Comparative Evidence For Associative Learning In Task Switching

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Abstract

Humans can perform several different tasks on the same set of stimuli in rapid alternation. Each task, signaled by a distinct task cue, may require the classification of stimuli using a different stimulus attribute. However, such "task switching" performance comes at a cost, as expressed by weaker performance when switching rather than repeating tasks. This cost is often claimed to be the consequence of a mental reorientation away from the previous task and towards the new task, requiring executive control of behavior. Alternatively, task switching could simply be based on the retrieval of different cue-stimulus-response associations. In this experiment, pigeons learned go-left/go-right discriminations between grating patterns according to either their spatial frequency or their orientation, depending on the color of the pattern (the task cue). When humans solved the same tasks on the basis of verbalizable rules, they responded more slowly and made more errors on trials where they had to switch between tasks than when repeating the same task. Pigeons did not show this "switch cost"; but like humans, their performance was significantly worse when the response (left or right) to a given stimulus varied between tasks than when it stayed the same (the "congruency effect"). Larger effects of both switch costs and congruency were observed in humans learning the tasks by trial and error. We discuss the potential driving factors behind these very different patterns of performance for both humans and pigeons.

Keywords: executive control; associative learning; task switching; humans; pigeons; comparative cognition.

Introduction

Humans are able to perform two or more different tasks on the same stimulus material when cued to do so (called "task switching"). Typically, each task requires the classification of a set of stimuli according to a different stimulus attribute. The task that is to be performed in a given trial is indicated by a specific task cue (for example, subjects might be asked to judge a grating pattern by its spatial frequency when the color yellow is presented, or to classify the same stimulus according to whether it is vertically or horizontally orientated when the color red appears).

However, it is still a matter of debate which cognitive mechanisms underlie human task-switching ability. Humans may classify the stimuli they see based on rules, and a common phenomenon of task switching, namely longer reaction times and higher error rates after switching tasks compared to repeating the same task ("switch costs"), has been assumed to reflect the executive control processes associated with this rule use. For example, humans might sort a series of stimuli based on their orientation while ignoring other available stimulus dimensions such as spatial frequency. In this context, switching from one task to the next involves executive control when identifying the current task, retrieving its specific stimulus-response rules into one's working memory (while deleting the rules of the previous task) and adjusting one's response reaction to the new requirements: in short, a mental disengagement from the previous task and preparation for the currently relevant task, known as "task-set reconfiguration" (Vandierendonck, Liefooghe & Verbruggen, 2010). Switch costs are thought to reflect the need for such reconfiguration in switch trials but not in repeat trials, for which the task-set is already available (Monsell, 2003).

But, if we believe that humans have multiple processes available that support learning (McLaren, Green & Mackintosh, 1994), task-switching phenomena might be the result of associative learning mechanisms, i.e., the retrieval of cue-stimulus-response associations (Logan & Bundesen, 2003). Learning to respond correctly in a task-switching paradigm could be accomplished by associating the overall appearance of a stimulus with a certain response (Lea & Wills, 2008). Each stimulus could be categorized by using its combined dimensions and comparing its similarity to a stimulus to which the correct response is known.

A task-switching phenomenon often observed in addition to switch costs, the effects of stimulus congruency (Monsell, Yeung & Azuma, 2000), might indeed be better explained by associative learning processes than task-set reconfiguration. As each task makes use of the same set of multidimensional stimuli, stimulus values on individual dimensions can be defined as either congruent or incongruent in relation to the correct response towards them. If a stimulus is congruent, it always requires the same response regardless of the current task; learning to discriminate between different congruent stimuli thus takes the form of a component discrimination, in which the correct response depends on a single element of a multidimensional stimulus. However, when an incongruent stimulus is shown, the correct response varies depending on the current task in the manner of a biconditional discrimination. Given that there is good evidence that such discriminations are difficult to learn (Harris & Livesey, 2008), it is no surprise that on trials in which a congruent stimulus is shown, reaction time and error rate are distinctly lower compared to trials with an incongruent stimulus, and humans can exhibit large congruency effects (Monsell, Yeung & Azuma, 2000). Experiments intended to elicit an associative approach to task switching in humans, either by only providing cue-stimulus-response contingencies instead of full task instructions or by forcing participants to learn how to respond by trial and error, have yielded very large congruency effects and switch costs that were considerably smaller than the effects of congruency (Forrest, Elchlepp, Monsell & McLaren, 2012).

