Vision Research 51 (2011) 1124–1128

Contents lists available at ScienceDirect

Vision Research

journal homepage: www.elsevier.com/locate/visres

The effect of semantic information on saccade trajectory deviations

Matthew D. Weaver [a,*], Johan Lauwereyns [b], Jan Theeuwes [c]

[a] Victoria University of Wellington, New Zealand
[b] Kyushu University, Japan
[c] Vrije Universiteit, Amsterdam, The Netherlands

ARTICLE INFO

Article history:
Received 16 November 2010
Received in revised form 3 March 2011
Available online 12 March 2011

Keywords:
Saccade control
Saccade trajectory deviations
Inhibition-of-return
Semantic information
Exogenous attention

ABSTRACT

In recent years, many studies have explored the conditions in which irrelevant visual distractors affect saccades trajectories. These previous studies mainly focused on the low-level stimulus characteristics and how they affect the magnitude of curvature. The present study explored the possible effect of high level semantic information on saccade curvature. Semantic saliency was manipulated by presenting irrelevant peripheral taboo versus neutral cue words in a spatial cuing paradigm that allowed for the measurement of trajectory deviations. Findings showed larger saccade trajectory deviations away from taboo (versus neutral) cue words when making a saccade towards another location. This indicates that due to their high semantic saliency, more inhibition was necessarily applied to taboo cue locations to effectively suppress their competing as saccade targets.

1. Introduction

There is an emerging research base using continuous movements as dynamic measures in order to understand higher-level cognitive processes (e.g., Spivey, 2007; for a review, see Song & Nakayama, 2009). The trajectory deviation of manual reaching movements in particular has been used to determine attentional focus (e.g., Howard & Tipper, 1997; Welsh & Elliot, 2005), the nature of language representations (Boulenger et al., 2006; Dale, Kehoe, & Spivey, 2007; Spivey, Grosjean, & Knoblich, 2005), and high level decision-making processes (McKinstry, Dale, & Spivey, 2008) in real-time. Deviations in saccade trajectory similarly represent a promising dynamic measure of cognitive processes.

Several recent studies have explored the specific stimulus features that cause saccades to curve towards or away from distractor stimuli (Godijn & Theeuwes, 2002b, 2004; Ludwig & Gilchrist, 2003; McPeek, Han, & Keller, 2003; McSorley, Haggard, & Walker, 2004; Mulckhuyse, Van der Stigchel, & Theeuwes, 2009; Theeuwes & Godijn, 2004; Van der Stigchel & Theeuwes, 2005, 2007; Walker, McSorley, & Haggard, 2006). The prevailing view is that distractors cause activation within the saccade map of the oculomotor system. Comparable to manual reaching movements, when neural activity within this saccade map is still relatively strong at the moment a saccade has to be made, saccades tend to curve towards the distractor stimulus. When the neural activity at the location of the distractor is inhibited, the eyes tend to move away from the distractor (Godijn & Theeuwes, 2002b; for an overview see Van der Stigchel, 2010; Van der Stigchel, Meeter, & Theeuwes, 2006). While structures such as the frontal eye field and lateral intraparietal area have also been implicated in the operation of saccade trajectories (e.g., McPeek, 2006; Schall & Hanes, 1993), most research attributes the deviation of saccade trajectories to competitive interactions of activity within the superior colliculus (SC), a lower-level structure that basically operates as a motor map (e.g., Aizawa & Wurtz, 1998; Hanes & Wurtz, 2001; McPeek et al., 2003; McSorley et al., 2004; Quaia, Optican, & Goldberg, 1998; Schall, 1991; Sparks & Hartwich-Young, 1989).

Given the low level neural structures at which these competing interactions have been indicated to take place, it may not be surprising that most studies have focused on how low level stimulus features affect the saccade trajectory. Contrary to previous studies, here we explore whether high level semantic information can have a similar effect on saccade trajectories. More specifically, we investigated whether linguistic content can modulate the amount of inhibition that is generated at these assumed-to-be low level neural structures.

