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Original Articles

The roles of action selection and actor selection in joint task settings☆

Motonori Yamaguchi[a,*], Helen J. Wall[a], Bernhard Hommel[b]

[a] Department of Psychology, Edge Hill University, Ormskirk, United Kingdom
[b] Institute of Psychology, Leiden University, Leiden, the Netherlands

A R T I C L E I N F O

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A B S T R A C T

Studies on joint task performance have proposed that co-acting individuals *co-represent* the shared task context, which implies that actors integrate their co-actor's task components into their own task representation as if they were all their own task. This proposal has been supported by results of joint tasks in which each actor is assigned a single response where selecting a response is equivalent to selecting an actor. The present study used joint task switching, which has previously shown switch costs on trials following the actor's own trial (intrapersonal switch costs) but not on trials that followed the co-actor's trial (interpersonal switch costs), suggesting that there is no task co-representation. We examined whether interpersonal switch costs can be obtained when action selection and actor selection are confounded as in previous joint task studies. The present results confirmed this prediction, demonstrating that switch costs can occur within a single actor as well as between co-actors when there is only a single response per actor, but not when there are two responses per actor. These results indicate that task co-representation is not necessarily implied even when effects occur across co-acting individuals and that how the task is divided between co-actors plays an important role in determining whether effects occur between co-actors.

1. Introduction

A successful completion of a joint task requires both the division of labor between co-acting individuals and the integration of divided task components into the individuals' task representations. The integration of divided components of the task is advantageous in a joint task setting because the mutual understandings of the current states of the co-actors allow each actor to monitor what their co-actors are doing and how they are doing it. The integration would be necessary especially under a condition for which precise coordination of co-actors' actions is crucial for a successful completion of a task (e.g., pair skating or rowing a boat). In previous studies of joint performance, there have been strong emphases on the integration of divided task components into a single mental representation. The resulting representation, or the act of creating such a representation, is termed *co-representation* (Sebanz, Knoblich, & Prinz, 2003). Nevertheless, little has been said about the division of labor in a joint task. The division of labor enables each actor to concentrate on their own components of the task, while their co-actors work on other parts independently (Yamaguchi, Clarke, & Egan, 2018). It reduces workloads of individual actors, in a way that allows individual actors to complete their parts to a higher standard. In organizational contexts, the division of labor also allows individuals to be specialized in areas of their expertise (Moreland, 1999). The division of labor and the integration of divided task components are both important factors in a joint task, but they also provide two opposing forces: the former promotes independence and autonomy of individual actors, whereas the latter facilitates collaboration and coordination between actors. The question of how these two forces operate in a joint task setting is of central importance when understanding the nature of collective behaviors. The purpose of the present study was to investigate what factors contribute to the balance between the division of labor and the integration of divided task components in a joint task setting.

In the last decade, joint task performance has been studied in various task settings that are used traditionally to investigate cognitive processes and representations underlying individuals' performance. These tasks include the Simon task (Sebanz et al., 2003), flanker task (Dolk, Hommel, Prinz, & Liepelt, 2014), Stroop task (Saunders, Melcher, & van Zoest, 2018; Yamaguchi, Clarke, et al., 2018), and task switching (Yamaguchi, Wall, & Hommel, 2017b), among others. The

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* Corresponding author at: Department of Psychology, Edge Hill University, St Helens Road, Ormskirk, Lancashire L39 4QP, United Kingdom.
E-mail address: yamagucm@edgehill.ac.uk (M. Yamaguchi).

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integration of co-actors' tasks was highlighted especially in the results of the joint version of the Simon task, called the joint Simon task. In the original version of the Simon task that is performed by individual actors, actors press left and right response keys to non-spatial aspects of stimuli (e.g., color) while they are encouraged to ignore stimulus locations. However, responses are still faster and often more accurate when stimulus and response locations are compatible than when they are incompatible, which is known as the Simon effect (Simon & Rudell, 1967). In the joint version of the Simon task (Sebanz et al., 2003), two actors are assigned two different responses that are mapped to two different stimuli. For instance, one actor presses a left key to green circles while the other actor presses a right key to red circles. Green and red circles appear in a random order, and each actor decides whether it is their turn to make a response, according to the stimulus presented on that trial. Hence, for each of the actors, the joint Simon task is essentially a go/nogo version of the Simon task, which usually produces no Simon effect when the task is performed alone (Hommel, 1996). When two actors perform the joint version of the go/nogo Simon task, the Simon effect is still obtained.

The occurrence of the joint Simon effect has inspired researchers to argue that two actors share a mental representation of the task when performing a joint task (Sebanz et al., 2003). This co-representation integrates two divided components of the Simon task into a whole representation that is equivalent to the original Simon task performed by single actors, and it provides the basis of spatial stimulus-response compatibility, producing the Simon effect in the joint setting. The co-representation account has been the major theoretical vehicle to interpret joint performance in the Simon and similar tasks in the past decade (e.g., Atmaca, Sebanz, & Knoblich, 2011; Atmaca, Sebanz, Prinz, & Knoblich, 2008; Demiral, Gambi, Nieuwland, & Pickering, 2016), although other alternative accounts have also been proposed recently (e.g., Dittrich, Dolk, Rothe-Wulf, Klauer, & Prinz, 2013; Dolk, Hommel, Colzato et al., 2014; Prinz, 2015; Wenke et al., 2011).

The co-representation account emphasizes the integration of divided task components, which is useful when two actors must coordinate their actions and achieve a cohesion in their collective behavior. Nevertheless, it can also introduce conflict between the motor programmes representing the actor's own action and the co-actor's action (Sebanz, Knoblich, Prinz, & Wascher, 2006). Such conflict would not occur if the actors only consider their own components of the task, which would be achieved by dividing the labor of the task. Therefore, there is a cost of integrating the co-actor's share of the task into one's own task representation. It should also be noted that a number of findings in recent studies are inconsistent with the central premise of the co-representation account. For instance, in a joint task, the co-representation account proposes that the actors represent their co-actor's actions automatically as if they were their own actions (Knoblich, Butterfill, & Sebanz, 2011; Knoblich & Sebanz, 2006), which implies that the actors would perform all trials (physically or mentally) as if they were all their own trials. However, participants are sensitive only to the proportions of compatible and incompatible trials in their own part, but not the proportions of these trials in their co-actor's part in the joint Simon task (Yamaguchi, Wall, & Hommel, 2018). Such a finding suggests that the actors represent their co-actor's trials differently from their own trials. More important to the present context, when each of the actors performs two different tasks that are administered in an unpredictable order, costs of switching between the two different tasks (switch costs) are obtained only if the previous trial is performed by the same actor as the current actor but not if it is performed by a different actor (i.e., by the co-actor; Wenke et al., 2011; Yamaguchi, Wall, & Hommel, 2017a; Yamaguchi et al., 2017b). This finding suggests that the actors do not represent their co-actor's trials in the same manner as they represent their own trials (also see Dolk, Hommel, Colzato et al, 2014; Saunders et al., 2018, for evidence against co-representation in other task settings). These recent observations are indicative of the division of labor between co-actors; the actors are concerned only with their own parts of the task.

