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ORIGINAL ARTICLE

Task conflict effect in task switching

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Abstract A part of action preparation is deciding what the relevant task is. This task-decision process is conceptually separate from response selection. To show this, the authors manipulated task conflict in a spatial task-switching paradigm, using conflict stimuli that appeared during trials with univalent targets (affording 1 task). The conflict stimuli afforded task identity because they were used as task cues with bivalent targets (affording 2 tasks) that were intermixed with the univalent targets. Thus, for univalent targets, irrelevant stimuli either caused low task conflict or high task conflict. In three experiments, the authors found poorer performance in high task conflict trials than in low task conflict trials. Task conflict was introduced during target appearance (Experiment 1) or task preparation (Experiments 2 and 3). In the latter case, the task conflict effect decreased with increasing task preparation time showing that task preparation involves task decision.

Task conflict effect in task switching

Objects in the environment can prompt many actions. Yet, these actions are usually constrained by a relevant goal/task. For example, when typing on a keyboard in Israel, the task can either be to type in English or in Hebrew. We consider it to be a case of different task identities (i.e., What task am I supposed to carry out?). This distinction is different from the distinction between specifically pressing on a key to express the English letter "g" or the Hebrew letter "ע", given that the key is used for both purposes. The latter is a case of a specific online action representation (What does pressing the key mean?). Note that choosing task identity is made regardless of a specific online action but rather regarding a number of potential actions.

The differentiation between the levels of action representations is not new. According to the theory of action identification, "any action can be identified in many ways, ranging from low-level identities that specify how the action is performed to high-level identities that signify why or with what effect the action is performed" (Vallacher & Wegner, 1987). A distinction that is more akin to the one we are making appears in theories of task switching (Altmann & Gray, 2008; Biederman, 1972; Gilbert & Shallice, 2002; Meiran & Daichman, 2005; Meiran, Kessler, & Adi-Japha, 2008; Norman & Shallice, 1986; Rubinstein et al., 2001; Sohn & Anderson, 2001; Steinhauser & Hübner, 2009). More broadly, Haggard (2008), while describing a model of human volition, referred to human action as a constant recursive serial loop of a set of different types of decisions, among them two hierarchically ordered decisions: "task selection" and "action selection". The first refers to the resolution of ambiguity with regard to task and the latter refers to the resolution of ambiguity with regard to a response.

There is plenty of evidence to show that the resolution of response conflict is a time- and effort-consuming process (e.g., Kornblum, Hasbroucq, & Osman, 1990). In contrast, very little direct evidence exists to show a similar picture regarding the resolution of task conflict, referred to as a task-decision process. The main problem is separating task conflict from response conflict. The scope of this study was to identify as-pure-as-possible manipulation of task decision difficulty to support the idea of a task-decision process that is differentiated from a response-selection process. We begin with a discussion of past attempts at finding a

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manipulation of task conflict and report three experiments in which we manipulated it.

Previous evidence for a time-/effort-consuming process of task decision

One example of a study that tried to show that the resolution of task conflict contributed to performance employed the Stroop task (MacLeod, 1991), in which participants named color of ink of printed words while ignoring the words themselves. The common finding is that responses to incongruent stimuli (such as the word RED, printed in green ink) are slow and more error prone than responses to congruent stimuli (such as the word GREEN, printed in green ink). Typically, neutral stimuli (such as XXXX, printed in green ink) produce intermediate levels of performance. Goldfarb and Henik (2007), building on research by Monsell, Taylor, and Murphy (2001), made a distinction between the informational conflict between the responses to be chosen (e.g., red vs. blue) and the conflict of simply having two possible tasks evoked by the two dimensions of the targets (e.g., physical color evokes color naming and word meaning evokes word reading). They referred to the latter as "task conflict" and argued that it would reflect in poorer performance in congruent trials relative to neutral ones. This trend was observed under conditions characterized by poor task context monitoring (neutral trials involving mostly non-words), but not when the conditions were characterized by high task conflict monitoring (neutral trials involving non-color words). Steinhauser and Hübner (2009) further showed an empirical dissociation between the two conflicts by modeling the reaction times (RTs) with the ex-Gaussian distribution. This distribution is characterized by two components, a Gaussian component with the parameters Mu and Sigma, and an exponential component with the parameter Tau. These authors showed that task conflict was mainly shown in the exponential component, while the response conflict was mainly shown in the Mu parameter of the Gaussian component.

For our study, we preferred to use the task-switching paradigm (Meiran, 2010; Monsell, 2003, for reviews). It involves high task conflict caused by frequent changes in task identity. It requires the resolution of both task conflict and response conflict as can be seen in the task rule congruence effect (TRCE, see Meiran & Kessler, 2008, for review). The TRCE is reflected in the comparison between (the quicker) response-congruent trials and (the slower) response-incongruent trials. Response-congruent trials are those in which the competing task rules generate the same response as a correct response. Response-incongruent trials are those in which the competing task rules generate conflicting responses. An example of a paradigm that would generate both options could be when switching between two numeric tasks, an ODD–EVEN decision and a HIGH–LOW (than 5) decision (Sudevan & Taylor, 1987). Note, again, that the TRCE seemingly reflects both response conflict and task conflict and as such is not a clean index of either. The interplay between these two types of conflict is explicated in Meiran and Daichman's (2005) model regarding errors in TRCE. These authors studied switching between two spatial location tasks, UP versus DOWN and RIGHT versus LEFT. They referred to two types of conflict, one at the goal (task) level and the other at the response level. The first refers to situations where the irrelevant goal (e.g., horizontal dimension) interferes with the relevant goal (e.g., the vertical dimension). The latter conflict is between the two possible action choices within a task. For example, the erroneous responses in incongruent trials, according to Meiran and Daichman's model, could reflect either (a) the correct choice of task (e.g., UP–DOWN was required and UP–DOWN was chosen) combined with an incorrect choice between UP and DOWN (DOWN was chosen instead of correctly choosing UP); (b) the incorrect choice of the task (RIGHT–LEFT was chosen instead of the correct UP–DOWN) combined with the correct choice between RIGHT and LEFT. Meiran and Daichman showed that task-decision efficiency and response-selection efficiency can be decomposed using a modeling approach. A major drawback of their approach is that, in the usual setups, errors are relatively rare. Consequently, these authors had to use an atypical setup in which participants were encouraged to respond extremely quickly (and make errors). Thus, their approach is very limited and a more promising approach is the one based on RT.

