Research report

Linguistic and spatial information for action

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Received 17 February 2007; received in revised form 19 June 2007; accepted 26 June 2007
Available online 29 June 2007

Abstract

Motor acts can be triggered according to either semantic or spatial objects attributes, which are thought to predominantly involve the ventral and the dorsal stream of the visual system, respectively, but with different time constraints. To date, no study has specifically addressed the issue of a possible interaction between spatial and semantic information when responding according to linguistic stimuli. In particular, it is not well established whether a motor response to a linguistic stimulus may remain immune to the influence of concurrent spatial information. In this vein, we tested the influence of the presentation of congruent and incongruent spatial information on a right–left motor response made towards a linguistic stimulus, and also the reverse condition. Results showed that the time to respond to a linguistic stimulus was greater than that observed to react to a spatial stimulus. Furthermore, we found an absence of interference of linguistic information on response accuracy and reaction time when responding to spatial stimuli. In fact, a strong interference of spatial information in the form of an increase in reaction time and misdirected responses was observed when responding to the linguistic stimulus, but predominantly for responses with short reaction times (300–500 ms) and in presence of incongruent spatial information. In the latter condition, correct responses showed in addition a tendency to veer away from the distracting spatial stimulus. We conclude that response selection can be influenced by irrelevant visual information. This suggests that information that is processed within the ventral and the dorsal visual streams compete very early under different time constraints, in order to specify the relevant visual signal for action.

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Keywords: Vision; Perception and action; Ventral and dorsal streams; Semantic and spatial interference

1. Introduction

Motor acts are generally performed towards visual objects that have a particular shape, location and orientation in space. The function of the visual system is, thus, to isolate one or few target-objects and to provide information about the relevant spatial characteristics that make possible the organisation of action, in relation to body constraints and motor abilities [1]. As a consequence, visual selection for action in the peri-personal space depends on the true limit of action-capability for the upper limbs [2,5]. Generally, the selection of action-relevant objects involves processing of intrinsic (e.g., colour, shape or texture) and extrinsic (e.g., location or orientation) visual (eventually auditory) attributes. It is, however, quite common to also use language for spatial description of target-objects in the peri-personal space. For instance, one may use spatial descriptors such as the object “to the right”, “near . . .”, “close to . . .”. Though it seems intuitively accepted that words can be used for action selection, spatial characteristics and words processing are generally considered as two independent activities involving specific and different brain areas, even when words and spatial information are processed within the same visual modality and concern peri-personal space [14,17].

In this context, the dominant view of the visual system is that there is a sharp division of labour between ‘vision-for-action’ controlled by the dorsal pathway from primary visual cortex (V1) to the posterior parietal cortex (including the intra-parietal sulcus-IPS and the superior parietal lobe-SPL) and ‘vision-for-conscious perception’ controlled by the ventral pathway from V1 to the inferotemporal cortex [29]. One of the main aspects of the visual system for perception is that it deals with explicit holistic descriptions of the visual input, even when such information leads to errors in spatial processing (e.g., visual illusion). Conversely, the visual system for action deals with the absolute metrics of the visual input that are relevant for specific actions (e.g., reaching and grasping), and, thus, remains unaffected by
illusory context that nevertheless lead to erroneous perceptual judgements. An interesting aspect of the ventral stream is that it is thought to participate in the processing of visual input associated with word reading and understanding. In a broader sense, word reading presumably entails basic sensory and motor components, as well as more central components, such as the analysis of visual word forms (orthography), the analysis of word sounds (phonology) and the analysis of word meaning (semantics). As a consequence, when focussing on the initial stage of word reading increased activity within specific brain areas was observed, principally the left-lateralised regions in occipital and occipitotemporal cortex including the superior and middle temporal cortex [33,11]1. These areas are, thus, different from that involved in the processing of spatial properties of visual objects, which mainly includes at least for perception of location and orientation the posterior parietal cortex when representing potential targets for action [6,29,50].

Besides from the dissociation made for the nature of the visual characteristics that would be processed either by the ventral or the dorsal visual streams, temporal dissociations between the two pathways have also been reported. Nowack and Bullier [30], for instance, reported that the latencies to visual stimulation are widely dependent on the underlying type of neural conduction. According to these authors, the major factor that influences the speed of activation of cortical areas appears to be whether or not a cortical area is activated by the heavily myelinated, fast conducting magnocellular channel, which is almost exclusively the case for the dorsal stream. Accordingly, visual latencies were observed around 40–80 ms within the parietal areas whereas they were observed around 100–150 ms within the temporal areas predominantly fed with parvocellular fibres characterised by slower transfer of information. Moreover, synaptic relays from the visual cortex to the premotor areas are more numerous via the ventral than via the dorsal pathway [46]. As a direct consequence, reaction times to a location–discrimination task were reported to be within the range of 350–450 ms [37,45], whereas reaction times to lexical and semantic stimuli when reading usual words were found to be within the range of 400–650 ms [28,39].

