



**HAL**  
open science

## Deciphering the nature of the joint Simon effect through electromyographic analyses

Karen Davranche, Clément Belletier, Thibault Gajdos, Carbonnell Laurence, Franck Vidal, Pascal Huguet, Thierry Hasbroucq

► **To cite this version:**

Karen Davranche, Clément Belletier, Thibault Gajdos, Carbonnell Laurence, Franck Vidal, et al.. Deciphering the nature of the joint Simon effect through electromyographic analyses. 2020. hal-02992934

**HAL Id: hal-02992934**

**<https://hal.science/hal-02992934v1>**

Preprint submitted on 10 Nov 2020

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

## Deciphering the nature of the joint Simon effect through electromyographic analyses

Karen Davranche<sup>\*1</sup>, Clément Belletier<sup>\*1,3,4</sup>, Thibault Gajdos<sup>1</sup>, Laurence Carbonnell<sup>1</sup>, Franck Vidal<sup>2</sup>, Pascal Huguet<sup>1,4</sup> & Thierry Hasbroucq<sup>2</sup>

<sup>1</sup> Aix-Marseille Univ, CNRS, LPC, Marseille, France

<sup>2</sup> Aix-Marseille Univ, CNRS, LNC, Marseille, France

<sup>3</sup> Département de Psychologie, Université de Fribourg, Fribourg, Switzerland

<sup>4</sup> Université Clermont Auvergne, CNRS, LAPSCO, Clermont-Ferrand, France

\* The authors contributed equally

**Abstract:** This study aimed to apply electromyographic techniques and distributional analyses to test whether an increase in the strength of stimulus-response mapping could explain the mechanisms underlying the joint Simon effect. Within a single protocol, participants performed a Simon task and a Go/NoGo task in isolation, and a joint Go/NoGo task with a co-actor (joint Simon task). Results showed that joint-action impairs cognitive control and shortened reaction time by impacting both pre-motor time and motor time. Joint-action induced a larger facilitation on pre-motor time of ipsilateral than contralateral associations. This potentiation of the spatial correspondence effect plausibly explains the larger Simon-like effect usually observed in the joint Go/NoGo task compared to that observed in the isolated Go/NoGo task. The propensity of making incorrect activations and their concentration among fast responses also increased when working co-actively. Together, these findings indicate that joint-action increases the strength of automatic response capture induced by the stimulus location, promotes the delivery of the stronger association in the behavioral repertoire of the individual, and reduces cognitive control.

**Keywords:** Go/NoGo tasks, Joint Simon Effect, Social facilitation, Increased arousal, Spatial correspondence, Automatic response capture

### Highlights

- The potentiation of spatial correspondence effect explains the joint Simon effect
- Joint-action increases the strength of automatic response capture
- Incorrect activations increased when working co-actively

**Corresponding author:** karen.davranche@univ-amu.fr

Dr. Karen Davranche, Aix-Marseille Université, 3 Place Victor Hugo, Case D, 13331 Marseille, cedex 3, France

## 1. Introduction

In the most common version of the standard Simon task, the participants have to choose between a left- and a right-hand key press according to the color of a visual stimulus presented a few degrees either to the left or the right of a fixation point. Mean choice reaction time (RT) is shorter for ipsilateral stimulus-response associations than for contralateral stimulus-response associations (Craft & Simon, 1970). This effect is termed the *Simon effect* (SE; see Simon, 1990). An influential scheme that accounts for the SE has been proposed by Kornblum, Hasbroucq, & Osman (1990). Accordingly, the irrelevant stimulus location automatically activates its spatially corresponding response and, because of this activation, ipsilateral (IPS) stimulus-response associations are performed faster – and are less error prone – than contralateral (CNT) stimulus-response associations. In an associationist stance, this notion amounts to consider that IPS associations are stronger than CNT associations (Davranche et al., 2018). In support of this interpretation, a small but significant advantage in favor of IPS associations can be found when participants are asked to respond to only one of the two stimuli, the task being thus transformed into a Go/NoGo task (Callan, Klisz, & Parsons, 1974; see Davranche et al., 2018).

Importantly, this spatial correspondence effect (cSE, in reference to Donders' type c task) is magnified when the Go/NoGo task is performed by two co-actors seated side to side, each of them responding to one of the two possible stimulus colors (Natalie Sebanz, Knoblich, & Prinz, 2003). During the last decade, such a potentiation termed the *Social Simon effect* or *Joint Simon effect* (JSE) has spawned an important literature (for a review, see Dolk et al., 2014). Several interpretations of the JSE have been proposed (e.g., Dolk et al., 2011; Dolk, Hommel, Prinz, & Liepelt, 2013; Sebanz, Bekkering, & Knoblich, 2006), but most of them neglected the small but significant advantage in favor of IPS associations which is also present (all things being equal) when the Go/NoGo task is performed in isolation. The existence of this small advantage can be seen in the frame of Kornblum et al.'s (1990) model as a variation in the strength of automatic response capture between the lateralized stimuli and responses.

Here, we tested the possibility that the JSE results from a potentiation of this preexisting cSE caused by an increase of the strength of the automatic response capture in presence of a coactor. There is indeed evidence from a long-standing literature on social facilitation (Zajonc, 1965) that the presence of conspecifics increases the general arousal which, in turn, energizes the emission of the more dominant (for example the most automatic) response (Fagot, Marzouki, Huguet, Gullstrand, & Claidière, 2015; Huguet, Barbet, Belletier, Monteil, & Fagot, 2014; Zajonc, 1965; for reviews see Bond & Titus, 1983; Guerin, 2009; Seitchik, Brown, & Harkins, 2017). Testing this hypothesis in the context of the JSE requires quantifying the strength of the automatic response capture by the stimulus location. To this end, we resorted to electromyographic (EMG) techniques and distributional analyses. Many correct response trials contain subthreshold muscle activities that would lead to erroneous responding if their magnitudes were larger. These transient activities are partial errors that are successfully stopped to prevent response errors (Hasbroucq, Burle, Vidal, & Possamai, 2009). Since these partial errors enable to characterize the automatic response capture, we reasoned that if the JSE is due to increased automatic response capture, participants should display more incorrect activations (including both overt errors and partial errors) when performing the task with a co-actor than when performing the task alone. Moreover, in this case we should also observe a higher concentration of incorrect activation among fast responses, which can be measured by the Error Location Index (Servant, Gajdos, & Davranche, 2018).

