HOW TIME MODULATES SPATIAL RESPONSES

Antonino Vallesi\textsuperscript{1,2,\#}, Anthony R. McIntosh\textsuperscript{2,3}, Donald T. Stuss\textsuperscript{2,3}

\textsuperscript{1} International School for Advanced Studies, SISSA, Trieste, Italy
\textsuperscript{2} Rotman Research Institute at Baycrest, Toronto, Canada
\textsuperscript{3} University of Toronto, Canada

\#Corresponding Author:
Antonino Vallesi
Cognitive Neuroscience Sector
International School for Advanced Studies (SISSA-ISAS)
Via Beirut 2-4, 34014 Trieste, Italy
Phone: +39 040-3787622
Fax: +39 040-3787615
E-mail: vallesi@sissa.it
Abstract

Behavioural evidence suggests a left-to-right directionality in the representation of elapsing time. We tested whether this representation produces a spatial attentional shift that activates a corresponding left-to-right spatial response code. Fourteen participants judged whether a cross lasted for a short (1 sec) or a long (2 sec) duration with left and right responses, respectively, or vice versa, while event-related potentials (ERPs) were measured. Responses were faster when participants judged short and long durations with their left and right hand, respectively, than vice versa. In these compatible conditions only (short-left; long-right), ERP negativity developed over the right motor scalp region around the short duration, a finding that is compatible with an early pre-activation of left hand responses, and over the left motor region around the long duration, suggesting a later pre-activation of right hand responses. These findings confirm that in this task elapsing time is represented from left to right, and that this representation generates corresponding response codes that influence performance.

Keywords: Stearc Effect, Stimulus-response compatibility effect, Event-related Potentials, spatial attention, time processing, motor preparation.
It is still debated whether we perceive the passage of time through a dedicated neural system or through intrinsic representations arising from other systems (Ivry and Schlerf 2008). Time is a very abstract and yet ubiquitous concept. When dealing with abstract concepts, our cognitive system benefits from the use of concrete motor and perceptual representations (Gallese and Lakoff 2005; Lakoff and Johnson 1999; Rohrer, 2006; Scaife and Rogers 1996; Tversky 1995). Spatial representations in particular are an effective way to convey cognitive meaning (Lakoff and Johnson 1980; Zacks and Tversky 1999). For instance, spatial graphical representations improve performance in syllogistic reasoning (Stenning and Oberlander 1995), analytical problem solving (Cox and Brna 1995), and working memory tasks (Larkin and Simon 1987).

Cognitive representations of ordinal information, such as numerals, letters, and months, may also have spatial features. These spatial features can influence the speed of manual responses (Dehaene et al., 1993; Fischer et al., 2003; Franklin, Jonides, & Smith, 2009; Gevers et al., 2003; 2004). With respect to numerals, for instance, left-side responses are faster for relatively smaller numbers compared to right-side responses, whereas right-side responses are faster with relatively larger numbers (Dehaene et al., 1993). This suggests the existence of a left-to-right ‘mental number line’ which interacts with motor preparation in the horizontal space. This left-to-right representation of numbers is probably related to the writing direction (Dehaene et al., 1993; Zebian 2005).

Analogously, the representation of time can also be influenced by processing non-temporal perceptual features. Subjects judge the duration of an array of dots as longer if it contains more, brighter or bigger dots (Xuan et al., 2007). Moreover, subjects are more accurate in judging short and long durations of a low and high value digit, respectively, than the other way around (Xuan et al., 2009). These interactions suggest that the mechanisms for the representation of perceptual magnitude information are also used in the representation of the more abstract magnitude information concerning time durations.

