differed in how often they had used the rule they were asked to generalize. Because perseverators did not switch away from the first rule they were exposed to, they sorted up to 12 cards in a row (6 trials of preswitch and 6 trials of postswitch) by the rule that they were later asked to generalize. In contrast, switchers sorted up to only 6 cards in a row (during postswitch) by the rule that they were asked to generalize. This difference might make the findings from Experiment 1 even more striking: perseverators had twice as many opportunities as switchers to practice and learn the rule they were asked to generalize, but they nonetheless failed to apply this rule to novel cards. However, it is also possible that perseverators' representations of their sorting rule *became* more entrenched or stimulus-specific as a result of the repeated rule exposure that they experienced in Experiment 1, thus precluding generalization. Experiment 2 tests this possibility.

Experiment 2

To assess whether perseverators' prolonged use of a single rule led to the formation of more stimulus-specific representations, switchers received an extra block of six postswitch trials, thus equating rule use among switchers and perseverators before generalization.

Method

Participants—Forty-nine 3.5-year-old children (*M* = 44.7 months, range from 43.1 to 45.3 months; 15 boys) participated. Additional children were dropped from the analyses due to experimental error (3), fussiness (1), and mixed behavior in the postswitch phase (1). These participants were recruited through the same departmental participant pool as in Experiment 1.

Design, Procedure, and Analyses—This experiment was almost identical to Experiment 1, except that switchers received 12 postswitch trials instead of 6. Perseverators experienced the same number of trials (i.e., 12) as in Experiment 1. This equated the number of cards that switchers and perseverators sorted by the rule they were asked to generalize.

Results

Perseverators were just as reliable as switchers in applying the rule they were using to familiar cards (perseverators (N=17): M = 10.8, SD = 2.5, across 6 trials of preswitch and 6 trials of postswitch; switchers (N=32): M = 11.3, SD = 2.4, across 12 trials of postswitch, $t(47) = 0.8$, $p = 0.5$). Differences between switchers' and perseverators' ability to generalize their rule to novel cards depended on the postswitch rule used, $F(1,48) = 7.8$, p =0.008 (Figure 3), controlling for age and postswitch reliability. When the postswitch rule used was color, the key prediction for the study was confirmed: Switchers generalized to more consecutive novel cards (M = 4.2, SD = 2.0) than did perseverators (M = 1.9, SD = 1.5), $t(20) = 2.9$, $p = 0.007$. Furthermore, switchers generalized their rule to novel colors better than expected by chance ($t(12) = 6.0$, $p < 0.001$), while perseverators' generalization with novel colors did not differ from chance ($t(8) = 1.8$, $p = 0.11$). These findings are consistent with the results of Experiment

1. However, when the postswitch rule used was shape, switchers (*M* = 1.4, *SD* = 1.6) and perseverators (*M* = 2.3, *SD* = 2.3) did not differ in their generalization to novel cards, $t(25) = 1.1$, $p = 0.3$, and neither group generalized better than expected by chance, all p's > 0.2. As in Experiment 1, color generalization (M = 3.3, SD = 2.1) was easier than shape generalization (M = 1.7, SD = 1.8), $F(1,48) = 6.5$, $p = 0.01$. Performance during the familiar phase was again consistent with postswitch behavior, with no differences between groups: 75% of switchers and 75% of perseverators passed the familiar phase (Yates $\chi^2(1) = 1$, $p = 0.7$).

Discussion

Switchers generalized the color rule to more novel cards than perseverators, even when the groups were equated for rule use before generalization. Thus, repeated rule use cannot explain why only switchers generalized the color rule to novel stimuli. This finding demonstrates that the synergy between adaptive responding and generalization is genuine.

The finding that switchers did not differ from perseverators in generalization to shape is consistent with two existing accounts. First, repeated rule use may lead to more stimulus-specific representations of *shape*, relative to other dimensions (Gelman & Bloom, 2000; Prasada, Ferenz & Haskell, 2002). Second, repeated emphasis on shape may lead to the formation of stronger semantic representations (Damian, Vigliocco, & Levelt, 2001). Semantics may constitute another conflicting dimension by which to sort the novel cards (e.g., “man-made” items, such as TV and mirror go with the red truck target and “natural” items such as apple, go with the blue flower target). Given that shape generalization was more difficult than color generalization across the two studies, repeated exposure to shape in Experiment 2 might thus have exacerbated the already more difficult task. Thus, generalization by shape may become selectively jeopardized after repeated shape exposure.

