# The influence of lateralized pointing on spatial relation processing

Master thesis Neuropsychology

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## Abstract

Our cognition interacts continuously with the environment, which is for example shown by effects of prism adaptation. Recently, two studies found out that pointing to one side of the visual field produces similar alterations as prism adaptation in pointing straight ahead and a local/global processing task, an attentional process which is strongly lateralized in the brain. Current study examined the effects of this so called lateralized pointing (LP) on spatial relation processing, which also has a strong lateralization pattern. Categorical relations are mainly processed in the left hemisphere and the right hemisphere is primarily involved with coordinate processing. Therefore, it was hypothesized that right LP improves performance on a categorical task and left LP improves performance on a coordinate task. Students from Utrecht University performed a cross-dot task both before and after LP. In order to control for possible effects of tiredness or practice, some participants performed the cross-dot task twice, but without intermediate pointing. Results showed that regardless of pointing direction, performance on the categorical task improved as a result of LP, while coordinate processing did not differ as a result of LP. Given these results, it is likely that the left hemisphere is activated as a result of a sensorimotor process which consequently activated left superior parietal lobe, rather than an attentional bias to one side of the visual field.


*Keywords*: spatial relation processing, lateralized pointing, sensorimotor integration, brain plasticity, lateralization

## Introduction

It is well known that our cognition is not static, but is influenced in many ways. For example, different modalities in the brain interact with each other and cognition is directly influenced by the environment (e.g., Deubel, Schneider & Paprotta, 1998; Dupierrix, Alleyson, Ohlmann & Chokron, 2008). In order to demonstrate this interaction between cognition and environment, much research focused on the influence of shifting visual attention on motor actions. Wearing prism glasses is useful to produce such shifts in attention and to explore the influence of this shifting attention on perception and cognition (for a review see Newport & Schenk, 2012). This so called prism adaptation can produce direct effects, in which wearing 10° rightward shifting prism glasses leads to errors to the right in pointing to a target or grasping an object (Redding, Rossetti & Wallace, 2005).

Besides these direct effects, opposite effects can be found when prism glasses are removed, the negative aftereffects. If sufficient adaptation has taken place, people are accustomed to a situation with glasses, so that they have a leftward bias in order to compensate for their adaptation. This is best observed when pointing to a visual stimulus or pointing straight ahead (Newport & Schenk, 2012). In addition to this perceptual bias in healthy persons, prism adaptation can also neutralise the attentional bias to one side of the visual field in neglect patients, which leads to an enhancement of various cognitive functions in patients with neglect syndrome. This was first observed by Rossetti et al. (1998), who showed that neglect patients improved significantly on line bisection, drawing by copying and from memory, cancellation tasks, and reading.

Based on the influence of prism adaptation on cognitive functions, recent research on healthy participants showed another way of interacting with the environment in order to improve cognitive aspects of functioning, namely through pointing towards one side of the visual field, which is called lateralized pointing (LP). Dupierrix, Gresty, Ohlmann and Chokron (2009) were the first to show that LP can produce a shifting visual bias. Participants in this study pointed to black dots presented on either the right or left side of a computer screen. Both before and after LP, participants had to determine their subjective midline by a pointing straight ahead task, which resulted in a significant difference between right and left LP in this task. Interestingly, even twenty hours after pointing, the effect was still there, so it seems to be a long lasting adaptation, as has also been shown in prism adaptation (e.g., Frassinetti, Angeli, Meneghello, Avanzi & Làdavas, 2002; Klapp, Nordell, Hoekenga & Patton, 1974; Pisella, Rode, Farnè, Boisson & Rossetti, 2002).

Dupierrix et al. (2009) thus showed that LP can produce similar effects as prism adaptation with regard to shifting visual bias. This finding raised the question whether LP has an effect on other cognitive functions that are not primarily related to a shifting visual bias, as has also been demonstrated in prism adaptation. Herlihey, Black and Ferber (2013) examined this by studying the influence of LP on a hierarchical figures task. In this task, which was first used by Navon (1977), participants had to determine either the local features or the overall global shape of a picture or object. These ways of processing object features seems to be lateralized in the brain, in which the left hemisphere is mainly involved in local processing and global features are mainly processed in the right hemisphere (e.g., Bultitude & Woods, 2010; Martin, 1979; Mevorach, Humphreys & Shalev, 2005; Robertson, Lamp & Knight, 1988; Van Kleeck, 1989). In line with evidence that prism adaptation has an effect on hierarchical figures task (Bultitude, Rafal & List, 2008; Bultitude & Woods, 2010) and the findings of Dupierrix and colleagues (2009), Herlihey and colleagues (2013) found a significant alteration in local and global processing after LP. More specifically, there was a greater interference from the overall global shape after left LP, which increased reaction time on the local processing task, whereas reaction time on the local processing task decreased after right LP. It seems that focusing sensorimotor attention towards one side of the visual field leads to activation of the opposite hemisphere and consequently improves performance on lateralized tasks such as local and global processing. This interesting suggestion is reason for the current study to examine whether the influence of LP can be generalized to other aspects of cognitive functioning. Therefore, this study examined the effect of LP on a process which is related to local/global processing and is also strongly lateralized in the brain: spatial relation processing.

The relative spatial relation between two objects can be determined in two ways (Kosslyn, 1987). At first, one can determine the relative position of an object by means of qualitative orientations such as above, below, right or left of another object, which is called categorical processing. Secondly, the relative position can be assessed by determining the absolute distance between two objects. This is related to quantitative aspects of spatial relations and is called coordinate processing. As mentioned before, these ways of processing spatial relations are strongly lateralized in the brain. Categorical relations are mainly processed in the left hemisphere, while the right hemisphere is primarily involved in processing coordinate information (for a review see Jager & Postma, 2003). Evidence for this lateralization has been found in patients with hemispheric deficits. Patients with left hemisphere damage showed an impairment on categorical processing, where patients who are right brain-damaged had deficits in coordinate processing (Palermo, Bureca, Matano & Guariglia, 2008). Furthermore, studies on healthy participants showed improved categorical processing when stimuli were presented in the right visual field and improved coordinate processing when stimuli were presented in the left visual field (Christman, 2002; Kosslyn et al., 1989; Laeng & Peters, 1995).