Humans can communicate the extent to which they refer to certain rules when reacting to a stimulus. It is therefore potentially possible to identify a group of participants who learned the responses based on rules about the stimulus dimensions and those who did not, and compare their performance to that of animals, who might not have the same cognitive mechanisms available.

Stoet and Snyder (2003) were the first to explicitly investigate task-switching effects in nonhuman animals. Their two rhesus macaques behaved very similarly to Forrest et al.'s (2012) humans who were presumed to be learning associatively: while their performance produced a large congruency effect, switch costs were rather small, and in fact absent in one animal. Stoet and Snyder (2003) acknowledged that monkeys might lack at least one of the cognitive control mechanisms necessary to solve task-switching paradigms in the typical human way, but they did not doubt that their subjects used some form of executive control. However, the possibility remains that both humans and nonhuman animals might solve a task-switching paradigm associatively.

If humans who claim to be unaware of any rules underlying a task-switching paradigm employ an approach similar to that in animals assumedly solving the task by purely associative processes, such as the pigeon (Mackintosh, 1988), their performance would be expected to resemble that of those animals. For this purpose, pigeons might make a more suitable comparison than primates; they can also be tested in larger numbers than monkeys, so more reliable results should be obtained.

To design a paradigm suitable for use with both humans and animals, instead of relying on language-based stimuli or cues, we used varying values of the visual dimensions of color, orientation and spatial frequency to indicate a correct response. Additionally, we used trial-and-error training on cues and stimuli that resembled the conditioning procedures usually employed in animal testing. To investigate whether human performance under these conditions can be compared to that based entirely on associative-learning processes, we trained humans and pigeons on the same paradigm.

Method

Subjects

Twenty-four Psychology undergraduate students, in exchange for course credit, and eight pigeons (*Columbia livia*) participated in this experiment. Pigeons were kept in an indoor aviary (2 x 1 x 2.5m) that housed 15 pigeons at the time of the experiment. They were maintained at or above 80% of their free-feeding weight. Both humans and pigeons were naïve to the testing stimuli, though pigeons had previously been trained to peck at a white observing key presented in the center of a black touch-sensitive display, followed by a peck at a red, blue, green or yellow colored circle appearing in the same position, and finally, to peck at a white reward key randomly presented either to the left or to the right of the display.

Apparatus

All experiments were carried out inside the Washington Singer Laboratories at the University of Exeter. Pigeons were tested in one of eight identical 71 x 50.5 x 43.5cm operant chambers. Each pigeon was always tested in the same chamber. One of the long walls of the chamber was fitted with a 31 x 23.5cm (15") touch monitor (Model 1547L 1024x768pxl TFT monitor, CarrollTouch infrared detector, ELO Touchsystems Inc.) mounted 12cm above the grid floor of the chamber. Two 2.8 Watt white houselights were mounted to either side above the screen; below the screen, mounted 4cm above the chamber floor and directly below each house light, two 6x5cm apertures gave access to grain hoppers when solenoids were activated. The food hoppers were illuminated by a 2.8 Watt light when activated and contained a 2:1 mixture of hemp seed and conditioner. Also mounted below the screen between the two food hoppers, a 50 Ohm loudspeaker played white noise into the box as well as indicating effective pecks to target areas with an immediate beep. The interior of the box was monitored by a video camera attached to the short wall of the chamber opposite the chamber door. Contingencies were controlled and data collected using a PC computer running the Whisker system (Cardinal & Aitken, 2010) with client programs written in Visual Basic 6.0. Humans were tested in a small experimental room on an iMac. The program was written in MatLab R2008b® using the Psychtoolbox (Kleiner, Brainard & Pelli, 2007) add-on and run using MatLab2011b®.

Procedure

For pigeons, each trial began with the presentation of an observing key (100 pixels in diameter) presented in the center of a black display. Following two pecks at the observing key, it was replaced by one of four task cues, a color-filled circle of 200 pixels in diameter, in the display center. Each of the two tasks was associated with two distinct cues: these were blue or yellow for task A, and red or green for task B. For humans, a trial started immediately with the presentation of the cue; that is, no observing key was presented. Pigeons had to peck the task cue twice, after which the task stimulus appeared, superimposed on the cue, making both the cue and the stimulus visible simultaneously. Humans were asked to mouse-click once on the cue, upon which the stimulus appeared in the same way as for pigeons.