## 2. Method

### 2.1. Participants

Forty right-handed volunteers [23 females, aged 18–33 ( $M = 21.43$  yrs;  $SD = 2.78$ )] participated in the experiment. They were paid 30€ for taking part. Participants had normal or corrected-to-normal vision. Informed written consent was obtained according to the Declaration of Helsinki.

### 2.2. Design and Cognitive Tasks

Within a single protocol, each participant completed a classic Simon task, a joint Go/NoGo task in co-action with a friend, and an isolated Go/NoGo task (performed in isolation). The experiment consisted in two sessions carried out at the same time of day. Participants went to the laboratory accompanied by a friend for a first session and alone for a second. In the session performed alone, participant completed 10 blocks of 100 trials in a Simon task (Figure 1, panel B) and 10 blocks of 100 trials in an isolated Go/NoGo task (Figure 1, panel C). In the session performed with a friend, participants share a Simon task or in other words complete a joint Go/NoGo task (Figure 1, panel A). The order of the sessions and the order of the cognitive tasks in the individual session were counterbalanced across participants.

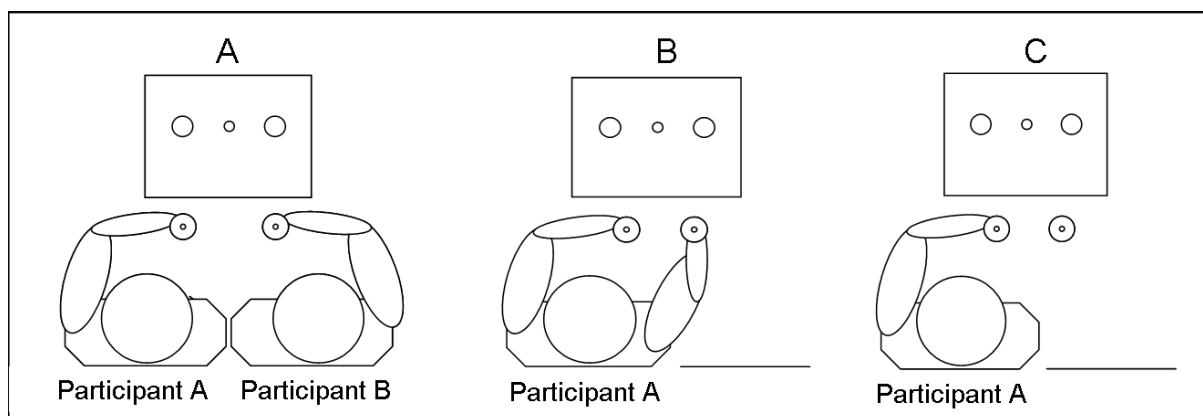


Figure 1. Illustration of the different cognitive tasks completed by a participant in the experiment: (A) participant A performed a joint Go/NoGo task in co-action with a friend; (B) participant A performed a Simon task and (C) an isolated Go/NoGo task. In the isolated Go/NoGo task, there is only one possible response. If the participant is seating on the left side, the response is given using the left response key with the left hand. Following the same logic when participant is seating on the right side of the device the response is given using the right response key with the right hand. Half participants reply to the lit of the green LED and the other half to the red LED. When participant performed the joint Go/NoGo task, each co-actor did exactly the same task than during the isolated Go/NoGo task. They sat on the same side, replied to the lit of the same colour and pressed the same response key with the same hand.

Participants were seated on chairs positioned side by side which faced a black panel 1.5 metre away. When participants shared the task, they were close but not in contact with each other; when performing the task individually the position was identical and the second chair remained empty (i.e., slightly on the left or right side of the device). Two green/red light-emitting diodes (LEDs), separated by 18 cm, were positioned at both sides of a central blue gaze-fixation LED. The response keys were two 10 cm plastic tubes, separated by 20 cm, equipped with a button on the top and fixed on a table placed in front of the chairs. Regardless of the correctness, the delivery of a response turned off the stimulus and the next trial began after a constant 1500 ms inter-stimulus interval (ISI). If 1 second elapsed without a response, the LED extinguished and the next trial began after the ISI.

Participants were asked to respond as quickly and accurately as possible. The light could be green or red and could be delivered either to the left or to the right side. The response was given by pressing the appropriate response key, according to the colour of the LED (task-relevant attribute) whatever the location of the LED (the task-irrelevant attribute). Half participants had to exert a press with the left thumb when the LED was red and a press with the right thumb when the LED was green, the other half participants were to perform the reverse stimulus-response mapping. There were two types of trials in each block: ipsilateral trials (50%) and contralateral trials (50%). In ipsilateral trials (IPS), the lateral locations of the stimulus and response are on the same side (e.g., left stimulus/left response). In contrast, in contralateral trials (CNT), the lateral locations of the stimulus and response are on the opposite side (e.g., left stimulus/right response).

### 2.3. Electrophysiological recording

Electromyographic (EMG) activities were recorded with bipolar Ag/AgCl electrodes (BIOSEMI Active-Two electrodes, Amsterdam) glued on the skin over the *flexor pollicis brevis*. The sampling rate was 1024 Hz (filters: DC to 268 Hz, 3 dB/octave). Electrodes were fixed 2 cm apart on the skin of the thenar eminence. The EMG signal was continuously monitored by the experimenter (that stayed in an adjacent room during the experiment) in order to avoid as much as possible any background activity in order to facilitate the EMG onset detection. If the signal became noisy, the experimenter immediately asked the subject to relax his (her) muscles.

