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Action-Effect Sharing Induces Task-Set Sharing in Joint Task Switching

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Abstract

A central issue in the study of joint task performance has been one of whether co-acting individuals perform their partner's part of the task as if it were their own. The present study addressed this issue by using joint task switching. A pair of actors shared two tasks that were presented in a random order, whereby the relevant task and actor were cued on each trial. Responses produced action effects that were either shared or separate between co-actors. When co-actors produced separate action effects, switch costs were obtained within the same actor (i.e., when the same actor performed consecutive trials) but not between co-actors (when different actors performed consecutive trials), implying that actors did not perform their co-actor's part. When the same action effects were shared between co-actors, however, switch costs were also obtained between co-actors, implying that actors did perform their co-actor's part. The results indicated that shared action effects induce task-set sharing between co-acting individuals.

Introduction

The cooperation between individuals is critical for numerous societal challenges such as productivity (Kirkman & Shapiro, 2001) and successful collaboration (Amici & Bietti, 2015). Nevertheless, a human society is diverse, consisting of unique individuals with various perspectives, beliefs, and desires that often make it difficult to achieve a cohesion among society members (Seijts & Latham, 2000). Common wisdom says that an effective strategy to unite such a diverse population is to set a common goal that can be shared by all members of the society. A shared goal introduces a coherent perspective amongst people and enables their shared efforts toward a set goal to be realized. In fact, setting a common goal has been shown to affect group performance positively (Beal, Cohen, Burke, & McLendon, 2003; Curşeu, Janssen, & Meeus, 2013; Kleingeld, van Mierlo, & Arends, 2011), and it may also be effective in facilitating a mutual understanding of a surrounding context between a pair of actors who perform a task in a joint fashion. The aim of the present study was to investigate the role of goal sharing between co-acting individuals who divide the labor of performing single tasks.

In everyday activities, there are numerous occasions in which people set a common goal to cooperate with others. For instance, while driving in an unfamiliar neighborhood, the driver may ask a passenger to navigate to a destination. This requires both the driver and the navigator to share a common goal of reaching the destination. In another case, a number of boat crew members may be required to paddle a boat together to reach a destination. To coordinate paddling, the crew members would need to synchronize their actions to move the boat in an intended direction. It is important to note critical differences in goal sharing between the two cases. In the case of driving, the driver and the navigator share a *task goal* of reaching a destination, but their *action goals* are separate; the driver's action goal is to maneuver the vehicle while the navigator's goal is to monitor the position of the vehicle and guide the driver to the best possible route to the destination. In the case of rowing a boat, the rowers share a task goal of reaching a destination as well as their action goals of maneuvering the boat to the destination. Task-goal sharing requires the understanding of the global task context (e.g., driving destination), but it does not necessarily require each actor to understand what another actor is doing (e.g., the navigator does not know each action of the driver). Action-goal sharing requires the understanding of what another actor is doing to synchronize or compensate actions (e.g., a team of rowers need to know whether others are 'catching' or 'releasing' the water). It is thus reasonable to assume that action-goal sharing would facilitate co-acting individuals to construct similar cognitive representations of a shared task to coordinate their actions.

Cognitive representations underlying joint task performance have been studied by using a paradigm called the *joint Simon task* (Sebanz, Knoblich, & Prinz, 2003). It requires a pair of actors to divide the labors of performing the *Simon task* (Hommel, 2011; Lu & Proctor, 1995; Yamaguchi & Proctor, 2012), such that one actor responds to one type of stimuli (e.g., red circles) by pressing one response key (left key) whereas the other actor responds to the other type of stimuli (green circle) by pressing the other response key (right key). Although each actor operates a single response to one type of stimuli, responses are still faster when the locations of stimuli and response are compatible than when they are incompatible. This *joint Simon effect* has led to the development of an important theoretical construct, *task co-representation*, which suggests that co-acting individuals in the joint Simon task share their mental representation of the task (i.e., task-set; Sebanz, Knoblich, & Prinz, 2005) and represent their co-actor's actions as if they were at their own command (Knoblich & Sebanz, 2006).

These proposals are based on the earlier findings that spatial compatibility between stimuli and responses does not yield the Simon effect in a go/nogo version of the task

(Hommel, 1996), whereby actors only respond to one type of stimuli and withholds responding to the other type of stimuli. As there is only a single response in the go/nogo version of the task, the spatial aspect of the response is no longer salient, which eliminates the effect of spatial compatibility. The joint Simon task is essentially a go/nogo version of the Simon task for each actor, so the Simon effect in that task condition implies that each actor represents both his/her own response and the co-actor's response. Therefore, researchers have assumed that co-acting individuals represent their own and co-actor's parts of the task to form a complete picture of the task setting. The idea of co-representation has inspired many others to investigate social factors that affect shared task representation, such as group membership (Aquino et al., 2015), the sense of social exclusion (Costantini & Ferri, 2013), empathy toward co-actors (Ford & Aberdein, 2015), competitiveness between co-actors (Ruys & Aarts, 2010), and co-actor's attitude (Hommel, Colzato, & van den Wildenberg, 2009). Indeed, these factors have been found to affect the joint Simon effect.

However, the idea of task co-representation has been challenged recently (Dolk et al., 2014; Prinz, 2015). For instance, the Simon effect has been obtained in an individual go/nogo task when there was a salient nonanimate object (e.g., Japanese weaving cat) at the place of a co-actor (Dolk, Hommel, Colzato, Prinz, & Liepelt, 2011). This finding suggests that a co-actor's presence only serves as a salient spatial reference based on which the actors represent their responses, but the co-acting individuals may not share the mental representation of a shared task. Our previous study has also suggested that, even in a joint task setting, actors did not monitor their co-actor's trials as if they were their own (Yamaguchi, Wall, & Hommel, 2017b). That study showed that the proportion of compatible trials affected the Simon effect only when it was manipulated for their own trials but not when it was manipulated for their co-actor's trials. Taken together, these findings indicate that jointly engaging in a task does not necessarily lead to co-representation of actors, tasks, or actions.

