## Title
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# Eye Movements During Mental Imagery are Not Reenactments of Perception

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**Abstract**

In this study eye movements were recorded for participants under three different conditions. All three conditions consisted of a perception phase and a mental imagery phase. The imagery phase was similar for all conditions: i.e., participants looked freely at a blank white screen. The perception phase was different for each condition. In the control condition, participants looked freely at a complex picture. In the first experimental condition, they looked at another complex picture but maintained fixation at the center of the picture. In the second experimental condition, they maintained central fixation while listening to a verbal scene description. The results revealed that despite central fixation during the perception phase under the two experimental conditions, participants' eye movements were spread out during the imagery phase, reflecting the spatial positions and directions within the picture or scene. These results contradict the theory that eye movements during mental imagery are re-enactments of perception.

**Keywords:** Eye movements, mental imagery, spatial cognition, visual attention, scene description.

## Introduction

Since the late Nineties, several eye-tracking studies have reported that spontaneous eye movements occur with mental imagery and that these eye movements closely reflect the content and spatial relations from an original picture or scene (e.g., Brandt & Stark, 1997; Holsanova, Hedberg & Nilsson, 1998; Laeng & Teodorescu, 2002; Gbadamosi & Zangemeister, 2001; Altmann, 2004; Johansson, Holsanova & Holmqvist, 2006; Humphrey & Underwood, 2008). A similar effect has been found for spatial relations and scenes that are verbally described (e.g., Demerais & Cohen, 1998; Spivey, Tyler, Richardson, & Young, 2000; Spivey & Geng, 2001; Johansson et al, 2006). It has further been shown that this effect is equally strong irrespective of whether the original elicitation was visual or verbal (Johansson et al., 2006). Additionally, an eye movement effect of this kind has also been found during problem-solving tasks (e.g., Yoon & Narayanan, 2004; Freksa & Bertel, 2007) as well as with visual motor imagery (Heremans, Helsen & Feys, 2007; Gueugneau, Crognier & Papaxanthis, 2008). From this large body of research, it appears that eye movements play an important role in visual imagery and in the construction of mental models. However, what role these eye movements have, and why they appear, are issues of debate (cf., Johansson et al., 2006; Ferreira, Apel, & Henderson, 2009; Richardson, Altmann, Spivey & Hoover, 2009).

Hebb (1968) suggested a *functional* role for eye movements during mental imagery, and proposed that they are necessary to assemble and organize "part images" into a whole visualized image. This functional view has gained strong support from a study by Laeng and Teodorescu (2002). In their study participants inspected visual stimuli of two kinds: 6×6 grid patterns with 5 black filled cells or a small fish in various locations on the screen. One group was instructed to maintain fixation onto the screen's center and another group was free to inspect the stimuli. In a subsequent imagery phase, both groups were instructed to 'build a visual image of the figure' they had just seen and were then allowed to move their eyes freely while looking at a blank screen. The results revealed that those who maintained their gaze centrally in the perception phase did the same, spontaneously, during the imagery phase, while those who inspected the original stimuli freely had eye movements during the imagery phase which, to a high degree, resembled those in the perception phase. Laeng and Teodorescu (2002) argued that this implied eye movements are stored along with a visual representation of the scene, and are used as spatial indexes to properly arrange the parts of a mental image. They concluded that eye movements during mental imagery are *re-enactments* of perception and have a necessary and functional role in "constructing" the mental image. However, the question can be raised whether the instruction to 'build a visual image', in combination with the relatively simple stimuli, might necessarily lead to spatial scanning of the mental image.

As discussed in Johansson et al. (2006), the task and the complexity of the stimuli are important when the scene is recalled during mental imagery. For instance, it is possible that the mental image is only covertly scanned or is not scanned at all. Thomas and Lleras (2009) have shown that shifts in covert attention can produce identical results in a problem-solving task to overt eye movements. It is however less likely that shifts in covert attention, or lack of scanning altogether, would be sufficient when recalling scenes that are rich in detail and contain many objects: i.e., visualizing highly complex scenes would increase the cognitive load such that more internal operations would be needed to construct the parts of the image and then tie them together and place them into a context.