Another line of relevant evidence for a task-decision process comes from studies that manipulates implicit goal expectancy. These studies showed that when the implicit expectation was violated (presumably increasing task conflict), there was a decrement in performance (Gotler, Meiran, & Tzelgov, 2003; Heuer, Schmidtke, & Kleinsorge, 2001; Koch, 2001). Similar effects were found with explicit task expectancy (Dreisbach, Haider & Kluwe, 2002; Ruthruff, Remington & Johnston, 2001; Sohn & Carlson, 2000; Sudevan & Taylor, 1987, Experiment 2).

There have been studies in which task conflict was manipulated through the task cue. Gade and Koch (2007) used a cued task-switching paradigm and reversed the cue–task associations mid-experiment. Such reversal presumably makes the previously unambiguous task cue ambiguous. They found that this reversal impaired performance and increased switching cost (the difference between task switch and task repeat trials). Gade and Koch further found that this deterioration was present not only in response-incongruent trials, but also in response-congruent trials. Note that the conflict in this case was at the level of the cue–task association and not at the level of the stimulus–response association. Sudevan and Taylor (1987, Experiment 2) also studied cues to make a similar distinction. They distinguished between primes and cues. Primes indicate the task with some likelihood, whereas cues are mandatory because they instruct which task to execute. Using this distinction, they presented a prime before the cue and found that when the cue was validly primed, RT was shorter suggesting that task conflict was partly resolved by the prime.

Finally, the two most relevant studies were Brass and von Cramon's (2004) and Rubin and Koch's (2006). Brass and von Cramon used a paradigm in which the task (parity or magnitude judgments performed on digits) was cued by arbitrary shapes. In some blocks, the cue shape determined the task, while in other blocks the cue color determined the task. Thus, there were conditions in which the task cue was congruent (both color and shape indicating the same task). In other conditions, the cue was incongruent. The authors observed slowing in trials with incongruent cues, suggesting high task conflict in these trials. Rubin and Koch had participants randomly switch between two spatial tasks. In their paradigm, a 2×2 grid appeared with a cue for either an UP–DOWN or a LEFT–RIGHT judgment. Then a target appeared in one of the four sectors of the grid and the judgment had to be made. The target color was an unattended dimension and was used to manipulate the task conflict. For half of the participants, the irrelevant target color depended on task type. For the other half of the participants, target color was random. In the following block, the target color was random for both groups. This block was associated with slow responses only for participants for whom the colors had previously been paired with tasks. The authors interpreted their results as evidence for interference to the task decision. According to them, the color coding became associated with a certain task, and then when this piece of information became random, it caused confusion as to which task was to be performed.

All the aforementioned studies involved manipulations that increased task conflict and found that such increase was accompanied by increased RT and error rates. These results support the hypothesis concerning the existence of a time-/effort-consuming process involved in resolving task conflict (i.e., task decision). Yet, all of this evidence is equivocal. The reason being that the target stimuli that were used in all the studies (except for one, Ruthruff et al., 2001) were bivalent. That is, the targets had two informative dimensions, one for each task causing potential response conflict. Therefore, it is quite conceivable that response choice did not proceed in two steps: task decision followed by response selection, as assumed by Biederman (1972), Haggard (2008), Meiran et al. (2008) and others. Alternatively, it could be that all of the relevant categorizations (such as UP, DOWN, RIGHT and LEFT, in Meiran & Daichman's, 2005, paper) simultaneously compete for selection, and the task identity information provides top–down biasing in favor of a sub-group of categorizations (Schneider & Logan, 2005). This line of reasoning would postulate the existence of a single choice process. Given Sudevan and Taylor's (1987) study as an example, the alternative account suggests that the categorizations HIGH, LOW, ODD and EVEN competed during response selection, and top–down biasing favored HIGH and LOW (for example) and made these categorizations more likely to be chosen. Along this line of reasoning, the incongruent cues used by Brass and von Cramon (2004), for example, provide poor top–down modulation of response selection, which is what caused responses to become slower. Note that according to this alternative account, a manipulation which was supposed to induce lengthening in task decision, actually lengthened response selection. Thus, it is still unclear whether the effects found in the previously described studies actually index task conflict, or rather just show differential constraints on response conflict. We argue that a more decisive way to demonstrate task conflict is to manipulate it in conditions in which top–down biasing cannot be used to exclude task-irrelevant categorizations because these are inapplicable. This can be done using univalent target stimuli (e.g., Meiran 2000, 2008) rather than bivalent ones. Univalent target stimuli carry information relevant to making decisions in one task only. That is, the possible targets are exclusive to each task and a given target affords categorizations for one task and never for another task. Consequently, response selection involves only categorizations for the relevant task and not for the irrelevant one. This way, the response conflict elicited by the stimuli can be fixed for all univalent trials, despite the level of task conflict.