Instead, contextual factors, the nature of which is yet to be understood, may determine whether and to what degree co-acting individuals integrate their co-actor's part of the task into their own task representation. The main aim of the present study was to investigate a specific aspect of the task sharing context – goal sharing – to assess the possibility that sharing salient action goals might be a prerequisite, or at least an important factor, in determining that degree. Although previous studies of task-sharing provided little evidence that the same task-set is shared between co-acting individuals, this might be due to the fact that the co-actors had different action goals in performing the shared task. In other words, goal sharing may not be the automatic consequence of co-representation but, quite to the contrary, co-representation may be the result of action-goal sharing.

The rationale underlying our study was motivated by some recent studies on task co-representation in joint task-switching (Yamaguchi, Wall, & Hommel, 2017a; see also Dudarev & Hassin, 2016; Liefooghe, 2016; Wenke et al, 2011). When two tasks are mixed randomly, responses are usually longer when the current task is different from the preceding trial (*task-switch trials*) than when it is the same as the preceding trial (*task-repeat trials*), representing a cost of switching between different tasks (*task-switch cost*). In joint task-switching, the main interest is to examine task-switch costs between co-actors, that is, switch costs on trials that follow the co-actor's trial. If the actor represents the co-actor's trial as if these were their own trials, the actor should monitor the task that the co-actor has just performed on the preceding trial, which should result in task-switch costs on the following trial. There have been two variations of joint task-switching. In the first variation (Dudarev & Hassin, 2016; Liefooghe, 2016), two actors are assigned two different tasks, and their trials are intermixed randomly. This variation produces switch costs between co-actors. However, a drawback is that this variation confounds task-switching with actor-switching; thus, when the tasks switch, the actors also switch, as two actors perform different tasks. Dudarev and

Hassin deconfounded task-switching from actor-switching by having two actors perform the same task, which produced no cost of actor-switching. However, having the same task might also promote feature migration between co-actors (Ma, Sellaro, Lippelt & Hommel, 2016), and this might have eliminated the cost of switching actors (see Yamaguchi et al., 2017a, for this argument).

In the second variation, two actors perform the same two tasks, and the relevant actor is cued on each trial. The cued actor responds to the stimulus and the non-cued actor withholds responding (Wenke et al., 2011; Yamaguchi et al., 2017a). Note that this version of joint task-switching does not involve confounding effects of actor- and task-switching. Importantly for our study, this setup was shown to produce task-switch costs within a given actor as one would expect, but no such costs after a switch from one actor to another. This observation is inconsistent with the idea that co-acting individuals share the same task-set when performing a joint task.

The Present Study

In the present study, we used this demonstration of the absence of switching costs after an actor switch as a point of departure and tested whether introducing a manipulation that is likely to emphasize action-goal sharing would generate switching costs even after actors switch. This manipulation was motivated by the ideomotor insight that actions are cognitively represented by their perceptual effects (Hommel, Müsseler, Aschersleben & Prinz, 2001; Hommel, 2009), so that the representations of intended perceptual effects can be considered action-goal representations (Verschoor, Weidema, Biro & Hommel, 2010). If so, creating conditions under which two co-actors are likely to code and represent their actions in terms of the same action effects can be considered to induce action-goal sharing.

Previous studies have shown that actors performing spatial responses tend to code their actions in terms of salient visual (Hommel, 1993; Yamaguchi & Proctor, 2011) or auditory (Elsner & Hommel, 2001) events that these actions generate, such as response-contingent signals on a screen or auditory events, at least if the action effects are sufficiently salient (Dutzi & Hommel, 2009) and the task is not too complex (Watson, van Steenbergen, de Wit, Wiers & Hommel, 2015). In the present study, we used visual action effects that were triggered by pressing the response keys (see Figure 1). Each co-acting individual was assigned two response keys, and pressing one key filled in one of the four circles on the display. For each actor, two responses resulted in two different action effects. The task was instructed based on the action effects rather than the response keys, which should encourage the actors to set their action goals as making the action effects rather than pressing the keys (Hommel, 1993).

For one group of participants, the action effects were spatially compatible with the actions (response-effect [R-E] compatible) and they were separate for the two co-acting individuals. That is, for one participant pressing his or her left key would result in the top left circle being filled while pressing the right key would result in the top right circle being filled; whereas for the other participant pressing the left or right key would result in the bottom left and the bottom right circle being filled, respectively (as in Figure 1A). Even though the introduction of additional action effects was novel, we expected that this group would replicate the findings reported by Yamaguchi et al. (2017a): task-switch costs should be observed within participants (i.e., in individual blocks and in trials for which the same actor repeats) but not between participants (i.e., after actors switch). A successful replication would reinforce our assumption that task-sharing is not observed in the absence of action-goal sharing.

For a second group of participants, the action effects were also spatially compatible with the actions (R-E compatible) but now they were shared between co-acting individuals. That is, pressing their left key would result in the same left circle being filled for both actors, and pressing their right key would result in the same right circle being filled (as in Figure 1B). We expected that this manipulation would induce action-goal sharing, which in turn should motivate task-sharing. If so, participants should show task-switch costs not only in individual blocks and with actor repetitions in joint blocks, but also after actor switches in joint blocks. In other words, the two R-E compatible groups should be comparable in individual blocks and with actor repetitions, but differ in trials after actors switch.