It is puzzling that the joint Simon task supports the integration of task components into a shared mental representation, whereas other tasks such as joint task switching and joint Stroop task support the division of labor between co-actors. One of the possible factors that might contribute to the discrepancy is the way by which a shared task is divided between co-acting individuals. The joint Simon task assigns a single response to each actor, in such a way that the presentation of a target stimulus is sufficient to determine which actor is responsible for a given trial. This would mean that it is only after the correct response is determined when an actor to perform the trial is known. Thus, response selection and actor selection are confounded in this situation, and any factors that influence actor selection (e.g., similarity between co-actors) could also influence response selection, from which the Simon effect is thought to arise (e.g., Hommel, 1995; Yamaguchi & Proctor, 2012). Joint task-switching of our previous studies assigned two alternative responses to each actor (Yamaguchi et al., 2017a,b), and actors would first have to determine whether it is their turn to respond or their partner's before they decide which response is the correct one. Actor selection and response selection are separated in this situation, and factors that influence actor selection could not affect response selection (i.e., switch costs) in this setting. Therefore, the number of responses assigned to co-actors may determine whether co-actors co-represent a shared task or divide the labor of the task.

The present study tested this hypothesis in the context of joint task switching, based on our previous studies that provided evidence for the division of labor (i.e., no co-representation; Yamaguchi et al., 2017b). In this procedure, actors had to make responses to the target stimuli based on either the color of the stimuli (color task) or the shape of the stimuli (shape task). A task cue was provided at the beginning of a trial to indicate which task the actors were to perform. There were two task cues for each task (COLOUR and HUE for the color task, and SHAPE and FORM for the shape task; Logan & Bundesen, 2003). On some trials, the task cue was the same as that presented on the preceding trial (cue-repeat trials); on other trials, the task cue was different from that on the preceding trial but the task was the same (e.g., COLOUR followed by HUE, or SHAPE followed by FORM; cue-switch trials); and on still other trials, the task cue and the task differed from those on the preceding trial (e.g., COLOUR followed by SHAPE, or HUE followed by FORM; task-switch trails). The difference between cue-repeat and cue-switch trials reflects the effect of switching task cues without switching tasks (*cue-switch cost*); the difference between cue-switch and task-switch trials reflects the effect of switching tasks (*task-switch cost*).

In a joint version of this procedure, two actors performed these tasks together. Each of the two actors were assigned two responses that were mapped to two possible target stimulus values in each task (red vs. green for the color task, and square vs. diamond for the shape task). The actors were also provided with an actor cue that occurred simultaneously with the target, indicating which actor to perform the task. In this setting, there were switch costs when the actor also performed the preceding trial (*actor repeat trials*) but not when their co-actor performed the preceding trials (*actor switch trials*). The result indicated that the actors represented their own trials differently from their co-actor's trials. This outcome implied that the actors did not co-represent their co-actor's trials as if they were their own. This may be because the actors first had to determine whether it was their own trial or their partner's, and then determined which of the two alternative responses to make, given the target. To examine this possibility, we carried out two experiments.

In Experiment 1, a major modification from the previous study was the number of responses assigned to each actor: each actor had a single response that was mapped to one of the two possible targets in each task. For example, one actor might be assigned a left response key that is mapped to green for the color task and to diamond for the shape task, whereas the other actor might be assigned a right response key that is mapped to red for the color task and to square for the shape task. Under this condition, the actors could determine if the relevant target stimulus required the response assigned to them or the other response assigned to their partner. Because the target determined which response to be made, this condition required no explicit actor cue to indicate who to perform the trial, unlike the previous studies. Experiment 2 compared joint task switching with different numbers of responses assigned to each actor more directly. Two groups of actors completed either joint task switching of Experiment 1 (with one response per actor) or joint task switching of our previous studies (with two responses per actor; Yamaguchi et al., 2017b, Experiment 1).

2. Experiment 1

In the present experiment, a pair of actors performed two tasks jointly, such that each actor was assigned one of the two alternative responses in each of the two tasks that were intermixed randomly. The target stimuli were colored shapes (green and red squares and diamonds), and one actor responded to one of the colors (e.g., green) and one of the shapes (square), whereas the other actor responded to the other color (red) and the other shape (diamond). On each trial, the actors were instructed to respond to either the color or the shape of the target, and which actor responded on the trial depended on the relevant target stimulus. For instance, in the color task, one actor responded to green squares and diamonds, and the other actor responded to red squares and diamonds; in the shape task, one actor responded to green and red squares, and the other actor responded to green and red diamonds. There was no explicit 'actor cue' in addition to the target stimuli.

The main purpose of the present experiment was to assess switch costs within individual actors (intrapersonal switch costs) and between co-actors (interpersonal switch costs). The intrapersonal switch costs were examined by observing how task transition from the preceding trial influenced task performance on the current trial when the same actor performed both trials (actor repeat trials); the interpersonal switch costs were examined by observing how task transition influenced task performance when the actor performing the current trial differed from the actor who performed the preceding trial (actor switch trials). In the previous joint switching studies with two responses per actor (Yamaguchi et al., 2017b), there were intrapersonal switch costs but no interpersonal switch costs. In the current experiment with one response per actor, selecting a response was sufficient to determine the relevant actor on a given trial. Hence, actor selection is confounded by response selection, just as in the joint Simon task (Sebanz et al., 2003). Each actor would select a response on every trial to decide whether they were to respond on a given trial. Thus, we expected that there would be both intra- and interpersonal switch costs in the current experiment.

2.1. Method

2.1.1. Participants

Fifty two undergraduate students (39 females, 3 undisclosed; mean age = 20.96, *SD* = 6.73, range = 18–49) at Edge Hill University were recruited from two seminar groups of the introductory psychology module. All reported having normal or corrected-to-normal visual acuity and normal color vision. They received experimental credits toward their module. They were naïve as to the purpose of the experiment. The experimental protocol was approved by the Departmental Research Ethics Committee of Edge Hill University.

2.1.2. Apparatus and stimuli

The apparatus consisted of a 23-in widescreen monitor and a personal computer. The target stimuli were squares (4.8 cm in side) and diamonds (i.e., squares tilted 45°), which were colored in green or red. The targets were presented at the screen center. The task cues were the words "COLOUR" and "HUE" for the color task, and "SHAPE" and "FORM" for the shape task, which were presented in the Courier New font at 36-pt. The cues appeared 6.8 cm above the screen center. Responses were registered by pressing the 'z' and '/' keys on a QWERTY desktop keyboard.