We are aware of only two studies in which task conflict was manipulated using univalent stimuli. Allport, Styles, and Hsieh (1994, Experiment 4) used a task-switching paradigm with two types of targets: Stroop stimuli (color words presented in colored ink) and numerical Stroop stimuli (groups of digits). In a given block of the experiment, each stimulus type was associated with one task, and was, in that sense, univalent. For example, in a given block, participants were asked to say the ink color of Stroop stimuli (color words presented in an incongruent ink color) and say the number of digits in the numerical Stroop stimuli (assemblies of digits in which the number of digits is incongruent with the digit's value). In the next block, the tasks performed on each stimulus type changed to the other dimension (e.g., say the word when this was a Stroop stimulus and say the digit when this was a numerical Stroop stimulus). This way, participants alternated between targets that incurred no response or task conflict between them, yet these targets had recently been associated with different tasks or goals. The results indicate that there were no switching costs in the first block. That is, performance was similar when participants performed the same task consecutively as compared to when they switched tasks. This is the typical result in this setup (see Jersild, 1927; Spector & Biederman, 1976). Importantly, there was large switching cost in the following blocks, despite the fact that the stimuli were locally univalent. Namely, within a given block of trials, each stimulus was uniquely linked to a single task. Still, it is quite conceivable (and this is what the authors actually claimed) that the targets did also incur response conflict, since the given target had been previously linked to another task. Thus, the target itself afforded two different sets of actions such as naming the ink color and reading the word. Note that Allport et al.'s results could also be explained in terms of response conflict, because the target stimuli could have evoked a competing *response*.

Ruthruff et al. (2001) asked participants to switch between color identification, performed on color patches, and letter identification, performed on letters presented in a neutral color. In some trials, task identity was known in advance, whereas in other trials the identity of the stimulus (letter or color patch) signaled which task to execute. The authors found that performance was impaired in the uncertain condition, a result which supports the notion of a task-decision process. Yet, the fact that all the stimuli were univalent leaves open the possibility that the participants treated the experiment as one involving a single task with eight stimuli as opposed to two tasks, each made of four stimuli. Thus, it cannot be ascertained that what has been described as task conflict was not actually a conflict regarding the stimulus category.

The current study

As seen, much support has been shown for a separate task-decision process, yet it is still not a clear-cut case, since response selection has never properly been controlled for. In the present study, this was done by using univalent targets and a novel design. Univalent targets elicit no irrelevant categorizations (such as UP–DOWN when making a RIGHT–LEFT decision). Thus, it is possible to cause task conflict in a manner that would not involve any response conflict other than the specific response dilemma relevant to the task at hand (e.g., LEFT or RIGHT?). We capitalized on the fact that the spatial tasks employed in spatial task-switching paradigms (e.g., Meiran, 1996) require marking the location to which participants respond by some stimulus. Because only location is relevant, the identity of the stimulus used to mark it is irrelevant. Specifically, we asked participants to execute two spatial tasks: UP–DOWN and RIGHT–LEFT. Then we mixed two types of (clearly distinguishable) targets: univalent and bivalent (Figs. 1, 2). Trials with bivalent targets included necessary task cues that were used to instruct the participants which one of the two possible tasks to execute on the bivalent target. Note that cue processing is necessary with bivalent targets, because without the cue, participants would not know which task to execute since the target affords both tasks. These task cues were then used during univalent trials to either mark the target location (Experiment 1) or were presented during the preparation interval (Experiments 2 and 3). These cues could either cause high task conflict (incongruent with the required task) or low task conflict (congruent with the required task). We were interested to see whether there would be a difference in performance between conflict levels. Note that even when using congruent interference, task conflict is assumed to be present since task identity is constantly changed in this paradigm. It was hypothesized that RT and possibly also

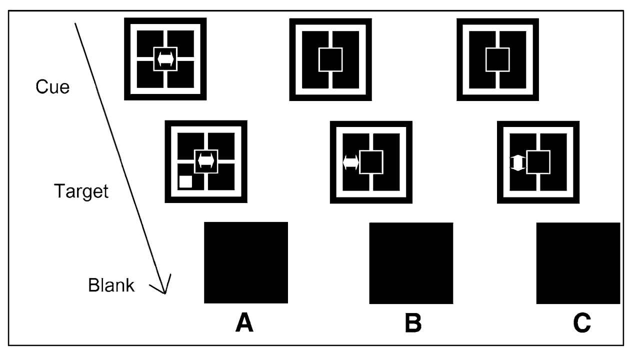

Fig. 1 Examples of trial sequences for Experiment 1. **a** A bivalent trial; **b** a task-congruent univalent trial; **c** a task-incongruent univalent trial. For all presented cases, the expected response was "LEFT"

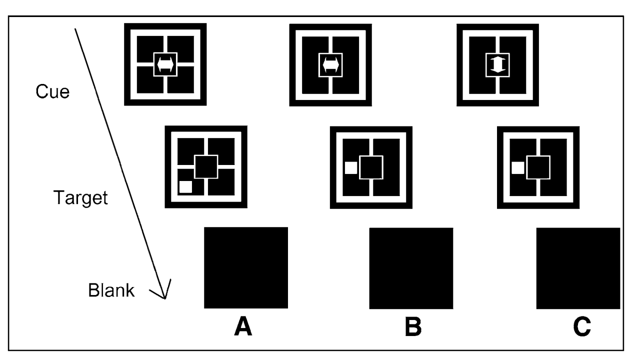

Fig. 2 Examples of trial sequences for Experiments 2 and 3. **a** A bivalent trial; **b** a task-congruent univalent trial; **c** a task-incongruent univalent trial. For all presented cases, the expected response was "LEFT"

error rates would be higher for trials with high task conflict as compared to trials with low task conflict. We call this predicted finding task conflict effect (TCE).

