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Effects of acoustic warning signal intensity in the control of visuospatial interference

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Previous studies have reported increased interference when a task-irrelevant acoustic warning signal preceded the target presentation in cognitive tasks. However, the alerting-congruence interaction was mostly observed for tasks measuring Flanker and Simon interferences but not for Stroop conflict. These findings led to the assumption that warning signals widen the attentional focus and facilitate the processing of irrelevant spatial characteristics. However, it is not clear whether these effects are because of the temporal information provided by the warning signal or because of their alerting effects. Based on these findings, and on the open question about the nature of the warning signal intervention on visuospatial interferences, we decided to test the impact of the warning signal on the processing of irrelevant spatial features, by using a procedure suitable for measuring both Simon and spatial Stroop interferences. We also manipulated the intensity of the warning signal to study the effect of the task-irrelevant characteristics of warning signals in visuospatial interferences. For the Simon conflict, results demonstrated an increased interference provoked by the presence (Experiment 1) and intensity (Experiment 2) of warning signals. In contrast, neither the presence nor the

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intensity of warning signals affected the spatial Stroop interference. Overall, these findings suggest that the impact of warning signals primarily depends on the processing of irrelevant spatial attributes and on the type of conflict (e.g., spatial stimulus-response interference in Simon vs. stimulus-stimulus interference in spatial Stroop). In general, acoustic warning signals facilitate the automatic response activation, but their modulatory effect depends on the task setting involved.

Alertness is a cognitive mechanism that allows an organism to rapidly mobilize resources when they are most needed and prepares the system for fast reactions to imminent events. When a warning signal (WS), anticipating the presentation of a target stimulus, activates the general state of readiness to respond, we refer to phasic alerting, which usually leads to shorter reaction times (RTs; Bertelson, 1967; Egan, Greenberg, & Schulman, 1961; Posner & Boies, 1971; Posner & Wilkinson, 1969). Furthermore, a WS's task-irrelevant characteristic, which is not its most essential feature, such as acoustic intensity, has been shown to affect performance. In particular, higher intensities are usually associated with faster RTs in simple reaction times tasks (Angel, 1973; Cappucci, Correa, Guerra & Lupiáñez, 2018; Coull, Frith, Büchel & Nobre, 2000; Jaskowsky, Rybarczyk & Jaroszyk, 1994; Miller, Franz & Ulrich, 1999; Näätänen, 1970).

Although phasic alerting and conflict resolution are considered to be dissociable mechanisms (Posner & Boies, 1971; Posner & Petersen, 1990), there is still a lack of consensus regarding the conditions and the specific processes involved in the interaction between them (Coull, Jones, Egan, Frith & Maze, 2004; Hackley & Valle-Inclàn, 2003; Weinbach & Henik, 2012). In their attempt to clarify the interaction between these two mechanisms, Callejas, Lupiáñez and Tudela (2004) found a detrimental effect of WSs on performance in a flanker task paradigm (Eriksen & Eriksen, 1974), where targets are presented centrally and surrounded by target-like distracters, associated to either the same (congruent condition) or the opposite (incongruent condition) response. The authors reported a larger interference effect after the presentation of a tone and explained their findings in terms of the alerting mechanisms inhibiting the conflict resolution mechanisms and facilitating the response activation (Callejas, Lupiáñez & Tudela, 2004).

However, a few years later, Fischer and collaborators carried out a series of experiments suggesting that WSs speed up the translation of the visual information code into the associated motor code, thus leading to faster responses and larger interference effects when the target stimulus is presented (Fischer, Plessow & Kiesel, 2010). This argumentation is based on findings with the Simon interference paradigm (Simon &Rudell, 1967; Simon &

Small, 1969), which is largely used to study stimulus-response (S-R) interference (for a review, see Proctor, 2011). In particular, the Simon interference helps to assess the impact of motor task-irrelevant features on conflicting responses, as a lateralized response must be given on the basis of a feature (e.g., colour or shape) to a lateralized target, being location task-irrelevant. After observing an increased Simon interference in concomitance with the presentation of a WS, Fischer suggested that a WS does not impact the general state of readiness but rather the strength of automatic response activation, speeded up by the WS itself (Fischer, Plessow & Kiesel, 2010).

This explanation was mainly based on the frame of the dual-route account (Kornblum, Hasbroucq & Osman, 1990). According to this account, the imperative stimulus during the Simon condition activates two parallel processes of response preparation: the direct processing route (priming responses corresponding to irrelevant stimulus location) and the indirect processing route (priming responses based on task- relevant features). The WS-related activation of the direct route produces a faster RT, while the activation of the indirect route increases interference. According to Fischer´s account, WSs speed up responses by activating the direct route, thus increasing interference, as they facilitate the activation of automatic responses, which are based on the direct translation of visual information into the corresponding motor codes (Fischer et al., 2010).

Weinbach and Henik (2012) also tested the modulation of phasic alerting over conflict resolution within several types of interference. One of those was the classical Stroop interference paradigm. The Stroop interference (Stroop, 1935) is frequently used as a tool to study stimulus-stimulus (S-S) interference. In the classic Stroop paradigm, the response is associated with a specific feature of the target (e.g., the ink colour of words), while another stimulus feature is irrelevant to the task (e.g., the meaning of words indicating colours). As in all conflict tasks, for incongruent conditions, the task- relevant feature diverges from the irrelevant one, and longer RTs are usually reported. Weinbach and Henik (2012) found strong Stroop interference, which was nevertheless not modulated by the WS. Conversely, in a flanker task paradigm, they found a clear modulation by a WS, with a larger interference effect in concomitance with the WS presentation, although this result was only observed under specific spatial arrangement of the visual stimuli (Schneider, 2018). Therefore, they concluded that WSs affect the conflict resolution mechanisms, thereby leading to larger interference, but only when there is spatial information to process. The authors claimed that alerting mechanisms induce a global processing bias, a larger attentional focus, and a higher accessibility to any spatial information in the visual field. As a consequence, when a distracter and a target are separated, alerting increases the congruence effect (Weinbach & Henik, 2012). The debate is still ongoing regarding which one is the best interpretation to explain the impact of WSs on the interference effect, the facilitated translation of a stimulus into a response, or the wider attentional scope following a WS.