2.1.3. Procedure

The experiment was conducted in two computer labs of the same room layout with 24 seats arranged in four rows of six computers each, plus an instructor's computer at the front end of the room. The distance between two adjacent computers was about 160 cm. There were at most three participant pairs in each row; pairs were seated at every other computer to avoid cluttering between pairs. Two pairs used the instructor's computers. The experimenter randomly paired two students from different seminar groups, and each pair of participants used one computer and sat in front of the computer monitor. Participants who sat on the left side placed their right index finger on the 'z' key, and those who sat on the right side placed their left index finger on the '/' key. Each participant read on-screen instructions that emphasized both speed and accuracy of responding.

Each participant performed two *joint-task blocks*, for which one participant responded to a subset of stimuli and another participant responded to another subset of stimuli, and one *individual-task block*, for which one participant responded to stimuli assigned to him or her and ignored other stimuli assigned to their co-actor; another participant remained inactive and only watched the trials. Hence, there were two joint-task blocks and two individual-task blocks for each pair. Each block consisted of 96 test trials, and there was a block of 16 practice trials before the first joint-task block and before each of the two individual-task blocks. For some pairs, two joint-task blocks were administered first and then two individual-task blocks; for other pairs, two individual-task blocks were administered first and then two joint-task blocks. The order of the joint- and individual-task blocks were determined randomly for each pair. Within the individual-task blocks, the order of the actor performing the block was also determined randomly.

In the color task, one participant responded to red stimuli, and another participant responded to green stimuli; in the shape task, one participant responded to squares, and another participant responded to diamonds. The assignments of the colors and the shapes were counterbalanced across pairs.

In the joint-task block, each trial started with a task cue that stayed on the screen for 450 ms, followed by a 50-ms blank screen. The target (colored square or diamond) appeared for 2000 ms or until a response was made. If the correct response was made, a blank display replaced the stimulus and lasted for 1000 ms; otherwise, an error message was presented for 1000 ms. The message was "Error!" for an incorrect response and "Faster!" for no response. The next trial started with another task cue. Response time (RT) was measured as the interval between onset of a target and a keypress.

The individual-task block was essentially the same, but participants were required to respond only when stimuli assigned to them were presented (go trials) but withhold responding when stimuli assigned to their co-actor were presented (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!" There was a 2000-ms window to respond on each trial.

2.1.4. Design

The independent variables included Block Type (joint-task block vs. individual-task block), Task Sequence (task-switch vs. cue-switch vs. cue-repeat), and Previous Trial Type (go trial vs. nogo trial). Task-switch referred to trials for which the current task was different from the task on the preceding trial; cue-switch referred to trials for which the current task was the same as the task on the preceding trial but the task-cue differed from the cue on the preceding trial; and cue-repeat referred to trials for which the current task and task-cue were the same as those on the preceding trial. The three types of transition occurred with equal probability, determined randomly at the beginning of each trial. The difference in performance between task-switch and cue-switch represents task-switch costs; the difference in performance between cue-switch and cue-repeat represents cue-switch costs. With respect to Previous Trial Type for the joint-task condition, "go" refers to trials for which the preceding trial was performed by the same actor as the current trial (*actor repeat* in the joint task); "nogo" refers to trials for which the preceding trial was performed by a different actor (*actor switch* in the joint task).

2.2. Results

Trials were discarded if RT was shorter than 200 ms or if there was no response (2.62% of all trials). Mean RT for correct trials and percentages of error trials (PE) were computed for each participant. RT and PE are summarized in Fig. 1. They were submitted to a 2 (Block Type: joint-task vs. individual-task) × 3 (Task Sequence: task-switch vs. cue-switch vs. cue-repeat) × 2 (Previous Trial Type: go vs. nogo) ANOVA, with all variables being within-subject. The results are summarized in Table 1.

2.2.1. Response time

For RT, a significant main effect of Block Type reflected faster responses in the joint task ($M = 502$ ms) than in the individual task ($M = 553$ ms). RT also depended on Previous Trial Type; responses were faster after go trials ($M = 519$ ms) than after nogo trials ($M = 537$ ms). There was a significant main effect of Task Sequence, which revealed that responses were fastest for cue-repeat trials ($M = 514$ ms), intermediate for cue-switch trials ($M = 520$ ms), and slowest for task-switch trials ($M = 550$ ms), yielding switch costs.

Switch costs depended on Previous Trial Type. After go trials, responses were shortest for cue-repeat trials ($M = 493$ ms), intermediate for cue-switch trials ($M = 518$ ms), and longest for task-switch trials ($M = 546$ ms). Bonferroni adjusted post-hoc multiple comparisons[1] indicated that cue-repeat trials were significantly different from cue-switch trials ($p = .047$) and from task-switch trials ($p < .001$), but cue-switch and task-switch trials were not different ($p = .179$). After nogo trials, RT was shorter for cue-switch trials ($M = 522$ ms) than for cue-repeat trials ($M = 535$ ms); RT was still longest for task-switch trials ($M = 555$ ms). Bonferroni-adjusted multiple comparisons indicated that responses were significantly faster for cue-switch trails than for task-switch trials ($p = .002$) but were not different between cue-switch and cue-repeat trials ($p = .542$) or between cue-repeat and task-switch trials ($p = .179$). Therefore, there were task-switch costs both after go trials (when the same actor repeated) and after nogo trials (when actors switched), but cue-switch costs were obtained only after go trials but not after nogo trials. Instead, responses were as slow for cue-repeat trials as task-switch trials.

Therefore, the RT data showed that the individual and joint tasks differed only with respect to the overall response speed, but there were no significant differences in terms of switch costs. As expected, there were switch costs after go trials (intrapersonal switch costs), which showed cue-switch costs but not task-switch costs; there were also switch costs after nogo trials (interpersonal switch costs) in the joint task, which showed task-switch costs but not cue-switch costs.

2.2.2. Percentage of error trials

For PE, a significant main effect of Block Type reflected more accurate responses in the individual task ($M = 1.20\%$) than in the joint task ($M = 8.61\%$). PE also depended on Task Sequence, and Block Type modulated this effect. PE was very small for the individual task to begin with, so there were little differences across the three type of trial transition ($Ms = 1.37\%$, 0.80%. and 1.43%, for cue-repeat, cue-switch, and task-switch trials, respectively). For the joint task, PE was similar between cue-repeat ($M = 7.24\%$) and cue-switch ($M = 7.12\%$), which were smaller than PE for task-switch ($M = 11.50\%$).

As in RT, switch costs depended on previous trial type. After go trials, Bonferroni adjusted multiple comparisons showed that responses were more accurate on both cue-repeat and cue-switch trials than on task-switch trials ($ps < 0.001$), but the former two trials did not differ ($p = 1$). After nogo trials, responses were more accurate on cue-switch trials than on task-switch trials, although the effect was only marginal statistically ($p = .065$). Cue-repeat trials were not different from cue-switch or task-switch trials ($p > .7$).

