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Looking up improves performance in verbal tasks

Christophe Carlei and Dirk Kerzel

Faculté de Psychologie et des Sciences de l'Éducation, Université de Genève, Genève, Switzerland

ABSTRACT

Earlier research suggested that gaze direction has an impact on cognitive processing. It is likely that horizontal gaze direction increases activation in specific areas of the contralateral cerebral hemisphere. Consistent with the lateralization of memory functions, we previously showed that shifting gaze to the left improves visuo-spatial short-term memory. In the current study, we investigated the effect of unilateral gaze on verbal processing. We expected better performance with gaze directed to the right because language is lateralized in the left hemisphere. Also, an advantage of gaze directed upward was expected because local processing and object recognition are facilitated in the upper visual field. Observers directed their gaze at one of the corners of the computer screen while they performed lexical decision, grammatical gender and semantic discrimination tasks. Contrary to expectations, we did not observe performance differences between gaze directed to the left or right, which is consistent with the inconsistent literature on horizontal asymmetries with verbal tasks. However, RTs were shorter when observers looked at words in the upper compared to the lower part of the screen, suggesting that looking upwards enhances verbal processing.

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KEYWORDS Hemispheric asymmetries; gaze direction; unilateral gaze; verbal memory; short-term memory

Introduction

Hemispheric specialization is a fundamental organizational principle of the human brain. Functional lateralization of language was initially related to gray matter (Herve, Zago, Petit, Mazoyer, & Tzourio-Mazoyer, 2013) with a dominance of the left hemisphere in 90% of the population. The network of language in the left hemisphere includes the temporo-parietal and inferior frontal gyrus (Wernicke's and Broca's area, respectively) that are connected by the inferior occipito-frontal and longitudinal fasciculi (Turken & Dronkers, 2011; Vigneau et al., 2006). Specialization of the right hemisphere is less pronounced. There may be a dominance in attentional orienting related to a

CONTACT Christophe Carlei christophe.carlei@unige.ch

ventral fronto-parietal network in the right hemisphere (Bartolomeo, Thiebaut de Schotten, & Chica, 2012; Corbetta, Patel, & Shulman, 2008), which may also result in better visuospatial abilities in the contralateral hemifield (Iturria-Medina et al., 2011; Van Kleeck, 1989). More recently, tensor imaging studies have also revealed differences in white matter structure between the two hemispheres (Takao, Hayashi, & Ohtomo, 2011; Thiebaut de Schotten et al., 2011). The main finding was that each cerebral hemisphere has its own structural network. The right hemisphere has more efficient connections, which could explain its involvement in processes such as visuospatial integration (Iturria-Medina et al., 2011) and global processing (Van Kleeck, 1989). In turn, the left hemisphere is structured less efficiently but counts more specialized regions, which could explain its dominant role in highly demanding processes such as language (Herve et al., 2013) or local processing (Lamb, Robertson, & Knight, 1990).

Perceptual asymmetries between the left and right hemifields are believed to reflect the functional differences between the left and right hemispheres (Jordan & Patching, 2004; Martinez et al., 1997) whereas perceptual asymmetries between upper and lower visual fields could be related to functional differences between the ventral and dorsal streams (Christman & Niebauer, 1997; Previc, 1990). The upper and lower visual fields are represented on the lower and upper cortical sheets of the occipital lobe, which project more strongly into ventral and dorsal streams, respectively. The ventral stream is associated with object recognition (i.e, "what" pathway), which may explain the advantages of the upper visual field in complex perceptual tasks (Rapcsak, Cimino, & Heilman, 1988; Shelton, Bowers, & Heilman, 1990). The dorsal stream, for its part, is associated with motion and location processing (i.e, "where" pathway), which may explain the advantages of the lower visual field in visuospatial tasks (Thomas, Schneider, Gutwin, & Elias, 2012). In general, many behavioural and neural differences have been observed between upper and lower visual fields (Barrett, Crosson, Crucian, & Heilman, 2000; Genç, Schölvinck, Bergmann, Singer, & Kohler, 2016; Loughnane, Shanley, Lalor, & O'Connell, 2015; Nasr, Polimeni, & Tootell, 2016).