The purpose of the present study is to investigate whether Laeng and Teodorescus' (2002) 'central gaze effect' occurs even for visual scenes of high complexity. To ensure that spatial scanning is actually employed, the experimental design and method from Johansson et al. (2006) was used. In this method the imagery task is to orally describe the scene from memory, which introduces a great need for spatial scanning. Additionally, by including two types of stimuli – visual scenes and verbal descriptions – we can investigate mental imagery for scenes that have never been seen in the first place.

## Experiment

The experiment consisted of three conditions: a *control* condition, a *fixed-picture* condition and a *fixed-verbal* condition. All three conditions consisted of a *perception* phase and a *mental imagery* phase. The imagery phase was similar for all conditions: i.e., participants looked freely at a blank white screen. The perception phase was different for each condition. In the control condition, participants looked freely at a complex picture. In the fixed-picture condition, they looked at another complex picture but were instructed to maintain fixation at the center of the picture. In the fixed-verbal condition, they were instructed to maintain central fixation while listening to a verbal description of a scene.

### Participants

Twenty students at the University of Lund – ten females and ten males – participated in the experiment. All subjects reported either normal vision or vision corrected to normal (i.e., with contact lenses or glasses). All participants were native Swedish speakers. The mean age of the participants was 21.4 years (SD = 1.9).

### Apparatus and stimuli

The participants were seated in front of a computer screen at a distance of 600-700 mm. (The distance varied slightly because of the subjects' freedom to move their head and body.) The eye tracker used was the SMI iView RED250, which has a sampling frequency of 250 Hz and a precision of 0.02°. The data was recorded with the iView X 2.4 software. The eye-tracking data was analyzed with BeGaze 2.4 and in-house MatLab programs.

The visual stimulus in the experiment was presented using Experiment Center 2.4 on a 480 mm. x 300 mm. computer screen with a resolution of 1680 × 1050 pixels. The auditory stimulus was a pre-recorded description (one minute and 38 seconds long). An English translation of the scene description follows:

*"In the center, right in front of me, I see a large, green spruce. At the top of the spruce, a bird is sitting. To the left of the spruce – to the far left – there is a yellow house with a black tin roof and with white corners. The house has a chimney on which a bird is sitting. To the right of the large spruce – to the far right – there is a tree as high as the spruce. The leaves of the tree are colored yellow and red. Above the tree a bird is flying. Between the spruce and the tree is a man in blue overalls, raking leaves. Below the spruce, the house, the tree and the man, i.e. in front of them there is a long red fence, which runs all the way from left to right. At the left end, a bike is leaning against the fence. Just to the right of the bike is a yellow mailbox. On top of the mailbox, a cat is sleeping. Below the fence, i.e. in front of and along the fence, a road leads from the left side to the right side. On the road, to the right of the mailbox and the bike, a black-haired girl is bouncing a ball. To the right of the girl, a boy in a red cap is sitting and watching her. To the far right along the road, a lady in a big red hat is walking with some books under her arm. Just to the left of her, on the road, a bird is eating a worm."*

### Procedure

Participants were told that the experiment concerned pupil dilation in relation to mental workload. It was explained that we would be filming their eyes, but nothing was said about us recording their eye movements. They were asked to keep their eyes wide open so that we could film their pupils, and to look directly ahead so that our equipment could accurately measure their pupil dilation. The eye tracker was calibrated using a five-point calibration procedure with validation. (This is the default setting in Experiment Center 2.4). Participants' eye movements were recorded during both the perception and imagery phase under all three conditions.

In the *control* condition, a picture was shown for thirty seconds. Then the screen went blank, and participants were asked to describe the picture in their own words. They were told explicitly to keep their eyes wide open and to look directly ahead so that the equipment could record their pupil dilation. Figure 1 shows the schematics of the control condition.