General Discussion

Taken together, results from these two experiments provide insight into common mechanisms that support flexible behavior and generalization. Our findings offer the first demonstration of a striking qualitative distinction between switchers' and perseverators' representations of rules, which affect not only the ability to flexibly update when rules change, but also the ability to generalize behavior to new stimuli. Despite the fact that switchers and perseverators were equally consistent in applying their respective sorting rules to familiar cards, only switchers were able to generalize their behavior to sorting novel cards. This finding supports the active-latent account that explains switching and perseverating in terms of differential use of active, abstract, prefrontal representations and latent, stimulus-specific, posterior representations, respectively. More generally, this finding is consistent with accounts that emphasize the importance of abstract representations in cognitive flexibility and other domains of higher-order cognition (Gentner, 2003; Jacques & Zelazo, 2005; Premack, 1984; Rougier et al., 2005; Vygotsky, 1962; Wallis et al., 2001).

Our results pose more of a challenge for alternate accounts of perseveration, which posit that perseverators and switchers represent the basic rules they use in the same way, but differ in other processes that operate on these rules (Dempster, 1992; Diamond & Kirkham, 2005; Milner, 1963; Norman & Shallice, 1986). For example, if perseverators are simply “stuck” on one dimension while switchers have moved on to a new dimension, as the Attentional Inertia account posits (Kirkham et al., 2003), there is no reason for the groups to differ in their generalization to new features within that same dimension. Similarly, the CCC account should not predict perseverators to be worse than switchers at generalizing within a single card-sorting rule, if perseverators “are capable of either description” (in terms of color or shape) and simply “have difficulty switching flexibly between them,” and “a higher order rule will not be required… within a dimension” (Zelazo, Muller, Frye & Marcovitch, 2003, pp. 101-102).

However, our findings may be compatible with other descriptions of the CCC account, which suggest that "increases in reflection on lower order rules are logically required for increases in embedding to occur" (Zelazo et al., 2003, p. 9). That is, reflection on lower order rules (which may support a more abstract understanding of sorting dimensions) may be a precursor to embedding of rules (which supports switching). Our account may provide a lower-level explanation of such theories.

One might ask whether perseverators experienced increased conflict during failed postswitch trials, such that their poor generalization reflected carry-over effects from postswitch rather than how abstractly they represented the rules. This possibility seems unlikely for several reasons. First, perseverators' excellent performance in the final familiar phase suggests that their failure on generalization cards is not due to high conflict experienced in the postswitch phase, since they had no trouble applying the rule they used in postswitch to familiar cards at the very end of the game. Second, we know of no evidence to support the idea that perseverators experience more conflict than switchers. In fact, the active-latent account and associated models predict that children should experience maximal conflict near the transition from perseverating to switching, when the competition between representations is closest (Stedron, Sahni & Munakata, 2005); this peak in conflict occurs both before and after the transition to switching, and is not limited to perseverators. Third, in our sample perseverators showed no signs of experiencing more conflict than switchers during postswitch. We tested for such conflict by recoding videotapes for reaction time data. Perseverators responded just as quickly as switchers across all postswitch trials (2.4 and 2.5 s, respectively, $t < .1$) and on the first postswitch trial (3.4 vs 4.1 s, respectively, $t = 1.0$). Thus, perseverators' difficulties with generalization do not seem to be driven by greater conflict.

Nonetheless, other forms of this idea, that the process of switching to a new sorting rule influences subsequent generalization performance, are possible and consistent with the active-latent account. For example, the act of switching may activate prefrontal representations that aid in generalization of a rule to novel exemplars. Further studies are needed to test this possibility.

