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Investigation of stimulus–response compatibility using a startling acoustic stimulus

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ABSTRACT

We investigated the processes underlying stimulus–response compatibility by using a lateralized auditory stimulus in a simple and choice reaction time (RT) paradigm. Participants were asked to make either a left or right key lift in response to either a control (80 dB) or startling (124 dB) stimulus presented to either the left ear, right ear, or both ears. In the simple RT paradigm, we did not find a compatibility effect for either control or startle trials but did find a right-ear advantage which we attribute to anatomical asymmetry of auditory pathways. In the choice RT paradigm, we found compatibility effects for both startle and control trials as well a high incidence of error for contralateral stimulus–response mapping. We attribute these results to automatic activation of the ipsilateral response, which must then be inhibited prior to initiation of the correct response. The presence of compatibility effects for startle trials also suggest that similar pathways are being used to initiate movements in a choice RT situation, as opposed to involuntary triggering that is thought to occur in a simple RT situation.

1. Introduction

In the examination of stimulus–response (S–R) compatibility, it has been shown that the stimulus location has a significant impact on the speed of the response, even if the location is irrelevant to the task. This so-called “Simon effect” was first shown by Simon and Rudell (1967), whereby participants were presented with the auditory word “left” or “right” presented to the left or right ear and were instructed to respond to the meaning of the word regardless of location. Participants, however, appeared to be unable to ignore the location of the stimulus and were faster to respond if the location of the word spatially corresponded to the response. This effect has been replicated using many different types of auditory and visual stimuli and allows for investigation of attention, perception, action planning, executive control, and neurological pathways (see Hommel, 2010; Lu & Proctor, 1995; Simon, 1990 for reviews).

A number of explanations have been proposed for the Simon effect. Given the contralateral cortical mapping of both visual stimuli and hand movements, an anatomical explanation would suggest that non-spatially compatible S–R pairs may require extra time due to the neural signals needing to travel a longer distance (Poffenberger, 1912). That is, for contralateral S–R pairs, the input and output are processed by different hemispheres, thus interhemispheric transfer time is required. However, this explanation has been challenged by the presence of a Simon effect for unimanual left and right responses (Simon, 1969) as well for auditory stimuli which are thought to be much less lateralized than visual stimuli (Iacoboni & Zaidel, 1999). Other explanations for the Simon effect are cognitive in nature, whereby the stimulus location automatically activates the ipsilateral response which can either have a facilitatory or interference effect, depending on the required response (e.g., de Jong, Liang, & Lauber, 1994; Kornblum, Hasbroucq, & Osman, 1990). These automatic activation hypotheses have also been disputed by data from studies using the measurement of a lateralized readiness potential (LRP; thought to indicate response preparation of a lateralized response) during a Simon-type task (Valle-Inclan & Redondo, 1998). In a delayed-reaction condition whereby the S–R mapping was presented after the stimulus, it was predicted by Valle-Inclan and Redondo that automatic activation would be indicated by LRP activity between the stimulus presentation and response key. This prediction was not supported, however, indicating a lack of automatic preparation when the response was unknown.

In an attempt to delineate between anatomical and cognitive contributions to the Simon effect, Hommel (1996) examined S–R compatibility effects during a simple reaction time (RT) paradigm. Although the effects were much smaller in magnitude as compared to choice RT, Hommel did find significant compatibility effects for simple RT confirming that response uncertainty is not a requirement for the Simon effect and thus the locus is not limited to response selection processes. These results are also consistent with the notion of an unconditional, automatically generated ipsilateral

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response which either facilitates or interferes with the prepared response, resulting in either faster or slower RTs.

In the current experiment, we examined the processes underlying S–R compatibility by using a lateralized auditory stimulus in both a simple and choice RT paradigm. In addition to a normal auditory tone, we also implemented on selected trials a loud acoustic stimulus capable of eliciting a startle response. A startling acoustic stimulus (SAS) presented in a RT task has been used to examine the processes involved in response preparation as it is capable of automatically triggering a prepared response, bypassing the usual voluntary command processes (see Carlsen, Maslovat, & Franks, in press; Carlsen, Maslovat, Lam, Chua, & Franks, 2011; Rothwell, 2006; Valls-Solé, Kumru, & Kofler, 2008 for reviews). Movements prepared in advance have consistently been shown to be triggered by a SAS at latencies too short to involve cortical processing (e.g., 60–100 ms; Carlsen, Chua, Inglis, Sanderson, & Franks, 2004; Valls-Sole, Rothwell, Goulart, Cossu, & Munoz, 1999), and are thought to involve different neurological pathways than voluntary initiation (Carlsen et al., in press). For this reason, the use of a SAS in a RT task is a novel methodology which can be used to delineate the role of cognitive processes in S–R compatibility effects as well as possible anatomical/neurological contributions to any RT differences.