Böckler and colleagues decided to bring a deeper level of knowledge about the attentional processes involved by recording event-related potentials (Böckler, Alpay & Stürmer, 2011). In a Simon interference paradigm, they found an increased activity of cortical areas involved in the response preparation after the presentation of a WS. Inparticular, they reported that a WS enhances the incorrect lateralized readiness potential (LRP) activation in incompatible trials. The early, incorrect LRP activation in interference trials supports the idea of facilitated response activation by the WS. These findings stand in clear contrast to interpretations of enlarged interference effects as a result of hampered cognitive control by a WS. In terms of the dual-route framework, their results rather suggest that a WS amplifies the response hand activation, triggered by the spatially corresponding stimulus location (Böckler, et al.,2011).

Another piece of the alerting-conflict resolution puzzle was added by Soutschek, Müller and Schubert (2013), who examined the effects of WSs on conflict processing and post-conflict adjustments in both the Stroop and the Simon paradigms. The results revealed that WSs affected the post-conflict adjustments of sequential congruency effects only in the Stroop interference, but not in the Simon interference, with the Simon effect depending on the congruency of the previous trial independently of the presence or absence of a WS, whereas this post-conflict adjustment was cancelled for the Stroop effect when a WS was presented. They concluded that differential conflict resolution mechanisms are involved in these paradigms, and the differentiation between different types of interference and their specific resolution strategies is essential to understand the differential effect of phasic alerting on post-conflict adjustments in Stroop and Simon interferences (Soutschek et al., 2013).

Considering all studies together, it seems that the modulatory effect of WSs on conflict resolution mechanisms depends on the types of interference involved. To test Weinbach and Henik´s account, Schneider (2019) conducted a series of eight Stroop- like paradigms, concluding that the alerting-conflict interaction typically found with the arrow flanker interference does not generalize to Stroop interference. However, he attributed this difference to the type of target stimulus used and the task setting. More specifically, the alerting mechanisms should influence conflict resolution primarily when the task goals are associated with spatial information processing. In fact, for tasks that have relevant visuospatial features (e.g., classifying the spatial direction of an arrow), the increased alertness affects multiple stages of information processing (e.g., stimulus encoding and response selection), especially when the target stimuli have well- established spatial connotations and the interaction between alerting and control mechanisms should be expected (Schneider, 2019). Weinbach´s work (2012) also motivated a series of Flanker-like paradigms used to measure the variation of attentional focus size (Seibold, 2018). However, in contrast to the predictions based on Weinbach and Henik, no differences between trials with vs. without a WS were reported. These results rather support Fischer´s account that locates the emergence of the congruency- by-alerting interaction at the level of response selection (Seibold, 2018).

However, in the above-mentioned studies (Seibold, 2018; Soutschek et al., 2013; Schneider, 2018; Weinbach & Henik, 2012), the separation of the relevant and irrelevant features of WS information was not taken into account. This is important because the mere separation of the target and distracter objects indicated by Weinbach and Henik (2012) cannot be the core element, as other studies found the interaction when target and visuospatial information are integrated (Böckler et al., 2011; Fischer et al., 2010; Funes & Lupiàñez, 2003; Seibold, 2018; Schneider, 2018). For this reason, in the current study, we directly manipulated alerting and conflict resolution in a task designed to have integrated target and task-irrelevant visuospatial information in the same visual object, which, according to Weinbach´s account (2012), should lead to no modulation of WSs over the conflict resolution mechanisms. Importantly, this paradigm was suitable to measure both S-S and S-R interferences and test how they are modulated by the presentation of a task-irrelevant acoustic WS. The task, involving the Simon interference and the spatial version of Stroop interference (Lu & Proctor, 1995), required participants to respond with left or right hands to target (arrows) pointing up or down and presented at the top, bottom, left, or right positions (Lupiáñez & Funes, 2005). Fischer´s account (Fischer, et al., 2010) indicated that a WS should speed up congruent responses and be followed by larger interferences, even in the case of integration between target and task-irrelevant visuospatial features. For this reason, we expected faster RTs in trials where a WS was presented, and we expected the Simon interference effect to be increased by the presence of the WS. We did not expect to report a modulation of the spatial Stroop interference, as the effect of the WS was expected at the level of response selection.

In addition, we studied the impact of a fully irrelevant characteristic of WS (i.e., acoustic intensity) in both types of interference. Note that not only is acoustic intensity task-irrelevant, but it also provides no temporal information beyond that provided by the mere presentation of the WS. This aspect is relevant because temporal preparation has been shown to modulate Simon and spatial Stroop interferences differently (Correa, Cappucci, Nobre & Lupiáñez, 2010). Thus, the manipulation of acoustic intensity allows for an increase in alertness, without temporal preparation. To test whether the influence of WS acoustic intensity is interference-specific, we presented the same stimulus as the WS but with two levels of intensity, and we expected faster responses in conditions in which the intensity of the WS was higher.

EXPERIMENT 1

In Experiment 1, we used a version of the Simon and spatial Stroop paradigm suitable to measure both S-S and S-R interferences within the same trial (for a similar paradigm see Luo, Lupiáñez, Funes & Fu, 2011). To test phasic alerting and intensity- related modulation, targets were preceded or not by an acoustic warning signal, and we presented the same stimulus as WS but with two levels of intensity.

METHOD

Participants. Thirty-two students (mean age: 21 years; age range: 18-25 years; 3 males) from the Universidad de Granada took part to the study. Participants had normal or corrected-to- normal audition and vision. The experiment followed the ethical guidelines from the Department of Experimental Psychology (Universidad de Granada), in accordance with the ethical standards of the Declaration of Helsinki (1964).

A priori power analyses were not performed. Therefore, we conducted a post-hoc sensitivity analysis using G*power (Faul, Erdfelder, Lang & Buchner, 2007). Results revealed that with our sample size (N=32), the minimum detectable effect size for α=.05, and $1-\beta$=0.80, isf=0.16.

Apparatus and stimuli. A PC running E-prime 2.0 (Schneider, Eschman & Zuccolotto, 2002) and a 17 Inches BenQ FP731 monitor located at approximately 60 cm from the participant were used for stimulus presentation and data collection. The warning signal consisted of an auditory burst of white noise presented for 40ms and amplified by a Logitec X-540 sound system through a pair of Philips headphones. A 1.43° x 1.15° white arrow, pointing either upwards or downwards, was displayed as target stimulus for 100ms in one of four possible positions at 4.39° from the 0.67° x 0.67° central fixation (see Figure 1).