Moreover, as for numbers, spatial attention and spatial representations can also influence time processing (e.g., Santangelo and Spence, 2009; Santiago et al., 2007; Torralbo et al., 2006; see
Oliveri, Koch and Caltagirone, 2009, for a review), while the opposite is not necessarily true (Casasanto and Boroditsky 2008). In a recent study (Weger and Pratt 2008; see also Weger and Pratt 2009), the task was to indicate the location of the target through a bimanual response, or to detect (with one button only) left- or right-side stimuli following prospective or retrospective time words. Only when a bimanual response choice was required with the spatial discrimination task, compatibility effects between the dimensions of space (left–right) and time (earlier–later) were found, with performance being better when left spatial position was associated with time words referring to the past and right spatial position was associated with time words referring to the future than vice versa. These findings suggest that the compatibility effect between temporal and spatial dimensions affects more response-related than stimulus-related processes (cf. Stoianov, Kramer, Umilta, & Zorzi, 2008). However, results of a recent study show that the discrimination of lateralized stimuli (leftward or rightward pointing arrows) can also benefit from past-future temporal cue words independently of the specific motor responses required (Ouellet, Santiago, Funes & Lupianez, in press, experiment 2). These data suggest a more central mechanism of spatial attention orienting driven by the processing of temporal information, which can flexibly boost the processing of spatially compatible stimuli or responses, depending on the specific experimental settings and task demands.

Compatibility effects between time and space emerge even when subjects have to judge the duration of stimuli that do not have any lateralized spatial feature. In a previous study of ours (Vallesi et al., 2008), the task was to judge the duration of a centrally presented cross (1 and 3 sec, for short and long durations, respectively) using a bimanual spatial response (left vs. right). The duration-hand correspondence was counterbalanced across blocks. Participants were faster to judge short durations with their left hand and long durations with their right hand than vice versa. Critically, no spatial information was presented along with the stimuli, since the temporal interval was operationalized as the duration of a cross which appeared foveally. The same results were obtained by using two hands or two fingers of the same hand to respond. These results suggest that
elapsing time can be mentally represented in terms of spatial coordinates developing from left to right and that this representation affects left-right responses (see Ishihara et al., 2008, for an analogous effect in the auditory domain).

This effect, known as Spatio-Temporal Association between Response Codes (Stearc) effect (Ishihara et al., 2008; Vallesi et al., 2008), may be analogous to those observed in other spatial compatibility tasks where stimulus spatial position is real and not imagined. For instance, in the Simon task (Simon and Small 1969), although subjects have to judge the stimuli on a non-spatial dimension and stimulus location is task-irrelevant, it still affects performance: responses are faster and more accurate if the stimulus position corresponds to the response position than vice versa (see Hommel and Prinz 1997; Umiltà and Nicoletti 1990, for reviews).

These effects have been observed not only with static spatial stimuli but also with moving ones (Proctor et al., 1993). A critical factor in the Simon effect seems to be the attentional shift towards the stimulus spatial location, which in turn generates a response code on the same side of the attentional shift (e.g. Umiltà and Nicoletti 1992; Vallesi et al., 2005). It is possible that a similar spatial attentional mechanism produces the Stearc effect and related time-space compatibility phenomena, as suggested by recent evidence (Ouellet et al., in press). Specifically, we hypothesize that the mental representation of elapsing time develops from left to right, orienting spatial attention and priming compatible responses accordingly. If this is the case, it should be possible to continuously detect pre-activations of the compatible responses (i.e., left responses for short durations, and right responses for long durations) during the response preparation stage.

The aim of this study was to test this hypothesis. So far, only behavioural studies of left-right spatial-temporal compatibility effects have been carried out, suggesting the testable hypothesis that the locus of this effect involves spatial attention (Ouellet et al., in press) and can have consequences at the response processing stages (Weger and Pratt 2008). However, to fully understand the nature of this family of effects, it is necessary to use a technique, such as event-related potentials (ERPs), that can continuously track cognitive processes, such as response preparation, as they unfold in
time, unlike RTs that only mark the final stage of the processing flow (i.e., response execution). To this aim, we recorded ERPs while participants performed a similar time judgment task as in Vallesi et al. (2008).

It is known that preparing a hand movement produces relatively more negativity over the hand motor area contralateral to the response side (Brunia and Van Boxtel 2000; Toma et al. 2002), as it can be appreciated by subtracting electrical activity in the ipsilateral scalp motor region from that in the contralateral one (Shibasaki et al., 1981). Given the hypothesis that a temporal time-line evolving from left to right, if it exists, would produce a response code that also continuously evolves from left to right, we focused our analyses to the two scalp electrodes that pick up most of the electrical activity from the hand motor cortices of both hemispheres (i.e., C3 and C4). By subtracting activity in one of those electrodes from that in the other, we obtained a continuous measure of which response side is more activated at a given time-point during a trial.