### 2.4. Data analysis and statistics

Reaction time less than 100ms and RT higher than 1000ms, considered as anticipated responses and omissions, were excluded from further analyses (27,23 % of trials in total). The EMG activities recorded during each trial were displayed on a computer screen aligned to the onset of the imperative stimulus, and the onsets of the changes in activity were determined visually and marked with the computer mouse. The experimenter was unaware of the nature of the trial or the task being processed. This method was preferred to an automated one because it allows more precise detection (Hasbroucq, Possamaï, Bonnet, & Vidal, 1999; Van Boxtel, Geraats, Van den Berg-Lenssen, & Brunia, 1993). Reaction time was measured to the closure of the switches located under the response keys and decomposed into premotor-time (PMT, from stimulus onset to the onset of the EMG involved in the response) and motor-time (MT, from the EMG onset to the switch closure). Mean RT, PMT and MT for pure correct trials (trials with no sign of EMG activation associated with the incorrect response) was calculated for each condition. Two subjects did not have enough trials after electrophysiological artifact rejections and the data of one participant were discarded because of technical dysfunction. The incorrect activation trials correspond to two categories of trials: overt errors and partial errors. During the Simon task, partial errors correspond to trials in which a correct activation was preceded by an incorrect activation. The force exerted by the non-required effector was not sufficient to elicit a response error and were followed by a correct activation reaching response threshold. During the joint and isolated Go/NoGo tasks, partial errors correspond to trials in which an activation of the effector was detected on a NoGo trial.

We also relied on the Error Location Function (ELF), which represents the proportion of incorrect activations located below each quantile of the overall PMT distribution, to measure the concentration of incorrect activation among fast responses. The Error Location Index (ELI), which represents the area below ELF, is used as a quantitative measure of automatic response capture (Servant et al., 2018): The more concentrated are the incorrect activations among fastest trials, the higher the ELF, the larger the ELI. It is important to note that the ELI is a relative index. It might thus increase either because incorrect activations are faster, or because overall

trials are slower. In the latter case, a larger ELI should not be interpreted as reflecting a stronger automatic response capture.

Response time distributions analyses were conducted to compare the time course of the spatial correspondence effect, the so-called delta plot developed by De Jong, Liang, & Lauber (1994), in the individual Simon task, isolated Go/NoGo task and joint Go/NoGo task. Curve density functions were constructed using individual RTs “vincentized” into ten equal-size speed bins (deciles) in each spatial correspondence condition for each task (Figure 4A). Then, the delta plots were computed by plotting the difference between the mean RTs of the two spatial correspondence associations in each bin against the mean RT across both conditions for that bin (Figure 4B). If the presence of a co-actor induces participants to code their unique response in terms of left or right relative to the other’s response, we expected that the time course of the spatial correspondence effect in the joint Go/NoGo task should follow a similar qualitative pattern to that of the Simon task. To test this result for statistical significance, the slope of the delta plots was estimated for each of the 38 participants separately by linear regressions (Ellinghaus & Miller, 2018).

Repeated-measures canonical analyses of variance (ANOVA) were performed on each dependent variable, with partial eta-squared ( $\eta_p^2$ ) reported as a measure of effect size. A first series of analyses was conducted on the Simon task, and then a second series was performed on Go/NoGo tasks to focus on the JSE. This latest series involved co-action (joint Go/NoGo vs. isolated Go/NoGo) and spatial correspondence of the trial (IPS vs. CNT) as within-subject factors. *Post hoc* Newman-Keuls analyses were conducted on all significant interactions. Significance was set at  $p < .05$  for all analyses.

### 3. Results

#### 3.1. Simon task

Repeated measures ANOVA conducted on the standard Simon task showed a main effect of Spatial correspondence ( $F(1,37) = 70.87, p < .001, \eta_p^2 = 0.66$ ). Reaction time was faster for congruent trials (CO:  $M=350\text{ms}, SE=6\text{ms}$ ) compared to incongruent trials (IN:  $M=374\text{ms}, SE=7\text{ms}$ ). Results on PMT mimicked the pattern observed on mean RT with participants displaying faster PMT for CO trials ( $M=242\text{ms}, SE=7\text{ms}$ ) than for IN trials ( $M=266\text{ms}, SE=8\text{ms}$ ) ( $F(1,37) = 61.07, p < .001, \eta_p^2 = 0.62$ ). No main effect of spatial correspondence was observed on mean MT ( $F(1, 37) = 1.17, p = .28, \eta_p^2 = 0.03$ ; CO:  $M=108\text{ms}, SE=5\text{ms}$  vs. IN:  $M=109\text{ms}, SE=5\text{ms}$ ). A classic effect of spatial correspondence was observed on overt errors ( $F(1,37) = 16.87, p < .001, \eta_p^2 = 0.31$ ; CO:  $M=4\%, SE=0.4\%$  vs. IN:  $M=6\%, SE=0.6\%$ ) and partial errors ( $F(1,37) = 20.50, p < .001, \eta_p^2 = 0.36$ ; CO:  $M=20\%, SE=2.4\%$  vs. IN:  $M=25\%, SE=1.9\%$ ).

#### 3.2. Go/NoGo tasks

##### 3.2.1. Reaction time.

Results showed main effects of Spatial correspondence ( $F(1,37) = 16.90, p < .001, \eta_p^2 = 0.31$ ) and Co-action ( $F(1,37) = 9.29, p < .01, \eta_p^2 = 0.20$ ), and a Spatial correspondence x Co-action interaction ( $F(1,37) = 15.04, p < .001, \eta_p^2 = 0.29$ ). Reaction time was faster for IPS trials ( $M=311\text{ms}, SE=6\text{ms}$ ) compared to CNT trials ( $M=319\text{ms}, SE=7\text{ms}$ ). Participants displayed faster RT in joint Go/NoGo ( $M=307\text{ms}, SE=7\text{ms}$ ) compared to isolated Go/NoGo ( $M=323\text{ms}, SE=7\text{ms}$ ). The Spatial correspondence x Co-action interaction showed that a Simon-like effect was observed in the isolated Go/NoGo task ( $321\text{ms}$  vs.  $326\text{ms}, p < .001$ ) and in the joint Go/NoGo task ( $301\text{ms}$  vs.  $312\text{ms}, p < .001$ ). The cSE effect was potentiated by the presence of a co-actor, resulting in a larger Simon-like effect in the joint task (isolated:  $5\text{ms}$  vs. joint:  $11\text{ms}$ , Figure 2).