Task and experimental design. Participant's task consisted of responding as fast and accurately as possible to the upwards/downwards direction of the arrow target, by pressing either the "v" key with the left hand or the "m" key with the right hand. The association between the key and the arrow direction was counterbalanced across participants: in 50% of participants "m" key was associated to "upward" arrow's direction and the "v" key to "downward" arrow's direction; for the remaining half of participants such association was reverted. The position of target was an important element of our manipulation. During the experiment, the arrow was equally presented in either of four positions of the screen: top left, top right, bottom left and bottom right. Each of the target locations leaded to S- S or S-R sources of interference and was equally distributed through each block with a pseudorandom order. In particular, when an arrow pointing up appeared above the fixation point or an arrow pointing down appeared below the fixation, the trial was categorized as spatial Stroop congruent; when an arrow pointing up appeared below the fixation or an arrow pointing down appeared above the fixation, the trial was categorized as spatial Stroop incongruent. On the other hand, trials where target position coincided with the associated hand to respond were categorized as Simon congruent; when the target appeared in opposite side to the corresponding hand, trials were categorized as Simon incongruent. Overall, and depending on the arrow´s direction, four types of conditions were obtained: spatial Stroop congruent/Simon congruent trials (25% of cases); spatial Stroop incongruent/Simon incongruent trials (25%); spatial Stroop incongruent/Simon congruent trials (25%); spatial Stroop congruent/Simon incongruent trials (25%) (Figure1).

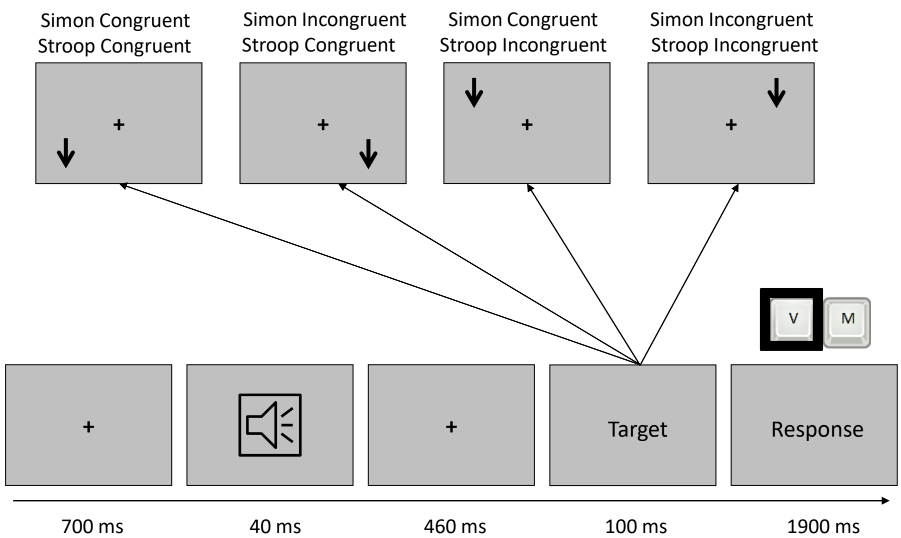

Figure 1. The timeline and all possible target positions in Experiment 1 (from left to right). The acoustic warning signals were accompanied by a fixation point and presented for 40 ms, only in 2/3 of trials. The remaining 1/3 of trials had no warning signal prior to target presentation. After a 460

ms interval, the target was presented for 100 ms and responses were allowed up to 1900 ms later; participants were asked to indicate as fast as possible the direction of the target (the up/down pointing arrow). The black contour framing the key´s letters indicates the correct response of the trial (in this case, the target is a down-pointing arrow and the "v" key is the correct answer). Each trial could be spatial Stroop and Simon Congruent (C) or Incongruent (I).

The experiment yielded one training block (32 trials) and nine experimental blocks of 48 trials each, for a total of 432 experimental trials. Each trial started with a black display and a white fixation point presented for 700 ms. Then, a burst of white noise was presented for 40 ms in 2/3 of the trials. When presented, this acoustic WS reached a medium intensity of 63 dB in half of trials and a high intensity of 83 dB in the other half, followed by a 460 ms long fixation point. In the remaining 1/3 of the trials, no warning signal was disclosed at all and just the fixation point was presented for 500 ms. At this point, we presented the target display with one of four possible targets. Intervals between WS and target presentation (stimulus onset asynchrony, SOA) at around 400ms were often associated in literature with a peak of alerting efficiency (Fernandez- Duque & Posner, 1997; Fan et al., 2002; Callejas et al., 2004; Callejas, Lupiàñez, Funes & Tudela, 2005; Fuentes & Campoy, 2008). The target (an arrow pointing up or down) was presented only for 100 ms, however responses were recorded for the following 1900 ms (Figure 1). During the experiment, feedbacks for anticipation/incorrect responses were provided.

RESULTS

Data analysis. Our analyses were based on the distribution of mean RT and error rates. Reaction times measured participant´s speediness to respond after the target onset. All anticipatory responses (e.i. participants responding after the WS onset but before the target onset) were excluded from analysis (0.36%). Concerning the error analysis, we considered a trials incorrect when participants pressed the incorrect key, or did not respond to the target appearance. This resulted on 4.08% of trials excluded. In line with the literature about behavioral post-error adaptations for reaction times and accuracy (Notebaert, Houtman, Van Opstal, Gevers, Fias & Verguts, 2009), trials preceded by anticipatory responses and incorrect trial were also excluded. In the RT analysis, all incorrect trials and trials with responses slower or faster than 2.5 standard deviations from the sample RT mean (M=529 ms, SD=117 ms) were also excluded from analyses (2.66%). To test the assumption of sphericity in both distributions, we ran the Mauchley's test. In case of violation of the assumption of sphericity (for one or more factors), p values were adjusted following the Greenhouse-Geisser correction of sphericity.

Mean reaction times and errors rate were analyzed by a mixed-design ANOVA with Warning signal (No WS, 63 dB, 83 dB), spatial Stroop interference (congruent, incongruent) and Simon interference (congruent, incongruent) as within-participants factors. For each experimental condition, in the Table 1 we reported the mean RT, the standard deviations and the errors percentages. Given that significant main effects for both visuospatial interferences were observed, we calculated two indices of interference effect, by subtracting congruent from incongruent mean RT for each one separately and submitted those indices to two separate univariate ANOVA.