All the following experiments applied this same logic. In Experiment 1, task conflict was introduced during target presentation. In Experiments 2 and 3, task conflict was introduced during task preparation, along with the task cue and before target appearance. In the first two experiments, each task was assigned to a different hand, thus even response keys did not incur response conflict. Yet, it was possible that what we conceived of as an effect caused by task conflict was in fact simply a conflict between responding hands. Therefore, Experiment 3 used overlapping responses for the two tasks to rule out this explanation.

Experiment 1

In this experiment, the task cues that were used with bivalent target stimuli were then used to mark location in univalent stimuli. The physical responses (response keys) of the two tasks were separated to further insure minimal response conflict between tasks. It was hypothesized that TCE would be found for the univalent targets.

Method

Participants

Sixteen Ben-Gurion University undergraduates participated in this experiment in return for monetary compensation of 30 NIS (approximately US $8). All of the participants reported having normal or corrected-to-normal vision and no diagnosed learning disabilities. The configuration of the response buttons was counterbalanced into four groups, but in all these configurations, each hand was assigned to one task. The first group pressed the "8" and "9" keys on the numerical pad of a standard keyboard ("numpad") for 'LEFT' and 'RIGHT' responses, respectively, and used "4" and "1" for 'UP' and 'DOWN' responses, respectively. The second group used "7" and "8" for 'LEFT' and 'RIGHT' responses, respectively, and "6" and "3" for 'UP' and 'DOWN' responses, respectively. The third group used "1" and "2" for 'LEFT' and 'RIGHT' responses, respectively, and "9" and "6" for 'UP' and 'DOWN' responses, respectively. The fourth group used "2" and "3" for 'LEFT' and 'RIGHT' responses, respectively, and "7" and "4" for 'UP' and 'DOWN' responses, respectively. The participants were instructed to keep both index fingers and middle fingers on the four keys throughout the experiment.

Apparatus and stimuli

Both univalent and bivalent targets were used. We used bivalent targets because processing these targets requires the processing of the task cue. Hence, the inclusion of bivalent targets made sure that the participants would process the cues and would associate them with the respective task. These same cues were then used to mark the positions in the univalent trials. Note that when responding to a univalent target, target shape was an irrelevant dimension and the response was made to targets' position exclusively. As mentioned before, these very cues were used as targets in the univalent grids, thus they could either cause low conflict (task congruent) or high conflict (task incongruent). For univalent tasks, no cue was needed because the displays themselves were exclusive to their respective tasks. The task cues and targets were presented inside a square grid in the center of the display. The grids subtended a visual angle of $7.63 \times 7.63°$, assuming a 60-cm viewing distance. All cues and targets subtended a visual angle of $1.53 \times 1.53°$. Within the inner square of the bivalent targets' grid, there appeared a cue. The task cues were two-headed arrows pointing to either both UP and DOWN or RIGHT and LEFT. The grids, cues and targets appeared in white on a black background.

Procedure

The experimental session lasted for approximately an hour. Vocal instructions were given along with the written instructions. Participants were instructed to respond as quickly and accurately as possible. Examples of trial sequences appear in Fig. 1. There were eight identical experimental blocks preceded by one practice block. The practice block had 80 bivalent trials. This block was introduced to further insure that the participants would form a strong association between the task cues and the respective tasks. For the experimental blocks, there were four possible task conditions (UP–DOWN univalent; RIGHT–LEFT univalent; UP–DOWN bivalent; RIGHT–LEFT bivalent). Each experimental block consisted of 96 trials. There was a break between blocks that lasted until the participants pressed the space bar to continue.

Half of the trials involved a task switch from trial $n - 1$ to n, and half involved a task repeat from trial $n - 1$ to n. There was a 50/50% chance of univalent or bivalent targets and a 50/50% chance of a short cue–target interval (CTI) of 100 ms or a long CTI of 1,000 ms. When the targets were univalent, there was a 50/50% chance of the trial being of low conflict or high conflict. For each trial, there was an equal chance of the target appearing in one of the possible sectors of the grid.

Table 1 Mean reaction times (ms), Experiments 1–3

Task conflict	CTI	Transition	Experiment 1	Experiment 2	Experiment 3
Low	100 ms	Repeat	655	577	552
		Switch	706	642	562
	1,000 ms	Repeat	538	435	424
		Switch	550	452	426
High	100 ms	Repeat	721	696	623
		Switch	774	719	645
	1,000 ms	Repeat	587	524	467
		Switch	608	485	451

CTI cue–target interval

A trial went as follows: a grid (depending on CTI) appeared for either 100 or 1,000 ms. During the bivalent trials, the grid appeared with an informative cue at the center. After this, a target (as described above) appeared in the grid and stayed there until a response was given. The participants responded to targets using numpad buttons as described above. The trial ended with a blank black screen for 1,500 ms.