Neuroimaging studies also provided evidence for hemispheric differences between both processes. In a positron emission tomography (PET) study from Kosslyn, Thompson, Gitelman and Alpert (1998) greater blood flow in right parietal areas was found when accomplishing a coordinate task with respect to categorical processing, while execution of a categorical task resulted in left frontal areas to be more involved relative to coordinate processing. Functional magnetic resonance imagery (fMRI) studies found strong involvement from prefrontal and parietal areas, especially superior parietal lobes, in both coordinate and categorical processing. These activated areas showed relative lateralization during coordinate and categorical processing (Trojano et al., 2002; Van der Ham, Raemaekers, Van Wezel, Oleksiak & Postma, 2009).

There are several explanations for this strong lateralization pattern between categorical and coordinate processing. For example, Kosslyn et al. (1998) supposed that activation of frontal areas in the left hemisphere during execution of a categorical task is related to language processes, which have a strong basis in these regions. This has also been shown by Kemmerer and Tranel (2000), who proposed a clear distinction between processing linguistic and perceptual categories. Suegami and Laeng (2013) also found a lateralized distinction between semantically and spatial categorical processing, but they attributed this to the interference of coordinate information in spatial categorical processing, since participants in the spatial task had to determine the relative position of a stimulus and this also could be defined by metric features. Furthermore, Van der Ham and Postma (2010) showed that although language is affecting categorical processing, the distinction between verbal and spatial categorical processing is not as strict as suggested by Kemmerer and Tranel. Holmes and Wolff (2012) studied whether labelling categories had an influence on categorical processing, but they found no difference between labelled and unlabelled categorization, suggesting that categorical processing does not depend on language.

So it seems that language provides an insufficient explanation for the fact that categorical processing is strongly lateralized in the left hemisphere, which means that there must be an alternative explanation for this lateralization pattern. Recently, the possibility of a relation between local versus global processing and spatial relation processing received attention, since both mechanisms have a strong lateralization pattern. Evidence was found that participants had a better performance on categorical processing after focusing on the local level of the hierarchical figures task of Navon (1977), while they were faster on a coordinate task after focusing on the global features of the hierarchical figures (Borst & Kosslyn, 2010). This finding was supported by a study of Michimata, Saneyoshi, Okubo and Laeng (2011) who used a more complex hierarchical structure in order to find a relationship between local/global attention and spatial relation processing. Furthermore, an fMRI study showed that categorical and coordinate information were processed differently in the visual cortex, with a more specific local focus during categorical processing and a non-specific global focus during coordinate processing (Van der Ham et al., 2012). This indicates that categorical and coordinate processing differ in attentional focus, rather than lateralization alone.

Because of the strong evidence for an existing lateralization pattern between categorical and coordinate processing and the assumed link with attentional focus on local or global features, spatial relation processing is thought to be suitable for further examination into the extent of plasticity of the brain with regard to LP. The aim of the current study is to examine whether LP leads to activation of the opposite hemisphere and consequently causes an alteration in spatial relation processing. It is hypothesized that right LP, which activates the left hemisphere, improves performance on a categorical processing task and that activation of the right hemisphere after left LP improves performance on a coordinate processing task. In addition, some authors suggested that activation of one hemisphere leads to inhibition of the other hemisphere (Daskalakis, Christensen, Fitzgerald, Roshan & Chen, 2002; Ferbert et al., 1992). For this reason, left LP is expected to reduce performance on the categorical processing task and right LP to reduce performance on the coordinate processing task.

In earlier research on spatial relations, different tasks were used to assess categorical and coordinate processing. One example is the dot-bar task in which participants in the categorical condition had to decide if a dot was presented above or below the bar, while participants in the coordinate condition had to decide whether the dot appeared within or not within one inch from the bar (Hellige & Michimata, 1989). However, this task brings disadvantages such as categorizing the coordinate condition (Baciu et al., 1999). A useful task that omits these disadvantages is the cross-dot task. In this task, participants first have to compare two pictures consisting both of a plus shaped cross and a dot, after which they have to decide whether the dot of both pictures appears in the same quadrant (categorical) or at the same distance (coordinate) with regard to the plus shaped cross. Categorical and coordinate conditions have approximately the same degree of difficulty and more important, cross-dot task has shown consistent lateralization between categorical and coordinate processing (e.g., Van der Ham et al., 2009; Van der Ham, Van Strien, Oleksiak, Van Wezel & Postma, 2010). Therefore, the current study made use of this task to be able to measure spatial relation processing.

## Materials and Methods

*Participants*

Thirty-nine students from Utrecht University participated in the experimental group voluntary or in exchange for course credit. Furthermore, to exclude tiredness or practice effects, a control group consisting of eight participants completed the spatial relation task twice, but without intermediate pointing. There were 11 males and 36 females and their age varied between 18 and 31 years (M = 22.1; SD = 2.6). All participants had normal or corrected to normal vision, were neurologically healthy and right-handed. Right-handedness was verified by a mean score of 74.9 (SD = 20.2) on the Edinburgh Handedness questionnaire (Oldfield, 1971), ranging from -100 (extremely left-handed) to +100 (extremely right-handed). Participants with a score lower than +40 on this questionnaire were excluded from further analysis. Participants were tested individually and were unaware of the purpose of the experiment.