Table 1. Experiment 1. The table indicates values of all possible levels of spatial Stroop interference, Simon interference and Warning signal. Value of mean reaction times and standard deviations are in milliseconds. Parentheses contain mean errors percentages for each condition.

	Spatial Stroop Congruent		*Spatial Stroop Incongruent*	
	Simon Congruent	*Simon Incongruent*	*Simon Congruent*	*Simon Incongruent*
No WS	541 ± 78 (2.2%)	562 ± 83 (6.1%)	551 ± 73 (3.8%)	572 ± 70 (5.8%)
63 dB	498 ± 65 (1.5%)	531 ± 66 (5.3%)	512 ± 61 (3.3%)	540 ± 64 (6.6%)
83 dB	491 ± 63 (0.8%)	520 ± 71 (4.8%)	510 ± 60 (2.4%)	527 ± 63 (7.9%)

RT analysis. O For the reaction times distribution, Mauchly's test indicated a sphericity violation for the Warning signal factor ($\chi^2(2)=12.8$, $p=.002$). From the ANOVA, a main effect of Warning signal was found, $F(2,62)=92.19$, $p<.001$, $\eta_p^2=.75$. Planned comparisons confirmed that trials without WS ($M=555$ ms, $SD=121$ ms) were slower compared to trials with WS of 63 dB ($M=520$ ms, $SD=114$ ms), $F(1,31)=77.32$, $p<.001$, and 83 dB ($M=512$ ms, $SD=112$ ms), $F(1,31)=12.86$, $p=.001$. Moreover, RT were significantly faster for 83 dB compared to 63 dB conditions, $F(1,31)=12.86$, $p=.001$. In line with our expectations, we also observed main effects of spatial Stroop, $F(1, 31)=16.02$, $p<.001$, $\eta^2=.34$, and Simon, $F(1,31)=57.7$, $p<.001$, $\eta^2=.65$, responses being faster for congruent (s. Stroop: $M=523$ ms, $SD=121$ ms; Simon: $M=517$ ms, $SD=118$ ms) than incongruent conditions (s. Stroop: $M=535$ ms, $SD=113$ ms; Simon: $M=542$ ms, $SD=115$ ms). In line with our initial premises, we reported a significant interaction between Simon interference and Warning signal factors, $F(2, 62)=4.2$ $p=.020$, $\eta_p^2=.12$. As shown in Figure 2, the Simon interference was modulated by the irrelevant dimensions of WS (i.e., the intensity and the presentation of the WS itself).

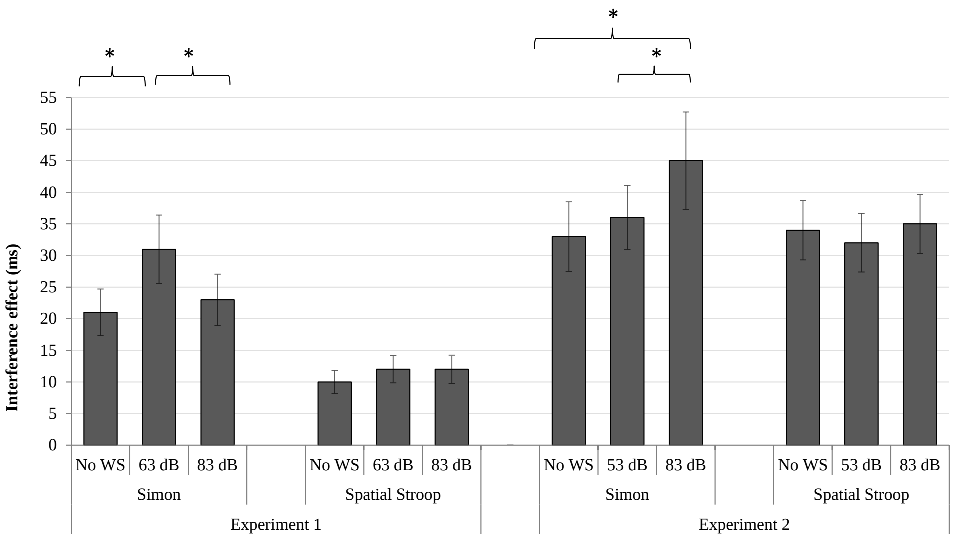

Figure 2. The Simon and Spatial Stroop interference effect (incongruent minus congruent mean RT) as a function of Warning signal (No WS, 53/63 dB, 83 dB) for Experiment 1 (left panel) and 2 (right panel). The gray lines above each bars indicate the standard error of the mean for each condition. Asterisks ("*") indicate p <.05.

On the other hand, Warning signal and spatial Stroop factors did not interact, $F(2,62)=.18$, $p=.832$. The Simon and spatial Stroop interferences are independent, $F(1,31)=1.92$, $p=.175$, and the three-way interaction Warning signal X spatial Stroop X Simon was also not significant, $F(2,62)=1.69$, $p=.195$.

The ANOVA on the Simon indices of interference effect showed a significant main effect for WS, $F(2,62)=4.11$, $p=.021$, $\eta_p^2=.12$. The planned comparisons showed a larger interference effect for 63 dB WS (interference effect: 31 ms) compared to No WS conditions (interference effect: 21 ms), $F(1,31)=7.52$, $p=.010$. However, the Simon effect decreased again for 83 dB WS (interference effect: 23 ms), $F(1,31)=5.33$, $p=.028$ (see Figure 2). No differences were found between No WS and 83 dB conditions, $F(1,31)=.28$, $p=.602$. As suggested from the ANOVA on RT, the main effect of spatial Stroop was not significant, $F(2,62)=.17$, $p=.841$, being negligible the difference between the effects observed in the No WS conditions (spatial Stroop effect: 10 ms), the 63 dB WS conditions (spatial Stroop effect:12 ms) and the 83 dB WS conditions (spatial Stroop effect: 13 ms).