To investigate the possible limits of our predicted effect, we also tested two other groups (one with separate action effects and another with shared action effects), in which we established incompatible spatial relations between responses and action effects. It has been shown that spatially incompatible action-effect relations impair performance as compared to compatible relations (Kunde, 2001; Janczyk, Yamaguchi, Proctor, & Pfister, 2015; also see Pfister, Dolk, Prinz, & Kunde, 2014, for a joint version), suggesting that incompatible action effects hamper response selection (see Paelecke & Kunde, 2007). If so, it is possible that findings obtained with compatible action effects do not generalize to incompatible action effects. This could either be because the integration of actions and incompatible effects create so much conflict that it renders the task too complex to consider the actions and the goal of the co-actor. In that case, one would expect a main effect of R-E compatibility, as obtained by Kunde (2001), and the absence of task-switch costs after actors switch, just like in the group with R-E compatibility and separate action effects. Or it could be that the presence of incompatible action effects works against their integration into the action plans, so that participants would be more motivated to code their actions in terms of their finger movements or keypresses. This would also work against task-sharing and, thus, we predict the absence of task-switch costs after actors switch. If so, a main effect of R-E compatibility should also be absent. Finally, it is of course possible that R-E compatibility has no impact on task-sharing, in which case we should be able to replicate the pattern obtained for the two R-E compatible groups in the two R-E incompatible groups.

Method

Participants

Ninety undergraduate students (77 females; age mean = 19.40, *SD* = 2.71, range = 18-32) at Edge Hill University participated in the present study. They were recruited from an introductory psychology module and received experimental credits toward the module or paid £3 for participation. All reported having normal color vision and normal or corrected-to-normal visual acuity. They were naïve as to the purpose of the experiment.

Apparatus and Stimuli

The apparatus consisted of a 23-in widescreen monitor and a personal computer for each pair of participants. The target stimuli were green and red squares (4.8 cm in sides) and diamonds (squares tilted 45°). The task cues were the word “COLOR” for the color task and “SHAPE” for the shape task, which were presented in the Courier New font at the 36-pt font size. The actor cue was the letter “A” for one actor (Actor A) who sat on the left, and the letter “B” for the other actor (Actor B) who sat on the right; the actor cue was presented in the Arial font at the 40-pt font size. The target stimuli appeared at the center of the screen, and the task cue appeared 6.8 cm above the screen center. The actor cue was superimposed on the target stimuli and was printed in white. The display background was white. Responses were made by pressing the ‘z’ and ‘c’ keys for Actor A, and the ‘1’ and ‘3’ keys on the numeric pad for Actor B. For both actors, the response keys were referred to as ‘left’ and ‘right’ keys with respect to their relative positions to the other keys. Pressing a key turned on an action effect on the display, which was an empty gray circle (3.2 cm in diameter) in an inactive state and turned into yellow as the corresponding key was pressed during the trial.

Procedure

The experiment was conducted in a group of 14-28 participants in a computer lab. Two groups were run in parallel in two separate computer labs. In one of the computer labs, there were 24 seats arranged in four rows of six computers each. In the other computer labs, there were three rows of eight computers each and one row of six computers. The distance between two adjacent computers was 160 cm. Each pair of participants were seated in front of a computer monitor and at every other computer to avoid cluttering between pairs (except for one pair whose computer had a technical issue and had to move to a computer adjacent to another pair). Participants were from seminars for the same introductory psychology module, and the experimenter assigned participants from different seminar groups to pairs in a random fashion. Each pair of participants read on-screen instructions. Participants who sat on the left side placed their left and right index fingers on the ‘z’ and ‘c’ keys, respectively, and participants who sat on the right side placed their left and right index fingers on the ‘1’ and ‘3’ keys on the numerical keypad.

Before the main task started, participants were given demo trials in which they were asked to press one or the other key, which was followed by their corresponding action effect on the screen. The action effect was to filling an empty circle, and this was referred to as “turning on a light” in the instructions. Participants could try this demo as many times as they wanted. During the demo, there were four empty circles on the screen, two above the screen center and two below it (see Figure 1). There were four different groups who experienced different types of action effects.

In the two groups with *separate action effects*, pressing response keys turned on the lights at the top for one co-actor and at the bottom for the other co-actor (see Figure 1A). For one of these groups, response keys and the corresponding action effects were spatially compatible (i.e., pressing a left key would fill a left circle and pressing a right key would fill a right circle), and for the other group, response keys and the corresponding action effects were spatially incompatible.

In the two groups with *shared action effects*, pressing the left and right keys turned on the same left and right lights either above or below the screen center, and the remaining two lights were never turned on (see Figure 1B). For one of these groups, response keys and the corresponding action effects were spatially compatible; for the other group, response keys and the corresponding action effects were spatially incompatible. In all cases, the task was instructed in terms of the visual action effects rather than the response keys or finger movements. Thus, participants were instructed to “turn on the left light or right light” according to the color or shape of the target stimuli.

For all four groups, each pair performed two *joint blocks*, for which one participant responded on half of the trials, and the other participant responded on the other half. Each participant in the pair also performed one *individual block*, for which one participant responded to stimuli and another participant only watched the trials. Thus, there were two joint blocks and two individual blocks for each pair. Each block consisted of 120 test trials, and there was a block of 16 practice trials before the first joint blocks and before each of the two individual blocks. The order of the joint and individual blocks was determined randomly for each pair, and two blocks of the same kind were administered together. Within the individual blocks, the order of the actor performing the block was also determined randomly.

An example of the trial sequence is shown in Figure 2. Each trial started with the four ‘inactive’ action effects and a task cue (“COLOR” or “SHAPE”) that stayed on the screen for 400 ms, followed by a 50-ms blank screen. The imperative stimulus (colored square or diamond) appeared for 2,000 ms or until a response was made. The actor cue was superimposed on the imperative stimulus, indicating which actor should respond. A response was followed by the corresponding action effect for 250 ms, which was replaced by a feedback display. In the joint block, the message “Correct!” was presented for 500 ms if the correct response was made. If an incorrect response was made, an error message was presented for 500 ms. The error message was “Error!” for an incorrect response and “Faster!” for no response. If a wrong actor responded, the message was “Not your turn!” In the individual block, participants were required to respond only when the actor cue indicated their trials (go trials) but withhold responding when the actor cue indicated their co-actor’s trials (nogo trials). If no response was made on a go trial, the error message was “Respond!” If a response was made on a nogo trial, the error message was “Don’t respond!” The individual and joint blocks were essentially the same in all other respects. Response time (RT) was measured as the interval between onset of the target stimulus and a depression of a response key.