Stimuli, made up as circular Gaussian patches of 200 pixels in diameter, consisted of one of four sinusoidal grating patterns, differing from another in two dimensions: spatial frequency - either low (2 cycles per 100 pixels (c/100px) for pigeons and 3 c/100px for humans) or high (12 c/100px for pigeons and 10 c/100px for humans) - and line orientation - either horizontal or vertical. All combinations of cue color, spatial frequency and orientation were used, resulting in 16 visually distinct images.

The correct response towards a stimulus depended on the task. For example, for some participants, task A required responding to the spatial frequency of the grating pattern, e.g., if a stimulus, regardless of the orientation of the pattern, had a low spatial frequency, the correct response towards this stimulus was to choose the left reward location, while stimuli with a high spatial frequency afforded choosing the right reward location. Conversely, in task B, stimuli would have to be classified according to the orientation of the grating pattern, regardless of its spatial frequency. That is, if a stimulus showed a horizontal pattern, it required a response to the left reward location, while a vertical pattern indicated a response to the right location as the correct one. Although blue and yellow were always assigned to task A, the stimulus attributes (spatial frequency or orientation) that were important for classification in task A and the reward location that was associated with any cue-stimulus combination were counterbalanced across pigeons and across humans. As each stimulus always contained both spatial frequency and orientation information, some stimuli always required the same response, e.g., a horizontal pattern of low spatial frequency might always require a left response regardless of the current task. In addition to these congruent stimuli, responses to incongruent ones depended on the task at hand, for example, a horizontal stimulus with a high spatial frequency pattern might require a response to the left reward location on the orientation task but a response to the right location if the spatial frequency was to be judged.

For pigeons, pecking twice at the composite stimulus in the display center resulted in it being deleted from the center and simultaneously reappearing 200 pixels to the left and to the right of the display center as response keys. Pigeons made a final response by choosing the correct reward location (left or right) by pecking at the stimulus presented on that side. The two response keys were effective between 3 and 6 seconds after the onset of their presentation, after which a single peck at the correct key resulted in the activation of the corresponding food magazine for 2.5 seconds. During training only, if a pigeon developed a position bias, i.e., showed a strong tendency to peck one of the two response keys, responses to the more attended side were made ineffective for one to two (or more if necessary) seconds longer than to the less attended side. The release of the food magazine ended a trial. The inter-trial-interval to the next presentation of the observing key lasted between 15 and 30 seconds. Human participants were asked to mouse-click on the stimulus in the center of the screen, which led to the appearance of two square, white response keys to the left and right side of the stimulus; the stimulus also remained on display. Participants responded to the stimulus by clicking on the response key that was associated with the present cue-stimulus combination. If the correct response key was chosen, the stimulus and response keys disappeared from the screen and the word "Correct" appeared in white letters next to a golden star for two seconds before the next trial began. If the wrong response key was clicked, the entire display was replaced by the phrase "WRONG!" in white letters. Participants were asked to respond as quickly as possible while making as few mistakes as possible.

Training Both pigeons and human participants received training on each task separately before attempting the task-switching paradigm. The order in which the tasks were learned was counterbalanced across individuals of each species.

Pigeons received daily training sessions of 3 blocks of 24 trials each, showing each possible combination of the two cues of the task to be trained and the different variations of spatial frequency and orientation three times per block. The first block included a 25th trial (a repeat of the first trial of the session), as that first trial was not included in analyses, resulting in 73 trials per day in total. The order of cue-stimuli combinations was randomized within blocks. Discrimination of the stimuli was considered successful if the pigeon responded correctly on at least 80% of trials within a daily training session, in at least three consecutive sessions. Pigeons thus received a minimum of 3 sessions, or 219 trials, on a task before starting training on the other task. The number of sessions on each task was gradually reduced until pigeons were able to switch between tasks from one day to the next and still perform at or above 80% correct responses in each session. For humans, training on each separate task was carried out in four blocks of trials. A block was considered successful if subjects reached the criterion of 80% or more correct responses in the previous trials that included each stimulus at least twice. Thus, the criterion was based on at least eight consecutive trials, two for each of the four different combinations of spatial frequency and orientation. The first training block of a task contained at least 32 trials, then, the second task was trained in at least 32 trials. After this, the first task was repeated for a minimum of another 16 trials until criterion was reached; finally, the second task was repeated for at least 16 trials until the participant reached criterion in this fourth and final training block.