Table 2 Mean reaction times (ms) of the task conflict effect (TCE)

Task conflict	Low	High	TCE	η_p^2
Experiment 1	612 (44)	672 (44)	60***	0.53
Experiment 2	527 (50)	606 (50)	79***	0.60
Experiment 3	491 (46)	546 (46)	55**	0.48

Numbers in parentheses denote 0.95 confidence intervals, as calculated for the reported comparisons

** $p < 0.01$, *** $p < 0.001$

Results

Because we were interested in TC (task conflict), only univalent trials were included in the analysis. Trials with RTs above 3,500 ms, trials with errors and trials following errors were removed from the analysis (a total of 4.34% of the trials). For this experiment and all others to follow, the trials of the practice block and the first 16 trials of each experimental block were removed from the analysis. Results qualified by interactions are not described (i.e., if both a main effect and an interaction including this effect were significant, then only the interaction is described). The mean RT data are shown in Table 1. An ANOVA according to TC (high; low), CTI (100 ms; 1,000 ms) and transition (repeat; switch) found that all the main effects were significant. Table 2 shows the results for the main effect of TC. CI denotes 0.95 confidence interval as calculated for the reported comparisons. Responses were slower when the CTI was short (714 ms) as compared to long (571 ms), $F(1, 15) = 38.28$, $\mathrm{CI} = 69.85$, $p < 0.01$, $\eta_p^2 = 0.72$. Responses were slower during switch trials (659 ms) as compared to repeat trials (625 ms), $F(1, 15) = 8.90$, $\mathrm{CI} = 34.35$, $p < 0.01$, $\eta_p^2 = 0.37$. No significant interactions were found. The lack of a significant CTI × transition interaction is the usual finding with these univalent target stimuli (Meiran, 2000, 2008).

The data on the proportion of errors (PE) were not analyzed for univalent data in any of the experiments since the average PE was 0.01 and always 0.04 or less for all of the participants. Nonetheless, there were no indications for a speed–accuracy tradeoff.

Experiment 2

Experiment 1 revealed target-related TCE, such that targets with high task conflict yielded slower reactions as compared to targets with low task conflict. Presumably, task identity became bound to the task cues (used in bivalent trials), and when these cues became targets, this incurred task conflict. Experiment 2 manipulated task conflict during task preparation (the CTI) and not during target presentation. The logic behind this change was twofold. Firstly, it would be better to cause conflict not during response selection but before that, since task decision presumably begins already prior to target appearance (i.e., during cue appearance) and thus task conflict could appear and disappear even before any specific response could be anticipated. Note that during the CTI, the target stimulus is not yet known and, consequently, the response cannot yet be chosen. Secondly, it was interesting to see whether preparation could diminish the task conflict. That is, it would be interesting to see whether TCE interacts over-additively with CTI. Meiran and Daichman (2005) found that task switching was associated with an increased level of task errors (errors associated with the correct execution of the wrong task) and that preparation resulted in the complete elimination of this switching effect. This finding suggests that task conflict is at least partially resolved during the preparation for a task.

Method

Participants

Sixteen Ben-Gurion University undergraduates participated in this experiment in return for monetary compensation. All of the participants reported having normal or corrected-to-normal vision. The configuration of the response buttons was the same as in Experiment 1.

Apparatus, stimuli and procedure

The apparatus, stimuli and procedure of this experiment were the same as in Experiment 1 except for the following differences. For all trial types, the targets were squares subtending a visual angle of 1.53 × 1.53°. A two-headed arrow appeared at the center of the grids during CTI for both bivalent trials (as a necessary task cue) and univalent trials (as unnecessary interference) and then disappeared with the appearance of the target. For the univalent trials, where the grid itself prompted the relevant task, the two-headed arrow caused either low or high task conflict under the same logic used in Experiment 1. Examples of trial sequences appear in Fig. 2. The participants were made aware of the differences between univalent and bivalent trials during the instructions. The two-headed arrow always disappeared the moment the target appeared for both univalent and bivalent trials.

Results

Data were treated as in Experiment 1 (a total of 4.32% of the trials were removed) and the ANOVA had a similar design. The mean RT data are shown in Table 1. The ANOVA found that the main effects of CTI and TC were significant. Table 2 shows the results for the main effect of TC. An interaction was found between TC and transition [$F(1, 15) = 8.39$, $p < 0.02$, $\eta_p^2 = 0.36$] such that TCE was larger for the repeat trials [104 ms, $F(1, 15) = 21.36$, CI = 47.81, $p < 0.01$] as compared to switch trials [55 ms, $F(1, 15) = 15.53$, CI = 29.57, $p < 0.01$]. An interaction was found between CTI and transition [$F(1, 15) = 15.09$, $p < 0.01$, $\eta_p^2 = 0.50$], such that switching cost was significantly positive when CTI was short [44 ms, $F(1, 15) = 10.21$, CI = 29.28, $p < 0.01$] and non-significantly negative when CTI was long [−9 ms, $F(1, 15) = 1.46$, CI = 19.17, $p = 0.25$]. A close to significant interaction was found between TC and CTI [see Table 3, $F(1, 15) = 3.99$, CI = 27.97, $p = 0.06$, $\eta_p^2 = 0.21$], such that TCE was larger for the short CTI (98 ms) as compared to the long CTI (60 ms).