Although spatial processing for action and semantic knowledge are considered in some respects to be independent one from another [35], recent data suggest that this is not the case in all circumstances [e.g., 25]. A convincing illustration was reported by Creem and Proffitt [4], who found that inappropriate grasping for household tools occurred when object grasping was paired with semantic information in a dual-task experiment (completing verbally a concurrent paired-associates task). This inappropriate grasping was, however, reduced when paired with a visuospatial dual-task (imagine a block letter and classify the corners). Thus, semantic processing can have an interfering effect when grasping a meaningful object. Interestingly, a similar effect was also observed when subjects had to bisect a vertical line in the presence of a word (“top” or “down”) placed at the extremities of the line [22,49]. However, controversial data exist concerning the interaction between semantic and sensori-motor processing [13] and most of the data available so far suggest that semantic information when using distracting words influences principally the kinematics of reaching and grasping motor acts [14–17]. Gentilucci et al. [15], for instance, reported that words denoting “far” and “near” printed on to-be-grasped objects had an effect on movement kinematics comparable to the greater or shorter distances that separate hand location and object. In the same vein, Glover and Dixon [17] reported that maximum grip aperture was enlarged when grasping an object with the word “large” printed on top, as compared to grasping the same object with the word “small”. However, no study has specifically addressed the issue of the interaction between spatial and semantic processing when responding according to a linguistic stimulus. In particular, it is not well established whether (1) motor performance varies when responding according to a linguistic rather than a spatial stimulus, (2) motor response to a linguistic stimulus may remain immune to the influence of contextual spatial information. In this respect, previous studies about the effect of irrelevant spatial information in a manual reaching task have shown that reach path is affected by the presence of distractor. For instance, Tipper et al. [47] found that the hand veered away from distractor, even though it does not represent a physical obstacle to the reaching hand. Whether this effect holds, when processing linguistic information in the presence of congruent and incongruent spatial information, remains an open issue.

In the literature on interference effects, the classic paradigm used to study of spatial and semantic interferences is based on reaction times (for an overview see [27]). To give some examples, the Simon-like effect paradigms explore the interference effect of spatial stimulus-response compatibility [42]. In this task, participants are instructed classically to press a right or left button to stimuli appearing either on the left or on the right side of a screen. When the spatial stimulus and the response codes correspond, it speeded up the response. Conversely, when there is no correspondence between the stimulus and the response, spatial contents can be in conflict, which leads to the consequence that reaction times increase. Similarly, in the spatial Stroop task, participants are asked to respond to the physical location of stimuli, whose content also designates a spatial location [27,40]. Here, a word can appear on the left or on the right side of a fixation point, when the word itself is either “left” or “right” [23,32,44]. Again, when the word position and its meaning are congruent, reaction times are faster than when they are not.

The common explanations of these Simon-like effect paradigms postulate two separate routes for perception and action [9,20,24]. In a conditional route, the appropriate response is intentionally selected and activated, whereas in a parallel, unconditional route the response that spatially corresponds to stimulus location is automatically activated. Thus, right-sided stimuli facilitate right-sided responses, whereas left-sided stimuli facilitate left-sided responses. As a result, when stimulus and response location are congruent, there is a reduction in reaction time. In contrast, for non-congruent stimulus and response loca-

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1 When taking the whole process of word reading into account, results of previous studies converge to reveal a set of areas, including the left-lateralised regions in occipital and occipitotemporal cortex, the left frontal operculum, bilateral regions within the cerebellum, the primary motor cortex, the superior and middle temporal cortex, the medial regions in the supplementary motor area and the anterior cingulate [11].
tion, the two routes activate conflicting responses, leading to prolonged reaction times.