It is worth mentioning that, in the electrophysiological literature, a common measure of lateralized motor preparation is the Lateralized Readiness Potential (LRP; De Jong, Wierda, Mulder, & Mulder, 1988; Gratton et al., 1988), which implies the further step of averaging the hemispheric differences for left and right responses in order to minimize the effect of possible lateralized hemispheric processes that do not co-vary with motor responses per se. However, this measure by definition does not allow to continuously tracking which of the two motor cortices (left vs. right) is more activated at each time-point. Therefore, we could not compute the full LRP here, since this measure would not be suitable to test our hypothesis that partial response activation should evolve along a specific direction, namely from left to right, and not vice versa.

Method

Participants

Fourteen young healthy volunteers (7 females; mean age: 26 years, range: 19-34) took part in the study after providing informed consent. The participants had normal or corrected-to-normal
vision and no history of neurological or psychiatric disorders. All were right-handed, with the average Edinburgh Handedness Inventory score (Oldfield 1971) being 84 (range: 40-100). They received 10 dollars per hour for participating in the experimental session, which lasted 1-2 hours (including EEG cap preparation and removal). The study was previously approved by the Baycrest Research Ethic Board.

Material and Task

Participants were tested individually in a sound-attenuated semi-dark room. A 64-channel cap was mounted at the beginning of the session (see ERP procedure). Visual stimuli were presented through a computer display at a distance of ~60 cm. A trial started with a central fixation cross (2 yellow crossed bars, 1.0 x 0.5 cm) lasting 1 or 2 sec (50% each). A downward pointing white arrow (a 1.5 x 1 cm bar attached to a 0.5 cm arrowhead with a maximum width of 2 cm) was then presented as a response-signal.

When judging two temporal intervals that are very different from each other with two responses, participants might prepare their responses in a bimodal fashion, for instance activating a response side close to the end of the short duration and then the opposite response side only when they get close to the end of the long duration. As an attempt to discourage this strategy, and therefore to stress the continuous nature of elapsing time, we used two durations that were closer than in the previous experiments (1 and 2 sec here vs. 1 and 3 sec in Vallesi et al., 2008; but see footnote 1).

The task consisted of pressing the left key ‘C’ of the computer keyboard (with the left index finger) for a short cross duration (1 sec), and the right key ‘M’ (with the right index finger) for a long cross duration (2 sec), respectively. The response key assignment to each cross duration was inverted for half of the four runs. The order of presentation of each run with each of the 2 possible Stimulus duration-Response position (S-R) mappings was randomized across participants. A familiarization run, consisting of 10 trials, was presented before each experimental run which
consisted of 80 trials each. The total number of test trials was 320. On each trial, a cross was presented for 1 or 2 sec. After this variable interval the response-signal (arrow) replaced the cross for 200 ms, followed by a blank screen for another 1800 ms. Therefore, the response deadline was 2 sec (from the arrow onset to the end of the trial). A short rest was provided after each run. Participants were discouraged from using any strategy (e.g., counting) in judging the cross duration, and asked to minimize eye blinks, eye movements or contractions of facial muscles.

**Behavioral data analysis**

Practice trials, the first trial of each test run and trials with responses beyond 100-1500 ms after the arrow onset were discarded from further analyses. RT analyses only included trials with correct responses. Both RTs and accuracy data were submitted to a 2x2 repeated-measures ANOVA with cross duration (1 vs. 2 sec) and response side (left vs. right hand) as the repeated measures factors.

**Electrophysiological recording and pre-processing**

Scalp voltages were recorded using ElectroCaps with 64 Ag/AgCl electrodes (10/20 system), which included electrodes on the external canthus and infra-orbital ridge. The EEG recording system was NeuroScan SynAmps (El Paso, TX). The online reference electrode was the vertex, with the mid-frontal electrode AFz used as the ground. Electrode impedances were maintained below 5 kΩ. The electrical signals were filtered with a 0.1-100 Hz bandwidth filter and digitized with a 250 Hz sampling rate.