Experiment 3

Experiments 1 and 2 consistently found a significant TCE (see Table 2). Given the fact that each task was associated with a different hand, it is still possible that TCE simply reflects a conflict regarding the choice between responding hands. It was therefore important to replicate TCE under conditions in which this alternative account does not apply. In Experiment 3, the response keys used in the two tasks overlapped so that knowing task identity was completely uninformative with respect to the responding hand. Specifically, responses were given with only two buttons. The same buttons were used for both tasks, thus no hand was associated with one specific task. The design of this experiment was otherwise identical to that of Experiment 2.

Method

Participants

Sixteen Ben-Gurion University undergraduates participated in this experiment in return for monetary compensation. All of the participants reported normal or corrected-to-normal vision. Unlike in Experiments 1 and 2, only two response keys were used. The keys were the numpad buttons 1 (used for DOWN/LEFT) and 9 (used for UP/RIGHT) or 3

Table 3 Mean reaction times (ms) of the task conflict effect (TCE) shown separately for short and long cue–target intervals (CTI)

CTI	100 ms			1,000 ms		
Task conflict	Low	High	TCE	Low	High	TCE
Experiment 2	609 (208)	707 (208)	98***	444 (129)	504 (129)	60**
Experiment 3	557 (46)	634 (46)	77**	425 (23)	459 (23)	34**

Numbers in parentheses denote 0.95 confidence intervals, as calculated for the reported comparisons

** $p < 0.01$, *** $p < 0.001$

(DOWN/RIGHT) and 7 (UP/LEFT). The two configurations were counterbalanced between participants.

Apparatus, stimuli and procedure

The apparatus, stimuli and procedure of this experiment were the same as in Experiment 2. The only difference was the key configurations as described above.

Results

Data were treated as in Experiment 1 (a total of 2.81% of the trials were removed) and the ANOVA had a similar design. The mean RT data are shown in Table 1. The ANOVA found that the main effects of CTI and TC were significant. Table 2 shows the results for the main effect of TC. An interaction was found between CTI and transition [$F(1,\ 15) = 5.48,\ p < 0.04,\ \eta_p^2 = 0.27$], such that switching cost was significantly positive when CTI was short [16 ms, $F(1,\ 15) = 5.76$, CI = 14.42, $p < 0.03$] and non-significantly negative when CTI was long [−7 ms, $F(1,\ 15) = 0.74$, CI = 17.17, $p = 0.40$]. More importantly, a significant interaction was found between TC and CTI [see Table 3; $F(1,\ 15) = 6.64$, $p < 0.03$, $\eta_p^2 = 0.31$], such that TCE was larger for the short CTI [77 ms, $F(1,\ 15) = 12.51$, CI = 46.46, $p < 0.01$] as compared to the long CTI [34 ms, $F(1,\ 15) = 9.87$, CI = 23.33, $p < 0.01$]. These results will be discussed in "General discussion".

Analysis of bivalent data

For completeness sake, we also analyzed the bivalent data of all three experiments. Remember that task conflict was not manipulated in these trials. The main importance of these analyses is in showing that the usual pattern of results was obtained, indicating that participants used their usual strategies despite the design change. Only bivalent trials were included in the analysis.

Results

Trials with RTs above 3,500 ms, trials with errors and trials following errors were removed from the analysis (a total of 7.01% of the trials). The ANOVA included experiment (1; 2; 3), CTI (100 ms; 1,000 ms) and transition (repeat; switch) as independent variables. A main effect was found for CTI and transition. An interaction between CTI and transition [$F(1, 45) = 30.16$, CI = 16.77, $p > 0.01$, $\eta_p^2 = 0.40$] was also found, such that there was a positive switching cost for short CTI (50 ms) and a negative switching cost for long CTI (−3 ms). Experiment was not involved in any significant effect.

General discussion

The goal of the present study was to provide relatively strong evidence for a control process involved in resolving task conflict irrespective of resolving conflict between responses associated with competing tasks. The results showed TCE, which was consistently found in all three experiments. TCE provides a relatively clean piece of evidence that task conflict takes time/effort to resolve, over and above the resolution of response conflict. This conflict can at least in part be resolved even prior to response selection as can be seen by the TCE by CTI interaction, which was significant in Experiment 3 and almost significant ($p = 0.06$) in Experiment 2. As such, we propose that TCE provides a useful index of task conflict resolution for future research.

The innovation of these experiments was the use of univalent targets while introducing the task conflict. Because the target stimuli were univalent, they did not invoke task-irrelevant categorizations. For example, a univalent stimulus serving in the UP–DOWN task probably did not bring to mind RIGHT or LEFT as potential categorizations, which competed during response selection. This was especially evident for Experiments 2 and 3, which demonstrated TCE through a manipulation that took place during the preparation stage, preceding target appearance and as such also logically preceding response selection. Experiment 3 showed that the conflict was not (only) at the level of hand selection, since the responses used in the two tasks were the same. Numerically, it seems that for Experiments 2 and 3, there was an element of hand confusion in TCE, since TCE was lower for Experiment 3 where hand confusion could not logically be a part of TCE. However, this difference of TCE between experiments (i.e., the interaction between TC (HIGH; LOW) and experiment (1; 2; 3) was not significant [$F(2, 45) = 0.65$, $p > 0.53$, $\eta_p^2 = 0.03$]. Notably, because of the grids used, the participants knew during preparation time whether a task was going to be bivalent or univalent. Moreover, knowing that the next target is univalent and that it is detrimental to make a task decision during preparation time, because of the interfering task identity information in this case (Experiments 2 and 3), advanced task decision is strongly discouraged. In other words, when univalent targets were anticipated, it was a worthwhile strategy to postpone task decision until target appearance. However, despite this, performance was still affected by task conflict. This suggests that TCE is a robust effect and that task decision usually (if not always) begins following cue appearance even when this is not a worthwhile strategy.