In the present study, our goal was to explore to which extent a spatial irrelevant information influenced goal-directed movements that were triggered by a linguistic stimulus. Instead of Simon-like effect paradigms where the position of the stimulus is in conflict with the meaning of the stimulus itself (i.e., the word “left” is posited on the right), we have employed a spatial interference task \([12,47]\), in which the semantic information (“left”; “right”) was never in conflict with the response code, since the word stimulus was always located in a central position. More specifically, participants were required to respond according to (1) a word that indicate the right or left direction, or (2) a spatial target that appear to the right or to the left of the mid-sagittal body axis. In some trials, the two types of information were simultaneously available but the instruction encouraged subjects to consider only one of them. Assuming that linguistic and spatial information involve independent processing, no interference effects were expected when presenting simultaneously the linguistic and the spatial stimuli. Conversely, assuming that processing of both linguistic and spatial information interact in some way, an interference effect was expected but predominantly when responding according to the linguistic stimulus due to the difference in latency characterising the processing of information within the ventral and dorsal pathways of the visual system.

2. Methods

2.1. Participants

Nine self-declared voluntary students from the University of Lille3 participated in the experiment (seven females and two males, mean age 25.2 years). All participants had normal or corrected-to-normal visual acuity and were naive as to the purpose of the experiment. They all gave their informed consent prior to their inclusion in the experiment, which was approved by the University Charles de Gaulle ethical committee and in accordance with the principles of the Helsinki 1964 declaration. They were all right-handed, as assessed by self-report from a 10-item questionnaire adapted from the Edinburgh Handedness Inventory \([31]\). The mean laterality quotient (LQ) of the participant was 86.66 with a range of 70–100.

2.2. Apparatus and procedure

The experimental apparatus consisted in a rectangular box (60 cm high, 100 cm wide and 70 cm deep) with the inside divided horizontally by a half-silvered mirror (see Fig. 1). A computer 20 in. computer monitor was placed upside-down on the top surface of the apparatus so that the image generated by the computer was reflected in the mirror, and due to the optical geometry, the image on the computer screen appeared to be projected onto the bottom surface of the workspace. The visual stimulus was an 11 cm × 6 cm empty rectangular frame (white lines; width: 1.5 mm; luminosity: 1.05 cd/m²) on a dark background (0 cd/m²) with a linguistic or a spatial stimulus. The inner surfaces of the box were smooth and painted matt black. No visual information from the external environment was available during the entire experiment.

The centre of the rectangular frame was located at 25 cm from the starting position of the hand, which was near the navel on the sagittal body axis. The vision of the hand at the starting position was available from a focused dim light beam but there was no visual feedback about arm displacement. The rectangular frame was presented either with a white dot (diameter 14 mm; luminosity 1.05 cd/m²) located halfway along its right or left side, or with a word within. The word (white colour; luminosity 1.05 cd/m²) could be either “DROITE” (right) or “GAUCHE” (left) and was displayed so that the distance between the first and the last letter was kept constant in reference to the left and right side of the rectangular frame (1.2 cm), as well as the distance between the letters and the nearer and the further side of the rectangular frame (2.2 cm). The two words contain the same number of letters and are encountered at similar frequency in the French language. The subjects’ task was to respond according to the target-dot or the word and to ignore all other stimuli. During the familiarisation session, the rectangular frame was presented together with either the dot (spatial stimulus) or the word (linguistic stimulus) or with both stimuli but in a congruent arrangement (e.g., right dot with the word “DROITE”). The rectangular frame was displayed following a delay of 1000 ms after the hand was stable at the starting position; this display persisted until the response was provided. In each of the two tasks (response according to the spatial or the linguistic stimulus, presented in block sessions counterbalanced across the participants), five trials were performed towards each location randomly presented. Thus, a total of 40 trials were performed (2 tasks × 2 locations in the single or the congruent condition). When responding according to the spatial stimulus, the participants’ task was to point as quickly and as accurately as possible with the right hand to the side of the rectangular frame corresponding to the target location. When responding according to the linguistic stimulus, participants were instructed to point as quickly and accurately as possible to the right or to the left direction (i.e., towards an imaginary target) according to the stimulus, but consistently and not in the direction of the rectangular frame (see Fig. 1 for an illustration). This response mode was chosen in order to avoid any a priori association between semantic code and true spatial cues. Subjects were required to react as soon as the visual stimulus was available.

During the experimental session, the two tasks were also performed in block sessions and counterbalanced across participants. The novelty was that an incongruent condition was introduced. When responding according to the linguistic stimulus, the word “DROITE” or “GAUCHE” was presented alone, or together with the right or left spatial stimulus in a congruent and incongruent relationship. When responding according to the spatial stimulus, the target-dot was presented either alone, or together with the word “DROITE” or “GAUCHE” in a congruent and incongruent relationship. Under each condition, 48 trials were performed towards each side: 18 trials with a single stimulus, 18 trials with congruent stimuli (e.g., word “DROITE” and right spatial stimulus) and 12 trials with incongruent stimuli (e.g., word “DROITE” and left spatial stimulus see Fig. 1) randomly presented. The incongruent condition corresponded, thus, to 25% of the trials intertwined with the other trials. In the dual-stimuli presentation, the participants were instructed to ignore the irrelevant information. A post-experiment interview revealed that the two tasks were judged by all participants as being equivalent in terms of difficulty and attentional cost.