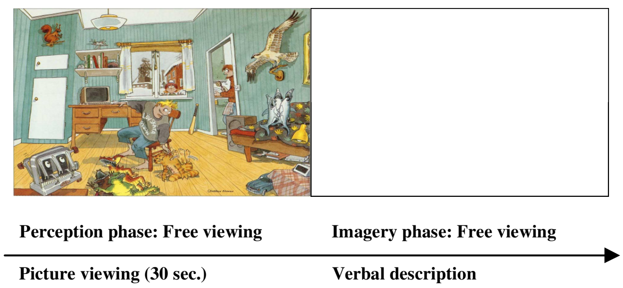


Figure 1: Control condition

In the *fixed-picture* condition, participants were instructed to maintain fixation on a cross in the center of the screen until it disappeared. The cross was first shown for five seconds, after which a picture appeared behind it for an additional thirty seconds. Then the screen went blank, and participants were asked to describe the picture in their own words. They were told explicitly to keep their eyes wide open and to look directly ahead so that the equipment could record their pupil dilation. Figure 2 shows the schematics of the fixed-picture condition.

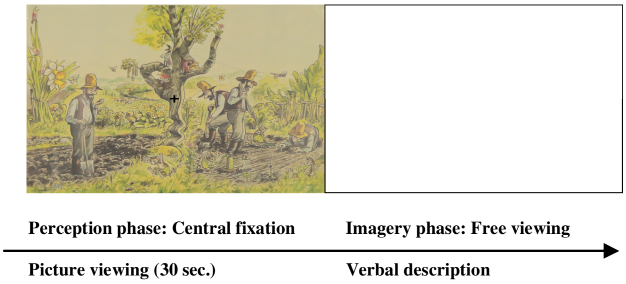


Figure 2: Fixed-picture condition

In the *fixed-verbal* condition, participants were likewise instructed to maintain fixation on a cross in the center of the screen until it disappeared. The cross appeared in an otherwise blank screen while a pre-recorded scene description was played from speakers in front of the participants for 1:38 minutes. Then the cross disappeared. Participants were asked to retell the scene. They were told that they could retell it in their own words and did not have to follow the same order. Participants were told explicitly to keep their eyes wide open and to look directly ahead so that the equipment could record their pupil dilation. Figure 3 shows the schematics of the fixed-verbal condition.

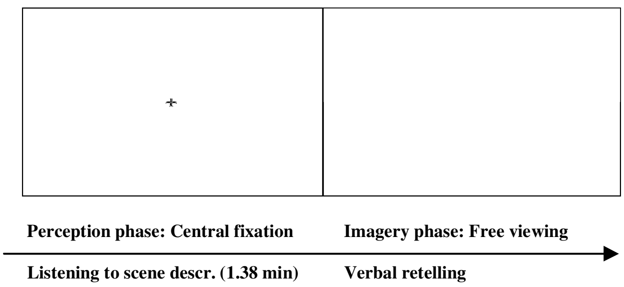


Figure 3: Fixed-verbal condition

Afterwards, to assess whether any of the participants had seen through the nature of the experiment, we asked what they thought the true objective of the experiment was.

## Analysis

If Laeng and Teodorescus' (2002) conclusion – that eye movements during imagery functionally reenact those of perception – is supported then participants' eye movements should remain centrally fixated during the imagery phase for the fixed-picture condition and the fixed-verbal condition: i.e., their eye movements should have similar spatial dispersion as during the perception phase and therefore not correspond to directions and positions from the imagined scene. To test this, we chose to analyze eye movements in two regards. First, the overall spatial dispersion of the eye movements was considered. However, spatial dispersion does not give any information about how eye movements correspond to directions and positions in a mental image. Also, it is common that participants "shrink" their mental image and only look at a limited part of the screen during imagery (Gbadamosi & Zangemeister, 2001; Johansson et al., 2006). Therefore, as a second step, a method combining eye movement data and verbal data (cf., Holsanova, 2008) was used.

