Seen in a flash: spatial and temporal aspects in movement related (mis)localization

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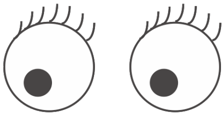

Chapter 9

Summary and conclusions

After four years of hard work there are still many questions to be answered. However, the studies reported in this thesis have unraveled some important issues on the localization errors that occur near the time of saccades. Of course, not all of the results were as we expected, but in the end we gained more insight into how the brain combines different signals. First, I will give a brief summary of the spatial and temporal aspects of the localization errors and then I will finish with some speculations.

Spatial aspects

In *Chapters 2 to 4,* I have shown that some spatial cues are used whereas others are not used when localizing objects that are briefly presented near the time of a saccadic eye movement.

In *Chapter 2* we asked subjects to localize flashes that were presented near the time of saccades in two different experiments. In the first experiment the saccade target jumped during the saccade, either in the direction or in the opposite direction of the saccade. In the second experiment the duration of the saccade target on the screen was manipulated. We found that subjects use the saccade target as a visual reference when localizing flashes that were presented before and after the saccade. The contribution of the relative positions of the flash and the saccade target to the perceived position of the flash was estimated to be about 30% under these conditions.

In *Chapter 3* we found that the predictability of the direction of the saccade target did not matter when localizing flashes that were presented near the time of the saccade. Flash positions are mislocalized systematically near the time of saccades, but the extent to which this occurs is largely independent of how long in advance the saccade can be anticipated.

In *Chapter 4* we studied the influence of differently colored segments in the background on the localization and detection of flashes. We asked subjects to localize flashes that are presented near the time of the saccade when the background consisted of differently colored segments (red-green or black-white). Subjects did not perceive the flashes when the colors in the background had a luminance contrast, however when the colors were iso-luminant the flashes were perceived. We found that the localization errors did not differ between contrast conditions (black-white or red-green) before and after the saccade. Flashes were suppressed if they were presented between saccade onset and some time after the saccade. However flashes were mislocalized even if they were presented before saccade onset. This shows that the detection and the localization of flashes result from different processes in the brain.

Temporal aspects

Chapters 5 to 8 show the importance of temporal aspects in the ability to localize a stimulus near the time of a saccade.

In *Chapter 5* we studied the errors that subjects made in localizing a bar by making arm movements across the bar. When touching a real object the localization errors are not fundamentally different from the ones that are previously reported with the use of artificial stimuli. In those studies the stimulus was delivered by a vibrator attached to the finger (Dassonville, 1995; Watanabe et al., 2009). Our results demonstrated that movement related mislocalization is not limited to artificial stimuli.

In *Chapter 6* we studied the effect of irrelevant tones on the localization errors of flashes that were presented near the time of saccades. We presented the tone at different moments with respect to the flash and found a temporal shift of the mislocalization as a result of the tone. Presenting a tone influenced the perceived location of the flash in the same way that presenting the flash nearer to the time of the tone would have done. We interpreted this as evidence that the tone changes the perceived time of the flash. We show that a model based on weighted averaging of the judged times of the flash and the tone, and which considers the probability of the two being perceived as arising from one event, provides a good description of the data. This demonstrates that additional temporal information (as provided by the tone) is taken into consideration when combining sensory information streams for localization.

In *Chapter 7* we examine the temporal aspects of the influence of differently colored segmented backgrounds on the perception of flashes. We found that flashes presented on a red segment were perceived on a green segment. This indicated that subjects use the time at which the flash was presented and not the color of the segment in the background. In addition we showed that we were able to model the mislocalization curves with the use of a temporal uncertainty about the time of the flash and a foveal bias to believe that the flash occurred at the location where the subject's eye is looking at that moment.

The model to explain the localization errors that is introduced in *Chapter 7* is expanded in *Chapter 8*. This model contains only two sources of errors: temporal uncertainty and a spatial bias to believe that the flash occurred where one's eye are directed. By only changing one of these normally distributed parameters or the saccade parameters (such as the amplitude), the great variety in the found localization patterns can be explained.

In this thesis there are of course some aspects that need to be further investigated or explained. This is done in the following paragraphs.

Influence of the irrelevant additional tone revisited

It sometimes happens that two groups perform the same experiment at the same time. This was the case between Paola Binda's experiment (Binda, Morrone, & Burr, 2010) and me for my first experiment (Maij et al., 2009; Chapter 6). Strangely enough our results were not the same: Binda and colleagues did not find an effect of the tone on the localization errors, whereas we did.