2.3. Data recording and processing

Horizontal pointing movements were performed on a digitizer tablet (Wacom UD-185, spatial resolution: 0.1 mm) which registered the \((X, Y)\) coordinates of an electromagnetic stylus held in the participants’ right hand (sampling rate: 100 Hz). Individual trajectories were used to evaluate initial (computed 200 ms after movement onset) and terminal directional accuracy determined from angular error according to the mid-point of the lateral side of the rectangular frame. This provides the means to have a common system of reference for the analysis of the spatio-temporal accuracy in the different tasks. Angular error was defined as the angle between the starting position-to-movement-end-point vector and the starting position-to-frame-side vector, with a minus sign to indicate a deviation to the right according to the side of the rectangular frame. The size and sign of the angular error served to determine those trials presenting a directional error. The right and left direction of the trajectory was determined for each subject according to the median value computed from the left and right angular errors with similar sign value. The cut-off of the directional error was, thus, the midpoint of the two median values. Then, a misdirected movement corresponded to a movement with an initial trajectory oriented in an opposite direction according to the mid-point reference and the target. The reaction times separating movement onset and stimulus appearance was also computed. Finally, we examined both the kinematics (peak velocity) and the temporal parameters (movement time, percentage of time to acceleration period) for the hand paths under the different experimental conditions.

As the left–right performances were similar, a two-way analysis of variance (ANOVA: task \((2) \times \text{context of stimulus presentation} (3)) was performed and
3. Results

3.1. Reaction time

Considering correct responses, mean reaction time was 577 ms (S.D.: 191 ms) and was shorter when responding to the spatial stimulus (mean: 484 ms, S.D.: 109 ms) than to the linguistic stimulus (mean: 670 ms, S.D.: 210 ms, \( F(1,8) = 11.86; p < 0.01 \)). Reaction time was influenced by the context of stimulus presentation \( F(2,16) = 3.90; p = 0.04 \), and an interaction between the two factors was revealed \( F(2,16) = 10.82; p < 0.01 \). Analysis of simple effects associated with the interaction showed that reaction time varied when pointing as a function of the linguistic stimulus (657, 642 and 711 ms for the single, congruent and incongruent condition, respectively, \( F(2,16) = 8.94; p < 0.01 \)) but not when pointing according to the spatial stimulus (492, 479 and 482 ms for the single, congruent and incongruent condition, respectively, \( F(2,16) = 0.62; p = 0.55 \)). This interaction was not modified by the direction indicated by the stimulus \( F(2,16) = 0.27; p = 0.76 \). When considering the task with the linguistic stimulus only, local analysis showed that even if reaction time decreased and increased in the congruent and incongruent condition, respectively, only the latter was significantly different from the single condition \( (t(16) = 3.38; p < 0.01) \) (Fig. 2).

3.2. Directional performance

3.2.1. Initial angular performance

For correctly oriented responses, initial directional performance was dependent on the stimulus (linguistic: 0.78°, spatial:
Fig. 2. Reaction times (ms) and standard deviations are presented as a function of the experimental condition (single, congruent, incongruent) when responding to the linguistic or the spatial stimuli.