Error analysis. Mauchley's test indicated that the errors rates distribution violated the assumption of sphericity for the Simon interference factor ($\chi^2(2)=25.84$, $p<.001$). Running the ANOVA we found a main effect of spatial Stroop, $F(1,31)=11.25$, $p=.002$, $\eta^2=.27$, with more errors in incongruent (4.81%) than congruent conditions (3.36%). The same was observed for the Simon interference, $F(1,31)=25.88$, $p<.001$, $\eta_p^2=.45$: participants committed more errors in incongruent (5.9%) compared to congruent conditions (2.28%). The effect of Warning signal was not significant, $F(2,62)=.45$, $p=.637$, but it was qualified by a marginally significant Warning signal X Simon interaction, $F(2,62)=2.99$, $p=.058$, $\eta_p^2=.09$, which showed an impact of WS on the Simon interference, without a clear difference in the Simon task reported for 63 dB and 83dB trials compared to those with No WS, $F(1,31)=3$, $p=.093$. Also, the two intensity levels did not significantly differ, $F(1,31)=2.97$, $p=.095$. On the other hand, the manipulation of WS neither affect the spatial Stroop interference observed in error rates, $F(2,62)=2.77$, $p=.077$. The three-way interaction Warning signal X spatial Stroop X Simon was also no significant, $F(2,62)=2.19$, $p=.120$, $\eta^2=.07$.

DISCUSSION

In order to test the relationship between phasic alerting and cognitive control, and in consideration of Fischer´s (Fischer et al., 2010) and Weinbach´s (Weinbach & Henik, 2012) frameworks, we used a Simon-spatial Stroop paradigm suitable to measure both S-S and S-R visuospatial interference in which the target and distracter dimensions were integrated in the same visual object. Results showed a significant effect of the WS, with faster RTs when it was presented. Significant spatial Stroop and Simon interference was also observed in both RT and error rates. Importantly, also in line with our expectations, results showed larger Simon incongruence in trials with a WS, so that the presence of WS affected S-R conflict (i.e., Simon interference) but not S-S conflict (i.e., spatial Stroop interference). On the other hand, the increased intensity of WS caused a reverse effect for Simon interference with a diminution of the interference effect for 83 dB compared to 63 dB WS. However, this advantage was reflected in RT but not in the accuracy rates. In general, WS with higher intensities seem to impact less the Simon interference than lower WS intensity. The fact that the WS modulated Simon but not spatial Stroop interference allowed the rejection of the hypothesis that the modulation of visuospatial interferences through WS implicates the involvement of a general, unspecific alerting activation, affecting all kinds of spatial conflict. Furthermore, the assumption that the separation between spatial distracters and target is required for the modulation of WS over spatial conflict (Weinbach & Henik, 2012) was therefore rejected, as in our paradigm the distracting dimension (i.e., target location) was an integrated feature of the target.

EXPERIMENT 2

Experiment 1 showed that acoustic warning signals and their internal characteristics (i.e. the acoustic intensity) modulate Simon but not spatial Stroop interference. However, the experimental design used does not allow to explain whether the modulation of WS over the Simon but not the spatial Stroop effect takes place in terms of co-occurrence of two competitive interferences. Moreover, in Experiment 1, the congruence effect for Simon was larger compared to the spatial Stroop. Therefore, it can be argued that a strengthened S-R conflict might minimize or conceal the impact of WS over the spatial Stroop interference. In order to clarify these two aspects, we conducted the Experiment 2, with a different procedure where the Simon and spatial Stroop interference were manipulated in distinct trials (Lupiáñez & Funes, 2005) and further grouped in Simon-trial and spatial-Stroop-trials blocks.

METHOD

Participants. Forty-eight students (mean age: 26.1 years; age range: 18-40 years; 13 males) from the Humboldt University of Berlin participated to the experiment. Participants had normal or corrected-to-normal audition and vision. The experiment was conducted in accordance with the ethical standards of the Declaration of Helsinki (1964).

A priori power analysis was not performed, for this reason we conducted a post-hoc sensitivity analyses using G*power (Faul, et al., 2007). Results revealed that with this sample size (N=48) the minimum detectable effect size for α=.05, and $1-\beta$=0.80, is f=0.12.

Apparatus and stimuli. The stimulus presentation, the software of data collection (E-prime 2.0) and the experimental setting were the same as Experiment 1. The sounds were presented by Sennheiser HD 201 headphones and the visual stimuli by an HDMI senseye 3 led screen.

Task and experimental stimuli. The task and experimental design were almost identical to Experiment 1. The main difference was the arrangement in distinct trials of the two visuospatial interferences. In the spatial Stroop trials, the target (an arrow) was presented along the central vertical axis of the screen, either 3.15° above or 3.15° below the fixation point. During the incongruent trials, the arrow pointing up appeared below the fixation and the arrow pointing down appeared above the fixation. For the Simon interference manipulation, the arrow was presented along the central horizontal axis, either to the left or to the right of the fixation point. When target position and hand associated with the correct response coincided, the trial was categorized as Simon congruent; when the target position was opposite to the response hand, it was categorized as Simon incongruent (see Figure3).

The experiment yielded two practice blocks (12 practice trials each), five Simon blocks (240 trials) and five spatial Stroop blocks (240 trials). Blocks of the same types of interference were grouped together in the first or second part of the experiment. The timeline and duration of displays were the same as for Experiment 1. Warning signals were presented in 2/3 of trials, 460 ms before the target, with a medium (53 dB) or high intensity (83 dB). In the remaining 1/3 of trials, the target was not anticipated by any warning signal[1].