*Spatial relation task*

The spatial relation task was adapted from a previous study (Van der Ham et al., 2009). A stimulus consisted of a black dot (0.15°) presented on a white background in one of the four quadrants of a black plus shaped cross (0.35° x 0.35°). There were forty possible dot positions with ten dot positions in each quadrant (figure 1[A]). One trial contained two different stimuli, both presented for a duration of 150 ms, with an interval of 1500 ms. The first stimulus of each trial was presented in the middle of the screen, whereas the second was presented laterally, by a distance of 50 pixels to the middle of the screen both horizontally and vertically. Each stimulus was preceded by a centrally presented black x-shaped fixation cross for 500 ms and trials were separated by a blue square, also presented for 500 ms, indicating the start of a new trial. A schematic representation of a single trial is shown in figure $1^B$.

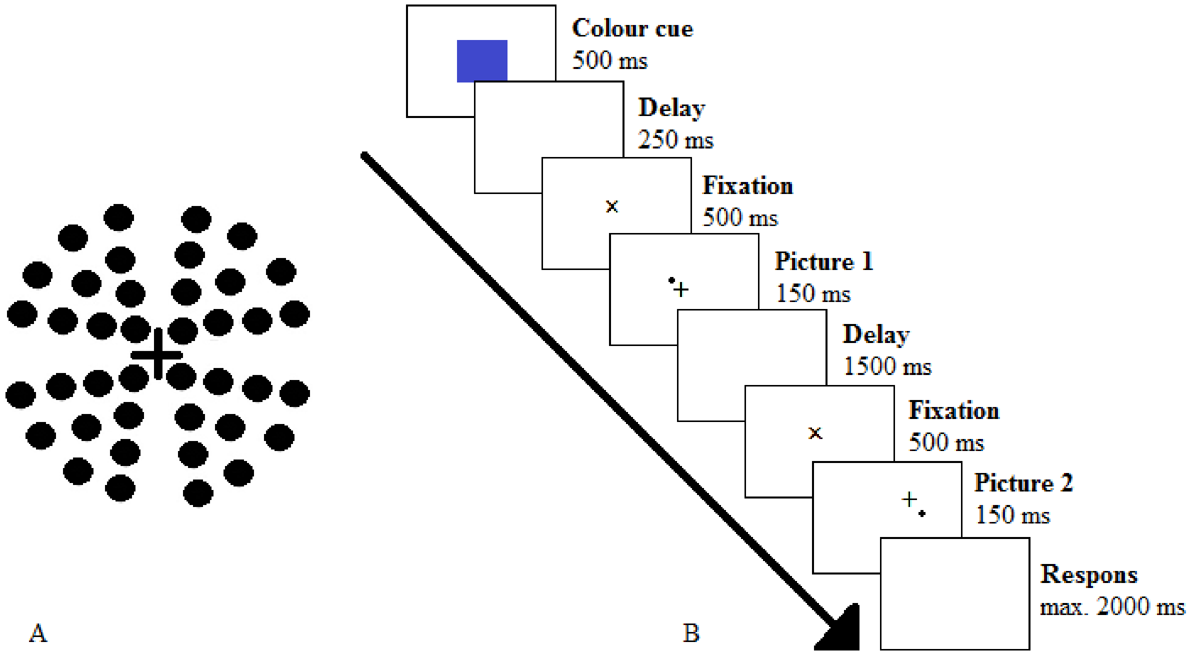


*Figure 1. A schematic lay out of the stimuli in the spatial relation task. Figure $1^A$ shows all possible dot positions (adapted from: van der Ham et al., 2009). Figure $1^B$ presents the timeline of a single trial.*

The task was to determine whether the second stimulus matched the first, depending on whether the given task instruction was a categorical or a coordinate one. In the categorical condition, participants were instructed to determine whether the second stimulus appeared in the same quadrant as the first stimulus. In the coordinate condition, participants had to decide whether both stimuli were at the same radial distance from the centre of the cross or not, disregarding the quadrant in which the stimulus appeared. To prevent the use of strategies such as overlapping the second stimulus by the first, the second stimulus was presented laterally. Participants had to make their decision as accurately and as quickly as they could by pressing the left arrow key with their right index finger when both stimuli were congruent to each other or by pressing the right arrow key with their right ring finger when the second stimulus was incongruent to the first. Both the categorical and coordinate condition consisted of 40 randomly presented trials, of which half were congruent and the other half were incongruent.

*Lateralized pointing (LP) task*

For the LP task, the design of Dupierrix et al. (2009) was used. A stimulus consisted of a black dot (0.6° x 0.6°) presented on a white background. This stimulus was presented either on the right or left side of the screen, depending on the participants' condition (right LP or left LP). Each condition contained nine different stimulus positions, ranging from 0° to ±13.6° along the central horizontal axis of the screen. In total, there were 153 trials (9 stimulus positions x 17 repetitions). A single trial started with a stimulus randomly presented for 1500 ms in one of the nine positions, followed by a random black and white pixel mask (36.9° x 24.9°) presented for 300 ms to erase afterimages.

The participants' task was to point to the presented dot as accurate and quick as they could with their right index finger having a stretched arm. Additionally, they had to fixate visually at the stimulus during pointing, to ensure optimal adaptation. After each trial, participants brought their index finger back to the starting position, which was indicated by a plastic round at the table. A path-like device was attached to their finger and although no recordings were actually made, participants were informed that this device recorded the movement and accuracy of their pointing.

*Procedure*

The experiment took place at Utrecht University concomitantly with another LP experiment, which tested the effect of LP on tactile temporal order judgements. The focus of this study is on the influence of LP on making categorical and coordinate spatial relation judgements and therefore the details of the tactile temporal order judgement task are not discussed further.

Participants started the experiment with signing informed consent and filling in the Edinburgh Handedness questionnaire and subsequently they were instructed about the tasks of the experiment. In the experimental set-up, participants were sitting 60 cm in front of a computer screen with a width of 377 mm and a height of 302 mm. Resolution was set to 1280 x 1024 pixels. To ensure that each participant was at the same distance from the screen, their head was supported by a chinrest in both the spatial relation task and the LP task. Each task started with five practice trials, in which participants could get used to the rapidness of the stimuli and the task itself and in which the experimenter could check whether the participant had understood the task and performed it correctly.