5.1°, $F(1,8) = 10.38; p = 0.01$) and its direction (right: $−12.12°$, left: $18.01°$, $F(1,8) = 80.52; p < 0.01$), but not on the presentation context (single: $2.75°$, congruent: $2.84°$ and incongruent condition: $3.23°$, $F(2,16) = 0.35; p = 0.66$, see Fig. 3). Initial movement direction was nearly symmetrical in reference to the middle axis of the rectangular frame whatever the stimulus. As expected, we found a significant interaction between the stimulus used as target and its direction ($F(1,8) = 63.59; p < 0.01$). The error was smaller when responding to the spatial stimulus (right: $0.11°$, left: $10.08°$) than when responding to the linguistic stimulus (right: $−24.35°$, left: $25.91°$). This confirms the fact that the subject stuck to the instruction to not direct the hand towards the side of the rectangular frame when responding to the linguistic stimulus. Furthermore, we found an interaction between the presentation context and the direction of the stimulus ($F(2,16) = 224.89; p < 0.01$), which was also dependent on the task ($F(2,16) = 635.76; p < 0.01$). Initial angular error was greater in the incongruent than in the single (right direction: $t(16) = 29.29; p < 0.01$, left direction: $t(16) = 31.21; p < 0.01$) and congruent condition (right direction: $t(16) = 30.25; p < 0.01$, left direction: $t(16) = 30.84; p < 0.01$), but only when responding accurately to the linguistic stimulus (respectively, single: $−16.95°$, right congruent: $−16.19°$, left incongruent: $−39.91°$, left congruent: $17.95°$, left incongruent: $42.13°$). The single and congruent conditions did not differ significantly (right direction: $t(16) = 0.96; p = 0.35$, left direction: $t(16) = 0.37; p = 0.71$). The sign of the error suggests that hand path was directed more to the right when responding to the word “DROITE” in the incongruent than the congruent and the single condition, the opposite was revealed when responding to the word “GAUCHE”. The effect of the irrelevant spatial stimulus was, thus, effective from the beginning of the movement, even with accurately directed motor responses. It is interesting to note that this effect was observed for all subjects (see Fig. 5) and consequently, it cannot be simply attributed to the instruction to point to a virtual rather to a physical target. Indeed, if this had been the case, a similar performance would have been expected in the congruent and in the single condition. As shown in Fig. 5b, the change of movement direction away from the disturbing spatial stimulus was specific to the incongruent condition.

3.2.2. Movement directional error

No directional errors were registered when responding to the spatial stimulus (0%), which contrasted with the performances reported in the presence of the linguistic stimulus (8.54%, S.D.: 12.91%; $F(1,8) = 13.44; p < 0.01$) (Fig. 4). However, this effect was dependent on the context of the stimulus presentation. For the linguistic stimulus, the percentage of directional errors was higher in the incongruent condition (20.37%, range of values: 4.16–50%) than in both the congruent

Fig. 3. Initial and terminal angular errors and standard deviations are presented in reference to the side of the rectangular frame as a function of the experimental condition (single, congruent, incongruent) when responding to the linguistic and the spatial stimuli.
Fig. 4. (a) Percentage of misdirected hand displacement and standard deviation as a function of the experimental condition (single, congruent, incongruent) when responding to the linguistic or to the spatial stimulus. (b) Examples of misdirected hand responses for a typical subject when responding to the linguistic stimulus “DROITE” in presence of a left spatial stimulus. Note that trajectories are corrected during the early or late part of hand transport phase.

(2.16%,  r(16) = 6.13; p < 0.01) and the single conditions (3.09%,  r(16) = 5.82; p < 0.01), the two latter conditions being non significantly different (r(16) = 0.31; p = 0.76). Furthermore, the single and congruent conditions did not differ when comparing the performances according to both the spatial and the linguistic stimuli, respectively (r(16) = 1.04; p = 0.31 and r(16) = 0.73; p = 0.48).

Intriguingly, we found that the directional error in the incongruent condition was a function of reaction time (Fig. 6). Indeed, for the shortest range of reaction times (300–400 ms), directional errors were observed in 48% of the trials. This percentage decreased as reaction time increased and reached 7.14% of the trials for the longest range of reaction times (900–1000 ms). As shown in Fig. 4 for one participant, directional errors were generally corrected on-line during the initial part of the trajectory or latter during the deceleration part of the trajectory. Finally, directional errors when performed towards the linguistic stimulus were not the consequence of the unexpected incongruent condition, which was discovered during the experimental session. Indeed, we observed 44% of misdirected movements in the first half of the set of 96 trials, and, thus, 56% in the second half. Consequently, inaccurate movement planning was the consequence of the influence of the irrelevant spatial information when planning motor responses according to linguistic stimuli.

