When task sharing reduces interference: Evidence for division-of-labour in Stroop-like tasks

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Abstract

Performing a task with another person may either enhance or reduce the interference produced by task-irrelevant information. In three experiments, we employed the joint version of a Stroop-like task (i.e., the picture-word interference - PWI - task) to investigate some of the task features that seem to be critical in determining the effect of task-irrelevant information when the task is shared between two individuals. Participants were asked to perform a PWI task, which required to name a picture while ignoring a distractor word, first individually (in a baseline block of trials) and then co-acting with an alleged partner. Results showed that, compared to the baseline and to a condition in which participants continued to perform the PWI task individually, the belief of co-acting with another individual who was thought to be in charge of the distractor words suppressed the semantic interference effect when these words were in case alternation letters (e.g., “mOuSe”). Conversely, the semantic interference effect persisted when the co-actor was thought to be in charge of the same task as the participant, that is, the co-actor was thought to respond to the pictures. These results are accounted for by assuming that, when the participant knows that another person is in charge of the task-irrelevant information, a division of labour between participant and co-actor can be established. Such a division of labour may provide the participant with a strategy to oppose the semantic interference effect. Our findings therefore suggest that sharing a task with another person in charge of potentially interfering information can enable people to filter out this information from their own task representation.

Keywords: joint picture-word interference paradigm, joint action, interference effect, social cognition, division of labour, Stroop-like effect.

1. Introduction

Recent years have witnessed an increasing interest in whether, and to what extent, performing a task with (or in presence of) another person may change individual performance.

Interference paradigms are particularly suitable for addressing this issue. Most of them can be split in two (complementary or different) parts, which, in turn, can be distributed between two different individuals. By comparing performance when participants act in the joint context and when they perform the same task individually, important information can be obtained about whether the co-actor's task is represented and how this representation influences one's own performance.

The joint Simon task, developed by Sebanz, Knoblich and Prinz (2003), is one of the most widely-used paradigms to address this issue. In the standard version of the Simon task, a single person is required to emit either a left- or right-side response depending on the colour (e.g., red or green) of a target stimulus that randomly appears on the left or right side of the screen (Simon & Small, 1969). The Simon effect refers to the finding that responses are usually faster and more accurate when the target position corresponds to the position of the required response than when it does not correspond. The presence of such an effect demonstrates that target position, although irrelevant to the task, is automatically processed and interferes with response selection, giving rise to a response conflict when the target appears on the opposite side of the required response (Kornblum & Lee, 1995; Treccani, Cubelli, Della Sala, Umiltà, 2009).

Sebanz et al. (2003) showed that this effect occurs also in the joint version of the Simon task. In the joint Simon task, the two alternative responses are distributed between two participants sitting next to each other and each participant performs a complementary Go/NoGo task (e.g., the left-side participant responds to the green stimuli only and the right-side participant responds to the red stimuli only). Even though stimulus position is irrelevant to the task, the left-side participant tends to respond faster when the stimulus is on the left, while the right-side participant responds faster when the stimulus is on the right. There would be nothing surprising about this effect, were it

not for the fact that no Simon effect occurs when participants perform this kind of Go/NoGo tasks individually, without a co-actor (Sebanz et al, 2003; Ansorge & Wuhr, 2009, 2004).

Even though the involvement of social components has been questioned (e.g., Dolk, Hommel, Prinz, & Liepelt, 2013, Guagnano, Rusconi, & Umiltá, 2010; see Dittrich, Bossert, Rothe-Wulf, & Klauer, 2017, and Dolk, Hommel, Colzato, Schütz-Bosbach, Prinz & Liepelt, 2014, for a review), the presence of the Simon effect in the joint but not in the individual Go/NoGo task can be accounted for by assuming that participants include in their task representation the action to be executed by the co-actor. This would give rise to the same conflict between actions that arises when the participant takes care of both left and right responses (the action/task co-representation account; cf., Sebanz et al., 2003; Sebanz, Knoblich, & Prinz, 2005).

The occurrence of interference effects induced by irrelevant information has been also observed by splitting other compatibility paradigms, similar to the Simon task, in two complementary Go/NoGo tasks, performed by two participants sitting side-by-side, for example, the SNARC task (Atmaca, Sebanz, Prinz, & Knoblich, 2008), and the flanker task (Atmaca, Sebanz, & Knoblich, 2011). Recent studies have shown that joint interference effects may also occur in picture naming tasks. In the study by Kuhlen and Abdel Rahman (2017), for example, two partners took turns in naming sequences of pictures in which members of the same semantic category were embedded. The cumulative interference effect typically found when the task is performed individually (i.e., an increase of naming latencies with each newly named member of a given semantic category) was observed in this study even when within-category pictures were named in previous trials by the co-actor. These results are explained by assuming that the participants simulated the co-actor's language production. Interference occurs because of a conflict between the target lexical entry in a given trial and competitive lexical representations activated by the responses emitted by the co-actor in previous trials.

However, Heed, Habets, Sebanz, and Knoblich (2010) reported a finding that questions the possibility that the occurrence of interference effects in joint tasks is an outcome generalizable to all conditions in which two individuals work together on the same task. In this study, participants performed a stimulus-stimulus compatibility task (i.e., a Stroop-like task; Kornblum et al., 1990) in which the target and distractor stimuli were of different sensory modality. In this task, participants were required to judge the location of a tactile stimulus (top or bottom) while ignoring a visual distractor (a light) that could be either spatially congruent or spatially incongruent with the target location (e.g., touch at the top and light at the top vs. touch at the top and light at the bottom). Participants performed the task both alone and with a partner who sat in front of them and responded to the visual distractors. Results showed that the joint setting significantly reduced the crossmodal interference effect (slower reaction times [RTs] for spatially incongruent trials), which typically occurs when the task is performed individually (Spence, Pavani, & Driver, 2004). The results of this study suggest that task sharing can lead to a facilitation effect (i.e., a reduction of the interference produced by distractor stimuli) rather than to produce (or increase) interference. Heed et al's findings were recently replicated by using another cross-modal interference paradigm, that is, an audio-visual, rather than visual-tactile, interference task (Wahn, Keshava, Sinnett, Kingstone, & König, 2017). In it, participants judged the location of an auditory stimulus while ignoring a spatially congruent or incongruent visual distractor and performed the task alone or with a co-actor who responded to the visual distractors. As in Heed et al, in this study too the interference effect was found to be smaller when the task was performed with a partner.

The finding that the cross-modal interference effect was reduced in the joint condition of these studies seems at odds with the action/task co-representation account (Sebanz et al., 2003, 2005). Indeed, following this account, the interference effect should be larger in the joint than in the individual condition, given that the co-actor's task (i.e., responding to the position of the irrelevant

lights) is supposed to be automatically represented, thus increasing the competition between alternative responses.

To account for the reduced cross-modal interference effect observed in their social condition, Heed et al. (2010) proposed that sharing a task with a partner acting upon stimuli from a different sensory modality could reduce the influence of these stimuli: Knowing that the co-actor is taking care of visual stimuli reduces their influence on the processing of tactile stimuli. According to Knoblich, Butterfill and Sebanz (2011), the results observed by Heed et al. are not at odds with the action/task co-representation account (Sebanz et al., 2003, 2005). They simply demonstrate that "representing the other's task could also facilitate task performance given that, unlike in previous studies, stimuli from two different sensory modalities were distributed between two co-actors" (Knoblich et al., 2011, pp. 79-80). Thus, following this hypothesis, the results observed by Heed et al. could be strictly related to the different sensory modalities of the target and distractor stimuli.