To analyze the overall spatial dispersion of the eye-tracking data, a modified version of the *coverage measure* proposed by Wooding (2002) was calculated for each phase (perception/mental imagery) and condition. An "attention map" was created by centering a Gaussian function ($\sigma$ = 0.1W, W = 1680 pixels) at each fixation point and then superimposing all the other functions. The volume under the attention map, after being normalized to unit height, was then used to estimate the spatial dispersion of the eye-tracking data. Within-subject ANOVAs were done to analyze the spatial dispersion between the perception and imagery phases in each condition, as well as between conditions for the imagery phase.

To analyze whether eye movements corresponded to directions and positions from the verbal descriptions and retellings, the method developed and described in Johansson et al. (2006) were used. Since it is possible that participants can make use of either the whole screen or only a part of it in imagining the scene, one cannot simply take physical coordinates on the computer screen as one's areas of interest. Instead, this method uses the relative position of an eye movement compared to each participant's individual gaze pattern over the entire description or retelling. Eye movements are then scored as correct or incorrect according to either *global correspondence* or *local correspondence* coding. The spatial criteria for an eye movement to be considered correct in global correspondence coding is defined as when an eye movement shifts from one object to another it must finish in a position that is spatially correct relative to the participant's gaze pattern over the entire description or retelling. The spatial criteria for local correspondence is defined as when an eye movement shifts from one object to another during the description or the retelling it must move in the correct direction (up, down, left or right). The minimum threshold for the saccadic amplitude to be considered an actual movement from one object to another was set at 35 pixels (10 mm on the screen). In addition to these spatial criteria, we used the temporal criteria from Johansson et al. (2006), where an eye movement from one position to another must appear within five seconds before or after an object is mentioned.

The key difference between global and local correspondence is that global correspondence requires fixations to take place at the categorically correct *spatial position* relative to the whole gaze pattern, whereas local correspondence only requires that the eyes move in the correct *direction* between two consecutively mentioned objects. Eye movements are considered incorrect when neither the local correspondence nor the global correspondence criteria are met: e.g., when the eyes move with amplitudes below the 35-pixel threshold or in the wrong direction.

As a consequence of applying these spatial criteria a binomial distribution in the data is obtained: the spatial relations are either correct or incorrect. The possibility that a participant would move his or her eyes to the correct position by chance was then defined. For global correspondence coding, both the direction and the distance of the movement must be correct. Many movements are possible. In this study a conservative estimate was chosen, whereby the eyes could move in at least four directions (up, down, left, and right) to at least two locations (full and half distance). In addition to these eight possibilities, the eye might stand still (or move with an amplitude below the 35-pixel threshold). For global correspondence, the probability that the eyes moved to the correct position at the correct time by chance is thus definitely less than one in nine (11%). For local correspondence coding, which requires only correct direction, the corresponding probability is one in five (20%). The data could then be analyzed using a Wilcoxon signed-rank test for significance between the total number of correct eye movements and the expected number of correct movements made by chance.

Finally, to compare the proportion of correct eye movements in global and local correspondence coding between the three conditions a within-subjects ANOVA was used.

## Results and discussion

None of the participants saw through to the true objective of the experiment and data from all participants could be included in the results.

The comparison of spatial dispersion between the perception and imagery phases revealed a significantly larger spatial dispersion in the imagery phase under the fixed-picture condition ($F(1,19) = 29.429$, $p < 0.001$) and the fixed-verbal condition ($F(1,19) = 32.934$, $p < 0.001$). The results for the control condition were the opposite: i.e., spatial dispersion was significantly larger in the perception phase ($F(1,19) = 114.553$, $p < 0.001$). The comparison of spatial dispersion in the imagery phase between conditions revealed a significant main effect ($F(2,38) = 8.175$, $p = 0.002$). Bonferroni *post-hoc* tests revealed that spatial dispersion was significantly larger for the control condition than for either the fixed-picture condition ($p = 0.01$) or the fixed-verbal condition ($p = 0.02$). No significant difference was found between the fixed-picture and the fixed-verbal condition.