For the simple RT paradigm, we were unsure if compatibility effects would be observed when presented with a normal auditory tone (control trials). Although compatibility effects have been shown in a simple RT paradigm (Hommel, 1996) the effects are not as robust as in a choice RT paradigm. In a review by Hasbroucq, Kornblum, and Osman (1988), only thirteen of twenty-one relevant simple RT studies showed a reliable S–R compatibility effect. Furthermore when compatibility effects are found in a simple RT situation, the effects are much smaller (2–6 ms) as compared to choice RT situations (20–70 ms). However, our predictions were clear for those trials where a SAS tone was employed. In a simple RT task, the required response is known and can be prepared in advance to minimize RT, and thus should be triggered by the startling stimulus at a very short latency. The neurological pathway proposed for this response triggering has recently been suggested to involve the startle reflex pathway from the cochlear nucleus to the caudal reticular formation, then following ascending pathways through the thalamus to the motor cortex whereby the activation would cause an involuntary triggering of the prepared response (Carlsen et al., in press). Compatibility effects would be predicted to be absent on startle trials as involuntary initiation of the prepared response would occur regardless of stimulus location and would not involve a cortical conflict between an automatic activation and the prepared response. A compatibility effect in control trials that is not present on startle trials would confirm that S–R compatibility effects involve a cortical component and are dependent upon voluntary response initiation.

For the choice RT paradigm, we predicted that a typical compatibility effect would be found for control trials whereby responses would be quicker when the auditory stimulus and required response were ipsilateral. For startle trials, our prediction was again tied to the hypothesized neurological pathways activated by the SAS. Although the same pathways would be involved during startle trials as detailed above for the simple RT paradigm, in a choice RT task advance preparation does not typically occur due to response uncertainty; thus no movement would be triggered at short latency. In contrast to the more dramatic RT decreases seen in simple RT, studies utilizing a SAS in choice RT situations have typically shown similar or slightly reduced RTs as compared to control trials (e.g., Carlsen et al., 2004; Kumru et al., 2006; Maslovat, Hodges, Chua, & Franks, 2011; Oude Nijhuis et al., 2007). In this case, the response is thought to be initiated by similar pathways as control trials with the limited RT facilitation attributed to increased residual activation in the motor pathways due to the high intensity "go" signal (Carlsen et al., in press). The use of the same pathway for movement initiation in both control and startle trials led us to predict that compatibility effects would be present on startle trials as well as control trials. This result would provide further support for a cortical locus for compatibility effects as well as providing additional support for the different initiation pathways when a SAS is used in simple versus choice RT paradigms.

2. Methods

2.1. Participants

The same participants volunteered for both the simple RT (Day 1) and choice RT (Day 2) experiments, which were performed on subsequent days. Data from 10 right-handed volunteers (6 male, 4 female; $M = 22.6$ yrs, $SD = 7.7$ yrs) who showed a consistent activation in the sternocleidomastoid (SCM) muscle during startle trials (a reliable indicator of a startle response; see Carlsen et al., 2011 for inclusion criteria) were analyzed. All participants were naïve to the hypothesis under investigation and this study was conducted in accordance with ethical guidelines established by the University of British Columbia.

2.2. Apparatus, task and experimental design

Testing sessions occurred with the participant seated in a height-adjustable chair in front of a 22-in. computer monitor (Acer X233W, 1152 × 864 pixels, 75 Hz refresh). On the table in front of each participant were two telegraph keys requiring 2 N to close (i.e., simply resting the hand on the switch was sufficient to close it), on which participants placed their hands to depress the switch. Participants were informed that they would see the word "Ready!" and a visual precue on the computer screen prior to the auditory "go" stimulus. For the simple RT experiment, the visual precue consisted of a blue box (5.25 cm × 5.25 cm) presented with the center either 9.5 cm to the left or right of a central fixation cross, which indicated either a left or right key lift off. For the choice RT experiment, the visual precue consisted of both a left and right blue box such that participants were unaware of the required response in advance. The visual precue (single or double box) was presented on the screen for 2000 ms, was then removed for a random foreperiod between 2000 and 2500 ms, followed by a auditory "go" stimulus and simultaneous presentation of the visual blue box indicating the required response (for the simple RT paradigm this was always a replication of the precue, for the choice RT paradigm a box appearing on either the right or left side indicated the required response simultaneously with the "go" signal). Note that although the location of the "go" signal was irrelevant, the visual response cue was spatially relevant and thus our methodology was not a true "Simon task" but rather an examination of spatial S–R compatibility.

All auditory signals were generated by a customized computer program and were amplified and presented via loudspeakers placed directly to the left and right of the participant. Auditory signals could be presented from the left speaker, right speaker, or both speakers and consisted of either a control stimulus (80 +/−2 dB, 100 ms, 1000 Hz) or startling stimulus (124 +/−2 dB, 40 ms, 1000 Hz, <1 ms rise time). The acoustic stimulus intensities were measured using a sound level meter (Cirrus Research model CR:252B; "A"-weighted decibel scale, impulse response mode) at a distance of 30 cm from the loudspeaker (approximately the distance to the ears of the participant).

Participants were asked to respond as quickly and accurately as possible to the "go" signal by either lifting the left or right hand