However, an alternative explanation can be advanced. The different nature of the tasks used in the studies testing interference effects in joint paradigms can account for their contrasting results (i.e, increase vs. decrease of the interference effect in the joint condition compared to the individual condition). The individual version of the Simon task and of other Simon-like paradigms (e.g., SNARC or flanker tasks) is a Go/NoGo task that involves the discrimination of two possible stimulus values, but the emission (or the lack of emission) of only one possible response. In the absence of a co-actor, only this response is represented. Such a response is not spatially coded (e.g., there is no *left* response if a *right* response is not represented), no response competition occurs, and no interference arises. In contrast, in the joint version of these tasks, participants perform a Go/NoGo task requiring them to take turns in responding to alternative values of the same target stimulus. The fact that another person is taking care of a different value of the same target stimulus provides participants with an action alternative to their own action that cannot be ignored because it is associated with the to-be-processed stimulus (Sebanz et al, 2003). The representation of this

alternative action interacts with that of the required response, thus producing interference at the response selection stage (cf. Treccani et al, 2009).

Conversely, the individual version of the Stroop-like paradigms adopted by Heed et al. (2010) and Wahn et al. (2017) is a proper interference task, as it involves *two* possible responses, among which the participant has to select the correct one, and the to-be-ignored stimulus can trigger the alternative response, thus giving rise to a response conflict. The joint version of the task does not provide any additional interfering information. The two participants do not take turns in responding; they execute two independent and simultaneous tasks, which require them to take care of two different stimuli. Importantly, the co-actor is in charge of exactly the stimulus that interferes with the participant's responses. The fact that another person is concurrently engaged in responding to distractor stimuli (i.e., the task interfering information) could provide participants with an effective strategy to ignore these stimuli, thus eliminating the effect of the competitive responses triggered by them, and reducing the interference effect. In other words, interference would be counteracted thanks to a division of labour between the participant and co-actor (Sellaro, Treccani, Rubichi, & Cubelli, 2013). If this were true, it does not matter whether or not the target and the distractor stimulus share the same sensory modality. Accordingly, the finding reported by Heed et al. (2010) and Wahn et al. (2017) should also be observed when the distractor stimuli that the co-actor is in charge of involve the same sensory modality as that of the target.

Previous studies have already investigated the effect of task sharing in Stroop tasks involving target and distractor stimuli of the same modality. However, the experimental designs were not such as to test this hypothesis. In most studies, the co-actor performed exactly the same task as the participant: The participant and co-actor were engaged in a classical word-colour Stroop task (McLoad, 1971) and both had to respond to the ink colour of colour words (i.e., names of colours; e.g., Huguet, Galvaing, Monteil, & Dumas, 1999). A reduction of the Stroop-effect is typically observed in this condition compared to when the task is performed individually, but this seems to

have nothing to do with task co-representation. It would be simply attributable to an enhancement of motivation and/or to a more efficient focusing of attention induced by the mere presence of another individual (i.e., the social facilitation effect; see Augustinova & Ferrand, 2012; Bond & Titus, 1983; Zajonc, 1965).

A recent study by Saunders, Melcher, and van Zoes (2017) used instead a colour-word Stroop task in which the co-actor, albeit being in charge of the same stimulus as the participant (i.e., the ink colour of colour words), had to respond to different values of this stimulus (e.g., the participant responded to words written in blue or yellow, while the co-actor responded to words written in green or red). The authors reasoned that, if the participant represented the co-actor's responses, then the names of colours that corresponded to these responses should produce the same interference as that produced by the names of colours that corresponded to the participant's responses. The same lengthening of RTs should be found in colour incongruent trials (e.g., words written in yellow that, however, denoted other colours) when the colour denoted by the word corresponded to the participant's alternative target colour (e.g., the presented word was BLUE) and when it corresponded to one of the co-actor's target colours (e.g., the word was RED). Results showed that this was indeed the case.

However, the same findings were observed when the participants performed the task alone, and the non-target colours were not assigned to anyone, but simply signalled NoGo trials. Clearly, the mere fact that the to-be-ignored information (i.e., the meaning of the colour words) is the name of a colour that corresponds to one of the possible values of the ink colour - the relevant stimulus dimension– is sufficient to produce interference. Stimulus values belonging to the stimulus set need to be represented, irrespective of whether they are associated with someone else's responses, and once activated by distractor information, such representations produces interference (cf. Styles, 2006, for a review of factors affecting the interference effect in Stroop-like tasks).

Having found comparable interference effects in both the individual and social conditions, Sauders et al. (2017) concluded that there is no evidence of task co-representation in their joint Stroop task. However, according to the division-of-labour hypothesis (Sellaro et al., 2013), one might have expected to observe the findings opposite of what predicted by Sauders et al. (2017), that is a smaller interference effect in the joint condition than in the individual condition. By associating the NoGo colours to another person, the participant might reduce their interfering effect when these colours appeared as distractors.

Yet, one has also to consider two facts. First, as explained above, unlike in Heed et al. (2010) and Wahn et al. (2017), in Sauders et al.'s (2017) joint Stroop task the co-actors were in charge of the same target stimulus as the participants, even if they had to respond to different values of this stimulus. Therefore, the co-actor could not provide the participant with a strategy to ignore this stimulus, as it was the relevant stimulus. Moreover, it has to be noted that the interference effect used by Sauders et al. to investigate task co-representations (i.e., the colour-word Stroop effect) is a very strong and stable phenomenon. This is because people cannot avoid reading the words the colour of which they have to judge. The Stroop effect is indeed interpreted as the demonstration that word reading occurs automatically (cf., Posner & Snyder, 1975). Thus, even if the co-actor had been in charge of exactly the information that interfered with participant's performance (i.e., the meaning of the presented colour words instead of their ink colours), participants might find it hard to ignore this stimulus: The access to the meaning of these words would be automatic and unavoidable.

The classical word-colour Stroop task might then not be the optimal task to pursue the aim of the present study, that is, to investigate whether a reduction of interference effects in task-sharing contexts can be attributed to the division of labour between the participant and co-actor. In order to test the division-of-labour hypothesis, we needed a Stroop-like task that used distracting information, such as the meaning of written words, presented in the same sensory modality as the

target information, but that allowed us to make it easier for the participants to inhibit or ignore such irrelevant information. To this end, we decided to use a joint version of the picture-word interference (PWI) paradigm (Rosinski, Golinko, & Kukish, 1975). In it, participants are required to name a target picture while ignoring the distractor written word superimposed on it. Despite the instructions to ignore the word, as happens with the classical Stroop task, participants cannot avoid reading and processing the word. This is attested by the finding that the relationship between the target and the distractor words influences the time needed to name the picture (e.g., Cubelli, Lotto, Paolieri, Girelli, & Job, 2005; Lupker, 1982). For instance, naming RTs are usually slower when the picture (e.g., a carrot) is shown with a word belonging to the same semantic category (e.g., pumpkin) than when it is accompanied by a semantically unrelated word (e.g., lion). This effect is known as semantic interference effect (Rosinski et al., 1975).

Given that the PWI task involves the simultaneous presentation of two different stimuli (i.e., a target picture and a distractor word), it can be split in two independent parts, that is, naming the picture and reading the word, which can be concurrently carried out by two different participants. Unlike in the joint paradigm used by Sauders et al (2017), the participant and co-actor can therefore take care of two distinct and separate stimuli. Importantly, as in the word-colour Stroop task, and unlike in Heed et al.'s (2010) and Wahn et al's (2017) visual-tactile and audio-visual interference tasks, in the PWI paradigm the two stimuli share the same (visual) modality.

In addition, there is evidence that in PWI tasks the recognition of distractor words can be made more difficult (e.g., writing the words with different characters) without this preventing the processing of such words, as shown by the fact that the semantic interference effect occurs even when procedures hampering distractor word recognition are used (Miozzo & Caramazza, 2003). We reasoned that these procedures very likely lead to a less automatic processing of distractor words, and this might enable participants to take an advantage on possible strategies for ignoring such words.

For these reasons, the PWI task appears particularly suitable to test the hypothesis that the reduction of interference effects in joint tasks (Heed et al., 2010; Wahn et al, 2017) is attributable to the co-actor working on the task irrelevant information that produces interference, rather than to the fact that the co-actor responds to a stimulus from a different sensory modality. If this hypothesis were correct, then sharing a PWI paradigm with a co-actor responsible for distractor words should allow participants to ignore these words. This would prevent the representation of the response associated with the distractors, thus eliminating (or reducing) the semantic interference effect.