The ERP data were pre-processed with Brain Electrical Source Analysis (BESA 5.2; Germany). Data were re-referenced to an average reference. Eye artifacts (i.e., eye-blinks, lateral and vertical movements) were compensated from the ERP waveforms using source components derived from the recordings obtained before and after the performance of the task (Picton et al. 2000). Stimulus-locked ERP data from correct trials were averaged as a function of the 4 conditions obtained by crossing 2 durations (1 vs. 2 sec) by 2 response hand (right vs. left) and digitally
filtered (0.1-10 Hz). ERP epochs for short durations were averaged over a 2700 ms period beginning 200 ms before the cross onset and ending 1500 ms after arrow onset. ERP epochs for the long durations were averaged over a 3700 ms period beginning 200 ms before the cross onset and ending 2500 ms after the arrow onset. All ERPs were baseline-corrected according to the 200 ms preceding the cross onset. The final ERPs (averaged across runs) were based on a total of 57-79 trials per condition (average: 72).

**C3-C4 differential waveform analysis.** To calculate the differential activation of the scalp regions over the left vs. right hand motor cortex, we subtracted amplitude in the right electrode C4 (over the left hand motor area) from amplitude in the left electrode C3 (over the right hand motor area) for each of the 4 conditions. To evaluate when one of the two response sides was consistently more activated than the other, a bootstrap procedure was implemented (1000 bootstrapped samples) to calculate 95% confidence intervals for each time point from 100 ms after the cross onset to 1000 ms after the arrow onset. When both inferior and superior confidence intervals were above the zero line, a left-more-than-right motor activation was inferred. On the other hand, when both inferior and superior confidence intervals were below the zero line, a right-more-than-left motor activation was inferred.

To test whether the phenomenon reflected an effect of spatial attention on the response activation and not other lateralized processes unrelated to the response, the response-locked differential waveform was also extracted. By triggering the ERP averaging on the response rather than on the stimulus, response-related processes are further enhanced while stimulus-locked processes will be much less evident (cf. Osman et al. 1995). This measure was calculated from 600 ms before to 400 ms after the RT. Response-locked waveforms were baseline-corrected by subtracting the average voltage during the 600-400 ms before RTs from the whole segment (cf. Osman et al., 1995).
Results

Behavioral results. Trials with RTs shorter than 100 ms (0.6%) and longer than 1500 ms (0.6%), and the first trial of each run (1.25%) were discarded from the analyses. The error percentage was almost equally distributed across conditions (4.5-5.2%) and no effect was significant in the ANOVA concerning accuracy. Figure 1 represents mean RTs according to the 4 experimental conditions. Responses were overall faster for long durations as indicated by the duration main effect [F(1,13)= 16.3, p < .01], and the critical duration by response side interaction was also significant [F(1,13)= 11.3, p < .01]. This interaction demonstrates that participants were faster in judging short durations with their left hand and long durations with their right hand than vice versa (i.e., the classical Stearc effect). More detailed planned comparisons showed that the RT difference between right and left responses was significant for the long duration (40 ms, p = 01) and was a strong tendency for the short duration (-26 ms, p = .07).

---Insert Figure 1 about here---

Stimulus-Locked C3-C4 differential waveform analysis. Figure 2 shows the activity in the critical electrodes C3 and C4 according to the 4 different conditions. Figure 3 shows the results of the bootstrap procedure used to evaluate the differential activation of left vs. right motor scalp regions for the stimulus-locked ERPs. The circles above each differential waveform indicate time-points that were reliably positive (left motor activation), whereas the circles below mark time-points that were reliably negative (right motor activation). The intervals in which sample-points were reliably different from 0 are also reported in the table 1.

A left-hand response was pre-activated for short durations soon after the cross onset in all conditions (range from 160 to 510 ms post-cross onset). Moreover, in the compatible conditions (short duration: left response; long duration: right response), there was an increase of negativity in the scalp motor site contralateral (vs. ipsilateral) to the left response around the end of a short cross
duration (from 824 ms post-cross onset), which then slowly shifted towards the opposite side if time passed by towards the long duration. The mirror phenomenon was not observed during the incompatible long duration condition; that is, a right motor response was not pre-activated around the possible occurrence of the stimulus for short durations. On the contrary, when a short duration was associated with a right response (incompatible condition), after the arrow onset there was a brief pre-activation of the wrong (left) response side (56-216 ms) that was then inverted towards the correct (right) response side (most time-points from 348 to 996 ms). Finally, there was a rebound effect with negativity developing in the opposite (left) hemisphere for left responses only (both with short and with long durations).