Design

The experiment consisted of the joint and individual task blocks (Task Condition). In both blocks, trials were either task-repeat or task-switch (Trial Transition). Trials were determined randomly on each trial, so there was an equal probability of .5 for each transition type. In the individual condition, a previous trial could be a go or nogo trial. In the joint condition, a previous trial could be performed by the same actor as the current trial (go trial) or by a different actor (nogo trial). The action effects could be *shared* or *separate* between co-actors. In each group, the relationship between response and action effect was compatible (*R-E Compatible*) or incompatible (*R-E Incompatible*).

Results and Discussion

Mean RT for correct trials and percentage errors (PE) were computed for each participant. Trials for which no response was made, a wrong actor responded, or RT was less than 200 ms, were excluded (2.98% of all trials). There were two participants in the Separate Effect Group with compatible R-E mappings, three participants in the Separate Effect Group with incompatible R-E mappings, and four participants in the Shared Effect Group with incompatible R-E mappings, whose PE was greater than 50%. These participants were excluded from the analyses. In the end, there were 20 participants in the Separate Effect Group with compatible R-E mappings, 22 participants in the Separate Effect Group with incompatible R-E mappings, 18 participants in the Shared Effect Group with compatible R-E mappings, and 21 participants in the Shared Effect Group with incompatible R-E mappings.

RT and PE were submitted to separate 2 (Effect Sharing: shared vs. separate) x 2 (R-E Compatibility: compatible vs. incompatible) x 2 (Task Condition: individual vs. joint) x 2 (Previous Trial: go vs. nogo) x 2 (Trial Transition: task-repeat vs. task-switch) ANOVAs. The first two factors were between-subject variables, and the remaining three factors were within-subject variables. RTs are shown in Figure 2, and PE are given in Table 1. The results of the ANOVAs are summarized in Table 2 for RT and Table 3 for PE.

Response time

The RT data showed that responses were faster for task-repeat trials (*M* = 900 ms) than task-switch trials (*M* = 959 ms), yielding a task-switch cost. Responses were also faster when the preceding trial was a go trial (*M* = 897 ms) than when it was a nogo trial (*M* = 962 ms). These two variables interacted, reflecting a larger task-switch cost when the preceding trial was a go trial (*M* = 104 ms) than when it was a nogo trial (*M* = 12 ms). Importantly, there was no main effect of R-E compatibility; RT was even longer (but not significantly so) for the R-E compatible groups (*M* = 941 ms) than for the R-E incompatible groups (*M* = 918 ms). There was no main effect of action-effect sharing either; RT was 955 ms when two co-actors had separate action effects and 903 ms when they shared action effects.

Importantly, however, there was a significant 5-way interaction among all variables. The interaction indicated that the influence of the preceding trial type on task-switch costs depended on Task Condition, Effect Sharing, and R-E compatibility. Unsurprisingly, in the individual conditions, task-switch costs were obtained only after go trials but not after nogo trials, regardless of whether action effects were shared. As expected, with compatible R-E relationships, switch costs were obtained in the joint task only after go trials (i.e., when the same actor repeated) but not after nogo trials (when actors switched) when co-actors had separate action effects (see Figure 3A). Note that this replicates the findings of Yamaguchi et al. (2017a). Of particular importance, however, switch costs were obtained after both go trials and nogo trials in the joint task when co-actors shared the same action effects, although switch costs were obtained only after go trails but not after nogo trials in the individual task (see Figure 3B). This implies that actors did monitor their co-actor's trial and selected a response (action effect) when the action effects were shared between the co-actors, which thus yielded task-switch costs even on trials that followed the co-actor's trials.

Interestingly, for those who had incompatible R-E relationships, task-switch costs were obtained only after go trials but not after nogo trials in both the joint and individual tasks. This was true both when co-actors had separate action effects (see Figure 3C) and when they shared the same action effects (see Figure 3D). Based on the visual inspection of the group with separate action effects (Figure 3C), there appeared to be a task-switch cost after nogo trials in the joint task (33 ms), but this was not statistically significant (p = .099). A possible reason for the lack of task-switch costs with incompatible R-E relationships is that the increased complexity of the co-actor's task made actors reluctant to monitor the co-actor's responses. Alternatively, the increased complexity of the task made actors reluctant to monitor action effects in general and code their actions in terms of response keys or locations instead. The lack of the R-E compatibility effect supports the latter explanation.

Percentage error

The PE data also yielded task-switch costs; responses were less accurate for task-switch trials (M = 22.48%) than for task-repeat trials (M = 17.21%). Responses were also less accurate when the preceding trial was a nogo trial (*M* = 21.10%) than when it was a go trial (*M* = 18.59%). Furthermore, responses were less accurate in the joint task (*M* = 23.40%) than in the individual task (*M* = 17.29%). There was also a main effect of R-E compatibility, showing that responses were less accurate for incompatible R-E relationships (*M* = 23.61%) than for compatible R-E relationships (*M* = 16.08%), and this effect was modulated by effect sharing. Thus, the R-E compatibility effect was larger when the action effects were separate (*M* = 12.01%) than when the action effects were shared (*M* = 3.06%). This is consistent with the earlier claim that the actors did not pay attention to the action effects when they were incompatible with responses, especially when the action effects were shared between the co-actors.