2. Experiment 1

In the critical experimental conditions of Experiment 1 (i.e., the social condition), participants were required to perform the typical PWI task first individually (i.e., in the baseline block of trials) and then co-acting with another person. The joint task was identical to the individual task except for the fact that participants were informed that they would have to perform the task with another person, who was in another room, and whose task was to read the words while ignoring the pictures. Actually, participants performed the task on their own.

To control for possible practice effects, we included in the experimental design another condition to which a second group of participants were assigned. After the baseline, participants of the control condition simply continued to execute the same task (i.e., they continued to perform the PWI task individually).

No differences between performances of participants in the two conditions were obviously expected in the baseline block of trials. In this block, participants in the control and social conditions performed exactly the same task (i.e., the individual PWI task) and a regular semantic interference effect (i.e., slower RTs in semantically related trials) should be observed for both

groups of participants. However, a difference between performance observed in the baseline block and that observed in the following block might be expected for participants in the social condition.

Following the division of labour hypothesis (cf., Sellaro et al., 2013), sharing an interference paradigm with another person, responsible for the stimuli that carry the potentially interfering task-irrelevant information, can allow participants to succeed in ignoring these stimuli just because another person is taking care of them. This should occur regardless of the sensory modality of stimulus presentation. According to this hypothesis, therefore, a reduction of the semantic interference effect in the joint task, compared to the individual task performed in the baseline block, should be observed in the social condition. Obviously, that also required that the processing of task-irrelevant information was not as such as to prevent the implementation of a (division-of-labour) strategy aimed to filter out such interfering information: As previously underlined, indeed, the access to the meaning of written words, when presented in standard, regular formats, appears to be strongly automatic, mandatory. Therefore, participants might find it hard to ignore distractor words in this experiment, even if a strategy to do so was made available.

2.1. Method

2.1.1. Participants

Thirty-two students (3 males, aged 19-28 years) of the University of Trento participated in the experiment. All participants were native speakers of Italian, they had normal or corrected-to-normal vision and they were naïve as to the purpose of the experiment.

2.1.2. Apparatus and Stimuli

Participants seated about 60 cm from the screen. The experiment was run using the E-Prime 1.1.4.1 software system (Psychology Software Tools, Inc., Pittsburgh, PA). Naming responses were collected with a voice key.

Stimuli (targets and distractor words) were the same used by Cubelli et al. (2005 - Experiment 1). Target stimuli were 16 pictures – belonging to different semantic categories – selected from the set of Snodgrass and Vanderwart (1980) and presented as black line drawings on a white background. Each target picture was paired with two distractor nouns of the same semantic category (semantically related trials) and two distractor nouns of a different semantic category (semantically unrelated trials). Overall 64 distractor words were chosen. The target and the distractor nouns were matched for a number of variables and they did not differ for length, frequency, familiarity, typicality, age of acquisition, and phonological overlap between the pairs of target and distractors (see Cubelli et al., 2005 for further details). A set of 16 additional pictures and 32 additional distractor words were also selected and used as filler stimuli. Target and distractor nouns belonging to the filler set were all semantically and phonologically unrelated. Both target pictures and distractor words were presented in the centre of the screen. The size of each picture was 6 × 6 cm, whereas distractor words appeared in upper case format (e.g., "MOUSE"), Courier new 18-point bold font.

2.1.3. Procedure

Once recruited for the experiment, participants were randomly assigned to one of two experimental conditions: social or control condition (see Figure 1). In each condition, participants performed the PWI task twice, in two consecutive blocks of trials. In the first block - the baseline block - all participants performed the task individually. In the second block - the critical one – participants of the social condition performed the task co-acting with another person (i.e., they performed the joint task), whereas participants of the control condition continued to perform the task individually (i.e., they repeated the individual task).

The order of the two blocks (i.e., the individual and joint tasks in the social condition) was not counterbalanced across participants. The reason is that if the joint task comes first, its impact

could persist in the following (individual) task, which would not then represent a proper individual task and could not be used as a baseline for comparisons (Huguet, Galvaing, Monteil, & Dumas, 1999).

In both the joint and individual tasks, trials began with the presentation of a fixation cross displayed in the center of the screen. After 500 ms, the fixation cross was replaced by a picture-word pair, which remained on the screen until the response but no more than 2000 ms. The target picture was always presented simultaneously with the distractor word. Offset of the picture-word pair was followed by a blank of 700 ms. Participants were instructed to name the target picture by producing the corresponding bare noun as quickly and accurately as possible while ignoring the distractor word. Errors and malfunctioning of the voice key were recorded online by the experimenter. In the joint task, participants performed the task with an alleged partner, who was in a non-specified room and was thought to read the distractor words. In order to remind online participants that another person was engaged in the task, a visual feedback (i.e., a green O) was presented in the center of the screen at the end of the blank to signal participants whether the co-actor had responded. Participants were informed that this feedback was not informative about the co-actor's speed and accuracy. Indeed, they were told that, given that the co-actor's response might overlap in time with their response, the feedback would not be provided when the co-actor responded, but at the end of the trial.

>>FIGURE 1 ABOUT here<<

Both tasks consisted of 96 trials. In either task, each picture-word pair was presented once. Among these trials, 32 were fillers and were not considered in the analyses. The remaining 64 pairs were half semantically related and half semantically unrelated. Pseudorandom experimental lists were created according to the following criteria: (a) the first two trials were filler; (b) either semantically related or unrelated pairs could appear in no more than three consecutive trials; (c)

target belonging to the same semantic category could not appear in consecutive trials. In all tasks, experimental trials were preceded by 8 practice trials, in which both target pictures and distractor words were different from those used in the experimental trials.

In order to allow participants to familiarize with the experimental pictures, familiarization trials were administered at the beginning of the experiment, before the baseline block of trials (cf., e.g., Sellaro, Treccani, Cubelli, & Job, 2015). In familiarization trials, participants were presented twice with all 16 pictures (i.e., there were 32 familiarization trials in total). A string of five #s, instead of the distractor word, was superimposed on the pictures. Neither response speed nor accuracy were stressed. Participants were simply asked to name the pictures, which remained on the screen for 2000 ms. After naming the picture, the string of #s was replaced by the picture name, which was shown on the screen for 2000 ms. This assured us that participants knew the name of the pictures and used the expected name in the following experimental trials.

At the end of the experimental sessions, participants were debriefed about the aim of the study (i.e., effects of joint action on interference effects in Stroop-like tasks). Contact information of the experimenter was given to participants in the case they wish to have further information about the nature of the research and, once the analyses had been completed, about its results. During debriefing, particular attention was paid to participants' impressions about the experimental procedure and instructions. Importantly, although participants of the social condition did not have any actual interaction with co-actors, they did not express any doubts about having co-acted with another person during the joint task.

2.2. Results and discussion

Four types of responses were excluded from the analyses: (a) naming errors; (b) failures of the voice key to record the response; (c) verbal disfluences that triggered the voice key; (d) RTs

exceeded two standard deviations from a participant's mean. Overall 10.99 % of the responses were excluded from the analysis, of which 1.66 % were naming errors. Errors were not analyzed.

We first analysed RTs of the baseline block of trials in order to evaluate whether there were differences in the semantic interference effect shown in these trials by participants assigned to the two experimental conditions. Correct mean RTs were submitted to an analysis of variance (ANOVA) with semantic relatedness (semantically related vs. unrelated trials) as within-subjects factor and condition (control vs. social) as between-subjects factor. The main effect of semantic relatedness was significant, $F = 6.71$, $p < .05$; $\eta_p^2 = .18$. In contrast, neither the main effect of condition nor the interaction between the two factors was significant, both Fs $\leq .60$, both ps $\geq .44$; both η_p^2s $\leq .02$.