Theories concerning a task-decision process

There are two groups of theories regarding task decision. The first group states that task identity information primarily affects response selection and that there is no separate task-decision process (e.g., Schneider & Logan's, 2005). The second group assumes that there is a task-decision process that precedes (at least in part) response selection (e.g., Meiran et al., 2008; Monsell, 2003; Rubin & Meiran, 2005; Rubinstein et al., 2001).

One particular theory in the first group postulates that task identity is simply a constraint on stimulus categorization with regard to response (Schneider & Logan, 2005). The theory postulates that participants use the cue–target combination as a compound stimulus and map this stimulus to the respective categorization. For example, in the present tasks, there were four categorizations UP, DOWN, RIGHT and LEFT. This theory might claim that the use of univalent targets simply narrowed down the number of potential categorizations from 4 to 2. One could postulate that in high conflict trials, the irrelevant information that was added made the irrelevant categorizations accessible. As a result, response selection was prolonged because it involved more categorizations (4 vs. 2). For example, assume a univalent UP target. For this target, there were only two relevant categorizations, UP and DOWN. Presenting an irrelevant RIGHT–LEFT cue (i.e., a high conflict trial) potentially made the categorizations RIGHT and LEFT accessible, so that the eventual response selection was made among four categorizations rather than just two. However, in light of the present results, this explanation is unlikely to be correct because of the interaction that was found between CTI and TCE, indicating that the TCE became smaller with increasing preparation time. If the task identity was simply a constraint on response selection, then we would expect to see an interaction in the other direction (larger TCE with a long CTI than with a short CTI) or at least no interaction at all. The logic behind this prediction is that the interfering information was presented for a longer period of time when the CTI was long as compared to when it was short, thus increasing the likelihood that the irrelevant categorizations would be activated. The fact that the exact opposite happened can only be seen as evidence for the second group of theories.

Task decision and task set reconfiguration

One question that arises is whether task decision is a part of a task set reconfiguration or whether this is a separate process. The present results can help resolve this controversy. Specifically, some models of task switching have claimed the existence of both an abstract task decision and a task set reconfiguration (e.g., Meiran et al., 2008; Rubinstein et al., 2001). In these models, task set reconfiguration is the implementation of the relevant task rules. Meiran et al.'s model posits that switching cost derives from the fact that during switch trials, the system is still configured to execute the previous task. That is why switch trials, which are considered harder to reconfigure, have worse performance compared to repeat trials, which are easier to reconfigure.

The current results suggest that task decision (indexed by the TCE) and reconfiguration (indexed by switching cost) reflect two separate phenomena and argue against the notion of a single reconfiguration process, in which task decision is a part. We reason that if task decision was part of task set reconfiguration, one would assume that the TCE could not logically be larger than switching cost. In contrast to this prediction, in all of the three experiments, the TCE was quite substantially larger than switching cost. The fact that transition and task conflict did not interact reliably except in Experiment 2 further supports the aforementioned conclusion.

Future research

For future research, it would be interesting to run studies in which a task conflict manipulation would be combined with additional manipulations. One prominent example is mixing cost, which is the cost associated with being in a context in which a task switch could occur. This is especially interesting in light of the claim that it reflects difficulty in task decision (Rubin & Meiran, 2005). Another example is backward inhibition (Mayr & Keele, 2000), which is the poorer performance in switch trials when these involve a repetition of the *n*-2nd task. This suggests the inhibition of a previous task when switching tasks. However, it is unclear whether this phenomenon is related to aspects of reconfiguration (Schuch & Koch, 2003). Therefore, it would be interesting to see whether BI is related to task identity or task set reconfiguration. Importantly, both of these phenomena, mixing cost and BI, have been found to be present when using bivalent stimuli and diminished when using univalent stimuli. This suggests that they are related to task or response conflict, or both.

Conclusion

To conclude, the present study manipulated task conflict by presenting information that was either congruent or incongruent with the required task identity. This caused either low or high task conflict, respectively. The novel aspect of the present experiments is the use of univalent stimuli, which afford only one task and thus ones without conflict between categorizations belonging to different tasks. Despite this fact, we found poorer performance when the irrelevant information was associated with the wrong task. We further found that this irrelevant information (when appearing during preparation time) could at least partially be controlled with sufficient preparation time. This finding demonstrates that the resolution of task conflict contributes to performance irrespective of the resolution of response conflict.

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References

Allport, A., Styles, E. A., & Hsieh, S. (1994). Shifting intentional set: Exploring the dynamic control of tasks. *Attention and Performance, 15*, 421–452.

Altmann, E. M., & Gray, W. D. (2008). An integrated model of cognitive control in task switching. *Psychological Review, 115*, 602–639.

Biederman, I. (1972). Human performance in contingent information processing tasks. *Journal of Experimental Psychology, 93*, 219–238.

Brass, M., & von Cramon, D. (2004). Selection for cognitive control: A functional magnetic resonance imaging study on the selection of task-relevant information. *Journal of Neuroscience, 24*, 8847.

Dreisbach, G., Haider, H., & Kluwe, R. H. (2002). Preparatory processes in the task-switching paradigm: Evidence from the use of probability cues. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 28*, 468–483.

Gade, M., & Koch, I. (2007). Cue–task associations in task switching. *The Quarterly Journal of Experimental Psychology, 60*, 762–769.