The average proportion for all participants of correct eye movements by local and global correspondence coding under each condition is presented in Table 1. Consistent with the results from Johansson et al. (2006) the control condition generated a high proportion of correct eye movements, both by local and global correspondence. However, also the central gaze conditions generated a high degree of correct eye movements in the local correspondence coding as well as a certain degree of correct eye movements in the global correspondence coding. Except for the eye movements in global correspondence coding in the fixed-picture-condition the results were significantly above chance ($p < 0.001$).

The comparison of correct eye movements by global and local correspondence coding in the imagery phase between the three conditions revealed a significant main effect for global correspondence coding ($F(2,38) = 5.544$, $p = 0.008$) but not for local correspondence coding. Bonferroni post-hoc tests revealed that there were significantly more correct eye movements (for global correspondence coding) under the control condition than under the fixed-picture condition ($p = 0.03$). No significant difference was found between the other conditions.

Table 1: Percentages of objects with correct eye movements in the imagery phase for all three conditions by both local and global correspondence coding.

| | Control | Fixed-Picture | Fixed-Verbal |
|---|---|---|---|
| Global | 55.8 % | 26.5 % | 34.5 % |
| Local | 81.6 % | 73.6 % | 60.0 % |

These results reveal that spatial dispersion of the eye movements was significantly larger in the imagery phase than in the perception phase under the two central gaze conditions, and that there was a significant degree of correct eye movements under the two central gaze conditions; especially for local correspondence coding. However, the results also showed that spatial dispersion was smaller in the imagery phase under the two central gaze conditions than under the control condition.

Figures 4-6 show scanpaths in both the perception and imagery phase for one and the same participant. Figure 4 shows that in the control condition this participant used a lot of the computer screen during imagery and her eye movements had a large spatial dispersion. Positions and directions for the eye movements corresponded to a high degree with described elements of the picture. Figure 5 shows that in the fixed-picture condition this participant had a large number of fixations in the center of the screen during the mental phase but also executed eye movements away from the center, resulting in a larger spatial dispersion than during the perception phase, and eye movements that spatially corresponded to what was described. For example, the eye movements to the far left were executed when the flowers to the far left of the picture were described. It is clear that during the perception phase, the participant looked at the central cross the entire time and never shifted to the flowers. Figure 6 shows that in the fixed-verbal condition this participant executed a lot of eye movements across a large extent of the screen during the imagery phase, resulting in a larger spatial dispersion than during the perception phase, and eye movements that spatially corresponded to the described scene. For example, the eye movements to the left in this figure were executed when the house, the bike and the mailbox were mentioned, and the eye movements to the far right were executed when the second tree and the lady on the road were mentioned.

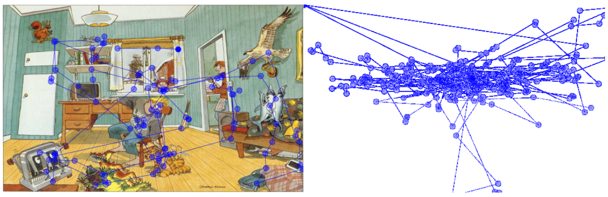

Figure 4: Control condition
(left: perception phase, right: imagery phase)

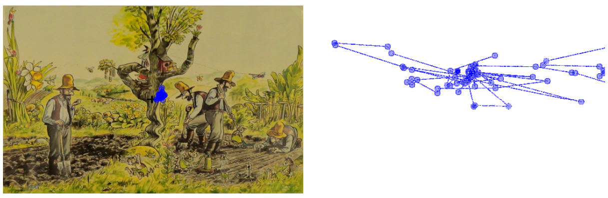

Figure 5: Fixed-picture condition
(left: perception phase, right: imagery phase)

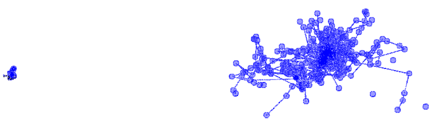

Figure 6: Fixed-verbal condition
(left: perception phase, right: imagery phase)