For each experimental condition (control and social), correct RTs were then submitted to an ANOVA with two within-subjects factors: block (baseline vs. critical block) and semantic relatedness. The main effect of semantic relatedness was significant in both control and social conditions, both Fs ≥ 5.86, both ps $< .05$; both η_p^2s $\geq .28$: Participants were slower in semantically related than unrelated trials (737 vs. 714 ms and 747 vs. 729 in the control and social conditions, respectively). Block was significant only in the social condition, $F(1, 15) = 4.94$, $p < .05$, $\eta_p^2 = .25$: In this condition, participants were faster in the second, critical block than in the baseline block, i.e., they were faster in the joint than in the individual task (727 vs. 750 ms). The interaction between block and semantic relatedness was significant neither in the control nor in the social condition, both Fs $\leq .72$, ps $\geq .41$, η_p^2s $\leq .004$. This indicates that that the semantic interference effect was present both in the baseline block (i.e., when performing the individual task) and in the second block (i.e., when repeating the individual PWI task in the control condition, or performing the joint task in the social condition; see Figure 2).

>>FIGURE 2 ABOUT here<<

In the present experiment, the semantic interference effect was observed in both conditions and was not modulated by whether participants performed the task individually or with a co-actor. Indeed, this effect was observed not only in the group of participants who, after having performed the individual task in the baseline block, continued to perform the PWI task individually, but also in the group of participants who performed the joint task. Thus, in contrast to the predictions of the division-of-labour hypothesis, task sharing had no influence on the size of the semantic interference effect. The social manipulation only seems to reduce participants' naming RTs (social facilitation effect), which is considered a typical outcome in case of tasks performed in presence of other individuals (Guerin, 1993).

However, these results do not necessarily mean that the involvement of two different sensory modalities for relevant and irrelevant information is critical in order to observe a reduction of the interference effect in joint paradigms, as suggested by Heed et al. (2010). The null result observed in the present experiment can be traced back to the automaticity of written word recognition, which may prevent participants from ignoring the distractor words. As explained above, it is possible that written-word recognition is so mandatory that participants cannot avoid reading and processing written words even if they know that another person is in charge of these stimuli. If this were the case, any experimental manipulation able to hamper written-word recognition should provide participants with enough time to filter distractor words out from their task representation when someone else is thought to be in charge of these stimuli. This possibility was addressed in Experiment 2.

3. Experiment 2

The aim of this experiment was to test whether, in a PWI task, the belief of co-acting with another person who is thought to read the distractor words may allow participants to ignore the task irrelevant information conveyed by the words when the recognition of these words is delayed or

impaired. Success in ignoring irrelevant word information should turn into the disappearance (or at least the reduction) of the semantic interference effect in the joint PWI task. In order to hamper the recognition of distractor words, they were written with characters that alternate between upper-case and lower-case (e.g., “mOuSe”). Case alternation has been found to impair word recognition (Mayall, Humphreys, & Olson, 1997), but, importantly, it does not seem to modulate interference effects that occur in PWI tasks (Miozzo & Caramazza, 2003).

As in Experiment 1, participants first performed the PWI task individually (baseline) and then either continued to perform the task individually (control condition) or performed the task co-acting with an alleged partner who was thought to read the distractor words (social condition).

3.1. Method

3.1.1. Participants

Thirty-two students (3 males, aged 19-28 years) of the University of Trento who were all native Italian speakers took part in the experiment. They all had normal or corrected-to-normal vision, did not participate to the Experiment 1 and were naïve as to the purpose of the experiment.

3.1.2. Apparatus, Stimuli and Procedure

The apparatus, stimuli, procedure and the experimental design were the same as those in Experiment 1 with the following exception: Distractor words were written with alternated-case letters (e.g., “mOuSe”).

As in Experiment 1, participants were randomly assigned to one of two experimental conditions: social or control condition.

3.2. Results and discussion

Data were processed following to the same procedure used in Experiment 1, and 10.89 % of the data points were removed (2.40 % were naming errors). Correct RTs were submitted to the same analyses carried out in Experiment 1.

The ANOVA on RTs of the baseline trials did not show any significant differences between the baseline performances of participants assigned to the two conditions. This analysis revealed a significant main effect of semantic relatedness, $F(1,30) = 21.03$, $p < .0001$; $\eta_p^2 = .41$, but, as in Experiment 1, the main effect of condition and the Condition × Semantic relatedness interaction were not significant, both Fs $\leq .51$, both ps $\geq .48$; both η_p^2s $\leq .02$.

The analyses of the two experimental conditions revealed a significant effect of block, but only in the social condition, $F(1, 15) = 8.08$, $p < .05$, $\eta_p^2 = .35$: In this condition, participants were faster in the second block, where they performed the joint task, than in the baseline block (733 vs. 760 ms). The main effect of semantic relatedness was significant in both control and social conditions, both Fs ≥ 10.88, both ps $< .01$, both η_p^2s $\geq .42$. In both conditions, participants were slower in the semantically related than unrelated trials (747 vs. 725 ms and 756 vs. 737 ms in the control and social conditions, respectively). The interaction between block and semantic relatedness was not significant in the control condition, $F(1, 15) = .30$, $p = .60$ (see Figure 3). Semantic interference effects of 25 and 20 ms were observed in the baseline block and in the following block (where the individual task was repeated), respectively. Most importantly, this interaction was instead significant in the social condition, $F(1, 15) = 5.33$, $p < .05$, $\eta_p^2 = .26$. Post-hoc analysis (Newman-Keuls) revealed that the difference between semantically related and unrelated trials (775 vs. 744 ms and 736 vs. 731 ms in the baseline and critical blocks, respectively) was significant in the baseline block ($p < .005$) but not in the following, critical, block ($p = .53$), where participants performed the joint task.

>>>FIGURE 3 about here<<

In the baseline block, although alternated-case distractor words were used, we observed the typical semantic interference effect occurring in PWI tasks. This finding is consistent with that of Miozzo and Caramazza (2003). More interestingly, the results of the present experiment demonstrate that when written-word recognition is impaired by case alternation, the mere belief of co-acting with another individual in charge of the distractor words, besides speeding up participants' RTs, is sufficient to eliminate the semantic interference effect. This finding cannot be attributed to the significant reduction of RTs. Indeed, in the social condition of Experiment 1, the semantic interference effect continued to occur in the joint task, although participants were significantly faster in this task than in the individual task performed in the baseline block.

The results of the social condition of Experiment 2 can instead be explained by assuming that task sharing led participants to succeed in ignoring the distractor words because another person was in charge of them. Furthermore, given that in the PWI paradigm the target and the distractor stimuli share the same sensory modality, the present results allow us to reject the hypothesis that the reduction of the interference effect observed by Heed et al. (2010) and Wahn et al. (2017) is strictly restricted to tasks with stimuli from different sensory modalities distributed between two participants. The disappearance of the semantic interference effect we observed seems to be due to the fact that the co-actor was thought to work simultaneously on independent stimuli carrying the task-irrelevant information that produced interference.

However, an alternative interpretation deserves to be considered. The disappearance of the semantic interference effect might be due to a mere social facilitation effect: Knowing that another person was involved in the task might have a distracting effect. In order to concentrate fully on the task, participants might narrow their attention on the relevant information (the pictures) and suppress the processing of all stimuli unrelated to their task (Baron, 1986; Huguet et al., 1999). If this were the case, then what the co-actor is supposed to do is irrelevant: The semantic interference effect should disappear even when the co-actor is thought to be in charge of a task-irrelevant

stimulus dimension that does not overlap with the relevant task dimension (Kornblum & Lee, 1995), and thus cannot interfere with participant's performance. In contrast, if what allows the semantic interference effect to disappear is the fact that the co-actor is thought to work on the distractor stimuli (i.e. the task-irrelevant information that produces interference), then the semantic interference effect should persist when the co-actor is thought to be in charge of task-irrelevant information that does not interfere with lexical access. In order to test these two alternative hypotheses we ran Experiment 3.