3.2.3. Terminal directional accuracy

Terminal directional accuracy was dependent on the stimulus (linguistic: −1.98°, spatial: 1.88°) and its direction (right: −18.14°, left: 18.04°, F(1,8) = 134.53; p < 0.01), but not on the context of stimulus presentation (single: 0.04°, congruent: −0.22° and incongruent condition: 0.04°,  F(2,16) = 0.37; p = 0.6, see Fig. 3). Thus, movement-end-points were nearly symmetrical in reference to the middle axis of the rectangular frame. We found an interaction between the task and the direction of the stimulus (F(1,8) = 76.52; p < 0.01). The error was smaller when responding to spatial stimuli (right: −4.78°, left: 8.54°) than to linguistic stimuli (right: −31.49°, left: 27.53°), confirming that subjects stuck to the instruction to not direct the hand towards the rectangular frame in presence of linguistic stimuli. An interaction between the context of stimulus presentation and its direction was also observed (F(2,16) = 860.64; p < 0.01), which was dependent on the nature of the stimulus (F(2,16) = 1111.77; p < 0.01). Terminal angular errors were greater in the incongruent than in both the single and the congruent condition (which did not differ), but only for the linguistic stimulus. The sign of the errors indicates that hand path was directed more to the right when responding to the word “DROITE” in the incongruent condition, and the opposite effect was observed when responding to the word “GAUCHE”. The
Fig. 5. Variation for every subject of the initial angular error for right and left stimuli in the congruent and incongruent conditions with respect to the single condition when responding to (a) the spatial and (b) the linguistic stimulus. The horizontal bar shows the within-subject standard deviation. The central dashed line indicates 0° of variation during the single condition.
effect of the irrelevant spatial stimulus was, thus, effective until the end of the movement, even with correctly oriented hand movements.

Interestingly, we found no interaction when comparing the initial and terminal-increase of angular errors in the incongruent condition when taking into account the direction of the stimulus ($F(1,8) = 0.39; p = 0.55$), with right-terminal-increase: $-24.05^\circ$, left-terminal-increase: $24.14^\circ$, right-initial-increase: $-22.96^\circ$, left-initial-increase: $24.46^\circ$); this suggests a strong influence of the irrelevant spatial stimulus mainly during the phase of movement planning.

### 3.2.4. Kinematic parameters

Movement duration was shorter when responding to linguistic (414 ms) than when responding to spatial stimuli (521 ms, $F(1,8) = 5.51; p = 0.04$, see Table 1). This was due to the shorter distance covered by the hand when processing linguistic information. This effect was not affected by the direction indicated by the stimulus ($F(1,8) = 0.03; p = 0.95$) nor by the context of stimulus presentation ($F(2,16) = 2.59; p = 0.13$). The duration of the acceleration and the deceleration phases in terms of percentage of movement duration was not different when responding to the linguistic stimulus (53.25%) or to the spatial stimulus (52.65%, $F(1,8) = 0.05; p = 0.82$). This result was not affected by the direction indicated by the stimulus ($F(1,8) = 1.29; p = 0.29$) nor by the context of stimulus presentation ($F(2,16) = 1.59; p = 0.24$). Though peak velocity was lower when responding to the linguistic stimulus (884 mm/s) than when responding to the spatial one (1014 mm/s), the difference did not reach significance, $F(1,8) = 1.99; p = 0.19$. This result was not affected by the direction indicated by the stimulus ($F(1,8) = 2.53; p = 0.15$) nor by the context of stimulus presentation ($F(2,16) = 0.77; p = 0.48$). In conclusion, the dynamic properties of the motor responses when responding to linguistic and spatial stimuli were very similar.

### 4. Discussion and conclusion

The aim of the present experiment was to explore to which extent irrelevant spatial information can influence goal-directed movements that are triggered by a linguistic stimulus. Overall,
the linguistic stimulus was processed much slower than the spatial stimulus. The temporal difference that we observed (186 ms) is consistent with the differences previously reported between location and discrimination tasks and word processing tasks. This effect statistically revealed despite the presentation of only two different words. This suggests that the temporal difference obtained for an integrated response is not only the consequence of a more complex processing of the stimulus features in the occipital cortex, but also to the longer latency for stimulus processing, which is performed through the extra-striate cortex within the ventral visual stream. The difference in reaction times when processing linguistic and spatial stimuli is in line with the findings that (1) there are more synaptic relays within the ventral than the dorsal stream and that (2) there are anatomical differences between the fast magnocellular channel and the slower parvocellular channel [30]. This neuroanatomical organisation might have influenced not only the selected attributes of the objects that are processed but also the temporal processing of those objects within the dual visual system. Furthermore, response selection associated with a linguistic stimulus seems more complex or at least less familiar than that associated with a spatial stimulus since few directional errors were observed when responding to the isolated linguistic stimulus (3% of the trials). This was not the case when responding to the isolated spatial stimulus (0% of the trials). As a consequence, an asymmetrical interference effect was revealed here when presenting simultaneously linguistic and spatial information instead of only one at a time. When responding to the spatial stimulus, directional performance was very accurate (angular error was 1.88° on average) and the concomitant presentation of linguistic information did not modify this performance, even in the incongruent condition.