## General discussion

The results show that despite maintaining central fixation during visual perception of either a complex picture or a verbal scene description, eye movements spread out and to a high degree correspond to spatial positions and directions during mental imagery of the picture or scene. These results contradict Laeng and Teodorescus' (2002) conclusion that eye movements during visual imagery reenact those of perception of the same scene. Nevertheless, it was also revealed that eye movements were less spread out during imagery under the two central gaze conditions than under the control condition and the proportion of correct eye movements was by global correspondence coding significantly lower (and not significantly above chance) for the fixed-picture condition than for the control condition. Therefore, it seems that central gazing in the perception phase to some degree did affect eye movements during imagery. We do, however, propose that this is an effect of the limitation of not being able to move the eyes during perception rather than a support for Laeng and Teodorescus' (2002) functional view. For example, under the fixed-picture condition most of the picture was only seen peripherally and participants were not able to describe as many objects (mean: 4.1) as in the control condition (mean: 7.6) and the description focused to a high degree on picture elements that were in focus during perception (the tree and the bird's nest). For the fixed-verbal condition we propose a similar explanation. Since the participants could not move their eyes when they listened to the scene description it was harder for them to form a mental image of the scene and less objects and spatial relations among them were remembered when the scene was recalled.

If eye movements during imagery are not reenactments of perception would this mean that they do not have a functional and necessary role for the construction of mental images? There has been a vibrant debate recently whether 'looking at nothing' can facilitate memory retrieval of visual scenes and what role internal depictive image representations have in this process (Ferreira, Apel, & Henderson, 2008; Richardson, Altmann, Spivey, & Hoover, 2009). Nevertheless, in this debate, eye movements to regions of a blank screen are interpreted in relation to a previous perception phase: i.e., again eye movements during mental imagery were seen as reenactments of perception. We propose that this is the wrong approach. Johansson et al. (2006) showed that participants who listened to a scene description while looking at a blank screen spontaneously performed eye movements that closely corresponded to spatial positions and directions from their visualizations of the scene. In this case, there was no previous perception phase that the eye movements could be reenacting. Another big problem for the 'reenactment approach' is that eye movements during imagery are idiosyncratic. For example, participants frequently "shrink" their mental image, and only look at a limited part of the screen when visualizing a previously seen picture that covered the entire screen (Gbadamosi & Zangemeister, 2001; Johansson et al., 2006). The results from the current study together with these previous findings strongly show that the phenomenon of eye movements during mental imagery is more complex than a mere reenactment of a perceptual phase. Therefore, to conclude that eye movements are necessary and functionally connected with the construction of a mental image is too strong of an assumption. A better approach might be to see them as a support that can relieve working memory load during imagery. If this is right, they become more likely to appear when a difficult imagery task is performed. This could explain why the results in this paper differ from those of Laeng and Teodorescu (2002). It is a much harder task to visualize and verbally describe a complex picture or scene description than to 'build an image' of the much simpler stimuli used in their study. Another possible interpretation comes from various versions of simulation theory (e.g.

Hesslow, 2002; Thomas, 1999), where eye movements during imagery do not have a direct and necessary link to eye movements from a perception phase. For example, the perceptual activity theory (Thomas, 1999) states that imagery is the reenactment of a perceptual behavior that would be appropriate for exploring the imagined scene as if it were actually present. Eye movements would therefore be likely to appear independently of how they were executed in perception.

Nevertheless, to explain the complex interplay between eye movements and mental imagery fully, further studies need to be performed: e.g., to investigate whether memory retrieval is enhanced by eye movements to blank areas of a screen and how individual differences in spatial cognition and working memory capacity are related to these movements.

## Summary

This study showed that despite maintaining central fixation, either while looking at a complex picture or listening to a scene description, participants' eye movements spread out and did correspond to directions and positions during mental imagery of the picture or the scene. Laeng and Teodorescus' (2002) conclusion that eye movements during imagery reenact those of perception was therefore not supported.

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## References

Altmann, G. T. M. (2004). Language-mediated eye movements in the absence of a visual world: the 'blank screen paradigm'. *Cognition*, 93 (2): B79-B87.