4. Experiment 3

Experiment 3 aimed at excluding the possibility that the disappearance of the semantic interference effect observed in the social condition of Experiment 2 was simply due to a generic social facilitation effect. To this end, once participants had completed the individual task in the baseline block, they were required to perform a joint task in which the co-actor was thought to work either on the distractor words (joint different-target task) or on the pictures (joint same-target task). In contrast with Experiments 1 and 2, target pictures were randomly shown in nine different colours, whereas distractor words were written with case-alternated (black) letters, as in the Experiment 2.

In the joint different-target task, the participant and the co-actor were supposed to work on different target stimuli: Participants were informed that the co-actor was reading the distractor words and ignoring the pictures. The instructions of this joint task were identical to those of Experiments 1 and 2 and, thus, they emphasized the fact the co-actor was taking care of the to-be-ignored stimuli producing interference. Conversely, in the joint same-target task, the participant and the co-actor were supposed to work on different dimensions of the same target stimuli: Participants were told that the co-actor was naming the colour of the pictures and ignoring the words. In this case, the instructions emphasized the fact that the co-actor was taking care of a different aspect of

the same target stimuli assigned to the participant, and that nobody was taking care of the to-be-ignored words producing interference.

Importantly, in both joint tasks, the co-actor was believed to perform a different task from that assigned to the participant, thus preventing the occurrence of possible competitive (or social comparison) effects (Huguet et al., 1999). As in previous experiments, we included a control condition in which participants continued to perform the PWI task individually in order to rule out possible practice effects.

The following predictions could be made. First of all, the semantic interference effect should occur when participants performed the individual task in the baseline block and it should continue to be observed in the repetition of the task (control condition). The only difference between this task and that administered in the previous experiment was the fact that the pictures were coloured - instead of black and white - line drawings, and there was no reason to expect that the semantic interference effect was modulated by the colour of the target pictures. Secondly, we expected the semantic interference effect to disappear in the joint task in which the co-actor was thought to be in charge of the distractor words, thus replicating the finding observed in the joint task of Experiment 2.

Most importantly, if the disappearance of the semantic interference effect was due to a nonspecific social facilitation effect, then the semantic interference effect should disappear even in the joint same-target task, where the co-actor was thought to name the colour of the pictures and to ignore the words. Following the social facilitation theories, indeed, the distracting effect produced by the involvement of another person in the task should make participants narrow their attention on the task-relevant stimuli, and this would occur regardless of the specific task performed by the co-actor. Conversely, if what caused the semantic interference effect to disappear was the fact that the co-actor was taking care of the distractor words, then the semantic interference effect should continue to be observed in the joint same-target task. In this case, indeed, given that the actor and

co-actor were working on two different dimensions of the target stimuli, which are associated to non-competitive responses, and that nobody was working on the stimuli producing interference (the distractor words), participants were expected to fail in ignoring these stimuli and to show the typical semantic interference effect.

4.1. Method

4.1.1. Participants

Forty-eight students (5 males, aged 19-28 years) of the University of Trento who were all native speakers of Italian took part to the experiment. They all had normal or corrected-to-normal vision, did not participate to the Experiments 1 and 2, and were naïve as to the purpose of the experiment.

4.1.2. Apparatus, Stimuli and Procedure

The apparatus, stimuli, procedure and the experimental design were the same as those in Experiment 2 with the following exception: Target pictures were coloured line drawings. Nine different colours were used: red, pink, azure-blue, yellow, brown, orange, blue, green and violet. The colour of the target pictures varied randomly with the following restrictions: a) pictures of the same colour could not appear in consecutive trials, and b) the colour of the picture was in no way related to the depicted object (e.g., the carrot was never shown in orange).

Participants were randomly assigned to one of three experimental conditions: social–different target, social–same target, or control condition (see Figure 4).

>>FIGURE 4 about here<<

4.2. Results and discussion

Data were processed following to the same procedure used in Experiments 1 and 2, and 9.2 % of the data points were removed (1.03 % were naming errors). Correct RTs of each experimental condition were submitted to the same analyses carried out in Experiments 1 and 2.

As in previous experiments, the ANOVA on baseline data revealed a significant main effect of semantic relatedness, F= 49.81, p <.0001; η_p^2=.52, whereas the main effect of condition and its interaction with semantic relatedness were not significant, both Fs ≤ 1.06, both ps ≥ .35; both η_p^2s ≤ .04.

The analyses of the three experimental conditions revealed a significant effect of block in both social conditions, both Fs ≥ 5.41, both ps ≤ .05, both η_p^2s ≥ .27: Participants were faster when performing the joint tasks in the second block of trials as compared to the individual tasks performed in the baseline block (701 vs. 729 ms in the social–same target condition and 691 vs. 712 ms in the social–different target condition). The main effect of semantic relatedness was significant in all conditions, all Fs ≥ 12.20, all ps < .005; all η_p^2s ≥ .45, with participants slower in semantically related than unrelated trials (704 vs. 684 ms, 728 vs. 702 ms, and 712 vs. 691 ms in the control, social–same target, and social–different target conditions, respectively). The interaction between block and semantic relatedness was significant only in the social–different target condition, $F(1, 15) = 9.14$, $p < .01$, $\eta_p^2 = .38$ (see Figure 5). Post-hoc analysis revealed that the difference between semantically related and unrelated trials (729 vs. 698 ms and 695 vs. 685 ms in the baseline and critical blocks, respectively) was significant in the baseline block (p <.001) but not in the second, critical block, when performing the joint different-target task (p = .08). The interaction was significant neither in the control nor in social–same target conditions, both Fs ≤ .40, both ps ≥ .40. In the control condition, semantic interference effects of 24 and 17 ms were observed in the baseline block and in the repetition of the individual task, respectively. In the social–same target condition, semantic interference effects of 30 and 23 ms were observed in the baseline block and in the joint different-target task, respectively.

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>>FIGURE 5 about here<<

The results of the present experiment indicate that the suppression of the semantic interference effect observed in the social condition is unlikely due to a broad social facilitation effect. Indeed, the disappearance of the semantic interference effect was observed in the joint task in which participants believed that the co-actor was reading the distractor words (joint–different target task), as in Experiment 2, but not in the joint task in which the co-actor was thought to name the colour of the pictures (joint same-target task). Based on social facilitation theories, we should have observed the same pattern of results in both joint tasks. According to these theories, knowing that another person is involved in the task might lead participants to focus their attention on the task relevant information and to filter out all task irrelevant information, regardless of the specific task performed by the other person.

The disappearance of the semantic interference effect cannot be attributed to the significant reduction of RTs either. Although the belief of co-acting with another person speeded up participants' RTs in both joint tasks, the semantic interference effect disappeared only in the joint task in which the co-actor was believed to read the distractor words.

Conversely, the present findings suggest that what allowed participants to succeed in ignoring the distractor words was precisely the fact that someone else was in charge of these stimuli. Indeed, when nobody was thought to take care of distracting stimuli, as occurred in the individual and in the joint same-target tasks, the semantic interference effect continued to be observed.

5. General Discussion

The current study was motivated by the observation that different studies aimed at investigating the effects of task sharing on individual performance have shown contrasting results.

Almost all studies (e.g., Atmaca et al., 2011, 2008; Sebanz et al., 2003) provided evidence that participants engaged in joint tasks exhibit interference effects that do not usually arise (or are strongly reduced) when they perform the same task individually. Some recent studies however showed the opposite finding: the reduction of the interference effect in the joint task as compared to the individual task (Heed et al., 2010 and Wahn et al., 2017).