On the contrary, a strong interference effect was found when responding to the linguistic stimulus in the presence of a spatial stimulus. Despite the higher reaction time in this condition, directional performance was highly influenced by the presence of a spatial stimulus, in particular in the incongruent condition. In our study, the first sign of interference was the number of misdirected movements. Participants directed their arm in the wrong direction in reference to the displayed word in more than 20% of the trials when incongruent spatial information was simultaneously presented. This percentage of errors increased significantly when reaction times were short; it could reach 48% of the trials when reaction times were between 300 and 400 ms.

One explanation for this interference effect could be that participants made an association between the two stimuli during the familiarisation period and developed a stereotypical response in favour of the spatial information rather than processing the linguistic stimulus solely when requested to do so. However, this interpretation is not compatible with the fact that there were many trials without spatial stimulus during both the familiarisation and experimental sessions. In the same vein, the incongruent condition in the experimental session should have informed participants about the absence of a stable relationship between the spatial and the linguistic stimulus. Despite the possibility to detect the presence of the incongruent condition, an interference effect was observed even at the end of the experiment (44% of the misdirected responses occurred in the second half of the experiment). Furthermore, no significant advantages for congruent spatial stimuli were found on reaction time, which would have been expected if participants did favour the spatial stimulus when available. For the same reason, the interference effect cannot be solely accounted for by a competition between exogenous and endogenous visual attention. According to this theoretical framework, the exogenous attention allocated towards the spatial stimulus when responding to the word should have produced a decrease in reaction time, and particularly under the congruent condition. However, this effect was not observed. Another and more convincing interpretation is that both stimuli were processed simultaneously when available, but with a temporal advantage in the processing of the spatial stimulus though not relevant for the task and not presenting the expected characteristics of the target. Indeed, as discussed earlier, the processing of spatial information obviously involved the dorsal pathway of the visual system, which is fed by heavily myelinated and fast conducting magnocellular fibres [30]. Thus, considering that information for response selection is available earlier in the dorsal than in the ventral pathway, it seems logical to assume that response errors would be observed in favour of the spatial stimulus, especially when the entire processing of the linguistic stimulus is not achieved. This is what seemed to have happened in the present experiment. The interfering effect of the spatial stimulus was more obvious when participants responded with short reaction times (48% of the trials when reaction times ranged between 300 and 400 ms) than with long reaction times (7% of the trials when reaction times ranged between 900 and 1000 ms). Interestingly, participants were generally aware of their misdirected response and corrected hand path on-line during the ongoing movement.

The second sign of interference was the observation that the direction of the movement was modified in the presence of an incongruent spatial stimulus, even when responding accurately to the linguistic stimulus. Trajectory deviation was highly significant and corresponded to a substantial change in movement direction. Despite the instructions that brought subjects to focus on the linguistic information only, both linguistic and spatial stimulators seem to participate conjointly to the specification of the target's goal. Variations in reaction times suggest the presence of competing stimuli within a complex visual scene. On the other hand, spatial responses seem to be specified and include a concomitant attractive effect from the target and a repulsive effect from distracting stimuli. Therefore, visual target and distractors seem to participate conjointly to the specification of the goal of action, following specific temporal constraints. As a consequence, a change of movement direction was observed even
when the subjects’ task was to respond to a word in the presence of incongruent spatial information. This observation is in line with the Tipper et al.’s [48] claim that a number of actions can be simultaneously represented, and, therefore, inhibitory selection mechanisms are necessary to select the appropriate action at the appropriate time. In this context, both target and distractors are automatically encoded and compete for the control of action. As a consequence, the trajectory of the reaching action is affected by the presence of the distractor in a way that the hand veered away from distractor, even though it did not represent a physical obstacle for the reaching hand [47]. Interestingly, such interference effect has also been found in saccadic or pursuit eye movements to predefined targets in the presence of to-be-ignored distractors [41,43]. In the present study, we extend this observation by showing that the competition can be observed for stimuli of very different nature, and this from the beginning of the movement with no noticeable modifications of hand trajectory during the entire course of the action execution. This corroborates that the influence of irrelevant spatial information operates very early during response selection to a linguistic stimulus and has a limited effect during on-line control of hand path.