Methods of investigation

Behaviourally, functional cerebral specialization can be investigated by presenting stimuli to one hemifield (lateralized presentation), restricting vision to one hemifield (unilateral deprivation), or looking to one side (unilateral gaze). Studies using lateralized presentation rely on the fact that the initial processing of visual stimuli occurs in the opposite hemisphere (Greenberg et al., 1981). To prevent eye movements, stimuli are only briefly displayed either to the right or to the left of participants' gaze direction. This manipulation allows researchers to investigate whether processing of a certain type of stimulus is more efficient when initially processed in the right or the left hemisphere.

Studies using the unilateral deprivation method rely on goggles or contact lenses to restrict visual input to a single visual hemifield (Dimond, Bureš, Farrington, & Brouwers, 1975; Fouty, Otto, Yeo, & Briggs, 1992; Propper, Brunyé, Christman, & Januszewskia, 2012; Schiffer, 1997; Schiffer, Anderson, & Teicher, 1999; Schiffer, Stinchfield, & Pascual-Leone, 2002; Sivak, Sivak, & Mackenzie, 1985). Because goggles or lenses are fixed to the eyes or the head, participants are allowed to move and the stimuli can be presented for an unlimited period. Therefore, long-term effects of unilateral visual stimulation on cognitive processing can be investigated. Schiffer et al. (2004) have shown that sustained vision of one hemifield activated the contralateral hemisphere, which is surprising given the strong connections between the two hemispheres. It is assumed that processing of the visual stimulus begins in the contralateral striate cortex and subsequently spreads to the occipito-temporal, posterior parietal and dorsolateral prefrontal areas (Schiffer et al., 2004). This general activation of the cortex is thought to facilitate subsequent tasks involving this hemisphere (Propper et al., 2012).

A third method that we proposed recently to test functional specialization is unilateral gaze where participants are asked to look at the stimulus that is presented at an eccentric position (e.g., on the left, right, top, or bottom of the computer monitor). Practically, observers' head movements are restrained by a chin/forehead rest in front of the centre of the screen and stimuli are displayed in one of the four quadrants of the screen. Our recent results (Carlei & Kerzel, 2014, 2015) suggested that unilateral gaze direction is an effective method to elicit both horizontal and vertical asymmetries. For instance, when investigating visual and positional subcomponents of visuospatial memory, better performance was observed when gaze was directed to the upper left quadrant.

Our findings support the hypothesis that directing gaze to the left or right increases contralateral hemispheric activation (see Propper et al., 2012) and facilitates cognitive functions associated with the activated hemisphere. We believe that the unilateral gaze method has similar effects as the unilateral deprivation method described above. When vision was limited to only one hemifield by wearing special glasses, Schiffer et al. observed stronger activation in the contralateral cerebral hemisphere and the same may be true when people simply look to the left or the right. However, there is currently no neurophysiological evidence to support this claim. Concerning vertical asymmetries, we suggest that directing gaze up or down will activate similar parts of the brain as directing attention to the upper or lower visual fields (Rapcsak et al., 1988; Shelton et al., 1990). That is, looking up may activate ventral parts of the brain (e.g., the temporal lobes), whereas looking down may activate dorsal parts of the brain (e.g., the parietal lobes). In particular, looking up may increase the activation along the ventral stream that may enhance higher-level object recognition.

Horizontal asymmetries

Results from lateral presentation studies suggest a right hemifield advantage in verbal processing, even if there are some inconsistencies. Gross (1972) and Samar (1983) demonstrated that responses in categorization or lexical decision tasks were faster when verbal stimuli were presented in the right hemifield. Similar results were observed for naming tasks (Jordan & Patching, 2004; Jordan, Patching, & Thomas, 2003) and for a recognition task with nonsense words (Hannay & Malone, 1976), but the latter results were restricted to male participants. In support of gender differences, Bradshaw and Gates (1978) found that men showed the right hemifield advantage with manual and verbal responses, but women only with verbal responses (see also Young & Ellis, 1985). While all these findings point to a right hemifield advantage in verbal processing, Shanon (1979) reported two experiments where she failed to find a right hemifield advantage for lexical decisions despite restricting her sample to right-handed males. Overall, however, it seems that verbal processing is facilitated in the left hemisphere and this effect is more pronounced in men than women even when the literature is somewhat inconsistent.