---Insert Figure 2 about here----

---Insert Figure 3 about here---

---Insert Table 1 about here----

Response-Locked C3-C4 differential waveform analysis. Figure 4 and Table 2 show the results of the bootstrap procedure used to evaluate the differential activation of left vs. right motor scalp regions (C3 vs. C4) for the response-locked ERPs. Like in Figure 3, the circles above each differential waveform indicate time-points that were reliably positive (left motor activation), whereas the circles below mark time-points that were reliably negative (right motor activation).

The task-relevant response side was activated earlier in the two compatible conditions than in the two incompatible ones. In particular, when a short cross duration should be responded to with the left hand (compatible conditions), the differential waveform becomes reliably positive (suggesting a right motor cortex pre-activation: from 508 ms before to 40 ms after the RT) much earlier than it becomes reliably negative when the same short duration should be responded to with the right hand (suggesting a left motor cortex pre-activation: from 164 ms before to 64 ms after the RT). Moreover, when a long cross duration should be responded to with the right hand (compatible
condition), the differential waveform becomes reliably negative (suggesting a left motor cortex pre-activation: most of the time-points from 480 ms before to 52 ms after the RT) earlier than it becomes positive when the same long duration should be responded to with the left hand (suggesting a right motor cortex pre-activation: most time-points from 360 ms before to 16 ms after the RT). Finally, for all the 4 conditions, the differential wave is reliably negative for a variable interval after RT, suggesting a post-response activation of the left motor cortex (right hand).

Discussion

The present results show that when a horizontal bimanual response is given according to the temporal duration of a stimulus, the response side affects performance. Specifically, participants are faster if they respond ‘short’ with the left hand and ‘long’ with the right hand one than vice versa. This pattern of behavioral results suggests that elapsing time is internally mapped onto left-to-right spatial coordinates and replicate previous findings (Ishihara et al., 2008; Vallesi et al., 2008).

The main effect of duration indicates the presence of the variable foreperiod effect, that is shorter RTs for longer durations (Niemi and Näätänen 1981; Vallesi et al. 2007a,b; Woodrow 1914). However, the duration by hand interaction cannot be explained in terms of a greater FP effect with either hand, because when only a single hand is used in a block, no interaction between duration and response side is observed (Vallesi et al., 2008, experiment 2).

The ERP data provide further insights towards the understanding of this phenomenon. Stimulus-locked ERPs, and in particular the differential C3-C4 waveforms, show that a left-hand response is pre-activated soon after the cross onset in all conditions (Figure 3). Moreover, when a right response is assigned to short durations (incompatible condition), there is a brief pre-activation of the wrong (left) response side that is then corrected towards the correct (right) response side after
the go-stimulus onset (Figure 3, panel B), an effect that resembles the inappropriate response pre-activation (Gratton dip) in the Lateralized Readiness Potential for the incompatible conditions of the horizontal Simon effect (Gratton et al., 1988; Vallesi et al., 2005). Finally, when subjects have to respond to short durations with the left hand and to long durations with the right one (compatible conditions), there is an increase of activation of the scalp motor site contralateral (vs. ipsilateral) to the left response near the end of a short duration, which then gradually shifts towards the opposite side if the duration becomes longer (Figure 3, panel C).

The mirror phenomenon is not observed during the incompatible condition in which a long duration should be responded to with a left response: a right motor response is not pre-activated around the possible occurrence of the go-stimulus for short durations (Figure 3, panel D). Hence, in this condition the relevant right response is not pre-activated around the short duration, but it is activated only in a stimulus-driven fashion if the response-signal (arrow) appears at the end of the short duration (1 sec), and only after a brief pre-activation of the wrong but compatible left response (Figure 3, panel B).