Therefore, the individual and joint tasks differed with respect to the overall error rates (more accurate in the individual task than in the joint task); together with the RT results, this outcome represents speed-accuracy trade-offs, whereby the actors were more cautious (i.e., slower and more accurate) in the individual task than in the joint task. There were very small error rates in the individual task, so all significant effects were driven by the joint task. And yet, PE data still showed switch costs after go trials (intrapersonal switch costs) and after nogo trials (interpersonal switch costs), although the latter was only marginal.

2.3. Discussion

The present results demonstrated little differences between the individual and joint tasks, except for the overall response speed and error rates. There appeared to be speed-accuracy tradeoffs, as responses were faster but less accurate in the joint task than in the individual task. In RT, there were intra- and interpersonal switch costs: switch costs were obtained when the same actor performed the preceding trial and the current trial, as well as when different actors performed these trials. Importantly, given that there was no significant difference between the individual and joint tasks, the interpersonal switch costs cannot be attributed to co-representation per se. In PE, there were much smaller error rates in the individual task than in the joint task, and any significant effects appear to have been driven by the latter task block. The joint task still showed both intrapersonal and interpersonal switch costs, although the latter effect was only marginal. The results are generally consistent with the prediction that, due to the confounding between actor selection and action selection, actors select a response to determine whether the trial was their own or their partner's, which then led to the interpersonal switch costs.

An interesting outcome of the present experiment is that although task-switch costs were obtained after go trials and after nogo trials, cue-switch costs occurred only after go trials but not after nogo trials. In fact, responses were as slow and less accurate for cue-repeat trials as task-switch trials after nogo trials. This outcome may reflect binding between the response and the task cue on the preceding trial; that is, as the actor inhibited their response on the preceding trial, the inhibition was associated with the task cue, which then primed an inhibition of the response on the current trial when the task cue repeated. A similar mechanism has been suggested in our previous study on the joint Simon task (Yamaguchi, Wall, et al., 2018), in which we found sequential modulations of the Simon effect on trials for which actors switched (after nogo trials); this interpersonal sequential modulation was also explained by binding of 'nogo' response to the stimulus location on the preceding trial. It would be interesting to test this account more systematically in future investigations, but as this finding was not of central concern for present purposes we did not pursue it further. Instead, in Experiment 2, we excluded cue-repeat trials to remove this possible binding effect.

3. Experiment 2

The results of Experiment 1 showed both intra- and interpersonal switch costs, which differed from our previous studies (Yamaguchi

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[1] There were three combinations of task-switch, cue-switch, and cue-repeat. Thus, p-values from paired-samples t-test were multiplied by three with alpha = 0.05.

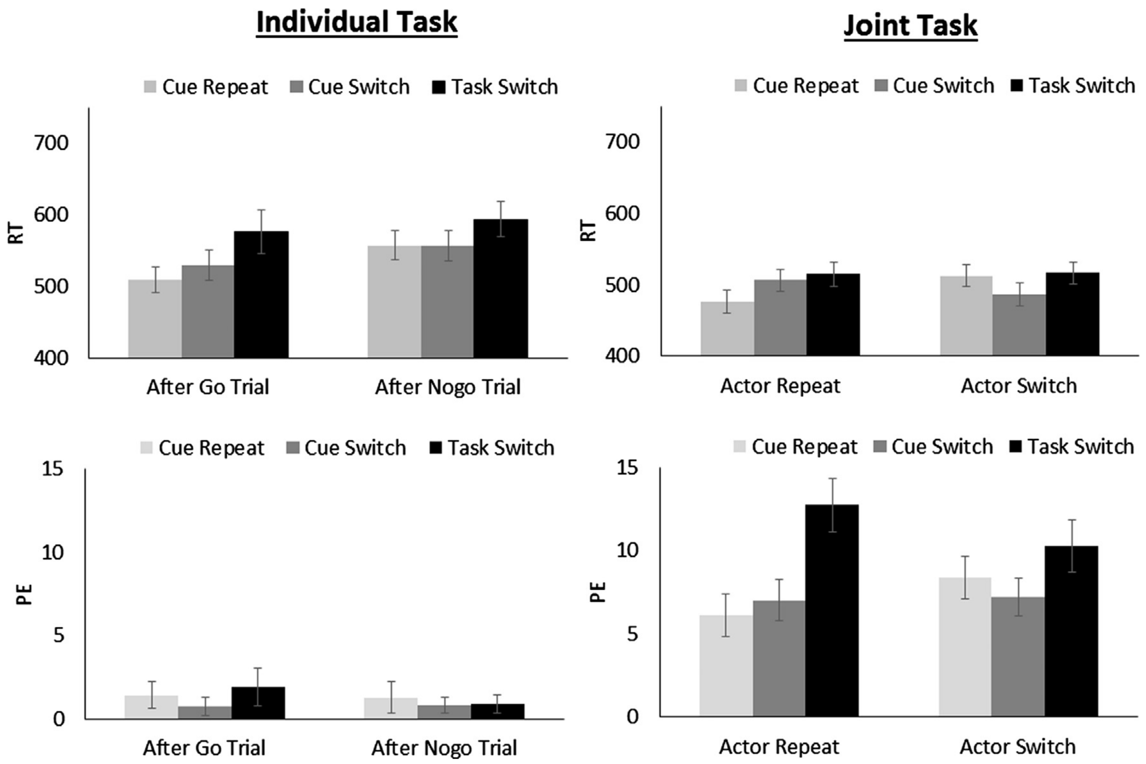


Fig. 1. Mean response times (RT) and percentage errors (PE) for individual and joint tasks of Experiment 1 (error bars represent one standard error of the mean).

Table 1
Results of ANOVAs on Response Time (RT) and Percentage Errors (PE) in Experiment 1.

Factors	*df*	*MSE*	*F*	*p*	η_p^2
	RT				
Block Type (BT)	**1, 51**	**58,546.89**	**7.09**	**0.010**	**0.122**
Previous Trial (PT)	**1, 51**	**11,276.09**	**4.67**	**0.035**	**0.084**
Task Sequence (TS)	**2, 102**	**6261.74**	**12.72**	**< 0.001**	**0.200**
BT × PT	1, 51	11,333.04	2.09	0.154	0.039
BT × TS	2, 102	5830.89	2.27	0.108	0.043
PT × TS	**2, 102**	**6703.09**	**3.37**	**0.038**	**0.062**
TB × PT × TS	2, 102	5865.36	< 1	0.458	0.015
	PE				
BT	**1, 51**	**208.34**	**41.15**	**< 0.001**	**0.447**
PT	1, 51	35.21	< 1	0.706	0.003
TS	**2, 102**	**247.68**	**15.51**	**< 0.001**	**0.233**
BT × PT	1, 51	33.74	< 1	0.705	0.003
BT × TS	**2, 102**	**31.50**	**8.74**	**< 0.001**	**0.146**
PT × TS	**2, 102**	**23.54**	**4.48**	**0.014**	**0.081**
BT × PT × TS	2, 102	28.87	1.68	0.192	0.032