An intriguing issue was what sort of effect was expected when responding to the linguistic stimulus in presence of congruent spatial stimulus. It has been proposed that spatial processing occurs earlier than the semantic one [30], and, thus, one may have expected a facilitation effect in the presence of redundant information when performing to the linguistic stimuli. Such a facilitation effect should have resulted in a reduction of reaction time and a reduction of directional errors. Accordingly, although it was not significant in the present study, reaction time decreased in that particular condition (15 ms) and fewer directional errors were made (0.93%). However, these effects were very small compared to the interference effect in the incongruent condition, and the decrease of reaction time was of about the same magnitude as when responding to the spatial stimulus in the presence of a congruent linguistic stimulus (13 ms). It follows that a facilitation effect is not clearly supported by the present data. On the other hand, considering the difference in latencies between the two visual streams, it seems probable that response selection occurred only after the linguistic stimulus had been processed (at least partly), thus, in agreement with the task’s constraint. Accordingly, a facilitation effect was not expected. Nevertheless, increase in reaction times in the incongruent condition indicates that both signals were taken into account during response selection, and a discrepancy between the two signals obviously necessitated extra time for selecting the spatial goal of action. In agreement with this interpretation, the interference effect of incongruent spatial information when acting towards the linguistic stimuli was more evident for trials with the shorter reaction times as discussed earlier. Thus, the speed-accuracy trade-off associated with a specific behavioural context may influence response selection in presence of competing information. Reacting fast leads to inappropriate behaviour in half of the trials, whereas increasing processing time enables a reduction of such inappropriate behaviour.

It is worth mentioning that the reported interference between linguistic and spatial information is in some respect in line with what has already been described in the literature about the interaction between semantic and physical properties of objects. Although action planning and semantic knowledge are generally considered as independent one from another [35], recent data have suggested that this is not true in all circumstances [25]. Data in the literature suggest furthermore that semantic processing can influence action towards a meaningful object [4,14–18]. As mentioned in the introduction, Gentilucci and Gangitano [14] have already reported that words can influence grasp characteristics when the linguistic information is placed on the object itself, and this has been confirmed in several other studies [15,17,18]. Within this context, the present study reveals for the first time that spatial information can also influence semantic processing in the context of action, and that this interaction can occur as early as action planning with an absence of effect during action execution.

The dual-processing hypothesis proposed by Milner and Goodale [29] on whether and how visual distractors can influence goal-directed movements claimed that visual information is processed along two largely independent routes in the primate brain: a ventral pathway for conscious object identification and a dorsal pathway for action control (see also [12,19]). Taken together, our results are compatible with the idea that the processing of spatial and linguistic visual information for action occurs in different parts of the brain with a temporal advantage for the spatial information. Indeed, the difference in time processing for spatial and linguistic stimuli fits well with a functional division of labour within the visual system as proposed by the perception–action model [29]. However, the asymmetrical interference reported when responding to a linguistic stimulus in the presence of incongruent spatial information claims against a strict independence between the two visual processing streams. Indeed, our data suggest that spatial and linguistic information are processed simultaneously, even when the task brings subjects to predominantly on only one of the two stimuli. Where the information is integrated in the brain is an issue that falls beyond the scope of the present study. However, it is worth speculating that among the brain regions that are concerned with visual analysis, the inferior parietal lobe receives projections from the primary visual cortex, from both the dorsal and the ventral visual streams as well as from the pre-frontal cortex [3,36]. The implication of this parietal subsystem in action planning has been repeatedly suggested [8,16,38]. Furthermore, such area is also involved in language processing. For instance, imaging studies have reported a specific activation of the left inferior parietal lobule during letter and word processing [26,34]. In line with this, lesions in the left inferior parietal lobule produce Wernicke’s aphasia [7]. Finally, inferior parietal regions have non-spatial functions, such as in sustaining attention, detecting salient information and controlling attention over time [21].

In conclusion, the present findings contradict the prediction made by the perception–action (P–A) model. According to the P–A model, visual pathways are selectively activated as a function of the output and, thus, the visual attributes that are action-relevant [29]. On the contrary, our results suggest that both streams are activated simultaneously when processing visual information for action, even when this does not produce...
performance improvement. One may hypothesise that this effect is dependent on the spatial proximity of the linguistic and spatial information. In a previous study using a dual-task paradigm, it was reported that the perceptual discrimination of the orientation of a character (a standard or mirror presentation of an “E”) was improved when it was presented at the location of a programmed oculomotor saccade [10]. The authors considered their finding as highlighting an obligatory and selective coupling of action programming with the perception of object attributes. This mechanism would in fact depend on the early integration of both the spatial and the semantic characteristics of an object that would be processed simultaneously across the ventral and the dorsal visual pathways.

Acknowledgements

Supported by Région Nord Pas de Calais and University Charles De Gaulle grants, European Science Foundation, Eurocores CNCC CRP grant and ANR “Neurosciences, Neurologie et Psychiatrie” program from the French Ministry. The authors gratefully acknowledge the assistance of Yvonne Delevoye-Turrell in the preparation of the paper.

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