All participants performed both the categorical and coordinate task before and after the LP task, because the final purpose of this study was to examine whether LP had an effect on spatial relation processing. Correct performance on the LP task was essential because this was the manipulation which distinguished between the different conditions. No data of this task was actually saved, which made it impossible to verify LP task performance of the participants afterwards. Therefore, the experimenter stayed in the room during the LP task.

To control for sequence effects, half of the participants started with the tactile temporal order judgement task while the other half started with the spatial relation task. Tactile temporal order judgement task was also performed before as well as after LP task.

Furthermore, the order in which categorical and coordinate tasks were performed was counterbalanced between the participants. This resulted in an equal distribution of the participants over four different task sequences.

*Control group*

In order to control for effects of tiredness or practice, a control group was added to the experiment. This group consisted of two males and six females with a mean age of 21.1 (SD = 2.1). Their mean score on the Edinburgh Handedness questionnaire was 76.3 (SD = 24.5) The procedure for this group was approximately the same as for the experimental group. They also performed both categorical and coordinate task twice and the sequence of these tasks was also counterbalanced between the participants. However, rather than pointing towards the left or right side of their visual field, they received a twenty minute break between the pre- and post-test. This twenty-minute break was based on the mean time between the pre and post spatial relation task in the experimental setting.

*Data analysis*

Before the data of the spatial relation task was analysed in SPSS, trials with reaction times lower than 200 ms were filtered out from raw data file because this could mean that these trials were not performed seriously. The upper limit of reaction times was already established at 2000 ms prior to the experiment. For analysis of differences in reaction time, incorrect trials were removed from data. Furthermore, participants with a mean accuracy lower than 0.50 were excluded from further analysis because they performed below guess chance, which could mean that they did not understand the task.

Left and right LP were analysed separately in both categorical and coordinate condition, because current study is interested in single effects of pointing direction on categorical and coordinate tasks rather than an interaction between pointing direction and task. This resulted in using a repeated measures ANOVA four times, with time (pre/post) as within subject variable. Change in accuracy and reaction time were analysed separately.

## Results

*Descriptive statistics and excluded participants*

Demographic variables of the experimental groups and the control group are represented in table 1. A one way ANOVA was conducted to compare these groups. The groups did not differ significantly on age, gender ratio and score on the Edinburgh Handedness Test.

One participant was excluded from further analysis because of a score of 20 on the Edinburgh Handedness test, which was below the cut-off score of 40. Furthermore, three participants in the categorical condition and two participants in the coordinate condition were excluded because they had a lower accuracy than the guess chance of 0.5.

*Table 1 Demographic comparison between the experimental groups and the control group*

| | Left LP group (*n* = 19) | | Right LP group (*n* = 19) | | Control group (*n* = 8) | | Statistics |
|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD | P |
| Age | 22.1 | 2.4 | 22.8 | 2.9 | 21.1 | 2.1 | .28 |
| Gender ratio [a] | 1.8 | 0.4 | 1.7 | 0.5 | 1.8 | 0.5 | .93 |
| Edinburgh Handedness Test score | 81.1 | 17.3 | 71.1 | 17.0 | 76.3 | 24.5 | .26 |
| Categorical exclusion | *n* = 2 | | *n* = 1 | | *n* = 0 | | |
| Coordinate exclusion | *n* = 1 | | *n* = 1 | | *n* = 0 | | |

[a] Males were scored with number 1 and females with number 2. Means of these values were statistically compared by a one way ANOVA.

*Effects of tiredness or practice*

The control condition was added to the analysis to provide a baseline measurement of possible significant effects without manipulation. These effects could be due to tiredness or practice rather than pointing. A repeated measures ANOVA was conducted on the control condition with time (pre/post) as within subjects variable on categorical and coordinate condition separately. Reaction time was not significantly different between pre- and post-test in the categorical condition, $F(1,7) = 3.21$, $p = .12$, neither in the coordinate condition, $F(1,7) = 3.81$, $p = .09$. Accuracy improved significantly in categorical condition, $F(1,7) = 11.19$, $p < .05$, $\eta_p^2 = .62$, but not in coordinate condition, $F(1,7) = 0.78$, $p = .41$. Thus, except for accuracy in the categorical condition, performance on both tasks did not change without manipulation of LP, indicating that possible effects in the experimental condition are likely due to LP.

Potential effects of tiredness and practice are further examined by comparing the control condition with the experimental conditions. Therefore, a new variable was created containing the change in both reaction time and accuracy between pre- and post-test in the categorical and the coordinate condition. Change in reaction time and accuracy were analysed separately, as well as the categorical and the coordinate condition. A one way ANOVA was performed with these variables as dependent variables and group as factor. No significant differences were found between all groups on change in reaction time in the categorical condition, $F(2,40) = 0.40$, $p = .96$, neither in the coordinate condition $F(2,40) = 1.70$, $p = .20$. Change in accuracy was not significantly different between left LP, right LP and control condition in both the categorical condition, $F(2,41) = 0.26$, $p = .77$, and the coordinate condition, $F(2,41) = 1.90$, $p = .16$. Mean changes in reaction time and accuracy in each condition are shown in figure 2.