Test Once each task was trained separately to success criterion, subjects entered the task-switching part of the experiment, in which task A and task B trials were intermingled. The task sequence was partially randomized to produce a switch trial in one third of the trials; for non-switch trials, the two task cues alternated so that the same cue was never shown for two trials in a row. Pigeons received 20 sessions of 73 trials each, or 1460 trials in total; in each block, the four combinations of spatial frequency and orientation were presented three times per task. Humans completed 24 blocks of 25 trials, a total of 600 trials, in the same manner as described above, with each of the combinations occurring twice on a task-repeat trial and once on a task-switch trial per two blocks. After completion of the task-switching procedure, we determined, via a questionnaire, which approach they used to solve the experiment and assessed their ability to describe the rules that defined a correct response. If a participant was able to correctly identify the contingencies between a task cue and certain stimulus characteristics, he or she was considered to have understood and successfully applied the underlying rule. If participants could not explain any relationship between stimuli, cues and the correct response, this was taken as an indication that they had not used task rules**.**

Results

The only basis for comparing the two species was accuracy (errors) when choosing a response key, as it was not possible to obtain an accurate estimation of response latencies for pigeons, although we did record each subject's latency to peck/click on a response key. Restricting pigeons' time to respond would have required differential reinforcement of short response latencies, which could potentially have impaired learning of the cue-stimulus-response contingencies. Thus, all results reported are for error rates when making a response. We ran four of the birds on ten more sessions with a strongly reduced inter-trial interval after they had completed the main study to assess whether allowing for unrestricted response times potentially decreased any effects, and this yielded similar results to those reported below. Nevertheless, the possibility remains that the particular timing requirements of the task we used may play an important role in producing our results.

For the human data, we calculated participants' error rate when choosing a response key as a percentage for each pair of consecutive blocks, i.e., for 48 trials (the first trial of each block was excluded from analysis, since it was neither a switch nor a repeat trial), resulting in 12 block pairs per participant. Pigeons' performance was calculated for each of the 20 sessions, excluding the first trial of each session.

The different training methods we employed for humans and pigeons resulted in substantially lower error rates for pigeons. However, while it was necessary to train pigeons to produce error rates below 20% throughout, we were reluctant to give more training to humans as it would have increased the chances of humans inferring the task rules. As it was, nine of the 24 human participants were able to verbalize the rules for both tasks at the end of the experiment. A further eight reported having discovered one of the two rules or having made up their own solving strategies. Because of the ambiguity as to what mechanisms these participants relied on to solve the tasks, we did not include their data in any further analyses. The remaining seven participants stated that they were not aware of any relationships between the stimuli and the correct response, and it is these participants that most naturally allow comparison with performance by the pigeons on this task.

To investigate the extent to which both humans and pigeons were influenced by switch costs or congruency effects, we conducted a 3-way repeated measure ANOVA using Switch/Repeat Trials, Stimulus Congruency and Block Pair Sequence/Session as within-subject factors. Analyses were carried out separately for humans, according to the number of rules humans could name (No Rule and 2 Rules) and for pigeons. F and p values for the effects mentioned below are reported in Table 1. All results were subjected to Huynh-Feldt correction.

Humans received an average of 137 trials before entering the task-switching stage; pigeons entered the test phase after an average of 109 training sessions. Since the pigeons had received substantially longer training, we conducted all analyses on the the first half of the sessions as well as on the full data set, to rule out potential floor effects. Results were the same for both data sets as the pigeons did not significantly improve their performance over time; accordingly, the results reported are from the full data set of 20 sessions.

Performance of humans was influenced by whether they were able to verbalize the discrimination rules or not; error rates were significantly lower for people who were able to verbalize both tasks (2 Rules; M=12.1%, SD=2.0) than if No Rule (M=36.1%, SD=2.3) had been inferred (F(1, 14)= 62.20, p<.001). Pigeons' error rates were low (M=9.1%, SD=3.7), due to the amount of they received.

Table 1: Overall F and p values for Switch/Repeat Trials, Stimulus Congruency, Block Pair Sequence/Sessions, and significant interactions between factors for humans depending on the number of rules they named and for pigeons. P values below .05 are marked in bold.