Note: Bold indicates a significant effect at alpha = 0.05.

et al., 2017b, Experiment 1) in which switch costs were obtained within the same actor but not between co-actors. A major discrepancy between the two experiments was the number of responses assigned to each actor. The present experiment compared more directly between switch costs for different numbers of responses per actor. Two groups of actors performed two tasks as in Experiment 1, but one group was given one response per actor for each of the two tasks with no explicit actor cue (as in Experiment 1) and the other group was given two responses per actor for each of the two tasks with an explicit actor cue (as Experiment 1 of Yamaguchi et al., 2017b). To avoid the possible binding effect after nogo trials suggested by the outcomes of Experiment 1, cue-repeat trials were excluded in the present experiment. It was expected that the one-response group would yield both intra- and interpersonal switch costs similarly, whereas the two-response group would yield only intrapersonal switch costs but not interpersonal switch costs.

3.1. Method

3.1.1. Participants

Ninety-six students (76 females; mean age = 19.53, *SD* = 4.99, range = 18–48) at Edge Hill University participated in the present experiment as part of the seminar activity in an introductory psychology module. None had participated in Experiment 1, and they were naïve as to the purpose of the experiment. Participants received experimental credits toward their module for participation. Participants were randomly assigned to one of the two groups (one-response group and two-response group) of an equal number (*N* = 48).

3.1.2. Apparatus, stimuli, and procedure

The apparatus and stimuli were essentially the same as those used in Experiment 1: target stimuli were squares and diamonds in green or red, and the task cues were *COLOUR*, *HUE*, *SHAPE*, and *FORM*. For the one-response group, response keys were the "z" key for one actor and the "3" key on the numeric pad for the other actor. For the two-response group, they were the "z" and "c" keys for one actor and the "1" and "3" keys on the numeric pad for the other actor. For the latter group, there was an additional 'actor cue,' which was the letter *A* or *B* superimposed on the target stimulus; this signaled an actor to make a response (see Yamaguchi et al., 2017b, for the same procedure).

The procedure closely followed Experiment 1 of the present study and that of our previous study (Yamaguchi et al., 2017b, Experiment 1). Participants were randomly assigned to pairs and were allocated to either the one-response group or the two-response group. The one-response group performed the same task as that of Experiment 1 of the present study, in which each actor was assigned one response key and responded by pressing the key only if one of the two target stimuli for a given task (shape or color) appeared on the screen. The two-response group performed the task used in Experiment 1 of Yamaguchi et al. (2017b), in which each actor was assigned two response keys and responded by pressing either of the keys only if the actor cue indicated their trial. The actor cue was the letter *A* for one actor or *B* for the other actor, which was superimposed on the target stimulus. As in the

Table 2
Results of ANOVAs on Response Time (RT) and Percentage Errors (PE) in Experiment 2.

Factors	*df*	*MSE*	*F*	*p*	η_p^2
	RT				
Between-subject					
Number of Response (NR)	**1, 92**	**23,285,027.96**	**182.99**	**< 0.001**	**0.665**
Within-subject					
Block Type (BT)	1, 92	34,923.53	3.06	0.084	0.032
BT × NR	1, 92	34,923.53	1.99	0.162	0.021
Previous Trial (PT)	**1, 92**	**125,857.34**	**7.31**	**0.008**	**0.074**
PT × NR	1, 92	125,857.34	< 1	0.939	< 0.001
Task Sequence (TS)	**1, 92**	**7845.83**	**4.01**	**0.048**	**0.042**
TS × NR	1, 92	7845.83	< 1	0.893	< 0.001
BT × PT	1, 92	9404.55	1.41	0.238	0.015
BT × PT × NR	1, 92	9404.55	< 1	0.883	< 0.001
BT × TS	1, 92	6419.93	< 1	0.803	0.001
BT × TS × NR	1, 92	6419.93	< 1	0.694	0.002
PT × TS	1, 92	5728.71	2.47	0.119	0.026
PT × TS × NR	**1, 92**	**5,728.71**	**12.61**	**0.001**	**0.121**
BT × PT × TS	1, 92	6469.79	1.15	0.286	0.012
BT × PT × TS × NR	**1, 92**	**6469.79**	**5.11**	**0.026**	**0.053**
	PE				
Between-subject					
Number of Response (NR)	**1, 92**	**84,597.05**	**116.67**	**< 0.001**	**0.559**
Within-subject					
BT	**1, 92**	**291.75**	**23.08**	**< 0.001**	**0.201**
TB × NR	**1, 92**	**291.75**	**10.02**	**0.002**	**0.098**
PT	1, 92	81.20	< 1	0.352	0.009
PT × NR	1, 92	81.20	2.08	0.152	0.022
TS	**1, 92**	**82.00**	**21.61**	**< 0.001**	**0.190**
TS × NR	**1, 92**	**82.00**	**4.04**	**0.047**	**0.042**
BT × PT	1, 92	37.38	< 1	0.614	0.003
BT × PT × NR	1, 92	37.38	< 1	0.410	0.007
BT × TS	1, 92	61.37	< 1	0.432	0.007
BT × TS × NR	**1, 92**	**61.37**	**4.35**	**0.040**	**0.045**
PT × TS	**1, 92**	**49.56**	**5.79**	**0.018**	**0.059**
PT × TS × NR	**1, 92**	**49.56**	**12.10**	**0.001**	**0.116**
BT × PT × TS	1, 92	58.96	3.16	0.079	0.033
BT × PT × TS × NR	**1, 92**	**58.96**	**3.94**	**0.050**	**0.041**

Note: Bold indicates a significant effect at alpha = 0.05.

previous experiments, each actor performed the joint task and the individual task. The joint task started with a block of 16 practice trials, followed by two blocks of 120 test trials each; the individual task started with a block of 10 practice trials, followed by one block of 120 test trials, for each actor. As cue-repetition had caused slow responses after nogo trials in Experiment 1, cue-repeat trials were excluded, so task cue alternated every trial. Cue-switch and task-switch trials occurred randomly with the probability of 0.5 each.

3.2. Results

Trials were discarded based on the same criteria as those used in Experiment 1 (3.00% of all trials), after removing one pair in the two-response group for whom more than 50% of trials did not meet the criteria and had to be discarded. Mean RT for correct trials and PE were computed in the same manner as before and were submitted to 2 (Block Type: joint-task vs. individual-task) × 2 (Task Sequence: task-switch vs. cue-switch) × 2 (Previous Trial Type: go vs. nogo) × 2 (Number of Response: one-response vs. two-response) ANOVAs, with the first three variables being within-subject and the last variable being between-subject. The ANOVA results are summarized in Table 2, and RT and PE are shown in Fig. 2.