Vertical asymmetries

Concerning vertical asymmetries, Goldstein and Babkoff (2001) have found faster and better discrimination in a lexical task in the upper visual field compared to the lower visual field. Reading involves local processing of high-spatial frequency information, which may be considered a recognition task that typically yields better performance in the upper visual field. On the contrary, neither Darker and Jordan (2004) nor Hagenbeek and Van Strien (2002) found differences between the upper and lower visual field for either word and non-word perception.

Aim of study

As mixed results have been found for visual field asymmetries in verbal processing using the lateral presentation technique, we decided to investigate the matter using the unilateral gaze method. We conducted three experiments where participants performed lexical decision, grammatical gender and semantic discrimination tasks while gaze direction was manipulated.

Observers were asked to look at eccentric positions on the computer monitor where the target stimulus was presented. In Experiment 1, participants decided whether the target stimulus was a word or a non-word.

Experiments 2 and 3 used more complex verbal tasks that involved judgments of grammatical gender and semantic categories. We expect that directing gaze to the right activates the left hemisphere with the language centres, similar to lateralized presentation (Gazzaniga, 2000; Jordan & Patching, 2004; Tzourio-Mazoyer et al., 2010). Therefore, we expect better performance for stimuli on the right. Previous results concerning differences in cerebral lateralisation of verbal processing between male and female participants further suggest that the effect may be stronger for men than women. Further, we expect better performance in the upper than in the lower visual field based on the conjecture that looking up will activate ventral parts of the brain, similar to research on lateralized presentation in the upper visual field (Rapcsak et al., 1988; Shelton et al., 1990),

Experiment 1

Methods

Participants

Thirty-four undergraduate students (16 females, mean age of 22.2 years, age range of 18–36 years) at the University of Geneva participated. All participants reported normal or corrected-to-normal visual acuity and participated in this experiment for class credit. All procedures were approved by the ethics committee of the "Faculté de Psychologie et des Sciences de l'Education" at the University of Geneva and were in accordance with the 1964 Declaration of Helsinki. Handedness of all students was assessed previously by the Edinburgh Handedness Inventory (Oldfield, 1971), only strongly right-handed participants with a score equal or above 70 on a scale of 100 were invited to participate (see Christman, Propper, & Dion, 2004). As in our previous experiments (Carlei & Kerzel, 2014, 2015), we deliberately chose strongly right-handed participants because their memory performance is more affected by eye movements (Lyle, Logan, & Roediger, 2008).

Stimuli and apparatus

The experiment was conducted in a dimly-lit room. Participants were seated at a distance of 40 cm from the screen. Participants' head position was stabilized with a chin rest in front of the centre of the screen. The experiment was controlled by E-Prime 2.0 (Psychology Software Tools, Pittsburgh, PA). Participants' eye movements were monitored by the experimenter from outside the experimental booth with the help of the image of the eye provided by an EyeLink 1000 eye-tracker (SR-Research, Ontario, Canada). Eye movements were not recorded or analysed, but the experimenter assured that participants followed the instructions and intervened if necessary.

Forty French words and forty non-words were used as target stimuli. Words were selected from the Brulex database (Content, Mousty, & Radeau, 1990) and were masculine or feminine nouns with a lexical frequency between 1021 and 1565, an imagery value between 4 and 5, and a number of syllables between 2 and 3. The forty non-words were automatically generated based on the 40 words using an online toolbox (New, Pallier, Ferrand, & Matos, 2001). Non-words differed from words by two letters, but remained pronounceable. For example, the French word "casquette" (cap) became "cosquatte". The size of the words was approximately 3 × 0.5 cm (4.3° × 0.7° of visual angle, width × height) and the size of the computer monitor was 39 × 30 cm (44.3° × 36.9°). Letters were rendered in Courier New, 18 pt. The eccentricity of the target stimuli was 22.4° horizontally and 18° vertically relative to the screen centre.

A trial started with the presentation of the fixation cross. After 250 ms, the fixation cross was replaced by an arrow pointing to one of the corners of the screen. After another 250 ms, the fixation cross reappeared at the indicated corner and was shown for 700 ms, which provides ample time for moving the eyes to this location. Finally, the target stimulus was flashed for 100 ms. Presentation time was short to force participants to look at the target location before target presentation. It was not possible to read the letters from another corner or the centre of the screen. Placement of the target stimuli was random with the constraint that 10 words and 10 non-words were shown in each quadrant of the screen. Participants responded by pressing one of two designated keys on a standard computer keyboard. Each participant worked through 80 trials in a single experimental session lasting about 15 min (Figure 1).