Gilbert, S., & Shallice, T. (2002). Task switching: A PDP model. *Cognitive Psychology, 44*, 297–337.

Goldfarb, L., & Henik, A. (2007). Evidence for task conflict in the Stroop effect. *Journal of Experimental Psychology: Human Perception and Performance, 33*, 1170–1176.

Gotler, A., Meiran, N., & Tzelgov, J. (2003). Nonintentional task set activation: Evidence from implicit task sequence learning. *Psychonomic Bulletin & Review, 10*, 890–896.

Haggard, P. (2008). Human volition: towards a neuroscience of will. *Nature Reviews Neuroscience, 9*, 934–946.

Heuer, H., Schmidtke, V., & Kleinsorge, T. (2001). Implicit learning of sequences of tasks. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 27*, 967–983.

Jersild, A. T. (1927). Mental set and shift. Archives of Psychology, Whole No. 89.

Koch, I. (2001). Automatic and intentional activation of task-sets. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 27*, 1474–1486.

Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional overlap: Cognitive basis for stimulus–response compatibility—A model and taxonomy. *Psychological Review, 97*, 253–270.

MacLeod, C. M. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin, 109*, 163–203.

Mayr, U., & Keele, S. W. (2000). Changing internal constraints on action: The role of backward inhibition. *Journal of Experimental Psychology: General, 129*, 4–26.

Meiran, N. (1996). Reconfiguration of processing mode prior to task performance. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 22*, 1423–1442.

Meiran, N. (2000). Reconfiguration of stimulus task-sets and response task-sets during task switching. In S. Monsell & J. Driver (Eds.), *Control of cognitive processes: Attention and performance XVIII* (pp. 377–400). Cambridge: MIT Press.

Meiran, N. (2008). The dual implication of dual affordance: Stimulus-task binding and attentional focus changing during task preparation. *Experimental Psychology, 55*, 251–259.

Meiran, N. (2010). Task switching: Mechanisms underlying rigid vs. flexible self control. In R. Hassin, K. Ochsner, & Y. Trope (Eds.) *Social cognition and social neuroscience*. NY: Oxford University Press (in press).

Meiran, N., & Daichman, A. (2005). Advance task preparation reduces task error rate in the cuing task-switching paradigm. *Memory & Cognition, 33*, 1272–1288.

Meiran, N., & Kessler, Y. (2008). The task rule congruency effect in task switching reflects activated long term memory. *Journal of Experimental Psychology: Human Perception and Performance, 34*, 137–157.

Meiran, N., Kessler, Y., & Adi-Japha, E. (2008). Control by action representation and input selection (CARIS): A theoretical framework for task switching. *Psychological Research, 72*, 473–500.

Monsell, S. (2003). Task switching. *Trends in Cognitive Sciences, 7*, 134–140.

Monsell, S., Taylor, T., & Murphy, K. (2001). Naming the color of a word: Is it responses or task sets that compete? *Memory & Cognition, 29*, 137–151.

Norman, D. A., & Shallice, T. (1986). Attention to action: Willed and automatic control of behavior. In R. Davidson, G. Schwartz & D. Shapiro (Eds.), *Consciousness and self regulation: Advances in research and theory* (Vol. 4, pp. 1–18). New York: Plenum.

Rubin, O., & Koch, I. (2006). Exogenous influences on task set activation in task switching. *The Quarterly Journal of Experimental Psychology, 59*, 1033–1046.

Rubin, O., & Meiran, N. (2005). On the origins of the task mixing cost in the cuing task-switching paradigm. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 31*, 1477–1491.

Rubinstein, J. S., Meyer, D. E., & Evans, J. E. (2001). Executive control of cognitive processes in task switching. *Journal of Experimental Psychology: Human Perception and Performance, 27*, 763–797.

Ruthruff, E., Remington, R. W., & Johnston, J. C. (2001). Switching between simple cognitive tasks: The interaction of top-down and bottom-up factors. *Journal of Experimental Psychology: Human Perception and Performance, 27*, 1404–1419.

Schneider, D. W., & Logan, G. D. (2005). Modeling task switching without switching tasks: A short-term priming account of explicitly cued performance. *Journal of Experimental Psychology: General, 134*, 343–367.

Schuch, S., & Koch, I. (2003). The role of response selection for inhibition of task sets in task shifting. *Journal of Experimental Psychology: Human Perception and Performance, 29*, 92–105.

Sohn, M. H., & Anderson, J. R. (2001). Task preparation and task repetition: Two-component model of task switching. *Journal of Experimental Psychology: General, 130*, 764–778.

Sohn, M. H., & Carlson, R. (2000). Effects of repetition and foreknowledge in task-set reconfiguration. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 26*, 1445–1460.

Spector, A., & Biederman, I. (1976). Mental set and mental shift revisited. *American Journal of Psychology, 89*, 669–679.

Steinhauser, M., & Hübner, R. (2009). Distinguishing response conflict and task conflict in the Stroop task: Evidence from ex-Gaussian distribution analysis. *Journal of Experimental Psychology: Human Perception and Performance, 35*, 1398–1412.

Sudevan, P., & Taylor, D. A. (1987). The cuing and priming of cognitive operations. *Journal of Experimental Psychology: Human Perception and Performance, 13*, 89–103.

Vallacher, R. R., & Wegner, D. M. (1987). What do people think they're doing? Action identification and human behavior. *Psychological Review, 94*, 3–15.