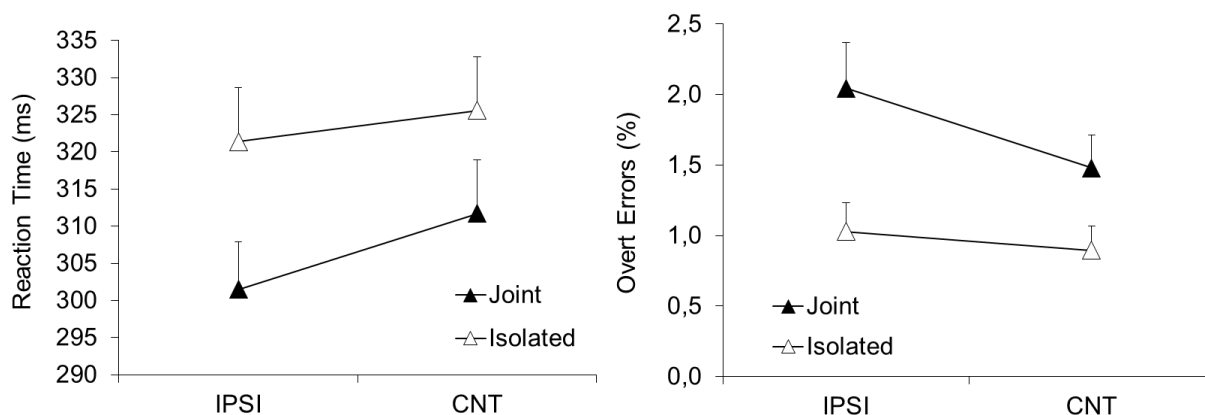


Figure 2. (Left) Mean RT in millisecond in the joint Go/NoGo (black) and in the isolated Go/NoGo (white) tasks as function of the spatial correspondence of the stimulus relative to the response (ipsilateral vs. contralateral). (Right) Overt error percentage in the joint Go/NoGo (black) and in the isolated Go/NoGo (white) tasks as function of the spatial correspondence of the stimulus relative to the response (ipsilateral vs. contralateral). Errors bars represent standard errors.

### 3.2.2. Premotor time.

Results on PMT mimicked the pattern observed on mean RT. There were main effects of Spatial correspondence ( $F(1,37) = 18.41, p < .001, \eta_p^2 = 0.33$ ) and Co-action ( $F(1,37) = 10.98, p < .01, \eta_p^2 = 0.23$ ), and a Spatial correspondence x Co-action interaction,  $F(1,37) = 12.96, p < .001, \eta_p^2 = 0.26$ . Premotor time was faster for IPS trials ( $M=216\text{ms}, SE=5\text{ms}$ ) than for CNT trials ( $M=224\text{ms}, SE=5\text{ms}$ ). Participants displayed faster PMT in joint Go/NoGo ( $M=213\text{ms}, SE=5\text{ms}$ ) compared to isolated Go/NoGo ( $M=227\text{ms}, SE=6\text{ms}$ ). The Spatial correspondence x Co-action interaction showed that joint-action induced a larger facilitation on IPS trials (joint:  $M=208\text{ms}, SE=5\text{ms}$  vs. isolated:  $M=224\text{ms}, SE=6\text{ms}$ ) than on CNT trials (joint:  $M=219\text{ms}, SE=6\text{ms}$  vs. isolated:  $M=229\text{ms}, SE=6\text{ms}$ ). The cSE was potentiated by the presence of a co-actor, resulting in a larger Simon-like effect in the joint task (joint: 11ms vs. isolated: 5ms).

### 3.2.3. Motor time.

Results showed main effects of Spatial correspondence ( $F(1,37) = 8.21, p < .01, \eta_p^2 = 0.18$ ) and Co-action ( $F(1,37) = 5.62, p = .02, \eta_p^2 = 0.13$ ). Motor time was faster for CNT trials ( $M=95\text{ms}, SE=4\text{ms}$ ) than for IPS trials ( $M=96\text{ms}, SE=4\text{ms}$ ). Participants displayed faster MT in joint Go/NoGo ( $M=93\text{ms}, SE=4\text{ms}$ ) compared to isolated Go/NoGo ( $M=98\text{ms}, SE=4\text{ms}$ ). The Spatial correspondence x Co-action interaction was not significant ( $F(1,37) = 0.21, p = .65, \eta_p^2 = 0.005$ ). Joint-action induced an equivalent facilitation on IPS trials (joint:  $M=94\text{ms}, SE=4\text{ms}$  vs. isolated:  $M=98\text{ms}, SE=4\text{ms}$ ) and on CNT trials (joint:  $M=93\text{ms}, SE=4\text{ms}$  vs. isolated:  $M=98\text{ms}, SE=4\text{ms}$ ).

### 3.2.4. Overt errors and partial errors.

ANOVA performed on overt errors showed main effects of Spatial correspondence ( $F(1,37) = 12.44, p < .01, \eta_p^2 = 0.25$ ) and Co-action ( $F(1,37) = 10.61, p < .01, \eta_p^2 = 0.22$ ), and a Spatial correspondence x Co-action interaction ( $F(1,37) = 4.31, p < .05, \eta_p^2 = 0.10$ ). Participants committed more overt errors in the joint Go/NoGo ( $M=1.8\%, SE=0.3\%$ ) compared to the isolated Go/NoGo ( $M=1\%, SE=0.2\%$ ), and IPS errors ( $M=1.5\%, SE=0.2\%$ ) were more important than CNT errors ( $M=1.2\%, SE=0.2\%$ ). The Spatial correspondence x Co-action interaction showed that the impact of coaction was larger for IPS trials (joint:  $M=2\%, SE=0.3\%$  vs. isolated:  $M=1\%, SE=0.2\%$ ) than for CNT trials (joint:  $M=1.5\%, SE=0.2\%$  vs. isolated:  $M=0.9\%, SE=0.2\%$ ).