3.2.1. Response time

For RT, a significant main effect of Number of Response indicates that responses were faster for the one-response group ($M = 580$ ms) than for the two-response group ($M = 933$ ms), which presumably reflected a need of response selection after actor selection in the latter but not in the former. Significant main effects of Previous Trial Type and of Task Sequence reflect faster responses after go trials ($M = 745$ ms) than after nogo trials ($M = 768$ ms), and for cue-switch trials ($M = 750$ ms) than for task-switch trials ($M = 763$ ms), respectively. This switch cost depended on Block Type, Previous Trial Type, and Number of Response.

To follow up the significant four-way interaction, RTs for the two groups were submitted to separate 2 (Block Type: joint-task vs. individual-task) × 2 (Task Sequence: task-switch vs. cue-switch) × 2 (Previous Trial Type: go vs. nogo) ANOVAs. For the one-response group, the only significant effects were the main effects of Block Type, $F(1,\ 47) = 4.52$, $MSE = 39414.35$, $p = .039$, $\eta_p^2 = 0.088$, and of Previous Trial Type, $F(1,\ 47) = 4.80$, $MSE = 10583.96$, $p = .034$, $\eta_p^2 = 0.093$. Responses were faster in the joint task ($M = 559$ ms) than in the individual task ($M = 602$ ms), consistent with Experiment 1. Responses were also faster after go trials ($M = 569$ ms) than after nogo trials ($M = 592$ ms). Importantly, the main effect of Task Sequence did not reach significance, $F(1,\ 47) = 3.38$, $MSE = 5414.15$, $p = .072$, $\eta_p^2 = 0.062$, although responses tended to be faster for cue-switch trials ($M = 574$ ms) than for task-switch trials ($M = 587$ ms). The three-way interaction among Block Type, Previous Trial Type, and Task Sequence, was not significant either, $F(1,\ 47) < 1$, $MSE = 5096.83$, $p = .344$, $\eta_p^2 = 0.019$. Switch costs were 0 ms after go trials and 35 ms after nogo trials of the individual task, and −6 ms after go trials and −14 ms after nogo trials of the joint task.

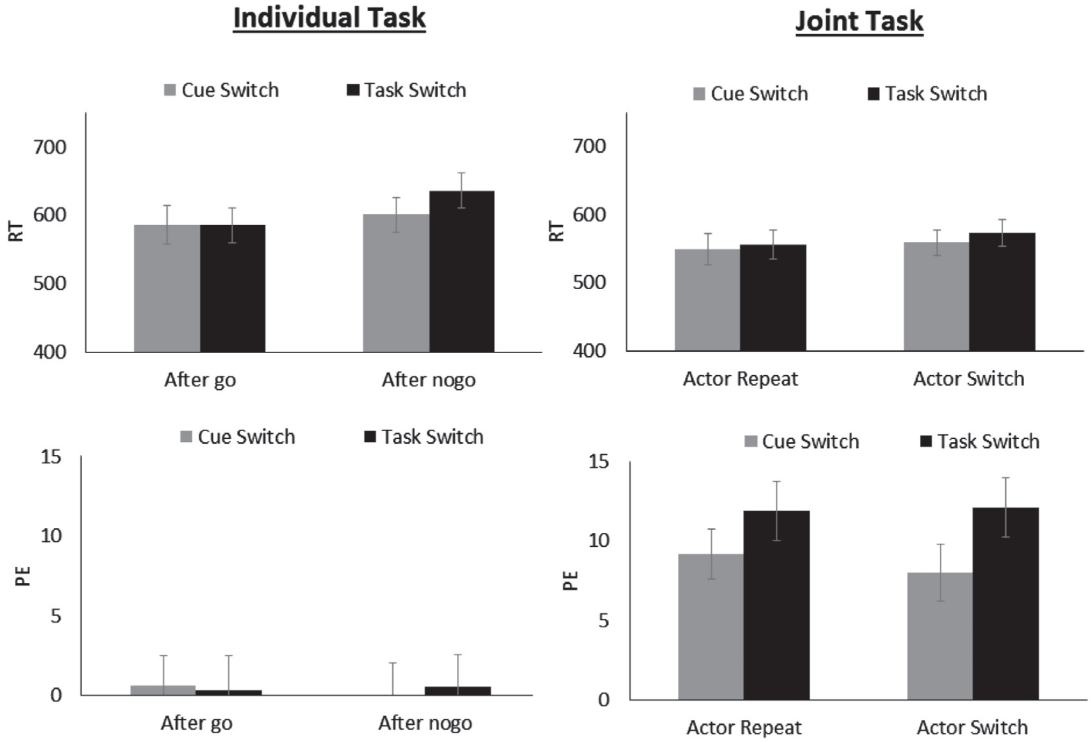
For the two-response group, there was a significant interaction between Previous Trial Type and Task Sequence, $F(1,\ 45) = 9.56$, $MSE = 7699.30$, $p = .003$, $\eta_p^2 = 0.175$, and a significant three-way interaction among Block Type, Previous Trial Type, and Task Sequence, $F(1,\ 45) = 4.46$, $MSE = 7903.77$, $p = .040$, $\eta_p^2 = 0.090$. The former interaction reflected a larger switch cost after go trials (i.e., when the same actor performed the preceding trial; $M = 41$ ms) than after nogo trials (when the co-actor performed the preceding trial; $M = -16$ ms). The latter interaction indicated that switch costs differed between after go trials and after nogo trials more in the individual task ($Ms = 59$ ms vs. −37 ms after go trials and after nogo trials, respectively) than in the joint task ($Ms = 22$ ms vs. 4 ms). Therefore, the results were generally consistent with the previous joint task switching study that showed intrapersonal switch costs but not interpersonal switch costs when there were two responses per actor, despite the reduction of switch costs in the joint task of the present experiment.

Overall, the RT data showed different patterns of switch costs for the one-response group and for the two-response group. Although switch costs were only marginal overall, the one-response group showed no difference between intra- and interpersonal switch costs. The two-response group showed intrapersonal switch costs but not interpersonal switch costs, with some reduction in intrapersonal switch costs in the joint task.