In their experiment the subjects were instructed to make saccades of 20 degrees and the flash was a large green bar on a red background, whereas in our experiments the subjects made 7.6 degrees saccades and we used a small white dot on a gray background. They did find effects of a tone when they used more similar stimuli to ours, so the differences in results were not due to errors in the experiment or data analysis. The differences revealed that small changes in the exact experimental conditions (the luminance of the flash and the size of the saccade) were important. Binda and colleagues (2010) explained our influence of the sound on the perceived location of the flash as being the result of the sound cueing flashes, drawing attention to them. However, after making the model (*Chapter 8*), we realized that a small change in the width of one of the parameters of the model (the temporal uncertainty or the foveal bias) and in the saccade amplitude can influence the mislocalization patterns. Changing the parameters could easily result in the temporal shift of the curves to change from no effect of the tone to a clear shift of the mislocalization curves due to the tone.

In that same chapter (*Chapter 6*) we made a model of the predicted temporal shift of the localization curves. We assumed that the curves would not differ when presenting the tone before or after the saccade. However, according to our model (*Chapters 8*) this should not be the case. This suggests that the model (*Chapter 6)* that we used to explain the found temporal shift of the mislocalization curves of that chapter is not fully correct, probably explaining why the model did not fit perfectly.

Compression and shift redefined?

We assume in *Chapters 2* and *3* that mislocalization can be described as a combination of a linear compression and a uniform shift. This assumption was first made by Lappe and colleagues (2000) where they determined the compression and shift indices by taking the mean and the standard deviation of the different flash locations at every time. In *Chapter 3* we use another method to determine the compression and shift by determining the slope and the offset of a linear fit of the perceived location of the flash for each flash location at each time. From figure 2B of *Chapter 3* it can be seen that there doesn't seem to be an exact linear relation, but the linear approximation holds reasonably well. Richard et al. (2009) have shown that there is no linear relation for larger ranges of flash locations. In *Chapter 8* we also addressed this issue, by showing that our model predicts such non-linearities for flashes presented further away from the saccade. This suggests that we need to come up with a better way to quantify the amount of compression and shift with single numbers.

Extension of the Model

The simple model that we have proposed in *Chapter 8* can explain most of the mislocalization patterns that are found in the literature. By only changing the parameters (the temporal uncertainty about the time of the flash and the foveal bias) or the saccade parameters (amplitude), we can easily reproduce many different mislocalization patterns. However, we have seen that the saccade target influences the localization errors before and after the saccade (*Chapter 2*) and that a border does so at some times (*Chapter 4*). As the only uncertainty in the model is a temporal one, it cannot reproduce these purely spatial effects. In order to be able to explain the influence of these references on the perceived location of the flash, an additional spatial parameter should be added. Many other factors could also play a role, however the main take home message is that our simple model (*Chapter 8*) can explain most localization patterns that are found in the literature.

Consequences for our daily life

Finally I want to speculate about the effects of mislocalization on daily life. I have been asked many times about this, but I feel as if I never really gave a good answer to this question. Of course this is fundamental research and off course most important findings were found by accident, but still there should be some better justification than this. So I will try. There are three chapters that I would like to use to illustrate the effects on daily life. First, in the haptic modality I have used an example to illustrate the problem (*Chapter 5*): imagine yourself coming home late at night and you enter a dark room. You will need to find the light switch and you will start making sweeping arm movements (not too slow, because you want to turn on the light quickly) across the wall. Once you have felt it (and realize that you felt it), you will already be at another location with your hand. At this time you need to go back to the location of where your hand was where you think the light switch is. It might not be surprising that you won't be at the correct location, but it might be surprising that you will make systematic localization errors.

This is a simple illustration of the errors that people can make when localizing haptically during arm movements. The critical readers will think, oh ok, well that is nice, but it does not really sound like a big problem to me. In the haptic domain there could be other examples, but when I go back to the localization errors during saccades it becomes harder to explain the effects on daily life.

The problem with saccades is that your eyes move so fast that it is hard to know from introspection whether you perceive something during the saccade. Ever since Matin and Pearce (1965) showed that people do perceive flashes during the saccade and that they misjudge the location of the flash we know that briefly presented objects will be perceived during the saccade. So people do perceive something, but not everything. These results are comparable to the results of the experiments in which we presented colored segments in the background; the subjects localized the flash just as simply on another color than that on which it was presented (*Chapters 4 and 7*). And in addition to this, people do not perceive flashes presented during the saccade when the background consisted of a high luminance contrast segments (*Chapter 4*). The latter result showed that this might be the reason why we don't seem to be bothered at all about mislocalization near the time of saccades. In daily life most scenes consist of high luminance contrasts, and thus this results in saccadic suppression during the saccade.

Also we normally do not perceive many flashes. Almost all objects that we see are present for at least several seconds. In those cases we don't make any localization errors. So, if we are not bothered by mislocalization in daily life, why study this phenomenon? Well, the information that we gained from these studies is important in order to know how different sensory signals are combined in the brain. This information could be important to design artificial systems or tools for people that are disabled (e.g. blind or deaf people, or other sensory disabled people). The way our brain functions, is one the most complex problems that we (as mankind) want to understand. I hope this thesis has contributed a little.