Results and discussion

Trials with reaction times that were more than 2 standard deviations above the respective condition mean were trimmed (4.4%), as were trials in which a response was not entered within the 2 s response period (0.3%). In addition, 11% of trials were associated with incorrect responses, leaving 84.3% of trials for analysis. The mean RT and standard deviation for each quadrant of the visual field are presented in Figure 2A.

A 2 (elevation: upper, lower) × 2 (laterality: left, right) × 2 (gender: male, female) mixed-factors ANOVA on mean RTs in correct trials showed an effect of elevation, $F(1, 32) = 19.85$, $p < .001$, $\eta_p^2 = .383$, with shorter RTs to stimuli displayed in the upper ($M = 469$ ms, $SD = 12.36$) than in the lower visual field ($M = 482$ ms, $SD = 12.59$), but no effect of laterality, $F(1, 32) = 1.56$, $p = .222$. No other effect reached significance, $ps > .278$. In particular, gender did not interact with laterality, $F(1, 32) = 0.67$, $p = .419$. Running the same analysis on proportion of correct responses did not reveal any significant effects, $ps > .104$.

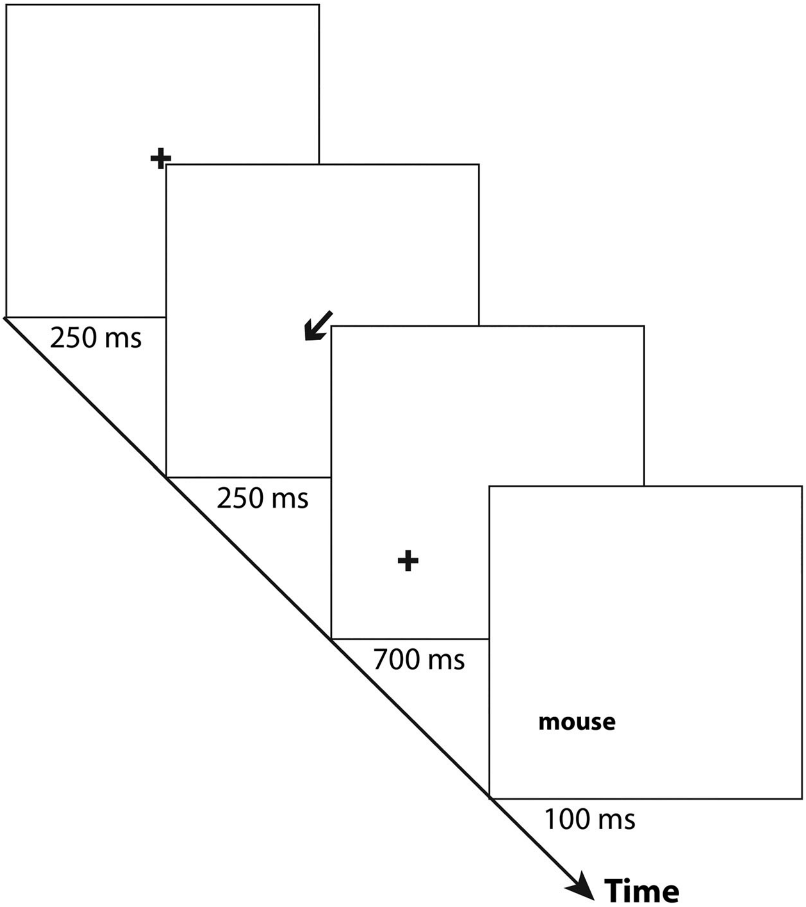

Figure 1. Experimental protocol of Experiment 1.

Experiment 2

Experiment 1 used a lexical decision task, which relies on lexical access. In Experiments 2 and 3, we tested whether more complex linguistic tasks would reveal the advantage of the right hemifield that we did not find in Experiment 1. In Experiment 2, we used a grammatical gender classification task, which requires retrieving a grammatical feature of the nouns and can therefore be considered as more complex than a simple lexical access task. As there was no difference between men and women in the previous experiment, we decided not to balance gender in our sample for reasons of convenience. As in most psychology departments, there was a larger proportion of women than men in our subject pool.