Results on partial errors showed a main effect of Co-action ( $F(1,36) = 8.86, p < .01, \eta_p^2 = 0.20$ ). Participants committed more partial errors in the joint Go/NoGo ( $M=23\%, SE=2\%$ ) compared to the isolated Go/NoGo ( $M=16\%, SE=2\%$ ). The main effect of Spatial correspondence was close to significance ( $F(1,37) = 4.09, p = .05, \eta_p^2 = 0.10$ ). IPS partial errors ( $M=20\%, SE=1\%$ ) tended to be more numerous than CNT partial errors ( $M=19\%, SE=1\%$ ). The Spatial correspondence x Co-action interaction was not significant ( $F(1,36) = 0.05, p = .83, \eta_p^2 = 0.01$ ).

### 3.2.5. Error Location Function (ELF) of incorrect activations.

ANOVA was performed on individual ELI which is an index of automatic response capture derived from the PMT distribution of incorrect activations compared to the PMT distribution of all trials (Error Location Function, ELF). The incorrect activations (overt errors + partial errors) committed on the same side than the NoGo signal were considered as ipsilateral incorrect activations, whereas incorrect activations committed on the opposite side than the NoGo signal were considered as contralateral incorrect activations. Results revealed a main effect of Co-action ( $F(1,34) = 26.44, p < .001, \eta_p^2 = 0.44$ ) and a Spatial correspondence x Co-action interaction ( $F(1,34) = 9.39, p < .01, \eta_p^2 = 0.22$ ). In the joint Go/NoGo, the errors were more concentrated among the faster trials (ELI:  $M=0.79, SE=0.01$ ) than in the isolated Go/NoGo (ELI:  $M=0.72, SE=0.01$ ). Given that overall RT were faster in joint Go/NoGo, this can be interpreted as reflecting a stronger automatic response capture. The Spatial correspondence x Co-action interaction showed that in the joint Go/NoGo CNT incorrect activations (ELI:  $M=0.81, SE=0.01$ ) were more numerous than the IPS incorrect activations (ELI:  $M=0.78, SE=0.01$ ) among the faster trials ( $p < .01$ ). Given that RT were slower for CNT trials than for IPS trials, this result cannot be interpreted as reflecting a stronger automatic response capture for CNT trials. This effect was not observed in the isolated Go/NoGo ( $p = .13$ , ELI CNT incorrect activations:  $M=0.71, SE=0.01$  vs ELI IPS incorrect activations:  $M=0.72, SE=0.01$ , Figure 3).

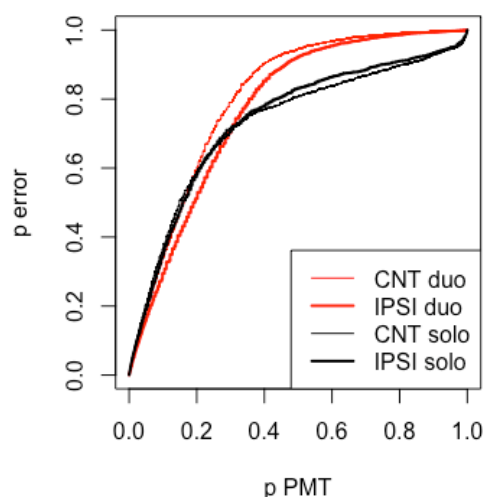


Figure 3. Error Location function (ELF) derived from the PMT distribution of incorrect activations compared to the PMT distribution of all trials in the joint Go/NoGo (red lines) and in the isolated Go/NoGo (black lines) tasks as function of the spatial correspondence of the stimulus relative to the response (ipsilateral vs. contralateral).

### 3.3. Delta plots

A t-test performed on the individual delta plot slopes suggested that the mean slope in the Simon task ( $M=-0.035, SE=0.16$ ) was different ( $t(37) = 2.01, p = .052, \text{Cohen-}d = 0.33$ ) from that in the joint Go/NoGo task ( $M=0.030, SE=0.14$ ).