Converging and complementary information can be gained from the response-locked differential waveforms. The task-relevant response side was activated earlier in the two compatible conditions than in the two incompatible ones. In particular, with a short cross duration, the moment in which the C3-C4 differential waveform becomes reliably positive (suggesting a right motor cortex pre-activation) for a left response is earlier than the moment in which the differential waveform becomes reliably negative (suggesting a left motor cortex pre-activation) for a right response. On the other hand, with a long cross duration, the moment in which the differential waveform becomes reliably negative (suggesting a left motor cortex pre-activation) for a right response is earlier than the moment in which the differential waveform becomes reliably positive (suggesting a right motor cortex pre-activation) for a left response.¹

---Insert Footnote 1 about here---
Finally, a rebound effect (more negativity) occurred in the opposite hemisphere, which in the stimulus-locked differential ERPs was significant only for left responses (both with short and long durations). A somewhat similar phenomenon could be observed in the response-locked differential ERPs, since C3 (i.e., the electrode picking up most of the right hand motor activation) was more negative than C4 for some time after the RT, independently of the condition. This pattern could be related to the fact that, in right-handed subjects, the left motor cortex keeps more in check the right homologous area through inhibitory control than the other way around (Ziemann and Hallett 2001). However, whatever are the physiological mechanisms underlying this hemispheric asymmetry, this effect is not relevant for the main hypotheses under study here, since it occurs after the RT and independently of the task condition.

Handedness could be a factor in determining the left-right direction of the Stearc effect. No study up to now has tested, together with right-handed subjects, a complementary sample of left-handed subjects. However, there is no apparent reason why right-handed subjects should show a left-hand advantage for short intervals.

Changing the experimental settings, such as the spatial presentation (back-front vs. left-right) of time words to be judged as belonging to the past or to the future, has been shown to flexibly change the nature of the association between time codes (past-future) and the spatial codes arising from the experimental context (Torralbo et al., 2006). Similarly, the experimental settings adopted in the present and related previous studies, such as the fact that the required responses to judge short and long time durations were located along the left-right horizontal plan, are likely to play a role.

This however does not entirely explain why left and right responses are associated with short and long durations, respectively, and not the other way around. The direction of writing is a likely factor in determining the direction of the association (Santiago et al., 2007; Tversky et al., 1991; Zwaan 1965). Directionality of writing affects also other spatial compatibility effects, such as the SNARC effect (Dehaene et al., 1993; Zebian, 2005). The prolonged exposure to timelines that run
from left to right, such as in the x-axis of the Cartesian coordinate system, may also play a role. A follow up study is desirable to test whether the phenomenon disappears or is reversed in people adopting writing systems with a directionality different from the left-to-right one (e.g., Mandarin, Hebrew, Arabic), provided that they have not been also exposed to left-to-right writing systems or time representations.

In summary, the present findings further confirm the hypothesis that, when responses should be given in the horizontal dimension, elapsing time is also represented as continuously evolving from left to right. This dynamic spatial representation of elapsing time produces a response code that pre-activates the corresponding motor cortex and speeds up the response when the response mapping is compatible with the short/left and long/right internal representation of time. The same is not true for incompatible mappings, which actually produces a cost in terms of speed due to the brief pre-activation of the compatible but task-irrelevant response side for short durations, and to the absence of pre-activation of the relevant response side for long durations. This study suggests that time mentally flies from left to right, and this spatial representation of time spreads, probably mediated by an attentional shift, to the response preparation stage affecting motor performance.
Acknowledgements

This research was supported by: postdoctoral fellowship funding from Canadian Institute of Health Research (CIHR, MFE-87658) and a research Award from the Jack & Rita Catherall Fund to AV; from Canadian Foundation for Innovation (CFI) and Ontario Innovation Trust to University of Toronto Functional Imaging Network (#1226) to DTS. We thank Juan Lupiáñez for useful suggestions.
Footnotes

*Footnote 1.* In the present task, we asked participants to judge two discrete durations (1 and 2 seconds). A task requiring a comparison between a standard duration and different target durations, perhaps, would have been a better way to encourage participants to monitor elapsing time continuously. However, that time was represented continuously and sequentially from left to right also in the present task was suggested by the measures provided by the C3-C4 ERP difference, which support the prediction that this representation produces a continuous spatial attentional shift from left to right, which in turn primes left-right responses.
Reference List


PICTON TW, BENTIN S, BERG P, DONCHIN E, HILLYARD SA, JOHNSON R, MILLER GA,
RITTER W, RUCHKIN DS, RUGG MD, and TAYLOR MJ Guidelines for using human event-
related potentials to study cognition: recording standards and publication criteria.


PROCTOR RW, VAN ZANDT T, LU CH, and WEEKS DJ Stimulus-response compatibility for
moving stimuli: perception of affordances or directional coding?