Conclusions

The present experiment examined the role of action-effect sharing in joint task performance. Although previous studies of task-sharing have provided little evidence that the same task-set is shared between co-acting individuals, this might be due to the fact that the co-actors had different action goals in performing the shared task. Here we are proposing that actors in a typical joint task setting, such as the joint Simon task, may share a task goal, but their action goals are distinct and separate. To induce the shared action goal, the present experiment utilized a situation in which actions of two actors performing the same tasks produced the same (or different) visual effects on a computer display. Although the setting did not require two actors' actions to be synchronized to bring about an effect together (as in the case of rowing a boat), actors shared the goal of making a visual event by responding to stimuli when their actions produced the same action effects. When the co-actors share the same action goals, they might integrate the co-actor's task context into their own task representations to support better coordination of actions. The results of the present experiment were consistent with this prediction. Using the joint task-switching paradigm, which previously provided no evidence of task-set sharing (Wenke et al, 2011; Yamaguchi et al., 2017a), task-switch costs were obtained across co-actors when the co-actors produced the same action effects in response to the target stimuli, but not when they produced separate action effects. In the task-switching studies with go/nogo signals, it has been shown that task-switch costs are obtained only after the actors actually select responses (Schuch & Koch, 2003; Verbruggen, Liefooghe, & Vandierendonck, 2006). Monitoring which task was performed (or was to be performed) is not sufficient to produce task-switch costs. Consequently, the present results indicate not only that the actors monitored which task their co-actor performed on the preceding trial but also that the actors actually selected the corresponding response to the target on their co-actor's trial. The actors were performing the co-actor's trial as if they were their own (Knoblich & Sebanz, 2006), supporting the idea of task co-representation.

Interestingly, though, this occurred only when the action effects were spatially compatible with responses. There is an indication that the actors did not represent their actions based on the action effects when they were incompatible with responses, because an expected R-E compatibility effect was absent in RT. This may be because the actors decided not to pay attention to the action effects, despite the emphasis given in the instructions, as the incompatibility made it more difficult to perform the task. This possibility further supports the claim that action-goal sharing (which in turn depends on action-effect coding) is a critical factor to task-set sharing.

It is worth noting that a study using a joint version of the inhibition-of-return (IOR) paradigm has suggested that the action goal of the actor does not necessarily affect performance of their co-actor (Janczyk, Welsh, & Dolk, 2016). In this task, two actors sit in front of each other with a barrier between the actors that blocked the view of their co-actor's action. The task was to move the finger to press a left or right key in response to a light on the left or right (Experiment 1), or to the color of a central light (Experiment 2). The researchers found the IOR across the co-actors (slower responses when the actor repeated the same response as the co-actor) based on the movement direction of the finger, but not based on the location or identity of the action effects resulted from keypresses. At a glance, such results seem inconsistent with the present findings, but it should be noted that the IOR in the joint task may be due to the repetitions of the same stimuli that signaled the same finger movements, not due to the movements themselves. If so, it makes sense that the action effects that resulted after the movements did not have any effect on the IOR.

Therefore, the present experiment provided the first evidence that action-effect sharing induces task-set sharing between co-actors in joint task-switching, indicating the importance of the shared action goals in joint performance. This finding is an important step forward in our understanding of cognitive representations underlying joint task performance. It should be emphasized that, in the present task, it was not a necessity for the co-acting individuals to share the action goals in the sense that they could still perform the task correctly without paying attention to the action effects. This is in contrast to the case of boat rowing in which all rowers must coordinate their actions to achieve a coherent maneuver of a boat. Thus, the results of the present experiment suggest a powerful role of action-effect sharing to induce task-sharing in joint performance.

Supplementary Material

The experimental data are freely available at the project page of the Open Science Framework (https://osf.io/5shjc/).

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Table 1. Percentage errors (parentheses are standard errors of the means)

R-E Compatibility	Effect Sharing	Previous Trial	Individual Task: Task-Repeat		Individual Task: Task-Switch		Joint Task: Task-Repeat		Joint Task: Task-Switch	
Compatible	Separate	After Go	8.83	(3.06)	21.47	(3.69)	11.13	(2.48)	17.08	(3.05)
		After Nogo	14.01	(3.76)	17.86	(3.83)	15.66	(3.18)	17.14	(3.19)
	Shared	After Go	17.72	(2.92)	28.01	(3.52)	20.43	(2.37)	33.83	(2.91)
		After Nogo	24.09	(3.59)	28.31	(3.65)	25.18	(3.04)	31.68	(3.04)
Incompatible	Separate	After Go	10.58	(3.23)	14.21	(3.89)	13.04	(2.62)	25.30	(3.21)
		After Nogo	14.49	(3.96)	14.64	(4.04)	21.74	(3.36)	20.06	(3.36)
	Shared	After Go	8.65	(2.99)	21.34	(3.60)	16.60	(2.43)	29.19	(2.97)
		After Nogo	17.07	(3.65)	15.43	(3.74)	26.19	(3.11)	24.06	(3.11)

Table 2. ANOVA results for response time

Factor	*df*	*MSE*	*F*	*p*	η_p^2
Between-Subject					
Effect Sharing (ES)	1, 77	139,364.74	3.12	.081	.039
Effect Compatibility (EC)	1, 77	139,364.74	< 1	.440	.008
ES x EC	1, 77	139,364.74	< 1	.914	< .001
Within-Subject					
Task Condition (TC)	1, 77	51,188.98	2.20	.143	.028
TC x ES	**1, 77**	**51,188.98**	**6.32**	**.014**	**.076**
TC x EC	1, 77	51,188.98	< 1	.493	.006
TC x ES x EC	1, 77	51,188.98	< 1	.719	.002
Previous Trial (PT)	**1, 77**	**15,733.48**	**42.57**	**< .001**	**.356**
PT x ES	1, 77	15,733.48	1.93	.168	.024
PT x EC	1, 77	15,733.48	< 1	.680	.002
PT x ES x EC	1, 77	15,733.48	< 1	.365	.001
Task Transition (TT)	**1, 77**	**6,583.81**	**84.03**	**< .001**	**.522**
TT x ES	1, 77	6,583.81	2.46	.121	.031
TT x EC	1, 77	6,583.81	3.71	.058	.046
TT x ES x EC	1, 77	6,583.81	.03	.880	< .001
TC x PT	1, 77	6,454.32	< 1	.884	< .001
TC x PT x ES	1, 77	6,454.32	< 1	.990	< .001
TC x PT x EC	1, 77	6,454.32	2.01	.160	.025
TC x PT x ES x EC	1, 77	6,454.32	< 1	.707	.002
TC x TT	1, 77	5,148.95	< 1	.324	.013
TC x TT x ES	1, 77	5,148.95	1.07	.304	.014
TC x TT x EC	1, 77	5,148.95	1.78	.186	.023
TC x TT x ES x EC	1, 77	5,148.95	< 1	.956	< .001
PT x TT	**1, 77**	**7,106.01**	**49.11**	**< .001**	**.389**
PT x TT x ES	1, 77	7,106.01	< 1	.555	.005
PT x TT x EC	1, 77	7,106.01	< 1	.729	.002
PT x TT x ES x EC	1, 77	7,106.01	2.39	.126	.030
TC x PT x TT	1, 77	6,112.01	3.59	.062	.044
TC x PT x TT x ES	1, 77	6,112.01	< 1	.771	.001
TC x PT x TT x EC	1, 77	6,112.01	< 1	.882	< .001
TC x PT x TT x ES x EC	**1, 77**	**6,112.01**	**5.00**	**.028**	**.061**