As stated in the Introduction, these contrasting results can be accounted for by taking into consideration the critical difference that distinguishes the joint tasks employed in these studies. In the joint tasks producing interference (i.e., joint Simon-like tasks in which the co-acting individuals performed two complementary Go/NoGo tasks) nobody was thought to take care of the task-irrelevant information (e.g., the stimulus position in the joint Simon task) and the co-actor responded to an alternative value of the same target stimulus as the participant. In contrast, in the joint task reducing interference (i.e., the joint visual-tactile and audio-visual interference tasks of Heed et al., 2010, and Wahn et al, 2017) the co-actor was responsible for the distracting information that typically causes interference. In the former case the involvement of a co-actor may lead participants to represent an alternative action to their own response (e.g., a response contralateral to their response in the joint Simon task), and this may cause the task-irrelevant information to interfere with their performance: An interference effect occurs when such information primes the alternative action. Conversely, in the latter case the opportunity of associating the interfering information with another person may allow a division of labour between the participant and the co-actor, thus (strategically) permitting participants to filter this information out from their task representation:

Following this rationale, in three experiments we implemented the PWI task (Rosinski et al., 1975) and we compared participants' ability of handling the task irrelevant information when performing this task individually and co-acting with a partner. Consistent with our hypothesis, we observed that when participants believe to perform the PWI task with a co-actor who

simultaneously was responding to the distractor words, this information made the semantic interference effect disappear. Importantly, the social setting was effective only when written word recognition was made more difficult by case alternation (Experiments 2 and 3).

These results confirm and extend the findings reported by Heed et al. (2010) and Wahn et al. (2017). Importantly, given that in the joint task of our study participants worked on two different stimuli involving the same modality, we can rule out that this outcome is restricted to conditions in which the co-actor works on stimuli of a different sensory modality (Knoblich et al., 2011). In addition, unlike in Heed et al. and Wahn et al., in the present study co-actors were not physically present and participants did not have any information about them, except for information about their task. Importantly, in Heed et al.'s study a reduction of the cross-modal interference effect occurred only when the co-actor performed the task in the participant's peripersonal space. In contrast, in our study, the mere belief of co-acting with unseen and unknown co-actors seems to have been sufficient to reduce the interference effect produced by irrelevant stimuli. This suggests that contextual and social factors linked to the co-actors' physical presence (e.g., proximity, spatial position, physical appearance) are not critical for the establishment of a division of labour between the participant and co-actor. Based on our findings, we propose that either the reduction or suppression of the interference effect produced by task-irrelevant stimuli can be the outcome of sharing an interference task with another person who is concurrently working on the interfering stimuli. The fact that this finding was observed in two experiments (Experiments 2 and 3) makes it rather reliable, and the pattern of results we observed allows us to rule out alternative interpretations to the division-of-labour account.

First of all, it seems unlikely that that the reduction of the interference effect was due to a nonspecific social facilitation effect (Huguet et al., 1999). Indeed, the results of Experiment 3, besides replicating those of Experiment 2, restrict the disappearance of the semantic interference effect to conditions in which the co-actor is thought to work specifically on the interfering

information conveyed by distractor stimuli. No modulation of the semantic interference effect was observed when the co-actor was believed to take care of task-irrelevant non-interfering information (i.e., the colour of the target pictures).

Further, it is hardly likely that the disappearance of the semantic interference effect was due to the establishment of a competitive relationship between the participant and the alleged co-actor. Competitive mechanisms do not usually emerge when the actor and the co-actor perform different tasks (Sanders, Baron, & Moore, 1978). Nevertheless, if this were the case, a competitive mechanism should have been also developed in the joint task in which the co-actor was naming the picture colour, thus determining the disappearance of the interference effect in this task as well.

To sum up, the results of the present study indicate that the belief of co-acting with a person who takes care of task-irrelevant stimuli can provide participants with an effective strategy that allows them to ignore such stimuli, which otherwise are destined to be processed. On the basis of the results observed in the present study and those reported by Heed et al. (2010) and Wahn et al. (2017), we propose that task instructions that make participants bind the distractor stimuli to the co-actor may help them discard these stimuli from their task representation. This proposal is in line with the integrated competition hypothesis of selective attention (Duncan, Humphreys, & Ward, 1997; Duncan, 1996), which underlines the importance of both top-down factors and binding processes in modulating the ability to deal with the distracting information.

It is worth noting that the paradigm employed in the present study, as well as those used by Heed et al. (2010) and Wahn et al. (2017), is an example of a task in which the interfering information is not bound to the target but is conveyed by a different object, which is physically separated from the target. This kind of tasks may be optimal to permit the association of task-irrelevant information to another person, thus allowing participants to ignore this potentially interfering information. In contrast, such a strategy could be more difficult to implement when the target object itself conveys the task-irrelevant information, as happens in the case of the classical

colour-word Stroop task (McLeod, 1991) and Simon task (Simon & Small, 1969). In these tasks, the target dimensions and the interfering task-irrelevant dimensions (the meaning of the target word and the stimulus position in the Stroop and Simon tasks, respectively) are bound together. To the best of our knowledge, no study has yet verified whether interference effects can be modulated in joint versions of this kind of paradigms when participants are let to believe that another person is in charge of the task interfering information.

On the basis of the results of the present study and of previous works investigating task sharing with interference paradigms, we can therefore conclude that:

1) Interference effects occur (or are enhanced) in joint tasks in which participants perform two complementary Go/NoGo tasks (i.e., they take turns in responding to the target stimulus) and in which the involvement of other people makes participants code an alternative response (e.g., in the joint Simon task; Sebanz et al., 2003) or activate competitive representations (e.g., in the joint picture naming task; Kuhlen, & Abdel Rahman, 2017) that are not coded or activated when the Go/NoGo task is performed individually;
2) Interference effects disappear (or are reduced) in joint tasks requiring to ignore distractor stimuli that become associated with another person who is concurrently responding to these stimuli, at least when the irrelevant information is conveyed by an object different from the target, and its processing is not automatic (i.e., unlike in the case of, e.g., recognition of same-case words, the processing of this information is not mandatory, but subject to controlled processes; cf. Posner & Snyder, 1975), thus allowing the participant to implement a strategy for ignoring such information. This strategy would be provided by the belief of co-acting with another person: In tasks in which the interfering information is represented even when the task is performed individually, sharing a task with another person who is concurrently taking care of this information (e.g., the distractor words in PWI tasks) makes

participants represent such information as associated with the co-actor, thus allowing them to filter it out from their task representation:

Based on our findings, we cannot draw conclusions about what participants exactly represent of the co-actor's actions and task, and, therefore, about what part of the participant's task representation can be linked to the co-actor, and filtered out, thanks to the division of labour. We do not know, for example, whether the coding of the co-actor's target stimuli is sufficient, or the action performed on these stimuli is instead critical. To complete the picture, we should assess the specific conditions that allow the division of labour to be effective. To this aim, it might be necessary that the co-actor performs the potentially interfering action (e.g., reading the distractor words in a PWI task). Alternatively, it might be sufficient that co-actors take care of the interfering stimuli- whatever they are believed to do on such stimuli (e.g., in a PWI task, it might be sufficient that the co-actors are believed to respond to the ink colour, font, or other physical features of the distractor words).

It would also be worth completing the picture by assessing the destiny of the task interfering information in joint tasks in which the co-actor is thought to take care of this information but, unlike in the present study, this information is bound to the target. Further studies should test the possible effects of task sharing in these kinds of tasks so as to achieve a more comprehensive overview able to clarify the extent to which task sharing affects individual's performance and under which circumstances it gives rise to either interference or facilitation effects.

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FIGUREs and figure legends

Figure 1

Schematic representation of the experimental design adopted in Experiment 1. Participants were randomly assigned to one of two experimental conditions: control or social. Each experimental condition comprised two blocks of trials: the baseline block, in which all participants performed the individual task, and the critical block. Conditions were defined as either control or social depending on the task participants performed in the critical block of trials. Participants assigned to the control condition, after completing the baseline, simply continued to perform the same task individually. In contrast, participants assigned to the social condition, after the baseline, were required to perform the same task with an alleged co-actor who was in a not-specified room and was thought to read the distractor words.