Alternatively, one might ask whether switchers are simply smarter and thus perform better than perseverators on all tasks, making the relationship between flexibility and generalization seem trivial. Indeed, using more active and abstract representations may be an important component of general intelligence (Conway, Kane, & Engle, 2003; Duncan et al., 2000; Gray, Chabris, & Braver, 2003). However, the reported synergy between switching and generalization seems unlikely to be trivially characterizable in terms of general smarts or better verbal ability, for several reasons. First, evidence for the role of general intelligence in cognitive flexibility is mixed. Correlations between verbal ability and executive function in children have been reported (Carlson, 2005; Carlson & Moses, 2001; Hongwanishkul et al., 2005; Hughes, 1998). However, some of these studies included a measure of switching only as part of a large battery of tasks that contributed to a composite executive function score and did not report specific correlations between switching and general intelligence (Carlson, 2005; Carlson & Moses, 2001; Hughes, 1998). The one study that reported a link between receptive vocabulary scores and card-sorting performance (Hongwanishkul, Happaney, Lee & Zelazo, 2005) relied on invalid analyses, treating categorical switching data as if it were continuous. Other evidence suggests that general intelligence only weakly predicts whether children switch or perseverate (Deák, Narasimham, Cepeda, & Legare, 2007), and children show age-related improvements in executive function that are not related to verbal ability (Carlson, 2005). Second, switchers do not perform better than perseverators on implicit memory tasks, thought to tap posterior rather than prefrontal cortical areas (Snyder & Munakata, in prep.; Kharitonova, Hulings, & Munakata, in prep). Finally, in the current study, perseverators had no trouble applying the first rule to the standard cards at both the start and the end of the session, suggesting their poor generalization performance does not stem from general difficulties with all tasks or all components of intelligence. Instead, we argue that perseverators' difficulty with the novel cards specifically reflects the use of less active and less abstract representations.

Why do flexibility and generalization go hand-in-hand early in development? This early synergy may reflect their reliance on common neural properties supported by prefrontal cortical regions. For example, active representations (supporting flexibility) and abstract representations (supporting generalization) may both rely on distance from posterior cortical regions responsible for veridically representing the perceptual details of the changing environment. The observed synergy might also reflect a more inherent functional dependence between active and abstract representations: active maintenance may serve as a critical component in the development of abstract representations (Rougier et al., 2005). A third factor, such as language development, may also contribute to the early synergy between flexibility and generalization. For example, language could serve to coordinate distinct facets of human intelligence (Spelke, 2003), or support developing abilities to both actively maintain information (Jacques & Zelazo, 2005; Vygotsky, 1962) and form abstract representations (Deacon, 1997; Gentner, 2003). Further developmental work is needed to establish the precise trajectory of the reported synergy, and to consequently advance understanding of the origins of these fundamental facets of human intelligence.