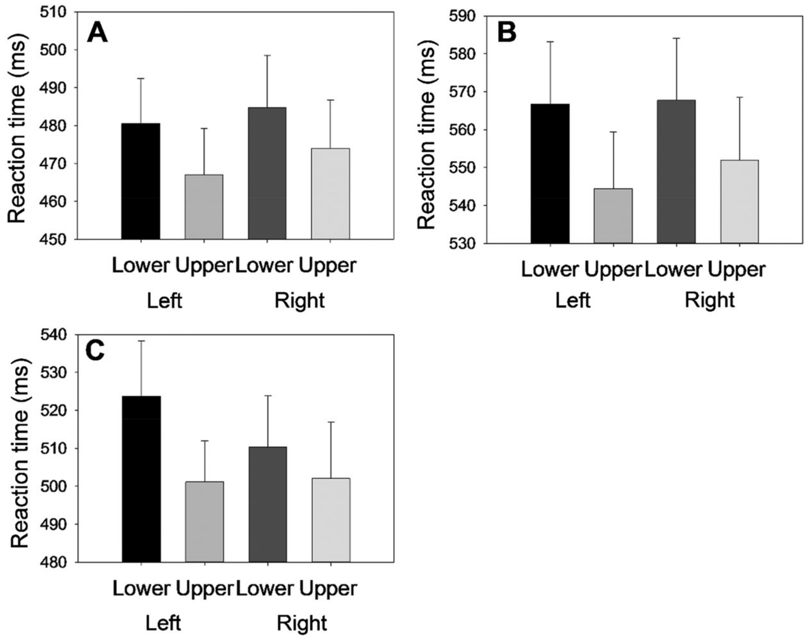

Figure 2. Results from Experiments 1–3 are shown in panels A to C, respectively. Experiments 1–3 employed a lexical decision task, a grammatical gender classification task, and judgements of animacy, respectively. Mean reaction time in correct trials are shown as a function of gaze direction (lower left, upper left, lower right, upper right). Error bars show the standard error of the mean.

Methods

The methods were the same as in Experiment 1 with the following exceptions. Twenty-five undergraduate students at the University of Geneva participated (21 female, mean age of 20.1 years, age range of 17–34 years). All participants were strongly right-handed. The selected French words were nouns (40 of masculine and 40 of feminine grammatical gender) with a lexical frequency between 4000 and 50000, an imagery value between 4 and 6 and a number of syllables from 2 to 3. Word position was randomized with the constraint that 10 masculine and 10 feminine words be presented in each quadrant of the screen. Participants responded by pressing one of two designated keys on a standard computer keyboard to determine if the word displayed was masculine or feminine (e.g., "artiste" (artist) is of masculine grammatical gender in French).

Results

Trials with reaction times that were more than 2 standard deviations above the respective condition mean were trimmed (4.9%), as were trials in which a response was not entered within the 2 s response period (0.3%). In addition, 10% of trials were associated with incorrect responses, leaving 84.8% of trials for analysis. The mean RT for each visual quadrant is presented in Figure 2B.

A 2 (elevation: upper, lower) × 2 (laterality: left, right) repeated-measures ANOVA on mean RTs in correct trials showed an effect of elevation, $F(1,24) = 8.46$, $p = .008$, $\eta_p^2 = .261$, with shorter RTs to words displayed in the upper ($M = 548$ ms, $SD = 15.35$) than in the lower ($M = 567$ ms, $SD = 15.83$) visual field, but no effect of laterality, $F(1, 24) = 0.67$, $p = .423$, or interaction, $F(1, 24) = 0.32$, $p = .577$. Thus, we fully replicated the results from the lexical decision task of Experiment 1. Running the same ANOVA on choice errors did not yield any significant effects, $ps > .798$.

Experiment 3

In Experiment 3, we asked observers to make judgments of animacy, which requires access to semantic characteristics of the words.