Brandt, S. A., & Stark, L. W. (1997). Spontaneous eye movements during visual imagery reflect the content of the visual scene. *Journal of Cognitive Neuroscience, 9,* 27–38.

Demarais, A., & Cohen, B.H. (1998). Evidence for image-scanning eye movements during transitive inference. *Biological Psychology*, *49*, 229-247.

Ferreira, F. Apel, A., & Henderson, J. M. (2008). Taking a new look at looking at nothing. *Trends in Cognitive Science*, 12(11), 405-410.

Freksa, C., & Bertel, S. (2007). Eye movements and smart technology. *Computers in Biology and Medicine,* 37, 983 – 988.

Gbadamosi, J., & Zangemeister, W. H. (2001). Visual imagery in hemianopic patients, *Journal of Cognitive Neuroscience.* 13 (7), 45–56.

Gueugneau, N., Crognier, L., & Papaxanthis, C. (2008). The influence of eye movements on the temporal features of executed and imagined arm movements. *Brain Research*, 1187, 95–102.

Hebb, D. O. (1968). Concerning imagery. *Psychological Review*, 75, 466-477.

Heremans, E., Helsen, W. F., & Feys, P. (2008). The eyes as a mirror of our thoughts: quantification of motor imagery through eye movement registration, *Behavioural Brain Research,* 187(2), 351–360.

Hesslow, G. (2002). Conscious Thought as Simulation of Behaviour and Perception. *Trends in Cognitive Science*, 6, pp. 242-247.

Holsanova, J., Hedberg, B., & Nilsson, N. (1998). Visual and Verbal Focus Patterns when Describing Pictures. In Becker, Deubel & Mergner (Eds.), *Current Oculomotor Research: Physiological and Psychological Aspects*. Plenum: New York, London, Moscow.

Holsanova, J. (2008). *Discourse, vision, and cognition*. Human Cognitive Processes 23. John Benjamins Publishing Company: Amsterdam/Philadelphia.

Humphrey, K., & Underwood, G. (2008). Fixation sequences in imagery and in recognition during the processing of pictures of real-world scenes. *Journal of Eye Movement Research*, 2(2):3, 1-15.

Johansson, R., Holsanova, J., & Holmqvist, K. (2006). Pictures and spoken descriptions elicit similar eye movements during mental imagery, both in light and in complete darkness. *Cognitive Science,* 30:6, 1053-1079.

Laeng, B., & Teodorescu, D.-S. (2002). Eye scanpaths during visual imagery reenact those of perception of the same visual scene. *Cognitive Science*, 26, 207-231.

Richardson, D. C., Altmann, G. T. M., Spivey, M. J., & Hoover, M. A. (2009). Much ado about eye movements to nothing: a response to Ferreira *et al.,*: Taking a new look at looking at nothing, *Trends in Cognitive Science,* 13(6), 235-236.

Spivey, M., & Geng, J. (2001). Oculomotor mechanisms activated by imagery and memory: eye movements to absent objects, *Psychological Research*, 65, 235-241.

Spivey, M., Tyler, M., Richardson, D., & Young, E. (2000). Eye movements during comprehension of spoken scene descriptions. *Proceedings of the 22nd Annual Conference of the Cognitive Science Society* (pp. 487-492). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Thomas, N. J. T. (1999). Are Theories of Imagery Theories of Imagination? An Active Perception Approach to Conscious Mental Content. *Cognitive Science,* vol. 23 (2).

Thomas, L. E., & Lleras, A. (2009). Covert shifts of attention function as an implicit aid to insight. *Cognition*, 111, 168-174.

Wooding, D. S. (2002). Fixation maps: quantifying eye-movement traces. *Proceedings of the 2002 symposium on Eye tracking research & applications*, New Orleans, Louisiana.

Yoon, D., & Narayanan, N. H. (2004). Mental imagery in problem solving: An eye tracking study. *Proceedings of the Third ACM Symposium on Eye Tracking Research & Applications*, Association for Computing Machinery, ACM Press pp. 77-83.