Note: Bold indicates a significant effect at alpha = .05

Table 3. ANOVA results for percentage errors

Factor	*df*	*MSE*	*F*	*p*	η_p^2
Between-Subject					
Effect Sharing (ES)	1, 77	700.94	2.23	.139	.028
Effect Compatibility (EC)	**1, 77**	**700.94**	**13.05**	**.001**	**.145**
ES x EC	**1, 77**	**700.94**	**4.60**	**.035**	**.056**
Within-Subject					
Task Condition (TC)	**1, 77**	**573.79**	**7.31**	**.008**	**.087**
TC x ES	1, 77	**573.79**	1.58	.213	.020
TC x EC	1, 77	**573.79**	1.09	.300	.014
TC x ES x EC	1, 77	**573.79**	< 1	.579	.004
Previous Trial (PT)	**1, 77**	**77.94**	**13.04**	**.001**	**.145**
PT x ES	1, 77	77.94	< 1	.341	.012
PT x EC	1, 77	77.94	1.21	.274	.016
PT x ES x EC	1, 77	77.94	1.57	.213	.020
Task Transition (TT)	**1, 77**	**70.23**	**63.51**	**< .001**	**.452**
TT x ES	1, 77	70.23	1.39	.242	.018
TT x EC	1, 77	70.23	< 1	.473	.007
TT x ES x EC	1, 77	70.23	< 1	.530	.005
TC x PT	1, 77	75.20	< 1	.356	.011
TC x PT x ES	1, 77	75.20	< 1	.468	.007
TC x PT x EC	1, 77	75.20	< 1	.596	.004
TC x PT x ES x EC	1, 77	75.20	< 1	.992	< .001
TC x TT	1, 77	73.60	< 1	.493	.006
TC x TT x ES	1, 77	73.60	3.37	.070	.042
TC x TT x EC	1, 77	73.60	< 1	.788	.001
TC x TT x ES x EC	1, 77	73.60	1.20	.277	.015
PT x TT	**1, 77**	**73.70**	**58.40**	**< .001**	**.431**
PT x TT x ES	1, 77	73.70	< 1	.347	.011
PT x TT x EC	1, 77	73.70	3.90	.052	.048
PT x TT x ES x EC	1, 77	73.70	< 1	.859	<.001
TC x PT x TT	1, 77	105.50	1.79	.184	.023
TC x PT x TT x ES	1, 77	105.50	< 1	.740	.001
TC x PT x TT x EC	1, 77	105.50	< 1	.697	.002
TC x PT x TT x ES x EC	1, 77	105.50	3.79	.055	.047

Note: Bold indicates a significant effect at alpha = .05

Figure 1. Illustrations of the separate (A) and shared (B) action effects. Circles are the action effects whose colors changed into yellow ('turned on') when the corresponding response keys (grey squares) were pressed. The illustrations depict the R-E compatible conditions in which left and right keypresses turned on the spatially compatible lights; the keypresses turned on the spatially incompatible lights in the R-E incompatible conditions.