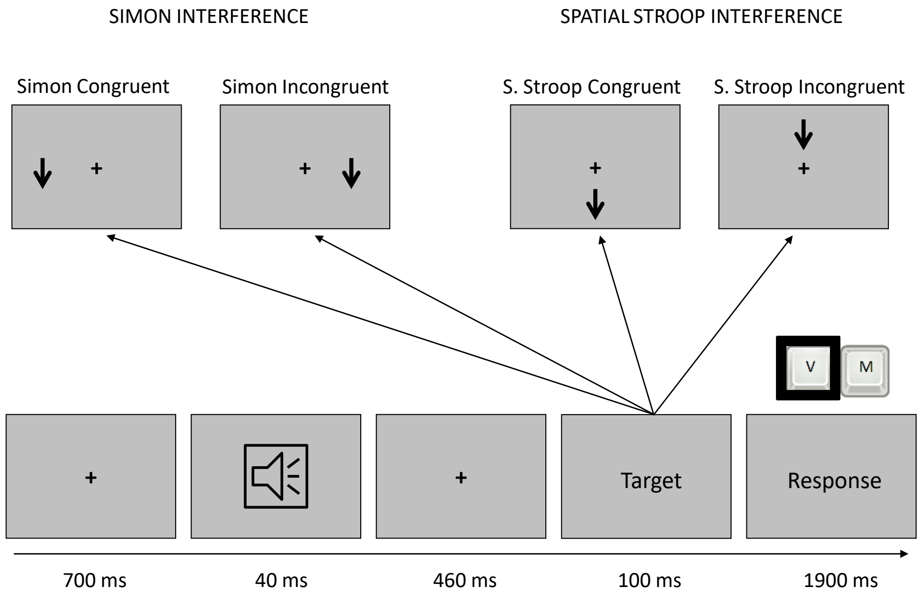

Figure 3. The timeline and all possible target positions in Experiment 2 (from left to right). Each trial presented only one type of interference and it could be Congruent (C) or Incongruent (I). Trials were distributed in spatial Stroop blocks (*S.Stroop Congruent* and *S.Stroop Incongruent* trials) and Simon blocks (*Simon Congruent* and *Simon Incongruent* trials). Warning signals were presented for 40 ms, only for 2/3 of trials. The remaining 1/3 of trials had no warning signal prior to target presentation. The target was presented for 100 ms and responses were allowed for a maximum of 1900ms. Participants were asked to indicate the direction of target (the up/down pointing arrow). The black contour, framing the key´s letters, indicates the correct response of the trial (in this case, the "v" key associated to down pointing arrows).

[1] Experiment 1 and 2 differ in the lower intensity level of WS (53 dB versus 63 dB). This was due to the different level of background noise through headphones between Experiment 1 (≈ 40/45 dB) and Experiment 2 (≈ 30/35 dB).

RESULTS

Data analysis. As for Experiment 1, we computed the errors rates for each participant and we excluded from analysis anticipatory responses (0.1%) and trials preceded by an incorrect response (4.23%). One participant reported more than 2 SD above the mean errors rate and was eliminated from the analysis. For the RT analysis, we excluded from analysis trials with anticipatory or incorrect responses, preceded by an incorrect response and with responses slower or faster than 2.5 standard deviations from RT mean (2.34%). Mean RT, standard deviations and errors standard deviation for Experiment 2 were detailed in Table 2. To test the assumption of sphericity in our distribution, we ran the Mauchley's test and correct *p* values following the Greenhouse-Geisser correction of sphericity. The ANOVA was performed for mean reaction times and errors rate with Type of Conflict (Simon, spatial Stroop), Warning signal (No WS, 63 dB, 83 dB) and Congruency (Congruent, Incongruent) as within-participants factors (see Table 2).

Table 2. Experiment 2. Conditions indicate all possible levels of Type of Conflict, Warning signal and Congruency factors. Values of the mean reaction times and standard deviations are in milliseconds. Parentheses contain mean errors percentage for each condition.

	Simon Congruent	*Simon Incongruent*	*Spatial Stroop Congruent*	*Spatial Stroop Incongruent*
No WS	513 ± 67 (2.1%)	546 ± 66 (5.9%)	515 ± 69 (2.1%)	549 ± 62 (4.1%)
53 dB	481 ± 67 (1.8%)	517 ± 64 (7.7%)	488 ± 79 (2.3%)	520 ± 81 (4.8%)
83 dB	472 ± 71 (1.7%)	517 ± 72 (6.1%)	481 ± 72 (2%)	516 ± 74 (5.7%)

In order to more specifically test our hypotheses, and in line with the analysis reported in Experiment 1, we computed interference effect indexes separately for spatial Stroop and Simon, by subtracting congruent from incongruent mean RT, and submitted the data to separate univariate ANOVAs.

RT analysis. Mauchly's test indicated that the assumption of sphericity was violated for the Warning signal factor ($\chi 2(2)$=33.1, p<.001) and the interaction Type of Conflict X Warning signal ($\chi 2(2)$=6.9, p=.032). A main effect of WS was found, $F(2,92)$=120.41 p<.001, η_p^2=.72: slower RT in the No WS conditions (*M*=532 ms, *SD*=116 ms) than in the 53 dB WS conditions (*M*=502 ms, *SD*=110 ms) were reported, $F(1,46)$=105.02, p<.001. Moreover RT were faster for 83 dB conditions (*M*=496 ms, *SD*=111 ms) than for 53 dB conditions, $F(1,46)$=14.94 p<.001. The main effect of Congruency, *F*(1, 46)=198.18, *p*<.001, η_p^2=.81, indicated faster RT for congruent (*M*=492 ms, *SD*=114 ms) than incongruent conditions (*M*=528 ms, *SD*=109 ms), but it did not interact with type of conflict, *F*(1, 46)=.85, *p*=.360,η_p^2=.02.

Importantly, the interaction Warning signal X Congruency reached significance, *F*(2,92)=3.67, *p*=.031, η_p^2=.07, with no difference between No WS and 53 dB WS trials, *F*(1,46)=.01, *p*=.921, but a difference in congruency effect between 53dB and 83 dB WS trials, *F*(1,46)=6.43, *p*=.015. Although the three-way interaction Type of Conflict X Warning signal X Congruency did not reach statistical significance, *F*(2,92)=2.16, *p*=.121, planned comparisons showed that Simon interference trials caused the WS modulation over interference. Indeed, as shown in Figure 2, the presence of the 53 dB WS did not affect the Simon effect, compared to the no WS condition, *F*(1,46)=.49, *p*=.489; however the Simon effect was significantly increased with WS of 83dB compared to 53 dB, *F*(1,46)=5.70, *p*=.021.On the other hand, as shown in Figure 2, the spatial Stroop interference was not modulated by either the presence, *F*(1,46)=.43, *p*=.516, or the intensity of WS, *F*(1,46)=.93, *p*=.339.

The ANOVA on Simon interference indices showed a significant main effect of Warning signal, *F*(2,92)=4.79, *p*=.010, η^2=.09. The presentation of a WS did not impact the performance as the No WS (interference effect: 32ms) and 53 dB WS (35ms) conditions did not statistically differ, *F*(1,46)=.49, *p*=.489, but significantly increased in the 83 dB conditions (45ms), *F*(1,46)=5.70, *p*=.021. On the other hand, the ANOVA for the Stroop interference confirmed an absolute absence of WS modulation, *F*(2,92)=.44, *p*=.644,η_p^2=.01.