3.2.2. Percentage of error trials

For PE, a significant main effect of Number of Response indicates that responses were also more accurate for the one-response group ($M = 5.33\%$) than for the two-response group ($M = 26.55\%$). There was also a significant main effect of Block Type, reflecting more accurate responses in the individual task ($M = 12.94\%$) than in the joint task ($M = 18.93\%$), but this effect depended on Number of Response: responses were more accurate in the individual task ($M = 0.36\%$) than in the joint task ($M = 10.29\%$) for the one-response group, and there were smaller differences between the individual task ($M = 25.53\%$) and the joint task ($M = 27.57\%$) for the two-response group. There was also a significant main effect of Task Sequence, showing more accurate responses for Cue-Switch trials ($M = 14.40\%$) than for Task-Switch trials ($M = 17.47\%$). This switch cost was modulated by a number of other factors, importantly by Block Type, Previous Trial Type, and

(A) One-Response Group



(B) Two-Response Group

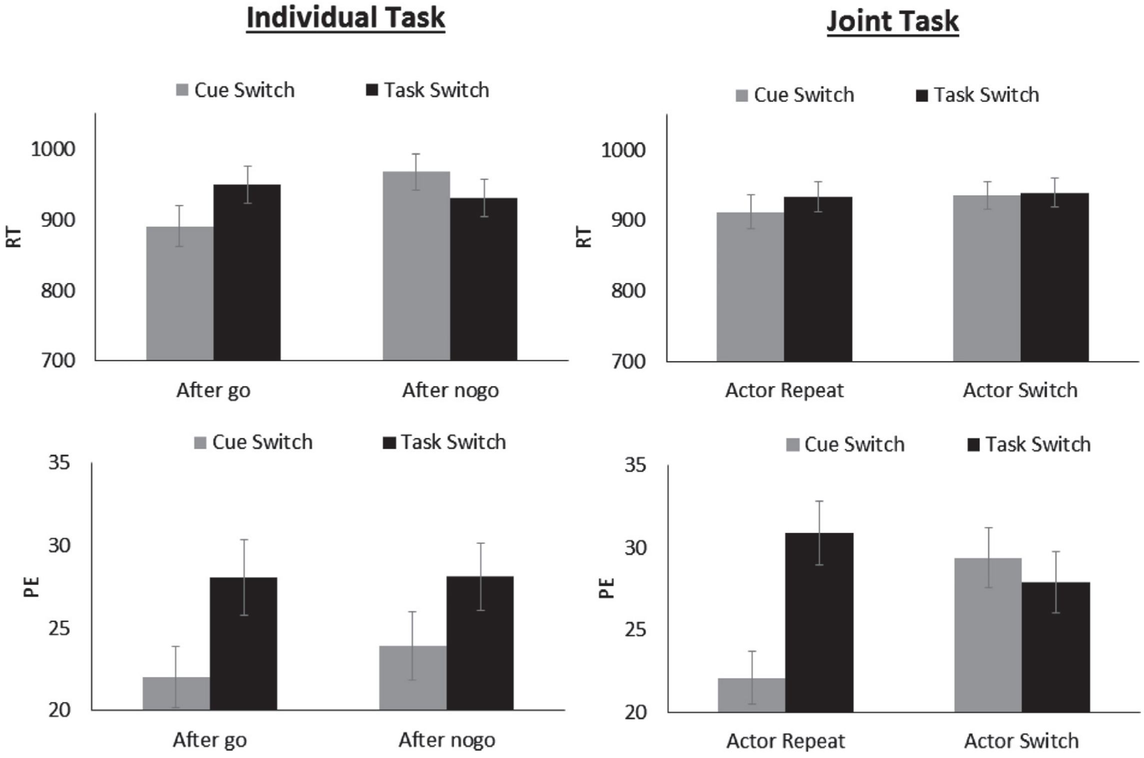


Fig. 2. Mean response times (RT) and percentage errors (PE) for individual and joint tasks for the one-response group (A) and the two-response group (B) of Experiment 2 (error bars represent one standard error of the mean).

Number of Response.

As in RT, this four-way interaction was followed up by separate 2 (Block Type: joint-task vs. individual-task) × 2 (Task Sequence: task-switch vs. cue-switch) × 2 (Previous Trial Type: go vs. nogo) ANOVAs for the one-response and two-response groups. For the one-response group, there were significant main effects of Previous Trial Type, $F(1, 47) = 20.24$, $MSE = 14.43$, $p < .001$, $\eta_p^2 = 0.301$, and of Block Type, $F(1, 47) = 65.86$, $MSE = 14375$, $p < .001$, $\eta_p^2 = 0.584$. These variables also interacted, $F(1, 47) = 11.53$, $MSE = 22.49$, $p = .001$, $\eta_p^2 = 0.197$. PE was lower for cue-switch trials ($M = 4.46\%$) than for task-switch trials ($M = 6.20\%$), and it was very low in the individual task ($M = 0.36\%$) as compared to the joint task ($M = 10.29\%$). Given the low PE, there was little difference between cue-switch trials ($M = 0.31\%$) and task-switch trials ($M = 0.41\%$) in the individual task, as opposed to a larger difference between cue-switch trials ($M = 8.60\%$) and task-switch trials ($M = 11.99\%$) in the joint task. No effect involving Previous Trial Type was significant, $Fs < 1.9$, $ps > 0.174$.

For the two-response group, the main effect of Task Sequence was significant, $F(1, 45) = 11.66$, $MSE = 152.56$, $p = .001$, $\eta_p^2 = 0.206$, but this effect was modulated by Previous Trial Type, $F(1, 45) = 9.84$, $MSE = 85.04$, $p = .003$, $\eta_p^2 = 0.179$, and by Previous Trial Type and Block Type, $F(1, 45) = 4.13$, $MSE = 98.88$, $p = .048$, $\eta_p^2 = 0.084$. For the individual task, switch costs were similar between trials after go trials ($M = 6.05\%$) and trials after nogo trials ($M = 4.22\%$), but for the joint task, switch costs were substantially reduced on trials after nogo trials ($M = -1.47\%$) as compared to trials after go trials ($M = 8.79\%$) than.

Overall, the PE data were consistent with RT, showing the differences between the one-response group and the two-response group in the patterns of switch costs. For the one-response group, responses were very accurate, but switch costs were obtained for the joint task regardless of the actor on the preceding trial (i.e., whether it was a go trial or a nogo trial). For the two-response group, switch costs were obtained only when the preceding trial was a go trial but not when it was a nogo trial.

3.3. Discussion

The present results showed clear differences between the one-response group and the two-response group, which suggests that interpersonal switch costs depend on the number of responses assigned to the actors. When there was only one response per actor, selecting the correct response would necessarily determine which actor to respond on that trial. Under this condition, there were both intra- and interpersonal switch costs. However, note that switch costs were marginal in RT and were reliable in PE in the present experiment, whereas they were obtained reliably in RT and were marginal in PE in Experiment 1, suggesting some tradeoffs. The smaller switch costs in the RT data of the present experiment might reflect a larger proportion of task-switch trials (50%) as compared to that in Experiment 1 (33%). Because RT would be faster for more frequent task transitions than for less frequent ones, task-switch costs would be reduced when task-switch trials occupied a larger proportion of trials (Logan, Schneider, & Bundesen, 2007). This might explain why task-switch costs were significant in Experiment 1 but were only marginal in Experiment 2. For the two-response group, there were intrapersonal switch costs but not interpersonal switch costs, which were consistent with our previous studies (Yamaguchi et al., 2017a,b). These outcomes corroborate the conclusion of Experiment 1 that the confound between actor selection and action selection (with one response per actor) gives rise to switch costs between actors. This conclusion has an important implication as to what task representations are involved in performing a shared task with co-actors.