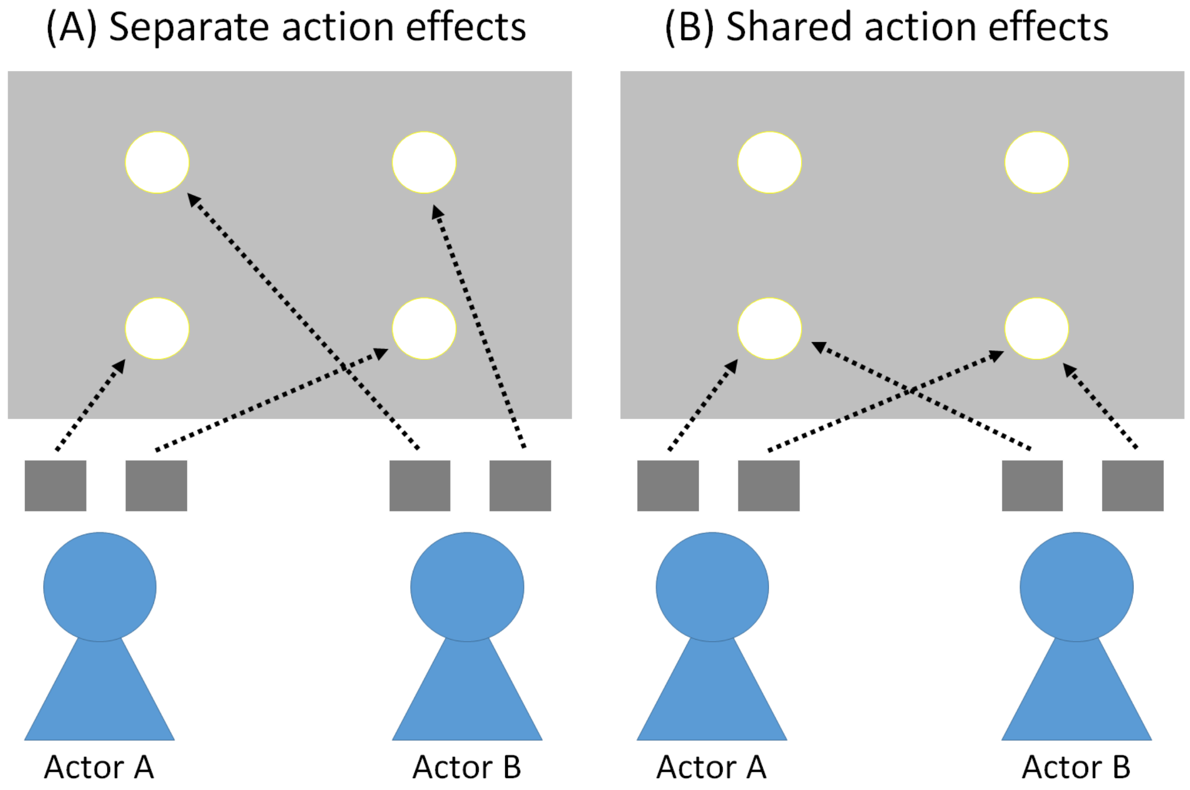


Figure 2. An example of the display sequence within a trial.

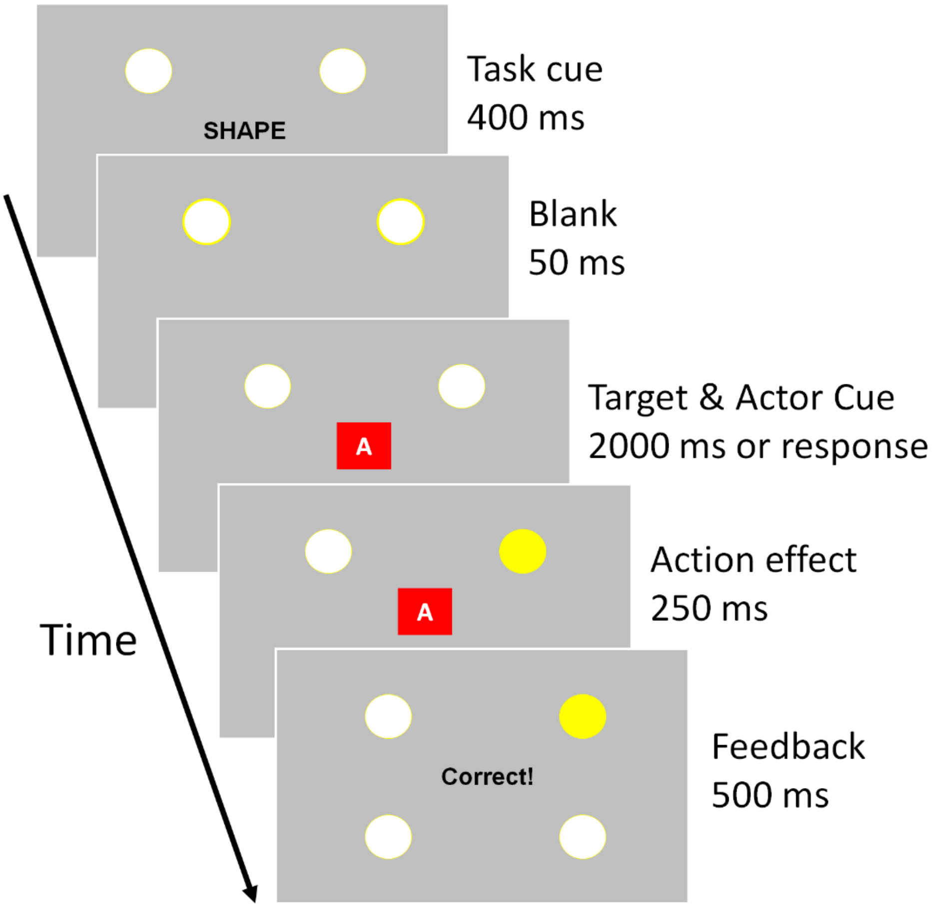
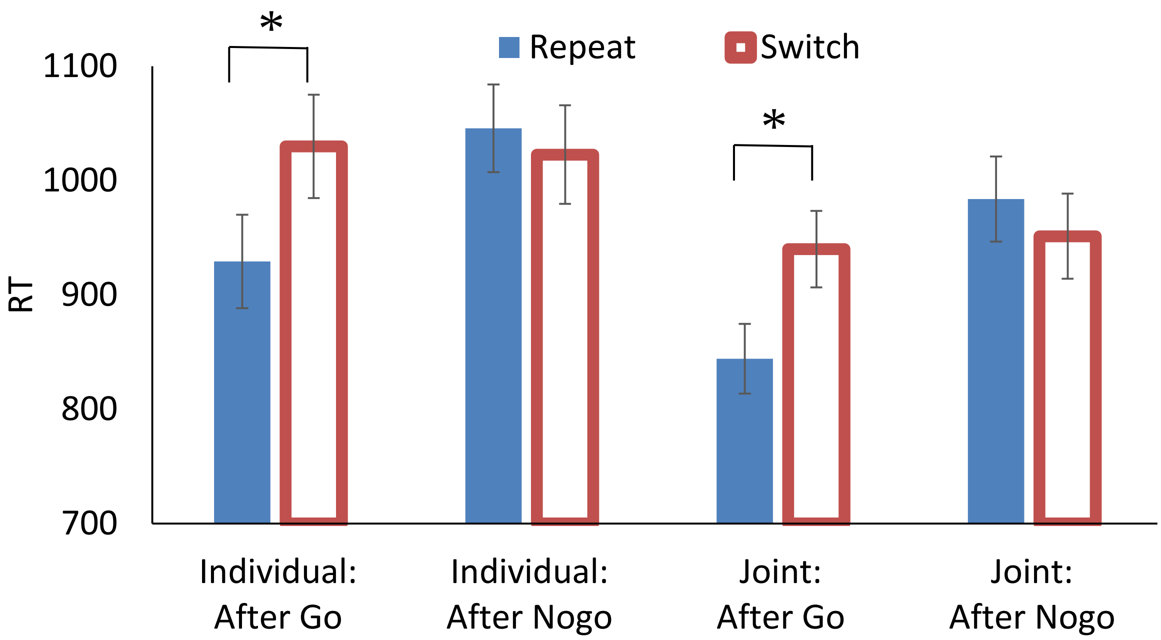
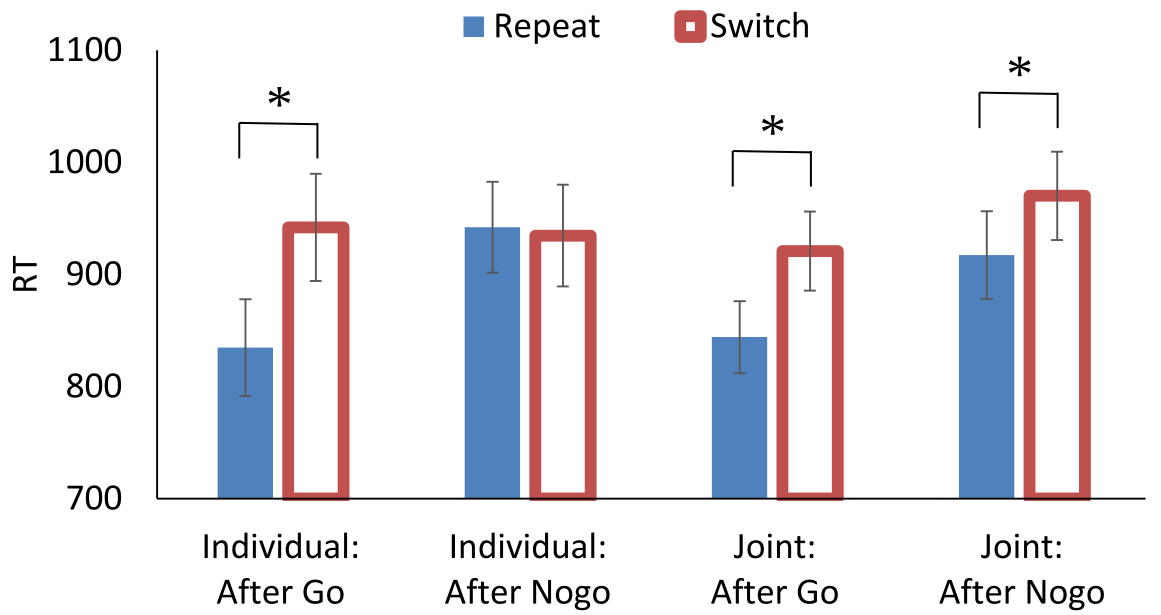