	Both Rules (N=9)		**No Rules (N=7)**		**Pigeons (N=8)**	
Factor	F (df)	p	F (df)	p	F (df)	p
Block Pairs/Sessions	8.92 (11, 88)	**<.001**	0.59 (11, 66)	.720	1.04 (19, 133)	.413
Switch/Repeat	57.29 (1, 8)	**<.001**	18.83 (1, 6)	**.005**	0.13 (1, 7)	.731
Stimulus Congruency	68.06 (1, 8)	**<.001**	19.10 (1,6)	**.005**	71.03 (1, 7)	<**.001**
Session * Switch	2.98 (11, 88)	**.002**	0.38 (11, 66)	.574	0.62 (19, 133)	.885
Session * Congruency	3.68 (11, 88)	**.002**	1.42 (11, 66)	.222	1.37 (19, 133)	.155
Switch * Congruency	14.18 (1, 8)	**.005**	10.69 (1, 6)	**.017**	0.55 (1, 7)	.484

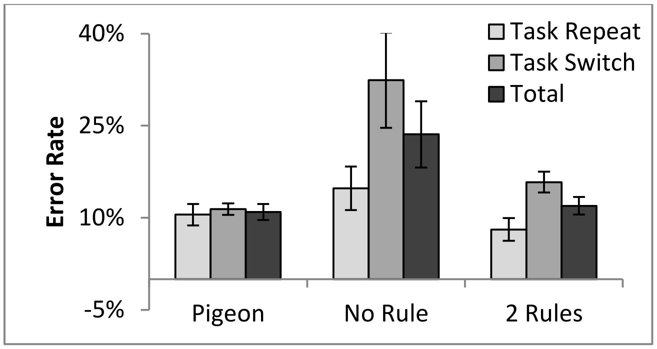

Figure 1: Stimulus congruency effects (difference in error rates between incongruent and congruent stimuli) in trials in which the task repeats and those in which it switches from the previous trial, and across all trials ('Total').

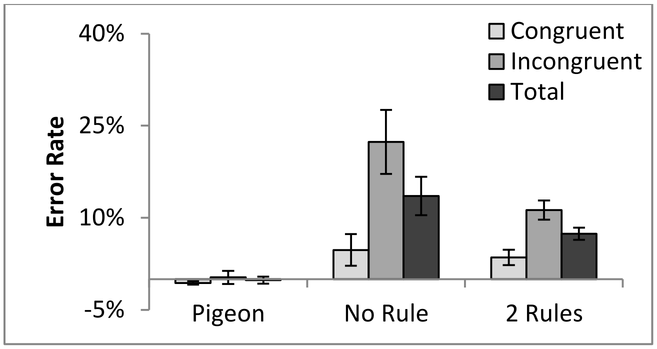

Figure 2: Switch cost (difference in error rates between task switch trials and task repeat trials) for congruent and incongruent stimuli, and overall ('Total').

The factor of Stimulus Congruency strongly influenced performance for all groups; human participants and pigeons made more errors when faced with incongruent stimuli than when dealing with congruent ones (Figure 1, 'Total').

Similarly, there was a highly significant effect of the factor Switch/Repeat for humans regardless of the number of rules verbalized: they performed less well on switch trials, which required executing the opposite task to the one on the previous trial, than on repeat trials (Figure 2, 'Total'). However, while the effect was present in both human groups, pigeons demonstrated a noticeable lack of switch costs (Figure 2, 'Total').

All human participants showed significantly higher switch costs on trials with incongruent stimuli than on those trials in which the stimulus was congruent, i.e. there was a significant interaction between the two factors for all three human groups (Figure 2).

The sequence of Block Pairs (or Sessions for pigeons) was reliable for 2-Rules users only, implying that these participants learned to make fewer mistakes as the experiment carried on, while No-Rule users and pigeons maintained their initial level of performance throughout. For those participants who were able to verbalize the two rules, both the effects of Switch/Repeat trials and Stimulus Congruency declined over the course of the experiment, i.e., this group experienced interaction effects of Block Pairs with the two other main factors.

Although not relevant for the species comparisons, it can be noted that, in their reaction times, human showed a similar pattern to what has previously been observed in humans using different learning approaches (Forrest et al., 2012); that is, those who inferred both rules suffered from switch costs much more (M=149.70ms) than from congruency effects (M=94.78ms), whereas humans who did not use any rules were largely affected by congruency effects (M=50.34ms) but barely showed any costs in switching between tasks (M=0.58ms).