SANTANGELO V and SPENCE C Crossmodal exogenous orienting improves the accuracy of

SANTIAGO J, LUPIANEZ J, PEREZ E, and FUNES MJ Time (also) flies from left to right.


SCAIFE M and ROGERS Y External cognition: How do graphical representations work?


SHIBASAKI H, BARRETT G, HALLIDAY E, and HALLIDAY AM Cortical potentials associated

SIMON JR and SMALL AM Processing auditory information: interference from an irrelevant cue.


STENNING K and OBERLANDER J A cognitive theory of graphical and linguistic reasoning:

STOIANOV I, KRAMER P, UMILTA C, & ZORZI M. Visuospatial priming of the mental number

TOMA K, MATSUOKA T, IMMISCH I, MIMA T, WALDVOGEL D, KOSHY B, HANAKAWA
T, SHILL H, and HALLETT M Generators of movement-related cortical potentials: fMRI-

TORRALBO A, SANTIAGO J, LUPIANEZ J Flexible conceptual projection of time onto spatial


XUAN B, ZHANG D, HE S, and CHEN X Larger stimuli are judged to last longer. *J. Vis.* 7: 2-5, 2007.


Table 1. Intervals (in ms, with respect to the cross onset) in which the differential ERP waveform (C3-C4) was reliably more positive or more negative than 0 for each task condition.

<table>
<thead>
<tr>
<th>Cross Duration</th>
<th>Short</th>
<th>Long</th>
</tr>
</thead>
<tbody>
<tr>
<td>Response Side</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>Polarity</td>
<td>Negative</td>
<td>Positive</td>
</tr>
<tr>
<td></td>
<td>824 – 1532</td>
<td>1876 – 1912,</td>
</tr>
<tr>
<td></td>
<td>1948 – 1996</td>
<td>1056 – 1216</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2. Intervals (in ms, with respect to the RT) in which the differential ERP waveform (C3-C4) was reliably more positive or more negative than 0 for each task condition.

<table>
<thead>
<tr>
<th>Cross Duration</th>
<th>Short</th>
<th>Long</th>
</tr>
</thead>
<tbody>
<tr>
<td>Response Side</td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>Polarity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive</td>
<td>164 – 396</td>
<td>-352</td>
</tr>
</tbody>
</table>
Figure Captions

Figure 1. Mean response times (and standard errors of the mean) as a function of cross duration (x-axis) and responding hand (histograms).

Figure 2. Grand-average amplitudes of the stimulus-locked ERPs in the two electrodes located on hand-motor scalp regions of the left and right hemisphere: C3 (continuous line) and C4 (dashed line), respectively. Panels (A) and (B) show waveforms associated to the short duration to be responded to with left and right hand, respectively (as shown by the drawing of the two hands). Panels (C) and (D) show waveforms associated to the long duration to be responded to with right and left hand, respectively. The two conditions with compatible spatio-temporal mapping (A and C) are surrounded by a bold rectangle, while the two conditions with incompatible spatio-temporal mapping (B and D) are surrounded by a thin rectangle. The two critical stimuli, that is the cross (whose duration had to be judged) and the arrow (i.e., the response-signal), are shown on the top two panels and their onset is marked on each panel with a continuous and a dashed vertical line, respectively.

Figure 3. Grand-average amplitude of the stimulus-locked differential waveforms between electrodes C3 and C4 (black lines) and inferior and superior 95% confidence intervals (grey lines). Panels (A) and (B) show waveforms associated to the short duration to be responded to with left and right hand, respectively (as shown by the drawing of the two hands). Panels (C) and (D) show waveforms associated to the long duration to be responded to with right and left hand, respectively. Black circles at the top of each panel denote time-points where both inferior and superior confidence intervals are above the 0 line, indicating that activity in C4 is reliably more negative than that in C3. Grey circles at the bottom of each panel mark time-points in which both inferior and superior confidence intervals are below the 0 line, indicating that activity in C3 is reliably more negative than that in C4. See Figure 2 for an explanation of the other symbols.
Figure 4. Grand-average amplitude of the response-locked differential waveforms between electrodes C3 and C4 (black lines) and inferior and superior 95% confidence intervals (grey lines).

See Figure 3 for an explanation of the symbols used.