Figure 3. Response time (RT) as a function of Joint Condition, Previous Trial, and Task Transition with R-E compatible mappings for the Separate Effect Group (A) and for the Shared Effect Group (B) and with R-E incompatible mappings for the Separate Effect Group with R-E compatible mappings (C) and for the Shared Effect Group (D). Error bars are standard errors of the means, and asterisks indicate significant switch costs (α = .05).

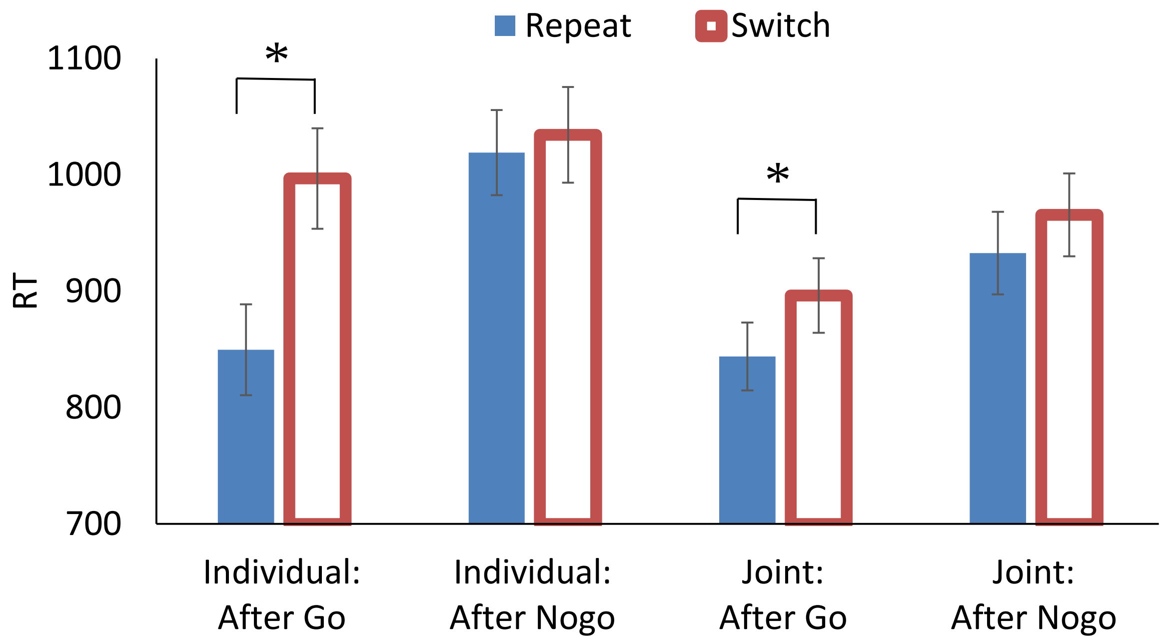
A. Separate Action Effects with R-E compatible relations



B. Shared Action Effects with R-E compatible relations



C. Separate Action Effects with R-E incompatible relations



D. Shared Action Effects with R-E incompatible relations