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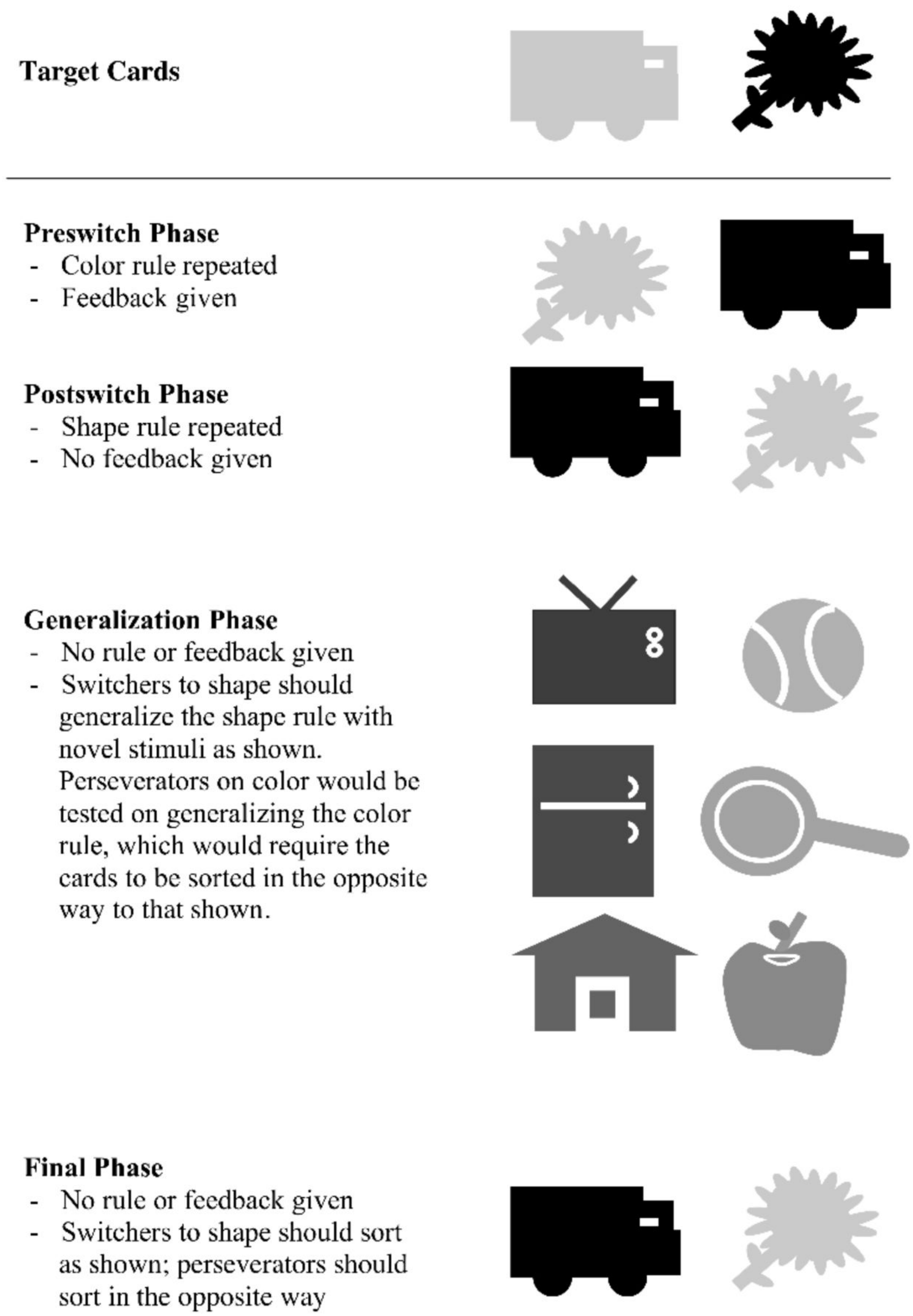

Figure 1.

Experiment 1: Cards to-be-sorted are shown under their corresponding target cards, for sample preswitch, postswitch, generalization, and final phases. Colors are converted into grayscale, such that red = the lightest gray and blue = black. For novel generalization cards, darkening of light grays corresponds to shifting away from red (to orange, orange-yellow, and yellow) and lightening of dark grays corresponds to shifting away from blue (to turquoise, teal, and green). Novel cards were designed so that generalization would be difficult without a representation of the appropriate abstract rule.