Error analysis. We reported a main effect of Congruency, *F*(1,46)=64.10, *p*<.001, η_p^2=.58, with higher errors score for incongruent (5.73%) than congruent trials (2%). The main effect of Type of conflict was also significant, *F*(1,46)= 5.05, *p*=.029, η_p^2=.1, with generally more errors for Simon (4.22%) than spatial Stroop (3.52%) conditions. However, the factor Warning signal was not significant, *F*(2,92)=1.72, *p*=.184. The Type of conflict X Congruency interaction, *F*(1,46)=11.13, *p*=.002, η_p^2=.19, showed a larger errors rate for Simon incongruent (6.58%) compared to Stroop incongruent (4.89%) conditions. However, the three-way interaction did not reach statistical significance, *F*(1,46)=2.35, *p*=.101.

DISCUSSION

As expected, in Experiment 2 we observed the classic interference effect of Simon and spatial Stroop (i.e., more errors and slower RT in incongruent conditions), the effect of alerting (faster RT after a warning signal), and the intensity effect (faster RT for the higher intensity condition). Again, the manipulation of the acoustic WS did not modulate the spatial Stroop interference. Therefore, the lack of interaction between WS and spatial Stroop, reported in both Experiment 1 and 2, was not attributable to the co- presence of the Simon interference in Experiment 1. An important difference with Experiment 1 was that the 53 dB WS did not significantly affect the Simon effect. Nevertheless, WS impacted those trials with the higher WS intensity. We therefore confirmed that the type of visuospatial interference (i.e., S-S versus S-R) is a fundamental aspect to consider in order to understand the interaction between cognitive control and alerting mechanisms, although the specific impact of WS on Simon interference (either due to WS intensity or mere presence) might depend on whether the two interferences are presented separately in different blocks or mixed within the same trial.

To further test the differential modulation of WSs over both Simon and spatial Stroop interferences, we conducted a Bayesian repeated measure ANOVA (for spatial Stroop conditions only) across data from Experiments 1 and 2. The Bayesian analysis is relevant in cases showing a non-significant effect with the null hypothesis testing approach. In particular, Bayesian analyses help to assess whether our data provide evidence favoring the alternative hypothesis (the larger the Bayes factor [BF10], the stronger the evidence; for references, see Jarosz & Wiley, 2014), the null hypothesis (the lower the BF10, the stronger the evidence), or no evidence (BF10 between .33 and 3). Therefore, a Bayesian ANOVA was carried out on the spatial Stroop interference, with the WS as a within-participants variable, providing a BF10=0.060. This constitutes strong evidence in favor of the null hypothesis (i.e., the absence of modulation of a WS over spatial Stroop being 1/.060=16.67 times more likely than its modulation). Together with the previous analysis, the Bayesian ANOVA confirmed our conclusion: the presence of an acoustic WS influences the Simon and spatial Stroop interference resolutions differently.

GENERAL CONCLUSIONS

The interaction between alerting and control mechanisms has heretofore been explained in terms of the involvement of cognitive mechanisms strictly related to spatial attention (Schneider, 2019; Weinbach & Henik, 2012) or not (Callejas et al., 2004; Fischer et al., 2010; Fischer, Plessow & Kiesel, 2012). In two experiments, we studied how the nature of interference impacts the interaction between phasic alerting and executive control mechanisms, taking into account the role of the irrelevant characteristics of a WS, such as its intensity. For this purpose, in Experiment, 1 we used a paradigm suitable for measuring both S-S (i.e., spatial Stroop) and S-R (i.e., Simon) interference in the same trial. We found that, on the one hand, the presence of a WS increased Simon interference, although the effect tended to disappear with a higher intensity. On the other hand, the spatial Stroop interference was not affected by any of the WS manipulations (i.e., presence and intensity). In Experiment 2, we presented both interferences again, but in separate trials, and the outcomes mostly replicated the results from Experiment 1. The influence of a WS in the Simon interference was confirmed, although, in this case, phasic alertness increased Simon interference for the high intensity condition. Altogether, we observed that alerting and intensity-related modulation influenced the Simon interference. In line with other literature about conflict control (Egner, 2008; Funes, Lupiáñez & Humphreys, 2009; Hommel, 1998), these findings confirm the different impacts of phasic alerting mechanisms on the two types of conflict. We therefore confirm that the type of visuospatial interference plays an important role in the reported interaction between conflict resolution and alerting mechanisms.

The most relevant finding in our study perhaps concerns the WS-related modulation separately for Simon and spatial Stroop interferences. In the past, the combination of Simon and Stroop paradigms has already been tested and has demonstrated additive effects (Kornblum et al., 1990; Simon & Berbaum, 1990; Hommel, 1998). Simon and spatial Stroop interferences were also used to investigate the differential effect of temporal cues providing information about the moment of target appearance (Correa, et al., 2010). In the present study, we confirm once more that the conflict resolution mechanisms, activated by the visuospatial interferences, are selective and specific for one type of conflict (Egner, 2008; Funes, Lupiáñez, & Humphreys, 2010; Kornblum et al., 1990; Torres-Quesada, Funes & Lupiáñez, 2013); however, they could be modulated by task-irrelevant features, such as the acoustic intensity of the WS.

To further test the differential modulation of WSs over both Simon and spatial Stroop interferences, we conducted a Bayesian repeated measure ANOVA (for spatial Stroop conditions only) across data from Experiments 1 and 2, which showed strong evidence in favor of the null hypothesis (i.e., the absence of modulation of a WS over spatial Stroop). Together with the frequentists analyses, the Bayesian ANOVA confirmed our conclusion: the presence of an acoustic WS influences the Simon interference but not the spatial Stroop interference.

Another recent work has highlighted the importance of the task setting for observing the alerting-related modulation – the modulation primarily found when the main task included some spatial information processing (Schneider, 2019). The author explained that for those types of tasks, the activated alerting mechanism passes through multiple stages of information processing, especially when the target stimuli has precise spatial connotations, and therefore an interaction between the two mechanisms takes place (Schneider, 2019). However, not all spatial conflicts involving targets with spatial connotations seem to be modulated by WSs. In our two experiments, the observed conflict was always of a spatial nature (participants had to respond to the direction of the target while ignoring its location); however, only one conflict type (i.e., Simon) was impacted by the WS, whereas the other (i.e., Stroop) was not. These results are consistent with the literature demonstrating that some functions of executive control (i.e., sequential conflicts) seem to depend on whether the same conflict type repeats in consecutive trials (Egner, 2008; Funes et al., 2010; Notebaert & Verguts, 2008). Moreover, the alerting modulation over sequential conflicts is also affected by the nature of the spatial conflict. In particular, Soutschek et al. (2013) found dissociable effects of WSs on the sequential congruency effect reported in Simon and Stroop interferences, when presented in separate experimental conditions. The effect of WSs on the sequential congruency effect, only observed in one type of incongruence, further supported the specificity of the control mechanisms involved in the resolution of spatial interference.