Methods

The methods were as in Experiment 1 with the following exceptions**.** Twenty-five strongly right-handed female students participated (mean age of 19.3 years, age range of 17–22 years). Stimuli were composed of eighty words. All words were chosen from the database by Syssau and Font (2005) and were either animals or objects (40 each) that were classified as concrete and neutral (between 40% and 94% neutral). Placement of the words was random with the constraint that there be 10 animal words and 10 object words in each quadrant. Participants responded by pressing one of two designated keys on a standard computer keyboard to indicate whether the word displayed was an animal or an object (e.g., “aigle” (eagle) is an animal).

Results

Trials with reaction times that were more than 2 standard deviations above the respective condition mean were trimmed (5.1%), as were trials in which a response was not entered within the 2 s response period (0.3%). In addition, 9% of trials were associated with incorrect responses, leaving 85.6% of trials for analysis. The mean RT for each visual quadrant is presented in Figure 2C.

A 2 (elevation: upper, lower) × 2 (laterality: left, right) repeated-measures ANOVA on mean RTs in correct trials showed an effect of elevation, $F(1, 24) = 10.83$, $p = .003$, $\eta_p^2 = .311$, with shorter RTs to words displayed in the upper

($M = 502$ ms, $SD = 12.30$) than in the lower ($M = 517$ ms, $SD = 13.60$) visual field, but no effect of laterality, $F(1, 24) = 1.20$, $p = .285$, or interaction, $F(1, 24) = 1.68$, $p = .207$. Analysis of choice errors did not find any significant effects. The present results fully replicate those of Experiments 1 and 2.

Combined analysis of experiments 1–3

Experiments 1–3 seem to yield very similar results. To confirm this impression, we included experiment as a between-participant factor and evaluated effects of elevation and laterality. The corresponding 2 (elevation: upper, lower) × 2 (laterality: left, right) mixed-model ANOVA with experiment (1, 2, 3) as between-participants factor confirmed shorter RTs to words displayed in the upper ($M = 506$ ms, $SD = 7.78$) than in the lower ($M = 522$ ms, $SD = 8.12$) visual field, $F(1, 81) = 34.20$, $p < .001$, $\eta_P^2 = .297$. The main effect of experiment, $F(2, 81) = 9.63$, $p < .001$, $\eta_P^2 = .192$, showed that RTs were shorter in the lexical decision task ($M = 476$ ms, $SD = 12.19$) than in the gender classification task ($M = 558$ ms, $SD = 14.22$). No other effect reached significance, animacy task ($M = 509$ ms, $SD = 14.22$).

General discussion

In three experiments, we investigated whether gaze direction affects verbal processing using a variety of tasks: lexical decision, judgments of grammatical gender, and judgments of animacy. The main finding is that verbal processing was enhanced when participants read the words in the upper part of the computer screen, that is, when eye gaze was directed upwards. In contrast, we did not observe differences between gaze directed to the left and right. Experiment 1 showed that the horizontal asymmetry was absent even with strongly right-handed male participants. Experiments 2 and 3 showed that the results obtained with a lexical decision task in Experiment 1 generalize to different levels of verbal processing.

The vertical asymmetry is in line with Previc's (1990) assumptions about different processing styles for stimuli in the upper and lower visual fields. He suggested that anatomical segregation promoted functional specialization and argued that perceptual capacities of the visual fields have been shaped by different environmental constraints. Processing in the lower visual field was shaped by near vision because visual stimulation generated by manual reaching and other body movements occurred below the line of sight. In contrast, the upper visual field was more strongly involved in visual search and object recognition in extrapersonal space that occurred more frequently above the line of sight. As mentioned before, Previc proposed that vertical asymmetries can be related to two functionally and anatomically separate processing streams for visual processing, the ventral and the dorsal stream. At an anatomical level, the lower cortical sheets (upper visual field) project more into the ventral stream of the temporal lobe, whereas the upper cortical sheets (lower visual field) project more into the dorsal stream in parietal cortex. The present results suggest that looking up activates ventral-stream processing similar to stimulus presentation in the upper visual field. The increased contribution of the ventral stream may enhance perception of fine visual detail that is involved in reading and verbal processing. However, we have to admit that there is currently no neurophysiological support for our hypotheses.