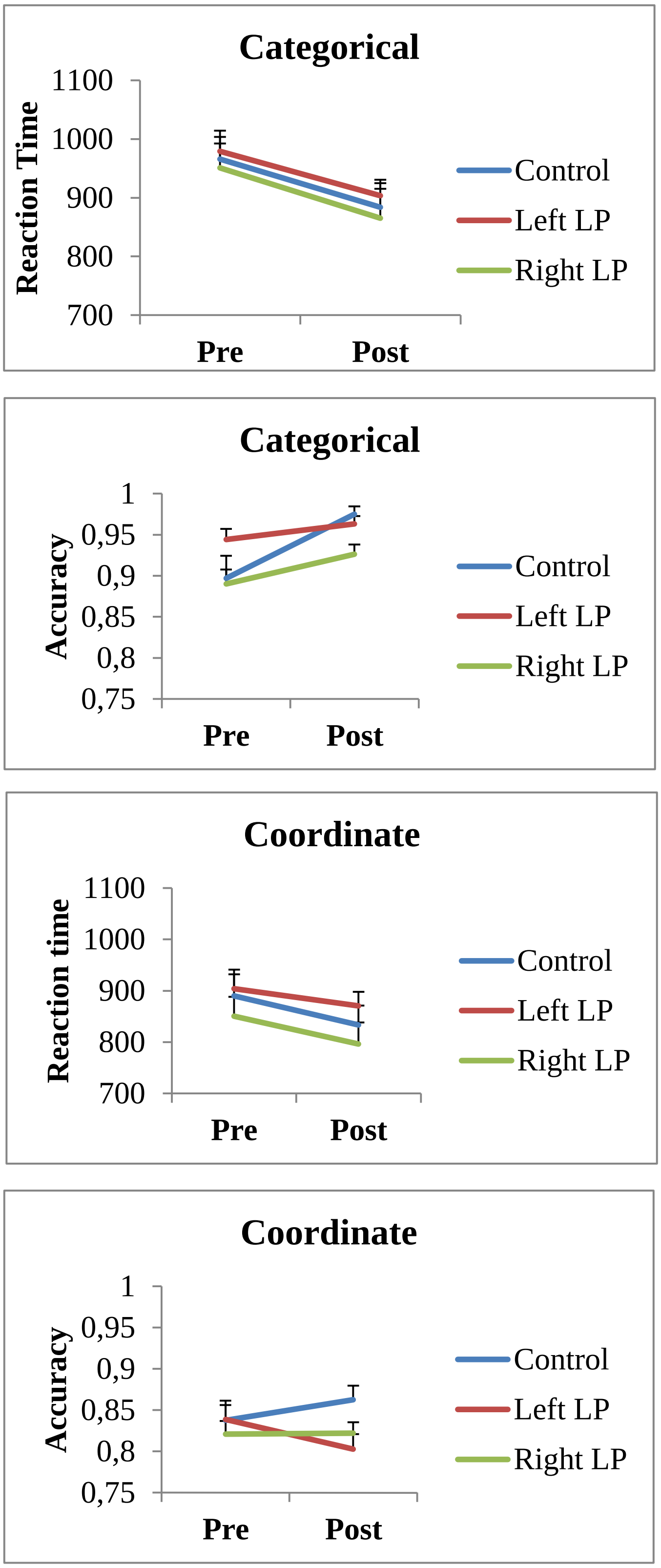


*Figure 2. Global overview of the mean change in reaction time (in ms) and accuracy (proportion correct answers) with separate lines for control condition, left LP condition and right LP condition. Error bars represent positive values of the standard errors of the mean.*

*Categorical condition*

A repeated measures ANOVA was performed with time as within subjects variable. Left and right pointing were analysed separately. A global overview of the results is shown in figure 3. Mean reaction time changed from 979.2 ms (SD = 145.2) prior to the left LP task, to 903.7 ms (SD = 114.3) after pointing to the left side of the visual field. This change in reaction time was significant, $F(1,16) = 12.72$, $p < .01$, $\eta_p^2 = .44$. This finding is inconsistent with the hypothesis of this study, since it was expected that left LP leads to activation of the right hemisphere and consequently resulted in a higher reaction time on the categorical task. Mean change in accuracy was differed not significantly as a result of left LP, $F(1,16) = 1.41$, $p = .25$.

As a result of right LP, mean reaction time in the categorical condition changed significantly from 950.6 ms (SD = 177.2) to 865.2 ms (SD=212.1) after right LP, $F(1,17) = 11.01$, $p = <.01$, $\eta_p^2 = .39$. A trend was found when comparing accuracy before and after right LP, $F(1,17) = 3,28$, $p = .09$, $\eta_p^2 = .16$. These results are in accordance with the hypothesis that pointing to the right side of the visual field improves performance on the categorical task.

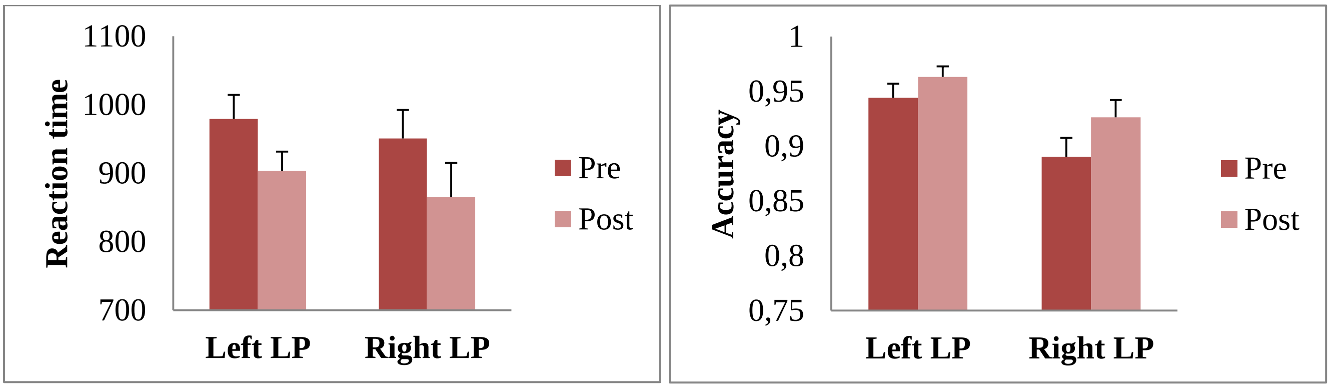


*Figure 3. Mean change in reaction time (in ms) and accuracy(proportion correct answers) in the categorical condition as a function of LP condition. Error bars represent positive values of the standard errors of the mean.*

*Coordinate condition*

The same analysis was conducted in the coordinate condition as in the categorical condition: a repeated measures ANOVA with time as within subjects variable on left and right LP data separately and separate analysis for change in reaction time and accuracy. Figure 4 shows mean changes of reaction time and accuracy after left and right LP.