Another aim of our study was to test whether the alerting-interference interaction was because of better perceptual encoding by the amplified attentional focus or rather because of the direct involvement of alerting mechanisms in the S-R association. In Weinbach and Henik´s study (2012), alerting did not facilitate the activation of the automatic irrelevant response, despite a robust congruency effect. Therefore, their attentional spotlight account assumes that a WS increases the attentional focus and causes general accessibility of spatial information (making possible the interaction) in cases where relevant and (spatial) irrelevant characteristics are separated. However, following this framework in Experiment 1, we should not observe an increase in either Simon or Stroop interferences, as the target direction and spatial irrelevant characteristics (target location) were integrated into the same object in all trial conditions. Nevertheless, we reported a clear modulation of the WS over the Simon effect in both Experiments 1 and 2. Therefore, the attentional spotlight account seems to be insufficient to explain the evidence reported in the current work. Indeed, our findings rather support the idea that attending a WS does not demand a general state of readiness but rather a stronger level of visuo-motor response activation (Fischer et al., 2010; 2012).

However, the role that spatial information processing might play in the interaction is not entirely excluded. As stated in Weinbach and Henik (2012, page 1538), alerting can influence the congruency effect only when there is spatial information to process. This was inspired by previous findings from our lab indicating that alertness induces a global processing bias (Weinbach & Henik, 2011). Global processing bias may drive any spatial information in the visual field (be it relevant for the task or not) to higher accessibility. It is true that in both manipulations the processing of some sort of spatial information was required. As a consequence, the current results do not completely eliminate the role that spatial information processing might play in the interaction. Nevertheless, both Experiments 1 and 2 confirmed the importance of a strong S-R association in the alerting-conflict resolution interaction. Indeed, we found that whether spatial interference is modulated by WSs clearly depends on the nature of the interference that is measured, rather than the mere co-occurrence of relevant and/or irrelevant spatial information.

Despite the number of studies on this topic, many aspects of the interaction between alerting and interference resolution are still unclear. A recent work has focused on the influence of task setting on the WS impact and has demonstrated a decreased efficiency of interference resolution, in terms of RT and accuracy of responses, caused by the manipulation of phasic alerting (Asanowicz & Marzecová, 2017). In particular, the researchers used the attention network test (Fan et al., 2002), which combines Posner's cueing task (Posner, 1980) and the flanker task (Eriksen & Eriksen, 1974), and they manipulated the strength of a visual and acoustic WS (i.e., no WS vs. single, centred WS vs. a double WS presented in the locations corresponding to target positions). Their results indicated a WS-related modulation of the interference by showing increased interference from conditions of no WS, to the centered WS, and to the double WS (Asanowicz & Marzecová, 2017).

An important, but still unsolved question concerns the perceptual vs. motoric nature of this interaction. It is still unclear whether these dissociable attentional mechanisms interact with those dedicated to the perceptual inhibition of irrelevant visual information or with response selection processing. There is some evidence in the literature about modulations of alerting in the earlier stages of visual perceptual processing (Matthias, Bublak, Müller, Schneider, Krummenacher & Finke, 2010; Fischer, Plessow & Ruge, 2013; Thiel, Zilles & Fink, 2004). In other words, Simon and Stroop interference may be affected in different stages of elaboration from the WS manipulation. Nevertheless, the two paradigms presented in the current work might not be sufficient to perfectly dissociate each of the perceptual and motor preparation steps involved.

The current study suggests that the impact of alerting and intensity effect might differ depending on the types of interference involved. On the one hand, the expected RT shortening with a highly intense WS was reported in both manipulations. On the other hand, however, we found that the direction of the influence of WS intensity on the Simon interference varies. In particular, Simon interference decreased in conditions of high WS intensity in Experiment 1 (compared to low intensity), while it increased under high WS intensity in Experiment 2. Previous studies have shown that sounds increase the perceptual rate over the visual cortex (Romei, Gross & Thut, 2012; Romei, Murray, Cappe & Thut, 2009), even when they are not relevant to the task (McDonald, Störmer, Martinez, Feng & Hillyard, 2013). Therefore, one possibility to interpret our findings is that the intensity features intervene at two levels of performance: the motor readiness (i.e., a faster RT) and the perceptual elaboration, which might improve the analysis and selection of a target. The involvement of the intensity in one or both levels might depend on visuospatial control demands. In particular, in a previous work, we demonstrated how highly intense WSs increase the motor preparation to respond in simple detection tasks (Cappucci et al., 2018; see Experiment 1). However, when the presence of catch trials required a stronger response control, the increased intensity impacted both the motor readiness and the target detection, also depending on the temporal information about the target provided by the WS (Cappucci et al., 2018; see Experiments 2 and 3). In the current study, we confirm that lower perceptual demands (Experiment 2; when the target only produces one conflict type in a given trial) raises the intensity-related motor readiness (i.e., faster RTs), while a high perceptual demand (Experiment 1) activates both motor readiness and perceptual elaboration (i.e., faster RTs and more efficient response selection). However, we acknowledge that the method employed in the current study might not be perfectly suited to fully test this hypothesis. Further studies would help to answer these still open questions.

To recapitulate, our findings show an interaction between alerting and conflict resolution mechanisms, supporting the existing literature on this topic (i.e., Callejas et al., 2004; Fischer et al., 2010; 2012; Weinbach & Henik, 2012). Importantly, different results for the Simon (S-R) and spatial Stroop (S-S) interferences were observed: the WS had a detrimental effect on Simon interference, increasing the interference, but not on spatial Stroop interference. Moreover, the WS intensity manipulation seems to play an important role in visuospatial conflict resolution, although how exactly it affects the S-R interference remains unclear. In general, these results confirm that an increase in the size of the attentional spotlight following a WS is insufficient to exhaustively explain the interaction between alerting and visuospatial interference. As previously suggested in the literature (Fischer et al., 2010; 2012; Seibold, 2018), the alerting mechanism is more likely interacting with the conflict resolution mechanism during the activation of the direct transmission of visual information into corresponding motor code processing.

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