Further, we did not observe better performance when gaze was directed to the right. We had expected better performance because the left hemisphere is specialized in verbal processing. However, the null effect is in line with the mixed results obtained in studies using the lateralized presentation method (see introduction). Further, the null effect is in line with results obtained in studies on spontaneous eye movements after verbal questions (Ehrlichman & Weinberger, 1978; Macdonald & Hiscock, 1992; Raine, 1991). These studies found that spontaneous saccades to the left and right were equally frequent during verbal processing. From our perspective, it seems consistent that asking people to look to the right will not improve their performance on verbal tasks if participants do not make more spontaneous eye movements to the right when engaged in verbal processing. In contrast to verbal processing, there is evidence that spontaneous eye movements are directed to the upper-left visual field when questions are asked that imply visuo-spatial processing (Ehrlichman, 1977; Ehrlichman, Weiner, & Baker, 1974; Galin & Ornstein, 1974; Kinsbourne, 1972). Interestingly, this finding is consistent with assumptions in Neuro-Linguistic Programming (NLP, Ahmad, 2013) stating that visuo-spatial processing is better when participants look up. We recently found experimental support for this hypothesis using the unilateral gaze method (Carlei & Kerzel, 2014, 2015). More precisely, performance on visuo-spatial tasks was facilitated when observers looked to the upper left corner of the screen.

It is hard to explain why horizontal asymmetries occur for visuospatial but not for verbal tasks. Based on Ehrlichman's work (Ehrlichman, 1977; Ehrlichman et al., 1974; Ehrlichman & Weinberger, 1978; Weiner & Ehrlichman, 1976), we know that verbal tasks result in more spontaneous eye movements than visuospatial tasks by a factor of 1.5-2. Therefore, one may suspect the link between eye movements and verbal processing to be particularly strong. However, we only observed a vertical, but not a horizontal asymmetry. On the other hand, our task involved eye fixation in one particular region of space and thereby prevented spontaneous saccades. In Ehrlichman's work, the stimuli were auditory and there was no need to fixate on any particular stimulus. Therefore, it may be possible that forcing eye fixation on a particular location was not optimal to facilitate verbal processing, even if there is evidence that gaze fixation does not degrade performance (Micic, Ehrlichman, & Chen, 2010). Possibly, asking participants to perform saccades in many directions, as in the Eye-Movement Desensitization and Reprocessing (EMDR) method (Christman, Garvey, Propper, & Phaneuf, 2003), or increasing saccade rate prior to stimulus onset may be a better way to improve verbal processing.

It is interesting to come back to the assumptions of NLP concerning non-visual eye movements and verbal learning, most of which have never been tested. For example, a pedagogical tool called “cognitive learning” has been developed for vocabulary learning and is already in use in some English private schools despite the complete lack of scientific evidence in favour of it. New words are presented to children in the top left of their visual field to generate the “best mental image of the word”, followed by a saccade to the bottom right, “in order to feel that the word has the correct spelling” (Thiry, 2006). No research has been able to confirm the role of the bottom-right position in kinesthetic feeling (Ahmad, 2013; Buckner, Meara, Reese, & Reese, 1987), but the present results confirm that it is indeed advantageous to look up during verbal tasks. Beyond simple gaze direction, however, it may be that it is not just a single eye movement but a sequential pattern of eye movements that will facilitate cognitive performance. For instance, bilateral saccades in EMDR have been shown to enhance episodic memory (Christman et al., 2003) and potentially, bilateral saccades between the upper and lower visual fields (or diagonal saccades), may have the same effect on verbal tasks. We leave this question for future research.

To sum up, we observed that gaze direction influenced performance on verbal tasks, regardless of the specifics of the tasks. That is, the results did not change between lexical decisions, judgments of grammatical gender, and judgments of animacy. Performance was improved when participants looked up, but there was no difference between looking to the left and looking to the right. The vertical asymmetry is consistent with differential involvement of the ventral and dorsal stream in the processing of stimuli from the upper and lower visual fields, but we have to admit that the neural mechanisms are currently unknown. The absence of horizontal asymmetries is unexpected when considering the specialization of the left hemisphere for verbal processing. However, it is not unexpected when considering the rather inconsistent behavioural literature on this topic. As we mentioned, the conclusions of our experiments are limited by characteristics of our stimuli, procedure, and sample. For instance, the words were only briefly presented and our sample was limited to undergraduate psychology students. More research is needed to generalize our conclusion with respect to horizontal and vertical asymmetries.

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ORCID

Christophe Carlei http://orcid.org/0000-0002-3084-8593

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