It was expected that left LP leads to activation of the right hemisphere and improved performance on the coordinate task. Reaction time decreased from 903.0 ms (SD = 120.7) to 870.9 (SD = 115.3). This difference was not significant, but it was large enough to establish a trend which was consistent with the hypothesis, $F(1,17) = 3.39$, $p = .08$, $\eta_p^2 = .17$. Accuracy did not change significantly as a result of left LP, $F(1,17) = 2.92$, $p = .11$.

In contrast with left LP, it was expected that right LP decreased performance on coordinate task, which resulted in higher reaction time and lower accuracy. However, reaction time was lower after right LP (pre-test: M = 850.3, SD = 165.8; post-test: M = 796.6, SD = 177.2) and although the effect was not significant, a trend was found in analysis of the mean change in reaction time, $F(1,17) = 2.47$, $p = .08$, $\eta_p^2 = .17$. Analysis of accuracy did not show a significant effect between pre- and post-test, $F(1,17) = 0.007$, $p = .93$.

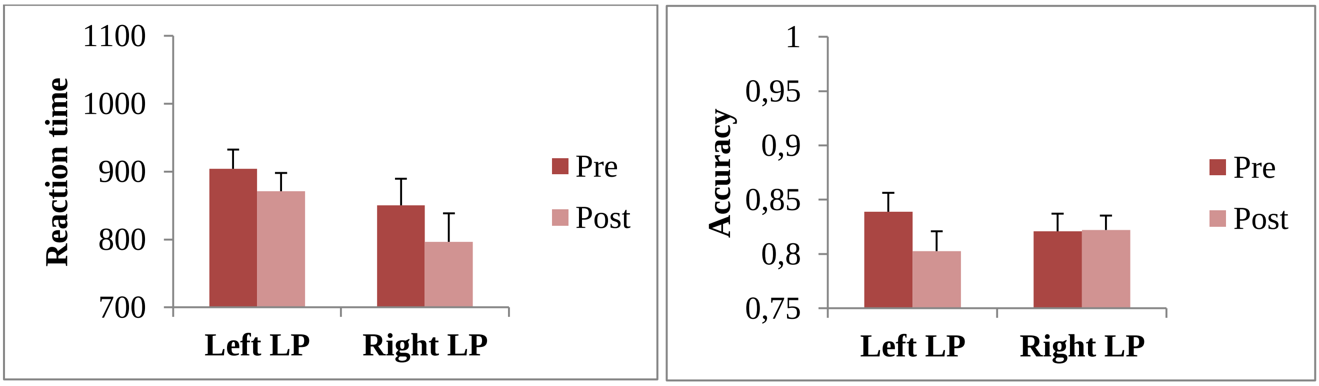


*Figure 4. Mean change in reaction time (in ms) and accuracy (proportion correct answers) in the coordinate condition as a function of LP condition. Error bars represent positive values of the standard errors of the mean.*

## Discussion

Earlier research provided evidence that interaction with the environment through pointing to the left or right side of the visual field produces biases in pointing straight ahead (Dupierrix et al., 2009) and changes in performance on local and global processing (Herlihey et al., 2013). Current study further examined the way in which brain plasticity could be influenced by LP. A spatial relation task was used, because distinct aspects of spatial relation processing are differently lateralized in the brain. Categorical processing, in which the relative position of two objects is determined by means of their qualitative orientations, is mainly processed in the left hemisphere. By contrast, the right hemisphere is primarily involved with coordinate processing, in which the relative position of two objects is characterized by the absolute distance between those objects. It was hypothesized that pointing to one side of the visual field produced activation of the opposite hemisphere and consequently improved performance on the task that is lateralized in that hemisphere and decreased performance on the task that is lateralized in the other hemisphere, since it is known that activation of one hemisphere leads to inhibition of the other hemisphere (Daskalakis et al., 2002; Ferbert et al., 1992). This resulted in four separate hypotheses which were all tested using a repeated measures ANOVA.

First, it was hypothesized that performance on categorical task would increase as a result of right LP, reflected by a lower reaction time and higher accuracy. The results confirmed this hypothesis for change in reaction time. In the analysis of accuracy only a trend was found rather than a significant effect. Secondly, it was expected that left LP produced opposite effects, since it is assumed that activation of the right hemisphere causes inhibition of the left hemisphere. However, results were inconsistent with this hypothesis and showed improvement of reaction time in the categorical condition rather than a higher reaction time. Change in accuracy was not significant in the categorical condition as a function of left LP.

In coordinate condition, there were also two different hypotheses with regard to left and right LP. It was expected that processing coordinate information was faster and more accurate after left LP. After left LP task both reaction time and accuracy did not differ significantly compared with before left LP, although a trend was found for improvement of reaction time. Furthermore, it was hypothesized that performance on coordinate processing would decrease after right LP. A trend was found in reaction time in the coordinate condition. However, reaction time was faster rather than slower after right LP, which is inconsistent with the hypothesis. Accuracy in the coordinate condition was not significantly influenced by right LP.

It is notable that participants were never slower and less accurate after LP than before LP, they were either faster or no significant difference was found. Since they had already performed both the categorical and the coordinate task once, it could be thought that this is the result of practice. If this is the case, it might be expected that participants are also faster and more accurate without manipulation of LP. Therefore, a control group was added who performed both categorical and coordinate task twice, but without intermediate pointing. The results showed no significant differences between pre- and post-test, except for accuracy in the categorical condition, indicating that practice alone does not explain the significant effects that are found in the experimental groups.