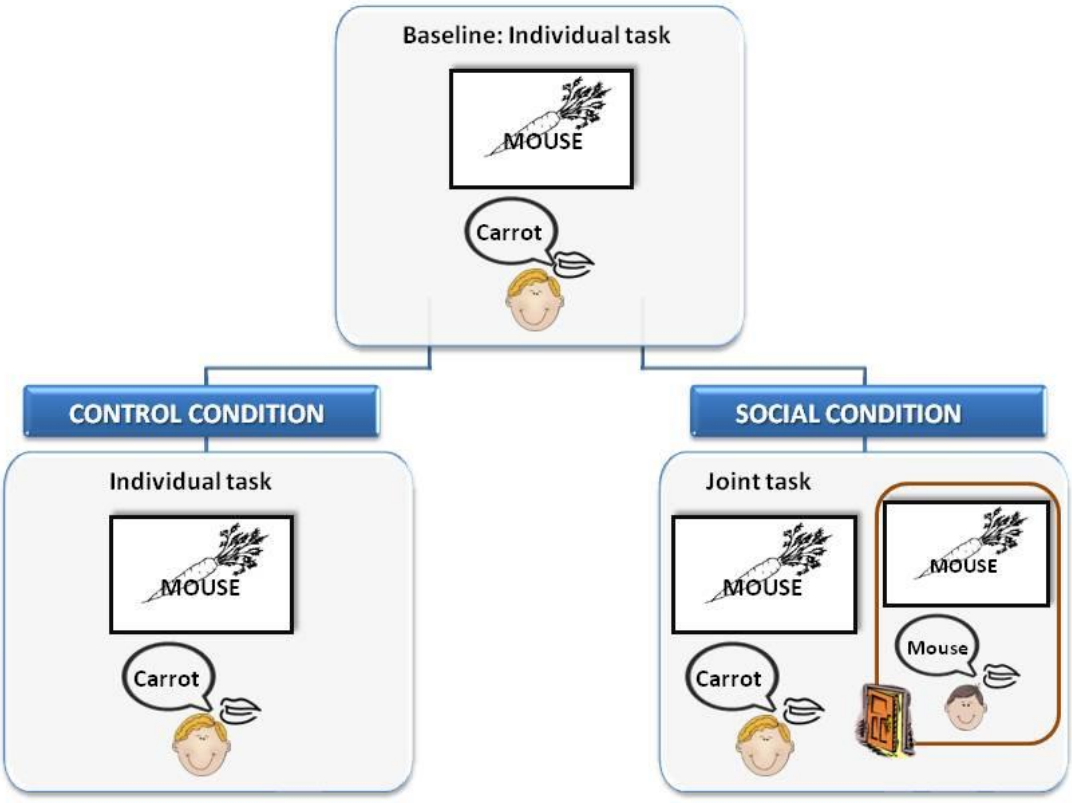


Figure 2

Means (± S.E.M.s) of correct RTs for each experimental condition in Experiment 1. For each condition, RTs are plotted as a function of semantic relatedness (semantically-related vs. -unrelated trials) and block of trials (baseline vs. critical block). In the baseline block, all participants performed the task individually, while in the second, critical block, participants either repeated the individual task (control condition) or perform the joint task (social condition). Asterisks indicate the presence of the semantic interference effect.

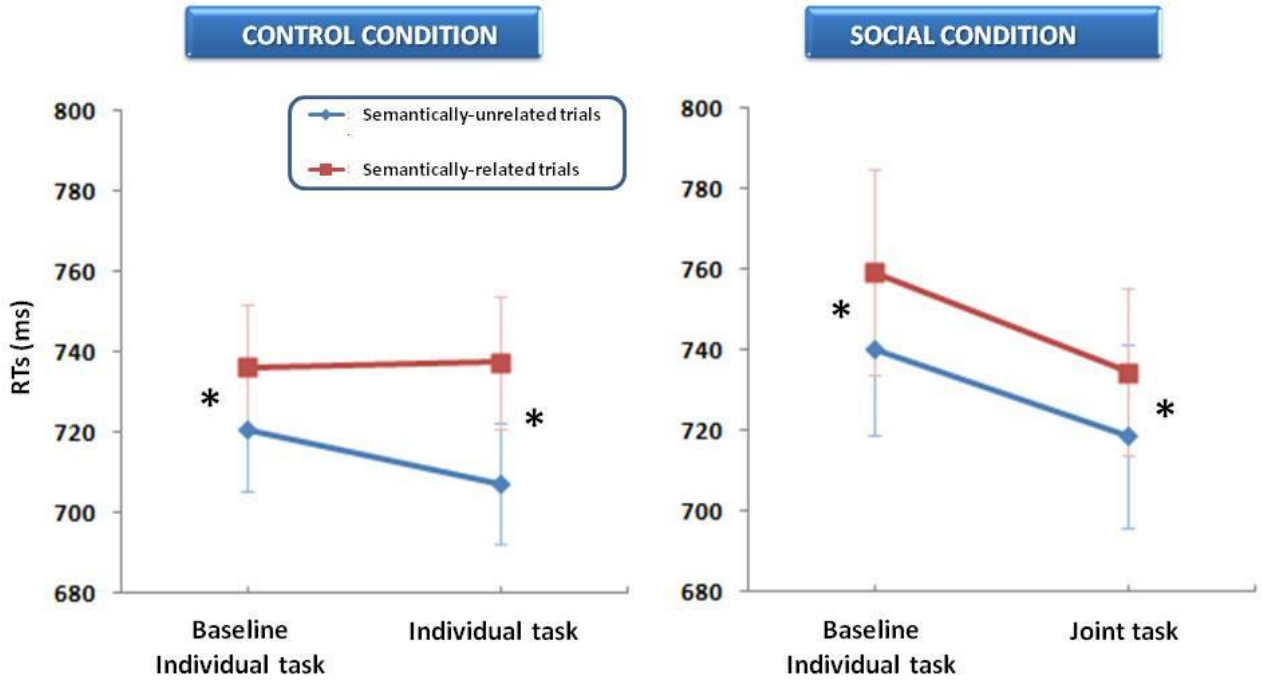


Figure 3

Means (± S.E.M.s) of correct RTs for each experimental condition in Experiment 2. For each condition, RTs are plotted as a function of semantic relatedness (semantically-related vs. -unrelated trials) and block of trials (baseline vs. critical block). In the baseline block, all participants performed the task individually, while in the second, critical block, participants either repeated the individual task (control condition) or perform the joint task (social condition). Asterisks indicate the presence of the semantic interference effect.