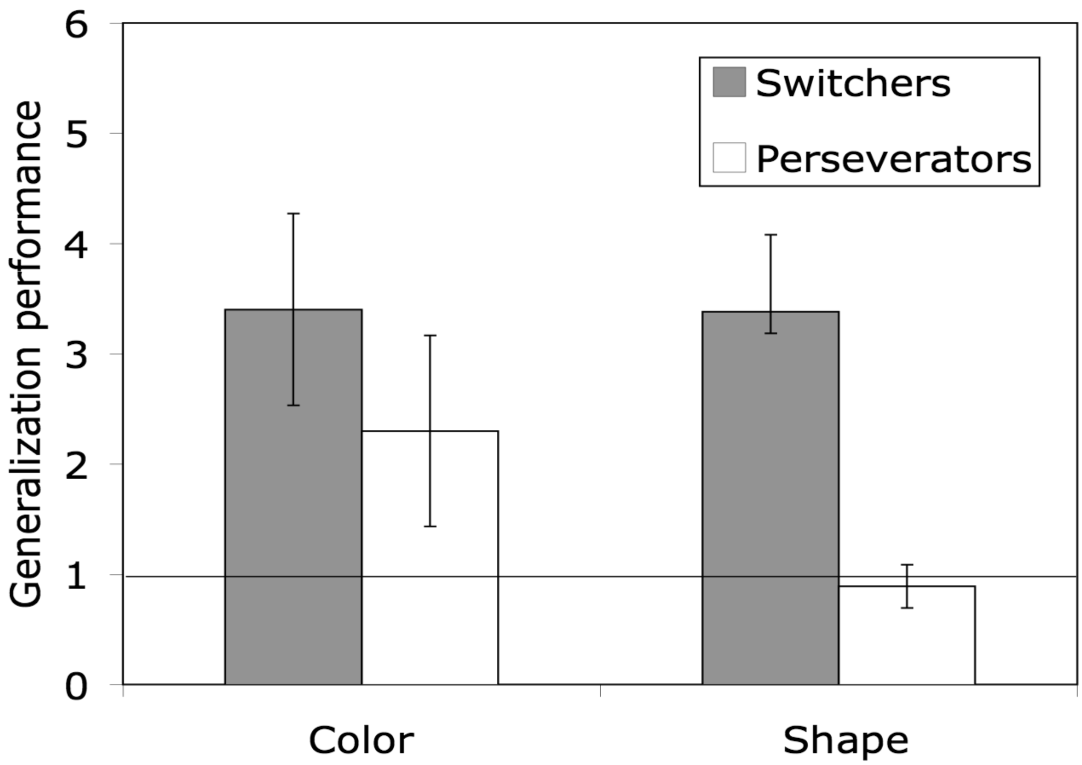

Figure 2.
Experiment 1: Switchers generalized their sorting rule to more novel cards than perseverators. Only switchers' performed better than chance, indicated by the horizontal line.

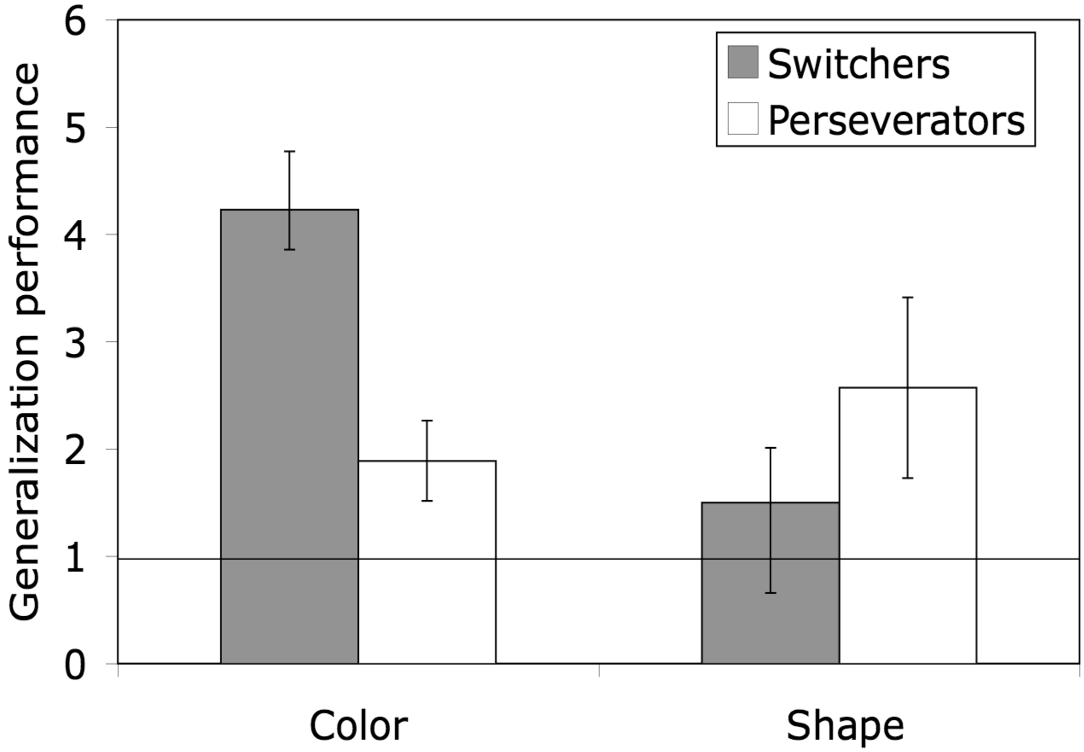

Figure 3.
Experiment 2: Switchers again generalized their sorting rules to more novel color cards than perseverators. Switchers and perseverators did not differ in generalizing by shape. Only switchers to color performed better than chance, indicated by the horizontal line.