If improved performance is not only attributed to practice, there must be another reason why some conditions improved significantly. This raises the question which processes actually activated the opposite hemisphere. It may be that attentional processes result in activation of the opposite hemisphere. Thus, when pointing to one side of the screen, visual attention is shifted to that side of the visual field and consequently produces activation of the opposite hemisphere. On the other hand, activation of the opposite hemisphere could be the result of motor action. Because all participants performed LP task with their right hand, it is suggested that this leads to activation of the left hemisphere. This assumption seems to be in line with the results of this study, because in categorical condition the reaction times improved significantly after pointing, regardless of the pointing direction, while in the coordinate condition only trends were found, but no significant effects.

Superior parietal lobe, which is involved in spatial relation processing (Trojano et al., 2002; Van der Ham et al., 2009), provides further evidence for the role of motor action in this study. Several fMRI studies showed that this area is involved with sensorimotor integration (Culham & Valyear, 2006; Evangeliou, Raos, Galletti & Savaki, 2009; Wolpert, Goodbody & Husain, 1998). This is interesting, because the LP task consisted of making a movement towards a visually presented dot on the computer screen, which is defined as sensory information. Hence, sensorimotor integration is necessary to be able to perform this task. In line with this, a study of Astafiev et al. (2003) found that superior parietal lobe was highly active compared to other regions during a pointing task.

Furthermore, there is evidence that the superior parietal lobe is activated in the hemisphere contralateral to the hand used to reach (Kertzman, Schwarz, Zeffiro & Hallett, 1997). In their study, participants had to reach towards a visually presented target with either their right or left arm. When reaching with the right arm, left superior parietal lobe was activated and vice versa. Because participants in the current study only pointed with their right arm, it is likely that this resulted in activation of superior parietal lobe in the left hemisphere and consequently improved performance on the categorical task independent of pointing direction, while there was no improvement of the coordinate task.

This explanation seems to be plausible, but it does not explain why there is no reduction of performance on the coordinate task. It is likely that a part of the effects are explained by activation of superior parietal lobe in the left hemisphere, but there is still a component of practice that plays a role. This is also shown by the fact that change of performance was similar in both the experimental groups and the control group. Particularly in the coordinate condition many trends are found, rather than significant effects, so it could be helpful to use more participants for providing stronger effect sizes and more evidence for the presence or absence of practice effects.

To further examine whether LP activation is driven by visual attention or motor action, future studies should focus on the exact processes of LP. It should be examined what happens when half of the participants point with their right hand while the other half point with their left hand. Furthermore, addition of a condition where participants focus their visual attention towards one side of the visual field without pointing and a condition in which participants point as a reaction on for example an auditory stimulus rather than a visual stimulus would be very helpful to gain more insight in the underlying processes of LP.

*Conclusion*

In summary, pointing to one side of the visual field has an effect on categorical processing, but not on coordinate processing. This result is partially in accordance with the hypotheses of this study, but there is some discrepancy since it was expected that LP also had an influence on coordinate processing. It seems likely that not the direction of pointing, but the hand that pointed accounts for the results. Because all participants pointed with their right hand, they all activated their left hemisphere and consequently improved their performance on the categorical task. This suggestion is confirmed by the role of the superior parietal lobe in the left hemisphere, since this area is involved in both the LP task and categorical processing. Future research is necessary to further examine the role of the superior parietal lobe and to study whether activation of the brain after LP is caused by motor action or visual attention.

## References

Astafiev, S.V., Shulman, G.L., Stanley, C.M., Snyder, A.Z., Van Essen, D.C., & Corbetta, M. (2003). Functional organization of human intraparietal and frontal cortex for attending, looking, and pointing. *The Journal of Neuroscience, 23(11)*, 4689-4699.

Baciu, M., Koenig, O., Vernier, M.P., Bedoin, N., Rubin, C., & Segebarth, C. (1999). Categorical and coordinate spatial relations: fMRI evidence for hemispheric specialization. *NeuroReport, 10*, 1373-1378.

Borst, G., & Kosslyn, S.M. (2010). Varying the scope of attention alters the encoding of categorical and coordinate spatial relations. *Neuropsychologia, 48*, 2769-2772.

Bultitude, J.H., Rafal, R.D., & List, A. (2008). Prism adaptation reverses the local proessing bias in patients with right temoro-parietal junction lesions. *Brain, 132*, 1669-1677.

Bultitude, J.H., & Woods, J.M. (2010). Adaptation to leftward-shifting prisms reduces the global processing bias of healthy individuals. *Neuropsychologia, 48*, 1750-1756.

Christman, S.D. (2002). Hemispheric asymmetries in categorical judgments of direction versus coordinate judgments of velocity of motion. *Psychonomic Bulletin & Review, 9(2)*, 298-305.

Culham, J.C., & Valyear, K.F. (2006). Human parietal cortex in action. *Current Opinion in Neurobiology, 16*, 205-212.

Daskalakis, Z.J., Christensen, B.K., Fitzgerald, P.B., Roshan, L., & Chen, R. (2002). The mechanisms of interhemispheric inhibition in the human motor cortex. *Journal of Physiology, 543(1)*, 317-326.

Deubel, H., Schneider, W.X., & Paprotta, I. (1998). Selective dorsal and ventral processing: Evidence for a common attentional mechanism in reaching and perception. *Visual Cognition, 5(1/2)*, 81-107.

Dupierrix, E., Alleysson, D., Ohlmann, T., & Chokron, S. (2008). Spatial bias induced by a non-conflictual task reveals the nature of space perception. *Brain Research, 1214,* 127-135.

Dupierrix, E., Gresty, M., Ohlmann, T., & Chokron, S. (2009). Long lasting egocentric disorientation induced by normal sensori-motor spatial interaction. *PLoS One, 4(2),* e4465.

Evangeliou, M.N., Raos, V., Galletti, C., & Savaki, H.E. (2009). Functional imaging of parietal cortex during action execution and observation. *Cerebral Cortex, 19(3),* 624-639.

Ferbert, A., Priori, A., Rothwell, J.C., Day, B.L., Colebatch, J.G., & Marsden, C.D. (1992). Interhemispheric inhibition of the human motor cortex. *Journal of Physiology, 453,* 525-546.