4. General discussion

Joint task performance involves two opposing forces, division of labor and integration of divided components (co-representation). Many studies of joint task performance have focused on the integration, but only a few studies examined the division of labor between co-actors (e.g., Saunders et al., 2018; Yamaguchi, Clarke, et al,. 2018). Previous studies have considered the integration of divided task components under conditions in which each actor is assigned a single response such as the joint Simon task (e.g., Sebanz et al., 2003), whereas the division of labor is observed under conditions in which each actor is assigned more than one response (Yamaguchi et al. 2017b). In the former condition, action selection and actor selection are confounded, so selecting a response is sufficient and necessary to select an actor; hence, intrapersonal effects (e.g., Simon effect) can occur as if they were interpersonal effects.

To test this prediction, the present study tested joint task switching that has demonstrated the division of labor in previous studies (Wenke et al., 2011; Yamaguchi et al., 2017a,b), but using a single response per actor with which actor selection is confounded with action selection. Consistent with the prediction, task-switch costs were obtained not only when the same actor performed the previous trial (after go trials or when the actor repeated) but also when the co-actor performed it (after nogo trials or when the actor switched). These results are in a sharp contrast to joint task-switching with two responses for each actor that only produced intrapersonal switch costs but not interpersonal switch costs. We consider possible cognitive mechanisms that are responsible for these outcomes.

4.1. How is the task represented in a shared task setting?

The results of the present study suggest that interpersonal switch costs depend on whether action selection is confounded by actor selection. As there were little differences between the individual task and the joint task, task co-representation cannot explain the present findings. A possible mechanism underlying interpersonal switch costs is that it is simply the response selection process that gives rise to the switch costs (Schuch & Koch, 2003; Verbruggen, Liefooghe, & Vandierendonck, 2006). When there is one response per actor, selecting a response is equivalent to selecting an actor. In fact, it was necessary in the present experiment that response was selected to determine whether it was the actor's own trial or their partner's trial, because there was no explicit task cue when there was one response per actor. Thus, response selection should have occurred on every trial when there was one response per actor. When there are two or more responses per actor, an actor cue is presented to indicate which actor is to perform a given trial. In this case, actor selection precedes response selection, and response selection may not occur when the actor has determined that it is not his or her own trial but is the partner's trial.

There has been a variation of joint task switching, in which two actors were assigned two different tasks (Dudarev & Hassin, 2016; Liefooghe, 2016), instead of two actors sharing two tasks as in the present study. When the actors are assigned different tasks, task switching is confounded by actor switching. Hence, task-switch costs observed under that condition could reflect actor-switch costs. Indeed, both experiments of the present study showed slower responses after nogo (actor switch) trials than after go (actor repeat) trials. These outcomes indicate that without involving task selection, actor switch could result in a cost. Note that the present study de-confounded between actor selection and task selection, allowing specifically pointing to the roles of actor selection and response selection in joint task switching.

Philipp and Prinz (2010) reported a joint task in which participants responded to diamonds and squares by uttering their own names or the names of other individuals whose faces were shown on a computer screen, although the faces were irrelevant to the task. When participants performed the task alone, responses were faster when the names corresponded to the individuals displayed on the screen than when they did not correspond. However, in a joint task, responses were faster when the faces on the screen matched the actor who should respond to the target on a given trial, not the name that had to be uttered (also see Baess & Prinz, 2017). Thus, Philipp and Prinz's experiments yielded a compatibility effect between stimulus and response in an individual task and a compatibility effect between stimulus and actor in a joint task. Wenke et al. (2011) also reported a version of the joint flanker task in which each actor was assigned two responses. They found a flanker effect when the flankers belonged to the actor's own target set, but no flanker effect when the flankers belonged to the co-actor's target set. These results differed from a version of the joint flanker task in which each actor is assigned a single response (e.g., Atmaca et al., 2011) and produces the flanker effect when the flankers belong to the co-actor's target.

Wenke et al. (2011) proposed an actor co-representation account, according to which actors in a joint task represent only the fact that another actor performs a complementary task part and when it is the co-actor's turn, but not what the co-actor is supposed to do. This actor co-representation creates additional conflicts with actor identification (i.e., actor selection), making it more difficult to determine whose turn it is in a joint task setting than determining whether it is a go or nogo trial in an individual task. Baess and Prinz (2015) reported findings consistent with the actor co-representation account. In their study, participants were first presented with an actor cue, followed by a response cue that specified one of the two alternative responses. The task was performed alone or with a co-actor, and the EEG recordings between the actor cue and the action cue revealed modulations of rapid attentional reactions (< 100 ms after the actor cue) in the joint task as compared to those of the individual task. Although we remain neutral as to whether actor selection is more difficult than determining go or nogo trials, we agree with the actor co-representation account that actor selection and action selection are confounded when there is only one response per actor. Interpersonal factors would only affect actor selection, but the influence of these factors can lurk into action selection in such cases.

It is also possible that interpersonal switch costs depend on the structure of cognitive processes underlying joint performance. For instance, actor selection and action selection may constitute two different levels of decision-making in a hierarchy. The higher level decision selects an actor to perform a given trial. This would occur in joint task switching when a cue indicates the actor who should perform the trial. When there are more than one response assigned to each actor, actor selection is not sufficient to determine the correct response, so the lower level decision has to select an action that should be made to the target. Switch costs are obtained only if the same actor has performed the preceding trial where actor selection and action selection have occurred, but not if a different actor has performed the preceding trial where only actor selection has occurred. However, when there is only a single response assigned to each actor, the lower level decision only needs to confirm the correct response, without the higher-level processing of selecting an actor. Thus, response selection always occurs on all trials, producing intra- and interpersonal switch costs.

Although the hierarchical model assumes that the higher-level decision requires a representation that integrates interpersonal factors, it is still unknown as to what factors are represented and how they are represented at this level. A strong claim of the co-representation account proposes that the co-actor's actions are co-represented automatically as if they were the actor's own actions (Knoblich et al., 2011; Knoblich & Sebanz, 2006). Other accounts of joint performance propose that the co-actor only serves as a spatial reference to represent the actor's own actions (e.g., Dolk, Hommel, Colzato et al., 2014; Dittrich et al., 2013). Dittrich, Rothe, and Klauer (2012) showed that the joint Simon effect was obtained only if the spatial alignment of co-actors matched the spatial alignment of response keys but not if they did not match. These findings may indicate that the actors can be represented based on multiple features, such as their physical locations and the locations of assigned responses (Prinz, 2015). Relative salience may allow one feature to dominate the actor representation or all features may contribute collectively. Further investigations need to determine how co-actors are represented in a joint task setting.

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