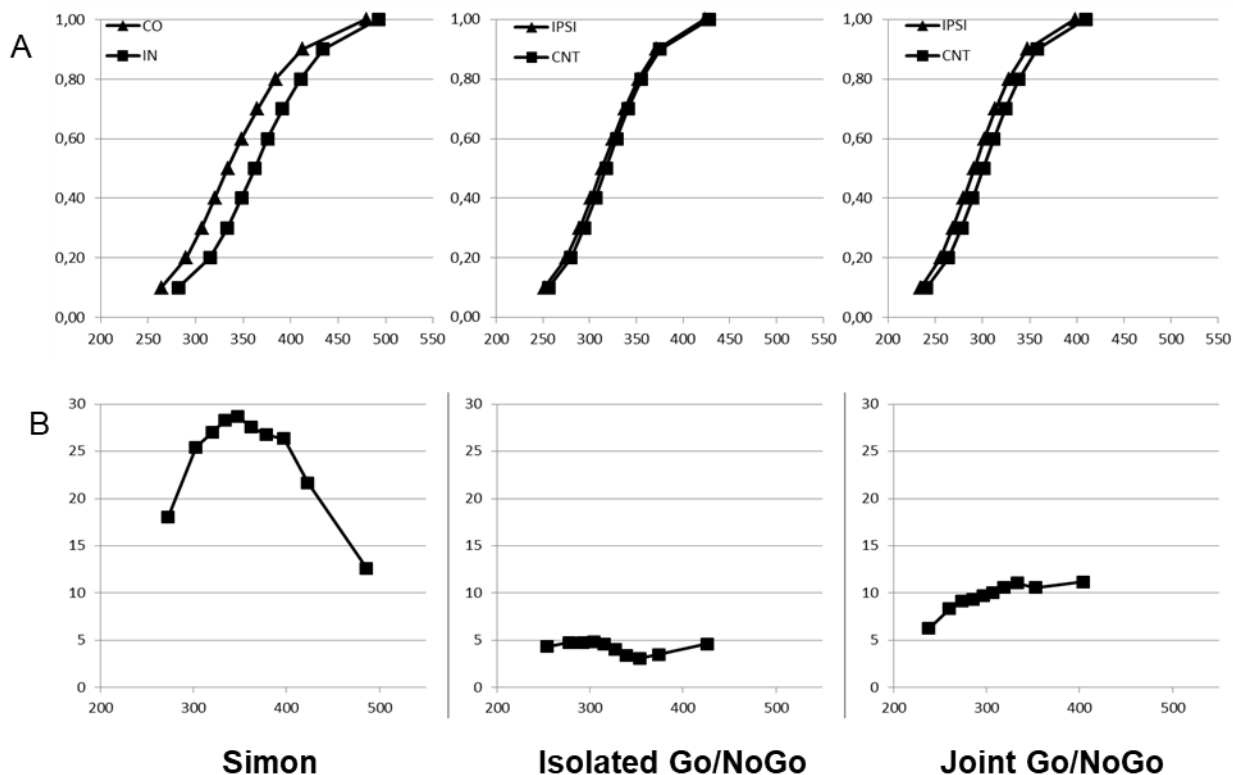


Figure 4. (A) Curve density function (CDF) (in milliseconds) in the individual Simon task, isolated Go/NoGo task and joint Go/NoGo task, from the left to the right, as function of the spatial correspondence. CO: congruent trials, IN: incongruent trials, IPS: ipsilateral trials, CNT: contralateral trials. (B) Delta plot of reaction time illustrating the spatial correspondence effect (in milliseconds) as function of mean reaction time in the individual Simon task, isolated Go/NoGo task and joint Go/NoGo task, from the left to the right.

#### 4. Discussion

EMG recordings and RT distributional analyses were used here in a single protocol to quantify the strength of automatic response capture induced by stimulus location when participants performed a standard Simon task, an isolated Go/NoGo task (performed in alone in the cubicle) and completed a joint Go/NoGo task with a co-acting friend.

The results might be interpreted in the light of the double-route model (Kornblum et al., 1990) for tasks where stimulus-response compatibility is manipulated. This model has two main features: first, automatic responses are triggered by the stimulus-response correspondence. Second, these automatic responses are aborted by control processes. While this model has been designed to account for the S-R effect in the Simon task it can be conceptually useful to understand the present data. Both behavioural and electromyographic data suggest a general increase of arousal, together with an increase of the strength of the stimulus-response association and a degradation of the cognitive control processes when subjects perform the task jointly rather than in isolation.

First, we confirmed the presence of a spatial correspondence effect (cSE) in the Go/NoGo task performed in isolation, replicating previous results (Callan et al., 1974; Davranche et al., 2018), and the presence of a JSE in the joint Go/NoGo task. The spatial correspondence effect found in isolation (cSE = 5 ms) was actually twice as large when the Go/NoGo task was performed under coaction (JSE = 11 ms). Note that, as illustrated on Figure 4, the magnitude of the effect of spatial correspondence observed in the Go/NoGo tasks remained much lower than that observed in a Simon task. This might be explained by the fact

that in Go/NoGo tasks, the single response is known in advance and so could be fully prepared, which is not the case during the Simon task, for which additional decision stages are required to select one of the two possible alternatives. Moreover, the time course of the spatial correspondence effect in the joint Go/NoGo task did not follow a similar qualitative pattern to that observed in a Simon task. Given these differences in the shapes of observed delta plots, it is worth considering that the interference effect in the Go/NoGo tasks is not of the same nature and may principally be driven by a facilitation of IPS associations. By contrast, it has been proposed that the negative-going slope obtained in the Simon paradigm constitutes a noteworthy phenomenon considered as a signature of some specific cognitive architecture (see Schwarz & Miller, 2012). This slope is mainly due to the fact that, for CNT associations, the incorrect response triggered by automatic response capture should be interrupted but also corrected (Kornblum et al., 1990). These additional processes require an extra time. Hence, even such processes are likely not purely “inserted” (in a Dondersian perspective, Donders, 1868; see also Vidal, Burle, Grapperon, & Hasbroucq, 2011), they increase RT and consequently lead to a larger spatial correspondence effect.

Second, the analysis performed on individual ELI suggests a stronger automatic response capture when participants performed the Go/NoGo task in presence of a co-actor than when they performed the task in isolation. These results are in line with a strengthening of ipsilateral stimulus-responses associations, and therefore support the fact that the JSE results from a potentiation of a preexisting cSE due to increased automatic response capture. It is worth noting that these results are difficult to account for in the framework of the referential coding theory (e.g., Dolk et al., 2011, 2013). According to this theory, the presence of a co-actor, and of a visual and/or auditory irrelevant object (be it social or not) placed nearby single participants would be subjectively coded as an alternative to the required response. The coexistence of these two representations would induce participants to code their unique response in terms of left or right relative to the other’s response. This coding would thereby induce a JSE while the participants objectively perform a Go/NoGo task. In other words, the match that drives the JSE would concern the perceptual representations of the stimulus and response events that the participants label “left” and “right” relative to a reference frame. In the course of a trial, the participant would thus have to choose between these two lateralized responses, which would be sufficient to generate a conflict and thereby a Simon-like effect (or a JSE in the case of the presence of a co-actor). The present results are difficult to explain in this framework mainly because it refutes (or at least neglects) the very existence of a cSE when the Go/NoGo task is performed in isolation. Additionally, referential coding theory predicts slower RT and PMT, at least for CNT trials. The current results highlight the opposite effect, showing a speed-up of both RT components (i.e., PMT and MT).