Frassinetti, F., Angeli, V., Meneghello, F., Avanzi, S., & Làdavas, E. (2002). Long-lasting amelioration of visuospatial neglect by prism adaptation. *Brain, 125*, 608-623.

Hellige, J.B., & Michimata, C. (1989). Categorization versus distance: Hemispheric differences for processing spatial information. *Memory and Cognition, 17*, 770-776.

Herlihey, T.A., Black, S.E., & Ferber, S. (2013). Action modulated cognition: The influence of sensori-motor experience on the global processing bias. *Neuropsychologia, 51,* 1973-1979.

Holmes, K.J., & Wolff, P. (2012). Does categorical perception in the left hemisphere depend on language? *Journal of Experimental Psychology: General, 141*, 439-443.

Jager, G., & Postma, A. (2003). On the hemispheric specialization for categorical and coordinate spatial relations: A review of the current evidence. *Neuropsychologia, 41*, 504-515.

Kemmerer, D., & Tranel, D. (2000). A double dissociation between linguistic and perceptual representations of spatial relationships. *Cognitive Neuropsychology, 17*, 393-414.

Kertzman, C., Schwarz, U., Zeffiro, T.A., & Hallett, M. (1997). The role of posterior parietal cortex in visually guided reaching movements in humans. *Experimental Brain Research, 114,* 170-183.

Klapp, S.T., Nordell, S.A., Hoekenga, K.C., & Patton, C.B. (1974). Long-lasting aftereffect of brief prism exposure. *Perception & Psychophysics, 15(2),* 399-400.

Kosslyn, S.M. (1987). Seeing and imagining in the cerebral hemispheres: A computational approach. *Psychological Review, 94(2)*, 148-175.

Kosslyn, S.M., Koenig, O., Barrett, A., Cave, C.B., Tang, J., & Gabrieli, J.D.E. (1989). Evidence for two types of spatial representations: Hemispheric specialization for categorical and coordinate relations. *Journal of Experimental Psychology, 15(4)*, 723-735.

Laeng, B., & Peters, M. (1995). Cerebral lateralization for the processing of spatial coordinates and categories in left- and right-handers. *Neuropsychologia, 33(4),* 421-439.

Martin, M. (1979). Hemispheric specialization for local and global processing. *Neuropsychologia, 17*, 33-40.

Mevorach, C., Humphreys, G.W., & Shalev, L. (2005). Attending to local form while ignoring global aspects depends on handedness: Evidence from TMS. *Nature Neuroscience, 8(3)*, 276-277.

Michimata, C., Saneyoshi, A., Okubo, M., & Laeng, B. (2011). Effects of the global and local attention on the processing of categorical and coordinate spatial relations. *Brain and Cognition, 77*, 292-297.

Navon, D. (1977). Forest before trees: The precedence of global features in visual perception. *Cognitive Psychology, 9*, 353-383.

Newport, R., & Schenk, T. (2012). Prisms and neglect: What have we learned? *Neuropsychologia, 50*, 1080-1091.

Oldfield, R.C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia, 9*, 97-113.

Palermo, L., Bureca, I., Matano, A., & Guariglia, C. (2008). Hemispheric contribution to categorical and coordinate representational processes: A study on brain-damaged patients. *Neuropsychologia, 26*, 2802-2807.

Pisella, L., Rode, G., Farnè, A., Boisson, D., & Rossetti, Y. (2002). Dissociated long lasting improvements of straight-ahead pointing and line bisection tasks in two hemineglect patients. *Neuropsychologia, 40*, 327-334.

Redding, G.M., Rossetti, Y., & Wallace, B. (2005). Applications of prism adaptation: A tutorial in theory and method. *Neuroscience and Biobehavioral Reviews, 29*, 431-444.

Robertson, L.C., Lamb, M.R., & Knight, R.T. (1988). Effects of lesions of temporal-parietal junction on perceptual and attentional processing in humans. *The Journal of Neuroscience, 8(10)*, 3757-3769.

Rossetti, Y., Rode, G., Pisella, L., Farné, A., Li, L., Boisson, D., & Perenin, M.T. (1998). Prism adaptation to a rightward optical deviation rehabilitates left hemispatial neglect. *Nature, 395*, 166-169.

Trojano, L., Grossi, D., Linden, D.E.J., Formisano, E., Goebel, R., Cirillo, S., Elefante, R., & Di Salle, F. (2002). Coordinate and categorical judgements in spatial imagery. An fMRI study. *Neuropsychologia, 40*, 1666-1674.

Van der Ham, I.J.M., Duijndam, M.J.A., Raemaekers, M., Van Wezel, R.J.A., Oleksiak, A., & Postma, A. (2012). Retinotopic mapping of categorical and coordinate spatial relation processing in early visual cortex. *PLoS ONE, 7(6)*, e38644.

Van der Ham, I.J.M., & Postma, A. (2010). Lateralization of spatial categories: A comparison of verbal and visuospatial categorical relations. *Memory & Cognition, 38(5)*, 582-590.

Van der Ham, I.J.M., Raemaekers, M., Van Wezel, R.J.A., Oleksiak, A., & Postma, A. (2009). Categorical and coordinate spatial relations in working memory: An fMRI study. *Brain Research, 1297*, 70-79.

Van der Ham, I.J.M., Van Strien, J.W., Oleksiak, A., Van Wezel, R.J.A., & Postma, A. (2010). Spatial working memory for categorical and coordinate information: An ERP study. *International Journal of Psychophysiology, 77*, 83-94.

Van Kleeck, M.H. (1989). Hemispheric differences in global versus local processing of hierarchical visual stimuli by normal subjects: New data and a meta-analysis of previous studies. *Neuropsychologia, 27(9)*, 1165-1178.

Wolpert, D.M., Goodbody, S.J., & Husain, M. (1998). Maintaining internal representations: The role of the human superior parietal lobe. *Nature Neuroscience, 1(6),* 529-533.