Discussion

Forrest et al. (2012) showed that humans in the cue-stimulus-response (no rule) condition of their task-switching experiment expressed reduced switch costs and larger congruency effects relative to a Tasks group that were told both of the applicable rules at the start of the experiment. They offer this as a "signature" of associatively-based performance on this type of task. We are not in a position to make a direct comparison with their study, as we did not run an equivalent of their Tasks group. Our 2-Rules participants are perhaps an approximation to this group, but had to induce the rules, and were not instructed to apply them. However, these participants demonstrated significant switch costs and exhibited a congruency effect, similar to the effects usually found when humans are informed of the task rules before engaging in a task-switching paradigm. This group was the only one that significantly decreased their error rates over the course of the experiment; it can be assumed that this was due to participants "figuring out the tasks": during the first few blocks, performance essentially matched that of No-Rule users, but then it dramatically improved to a level similar to the performance of the pigeons, i.e., at error rates of 10% or less. A third of participants were unable to report any task rules; these might instead be classified as employing an associative approach to task switching. In addition to a generally high error rate, solving the tasks without any knowledge of their underlying rules had considerable impact on the magnitude of typical task-switching phenomena: while a stimulus's congruency only moderately affected performance in those who used both rules, it heavily influenced humans' ability to solve the tasks if they had been unaware of the rules. This comes to no surprise, as it will always be easier, especially in regard to associative learning, to learn the correct response to a given stimulus when it is the same in both tasks - that is, when that stimulus is congruent - than when it varies between tasks, as it does for incongruent stimuli.

Clearly, there is a significant congruency effect in the pigeon data and no cost of switching between tasks. Similar levels - a much bigger congruency effect than switch costs - are also observed in the No-Rule humans and in Forrest et al.'s (2012) study. The typical signature for a task-based approach in humans instructed to use tasks is the reverse, a larger switch cost and a smaller congruency effect. Further research will establish if this true of the tasks used here.

Although we can draw parallels between the performance of pigeons and No-Rule-using humans, there are some very clear discrepancies between the pigeon data and that of either of the human groups. It is especially apparent that in incongruent trials, there is some switch cost in each of the human groups, which was also observed in Forrest et al.'s (2012) results. Even the human participants who were not using any rules exhibited some switch cost for the incongruent stimuli, yet the pigeons show no discernible trace of any such effect but are able to "task switch". Why is this?

The most interesting possibility is that pigeons simply do not suffer from a switch cost in this paradigm. That is, when given a combination of component and biconditional discriminations, they do not exhibit any difficulty in switching from one hypothetical task to another, even in the case of the biconditional discrimination (i.e., the discrimination involving the incongruent stimuli). This result would imply that there is no switch cost in associatively-mediated task switching, and lead to the conclusion that the switch costs in all our human groups were due, in some sense, to contamination by rule use. This would fit rather well with theories that explain switch costs in terms of task-set reconfiguration (Monsell & Mizon, 2006) but less well with theories that attempt to explain switch costs in associative terms (e.g., Logan & Bundesen, 2003). A potential way of testing this assumption would be to compare the groups' performance when faced with novel stimuli in a generalization task.

Another possibility would be that pigeons do exhibit switch costs in this paradigm, but that we either lack the power to detect it, or there is another factor masking it. The former possibility cannot be ruled out given that the predicted effect would be small, in any case, but there is simply no evidence of any switch cost to suggest that it would be worth running many more pigeons in an attempt to increase the power. The latter possibility is, however, worth investigating, especially if switch costs are potentially only present for incongruent stimuli while there will be little or no switch costs on congruent trials. A close examination of the paradigm reveals the possibility of an unwanted interaction between the difference between switch and repeat trials and a preference for novelty (e.g. in matching to sample, see Wright & Delius, 2005). Pigeons might preferentially respond to trials in which there is some change in stimulation (either in the form of a different stimulus or different response) compared to the previous trial, and avoid those in which both the stimulus and the response location are the same as in the preceding trial. The latter, for incongruent stimuli, is only possible on repeat trials, so, other things being equal, performance on those trials should then on average be worse than on switch trials. A disadvantage for repeat trials over switch trials for incongruent stimuli could potentially cancel out any switch costs in those trials, which by definition compose a disadvantage for switch trials over repeat trials. Whether this is the case or not is a matter for further empirical investigation.

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