Third, comparing isolated and joint Go/NoGo tasks, we found that joint-action shortened RT by impacting both pre-motor time and motor time. Moreover, participants committed more overt and partial errors in the joint Go/NoGo compared to the isolated Go/NoGo tasks. These observations are compatible with a global increase of arousal that would shorten both fractionated components of reaction time, and a strengthening of the stimulus-response association that would increase the number of incorrect activations, resulting in more overt and partial errors when the task is performed jointly in comparison to isolation.

Finally, we observed that 1) the difference between ipsilateral and contralateral RTs is increased when the task is performed jointly; 2) the difference between ipsilateral and contralateral overt errors is increased when the task is performed jointly (see Figure 2), while this is not the case for partial errors. These results might be also accounted by the conjunction

of a general increase of arousal and a strengthening of the ipsilateral stimulus-response association. A general increase of arousal would indeed simultaneously increase ipsilateral and contralateral incorrect activations. A strengthening of the stimulus-response association would specifically increase the number of ipsilateral incorrect activations. As a result, there would be a stronger increase of the number of incorrect activations for ipsilateral than for contralateral trials when the task is performed jointly rather than in isolation. For a given number of incorrect activations, an impairment of the cognitive control processes increases the number of overt errors and decreases the number of partial errors. Thus, a degradation of cognitive control processes when the task is performed jointly would amplify these effects (i.e., increased arousal and strengthening of the association) on overt errors, while reducing them on partial errors. All this would result in a larger increase in the difference between ipsilateral and contralateral overt errors compared to partial errors when the task is performed jointly rather than in isolation.

Importantly, this difference between the patterns of overt and partial errors cannot be explained by Zajonc's (1965) classic view of social facilitation. According to this view, the emission of ipsilateral responses would be facilitated in the joint Go/NoGo task, compared with the Go/NoGo task in isolation. Because ipsilateral responses might be either correct or incorrect, this facilitation effect would speed up correct responses and increase the number of errors, as observed. However, social facilitation theory also predicts that ipsilateral responses should be more facilitated than contralateral ones, inducing a larger increase of the number of both overt and partial responses for ipsilateral trials than for contralateral ones. Thus, the number of both overt and partial errors should increase more for ipsilateral than for contralateral trials when the task is performed jointly. This is actually what we observed for overt errors, but not for partial errors. Therefore, while behavioral results might suggest performing jointly the Go/NoGo task induce a social facilitation effect, electromyographic data reveal a more complex picture. Zajonc's theory accounts for a part of the JSE, as it predicts a facilitation of the ipsilateral stimulus-response association in the joint condition. However, our data indicate that additional processes are at work: (i) the general reduction of RTs and MTs in the joint condition suggest the existence of a global increase of arousal under coaction while (ii) the presence of an ipsilateral facilitation evidenced on overt errors but not on partial errors, when the task is performed jointly, also suggests that coaction impairs cognitive control processes. Importantly, these two last processes could not have been evidenced without EMG analyses. Indeed, overt and partial errors both result from an incorrect activation, which is corrected in the case of partial errors. The fact that only overt errors increase on ipsilateral trials suggests a decreased correction of the incorrect activations, and thus an impairment of cognitive control processes at stake in the joint Go/NoGo compared to the isolated Go/NoGo task. Consistent with the present results, there is evidence of reduced cognitive control in the presence of others (Belletier et al., 2015; Belletier, Normand, Camos, Barrouillet, & Huguet, 2019; Huguet, Barbet, Belletier, Monteil, & Fagot, 2014; Wagstaff, Wheatcroft, Brunas-Wagstaff, Blackmore, & Pilkington, 2008; Wühr & Huestegge, 2010; for a recent review, see Belletier, Normand, & Huguet, 2019). There is also evidence that socially induced facilitation of dominant responses and reduced cognitive control may occur simultaneously (Huguet et al., 2014; Mazerolle, Régner, Morisset, Rigalleau & Huguet, 2012).

In conclusion, our findings indicate that joint-action increases the strength of automatic response capture induced by the stimulus location, promotes the delivery of the stronger association in the behavioral repertoire of the individual, and impairs cognitive control.

**Funding:** This work was part of C.B.'s PhD funded by the "Direction General de l'Armement" under the supervision of P.H. and has also been supported by a public grant overseen by the French National Research Agency (ANR) with P.H. and T.H. as PI [reference: ANR-10-BLAN-1915]

**Author Contributions:** K.D., C.B., T.H., P.H., and F.V. conceived and designed the experiments. K.D., L.C., and C.B. performed the experiments. K.D., L.C., and T.G. analyzed the data. K.D. took the lead in writing the manuscript. K.D., T.H., and T.G. wrote the first draft of the manuscript. Both K.D. and C.B. contributed to the final version with input from all authors.

## References

Belletier, C., Davranche, K., Tellier, I. S., Dumas, F., Vidal, F., Hasbroucq, T., & Huguet, P. (2015). Choking under monitoring pressure: Being watched by the experimenter reduces executive attention. *Psychonomic Bulletin & Review*, 22(5), 1410-1416.

Belletier, C., Normand, A., Camos, V., Barrouillet, P., Huguet, P. (2019). Choking under experimenter's presence: Impact on proactive control and practical consequences for psychological science. *Cognition*, 189, 60-64.

Belletier, C., Normand, A., & Huguet, P. (2019). Social facilitation/impairment effects: From motivation to cognition and social brain. *Current Direction in Psychological Science*. 28(3), 260-265.

Bond, C. F., & Titus, L. J. (1983). Social facilitation: A meta-analysis of 241 studies. *Psychological Bulletin*, 94(2), 265-292. <https://doi.org/10.1037/0033-2909.94.2.265>

Callan, J., Klisz, D., & Parsons, O. A. (1974). Strength of auditory stimulus-response compatibility as a function of task complexity. *Journal of Experimental Psychology*, 102(6), 1039.

Craft, J. L., & Simon, J. R. (1970). Processing symbolic information from a visual display: interference from an irrelevant directional cue. *Journal of Experimental Psychology*, 83(3), 415-420.