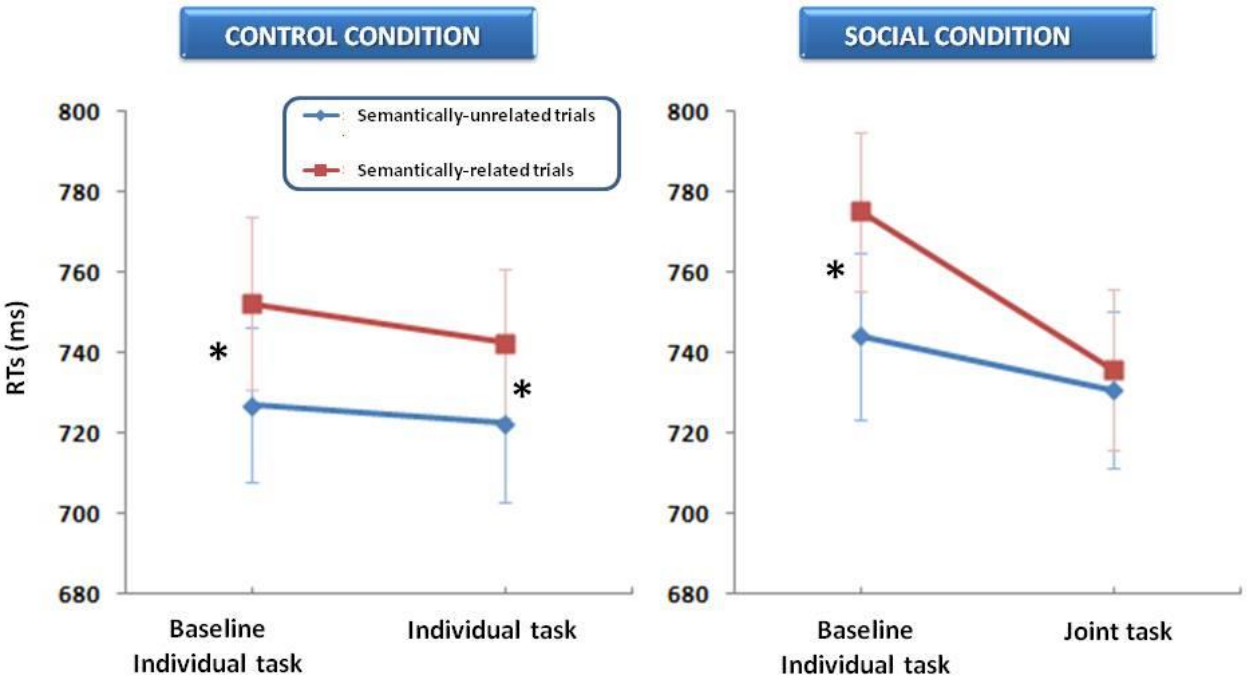


Figure 4

Schematic representation of the experimental design adopted in Experiment 3. Participants were randomly assigned to one of three experimental conditions: control, social–different target (-DT) or social–same target (-ST). In contrast to the previous experiments, target pictures were randomly shown in nine different colours (in the examples reported here pictures are blue). Distractor words were shown in alternated-case letters as in Experiment 2. The control and the social–different task conditions coincided with the control and social conditions of the previous experiments, whereas the social–same task condition was new of this experiment. Participants assigned to this latter condition, after the baseline, performed a joint task in which they were told that the co-actor was naming the colour of the pictures.

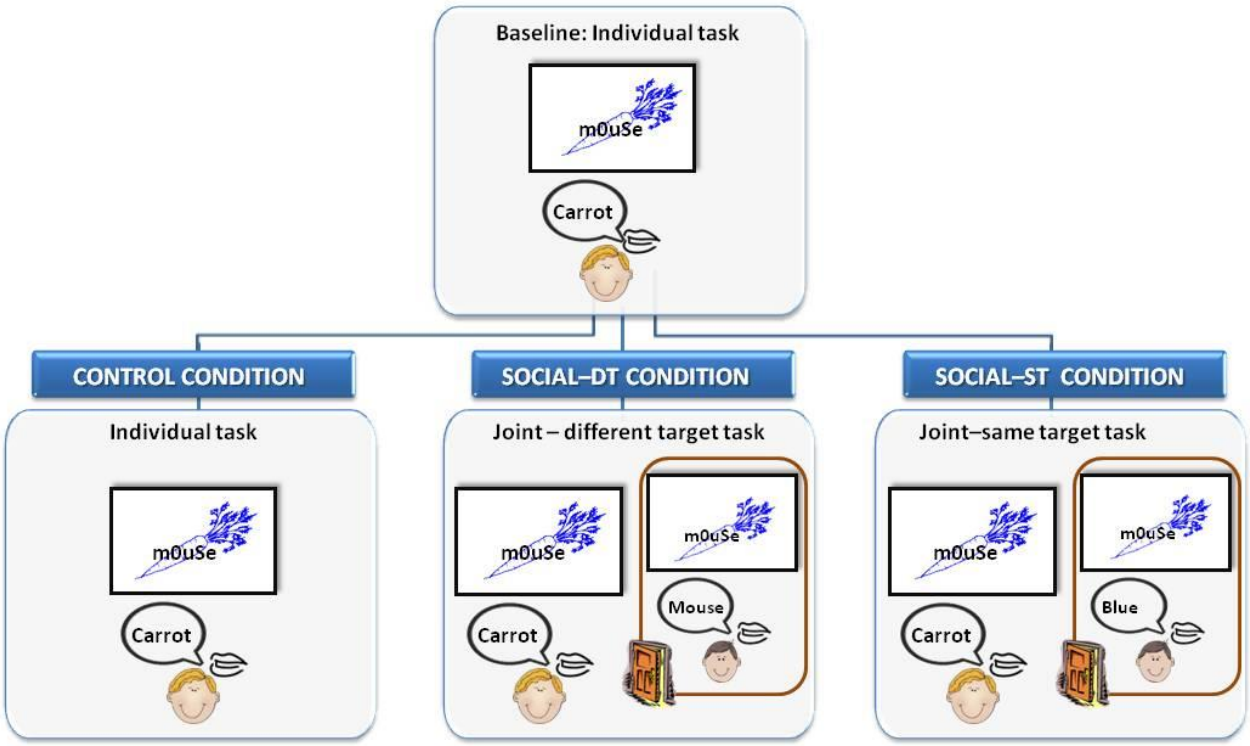
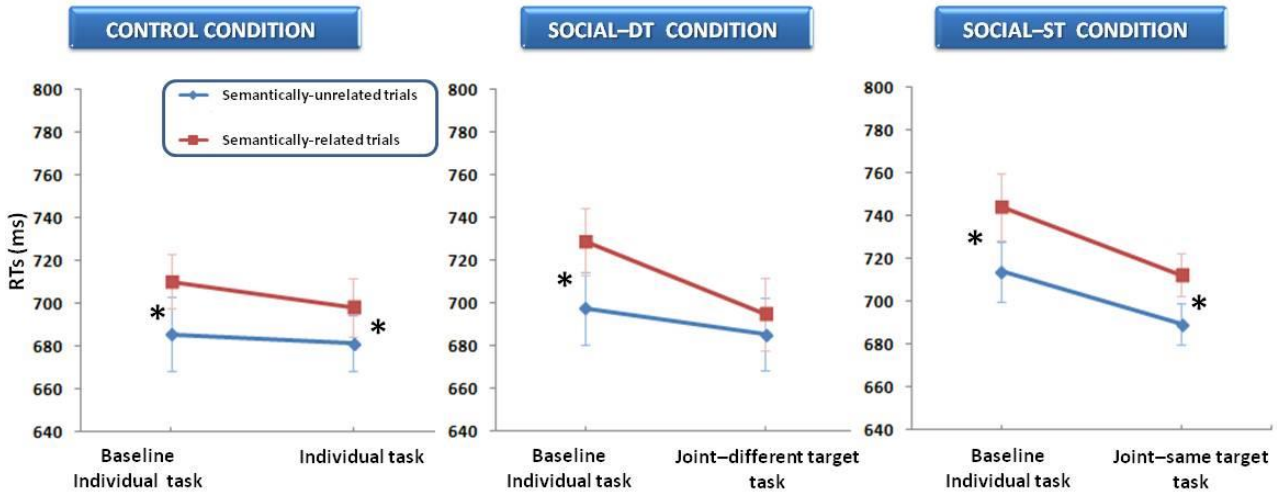


Figure 5

Means (± S.E.M.s) of correct RTs for each experimental condition in Experiment 3. For each condition, RTs are plotted as a function of the semantic relatedness (semantically-related vs. -unrelated trials) and the block of trials (baseline vs. critical block). In the baseline block, all participants performed the task individually, while in the second, critical block, participants performed either the individual task or one of two different joint tasks, according to the experimental condition: control, social-different target (-DT), and social-same target (-ST). Asterisks indicate the presence of the semantic interference effect.



DATA AVAILABILITY

The datasets during and/or analysed during the current study are available from the corresponding author on reasonable request.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of Interest: All the authors declare that they have no conflict of interest.

Ethical approval: The study described in this article involved human participants. All procedures performed in it were in accordance with the ethical standards of the institutional research committee (University of Trento) and with the 1964 Helsinki declaration and its later amendments, or comparable ethical standards.

This article does not contain any studies with animals.

Informed consent: Informed consent was obtained from each participant included in the study.