Davranche, K., Carbonnell, L., Belletier, C., Vidal, F., Huguet, P., Gajdos, T., & Hasbroucq, T. (2018). A Simon-like effect in Go/No-Go tasks performed in isolation. *Psychonomic Bulletin & Review*. <https://doi.org/10.3758/s13423-018-1534-6>

De Jong, R., Liang, C.-C., & Lauber, E. (1994). Conditional and unconditional automaticity: a dual-process model of effects of spatial stimulus-response correspondence. *Journal of Experimental Psychology: Human Perception and Performance*, 20(4), 731.

Dolk, T., Hommel, B., Colzato, L. S., Schütz-Bosbach, S., Prinz, W., & Liepelt, R. (2014). The joint Simon effect: a review and theoretical integration. *Frontiers in Psychology*, 5. <https://doi.org/10.3389/fpsyg.2014.00974>

Dolk, T., Hommel, B., Colzato, L. S., Schütz-Bosbach, S., Prinz, W., & Liepelt, R. (2011). How "social" is the social Simon effect? *Frontiers in Psychology*, 2. <https://doi.org/10.3389/fpsyg.2011.00084>

Dolk, T., Hommel, B., Prinz, W., & Liepelt, R. (2013). The (not so) social Simon effect: A referential coding account. *Journal of Experimental Psychology: Human Perception and Performance*, 39(5), 1248-1260. <https://doi.org/10.1037/a0031031>

Donders, F. C. (1868). La vitesse des actes psychiques. *Archives néerlandaises des sciences exactes et naturelles*, 3, 916-317.

Ellinghaus, R., & Miller, J. (2018). Delta plots with negative-going slopes as a potential marker of decreasing response activation in masked semantic priming. *Psychological research*, 82(3), 590-599.

- Fagot, J., Marzouki, Y., Huguet, P., Gullstrand, J., & Claidière, N. (2015). Using a network of computerized ALDM test systems for the assessment of social cognition in non-human primates. *Journal of Visualized Experiments (JOVE)*, 99, doi: 10.3791/52798
- Guerin, B. (2009). *Social Facilitation*. Cambridge: Cambridge University Press
- Hasbroucq, T., Possamaï, C. A., Bonnet, M., & Vidal, F. (1999). Effect of the irrelevant location of the response signal on choice reaction time: an electromyographic study in humans. *Psychophysiology*, 36(4), 522-526.
- Hasbroucq, Thierry, Burle, B., Vidal, F., & Possamaï, C.-A. (2009). Stimulus-hand correspondence and direct response activation: An electromyographic analysis. *Psychophysiology*, 46(6), 1160-1169. <https://doi.org/10.1111/j.1469-8986.2009.00865.x>
- Huguet, P., Barbet, I., Belletier, C., Monteil, J.-M., & Fagot, J. (2014). Cognitive control under social influence in baboons. *Journal of Experimental Psychology: General*, 143(6), 2067-2073. <https://doi.org/10.1037/xge0000026>
- Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional overlap: cognitive basis for stimulus-response compatibility--a model and taxonomy. *Psychological Review*, 97(2), 253-270.
- Mazerolle, M., Régner, I., Morisset, P., Rigalleau, F., & Huguet, P. (2012). Stereotype threat strengthens automatic recall and undermines controlled processes in older adults. *Psychological science*, 23(7), 723-727.
- Schwarz, W., & Miller, J. (2012). Response time models of delta plots with negative-going slopes. *Psychonomic Bulletin & Review*, 19(4), 555-574. <https://doi.org/10.3758/s13423-012-0254-6>
- Sebanz, N., Bekkering, H., & Knoblich, G. (2006). Joint action: bodies and minds moving together. *Trends in Cognitive Sciences*, 10(2), 70-76. <https://doi.org/10.1016/j.tics.2005.12.009>
- Sebanz, Natalie, Knoblich, G., & Prinz, W. (2003). Representing others' actions: just like one's own? *Cognition*, 88(3), B11-B21.
- Seitchik, A. E., Brown, A. J., & Harkins, S. G. (2017). Social facilitation: Using the molecular to inform the molar. *The Oxford handbook of social influence*, 183.
- Servant, M., Gajdos, T., & Davranche, K. (2018). ELF: A new measure of response capture. *Psychonomic Bulletin & Review*, 25(2), 539-547. <https://doi.org/10.3758/s13423-017-1389-2>
- Simon, J. R. (1990). The effects of an irrelevant directional cue on human information processing. In *Advances in psychology, Vol. 65. Stimulus-response compatibility: An integrated perspective*. (p. 31-86). Oxford, England: North-Holland.
- Tsai, C. C., & Brass, M. (2007). Does the human motor system simulate Pinocchio's actions? Coacting with a human hand versus a wooden hand in a dyadic interaction. *Psychological Science*, 18(12), 1058-1062.
- Van Boxtel, G. J., Geraats, L. H., Van den Berg-Lenssen, M. M., & Brunia, C. H. (1993). Detection of EMG onset in ERP research. *Psychophysiology*, 30(4), 405-412.
- Vidal, F., Burle, B., Grapperon, J., & Hasbroucq, T. (2011). An ERP study of cognitive architecture and the insertion of mental processes: Donders revisited: ERPs and the insertion assumption. *Psychophysiology*, 48(9), 1242-1251. <https://doi.org/10.1111/j.1469-8986.2011.01186.x>
- Wagstaff, G. F., Wheatcroft, J., Cole, J. C., Brunas-Wagstaff, J., Blackmore, V., & Pilkington, A. (2008). Some cognitive and neuropsychological aspects of social inhibition and facilitation. *European Journal of Cognitive Psychology*, 20(4), 828-846.
- Wühr, P., & Huestegge, L. (2010). The impact of social presence on voluntary and involuntary control of spatial attention. *Social Cognition*, 28(2), 145-160.
- Zajonc, R. B. (1965). Social Facilitation. *Science*, 149(3681), 269-274.