Previous research has shown that semantic content can have an effect on various eye movement parameters. Several 'classic' studies (Antes, 1974; Buswell, 1935; Mackworth & Morandi, 1967; Yarbus, 1967) as well as more recent studies have explored the specific conditions of semantic information effects on eye movement behaviour (e.g., Cerf, Frady, & Koch, 2009; De Graef, Christiaens, & d'Ydewalle, 1990; Henderson, Weeks, & Hollingworth, 1999; Loftus & Mackworth, 1978; Weaver & Lauwereyns, 2011). This wealth of research has examined many aspects of eye movements and explored how they interact with semantic information.

* Corresponding author. Address: School of Psychology, Victoria University of Wellington, P.O. Box 600, Wellington 6006, New Zealand.
E-mail address: matt.weaver@vuw.ac.nz (M.D. Weaver).

0042-6989/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.visres.2011.03.005

Surprisingly, however, one specific aspect of eye movement behaviour, saccade trajectory deviations, is largely unexplored. This is possibly due to an assumption that inhibition at these low level structures buried deep in the brain, cannot be influenced by high level semantics.

To date, there has been one experiment that has demonstrated an effect of picture content, a semantic property, on saccade trajectories (Experiment 3 of Nummenmaa, Hyönä, & Calvo, 2009). Specifically, this experiment examined whether complex scene representations affect the saccade trajectory. Participants had to execute vertical saccades while paired emotional and neutral scenes were presented in the periphery (e.g., an emotional scene to the left and a neutral scene to the right). Results showed that saccade trajectories deviated away from the visual field in which the emotional scene was presented, especially when there was a delay between the presentation of the scenes and the imperative stimulus. Nummenmaa et al. (2009) explained these results by suggesting emotional stimuli, even when they are completely irrelevant for the task, have the ability to attract attention outside foveal vision. The stronger deviation away may imply that more attention is allocated to the emotional picture than to the neutral picture presented at the other side. According to Nummenmaa et al. (2009), the semantic content of a picture (i.e., whether it is an emotional or neutral stimulus) may automatically alter the 'semantic' salience weight of a stimulus.

Previous research has shown the 'physical' salience of a distractor affects the size of trajectory deviations (e.g., Godijn & Theeuwes, 2004; Tipper, Howard, & Houghton, 2000; Tipper, Howard, & Paul, 2001). For example, in Godijn and Theeuwes (2004) observers had to make a vertical saccade and an onset or a colour singleton cue was presented in the periphery as an imperative stimulus. The results indicated that an abrupt onset cue (which is more salient than a colour cue, see Theeuwes, 1994) generated a stronger saccade curvature away than a colour singleton. Godijn and Theeuwes (2004) argued that the more salient the object at a particular location, the more attentional resources will be allocated to that location, creating more location-specific activation in the saccade map. When a saccade is not to be executed to the location having this high activation, more inhibition needs to be applied to the location that is most active. Consistent with the competitive integration model (Godijn & Theeuwes, 2002a, 2002b), when a saccade needs to be executed, the eyes will start moving in the direction of the mean vector of activity within the saccade map. When a specific location is inhibited, it results in a sub-baseline level of activation at this location. This sub-baseline level of activity is reflected in a saccade trajectory deviation away from the inhibited location. Importantly, because more location-specific oculomotor activity requires more inhibition for successful suppression, the degree of saccade deviation can be considered an important measure of the amount of attentional resources spatially allocated to a location (Theeuwes & Van der Stigchel, 2009; Van der Stigchel & Theeuwes, 2007). Evidence that deviations away are related to inhibition comes from a study by Aizawa and Wurtz (1998) who showed that after the deactivating of a location by an injection of a GABA agonist (muscimol) into the equivalent region in the SC, the eyes of a monkey deviated away from this location.

The present study examines whether semantic content of written words affects saccadic deviations. We used a variation of the spatial cuing paradigm of Godijn and Theeuwes (2004). Instead of using stimuli with different physical salience (onset versus colour singleton) we used words with high or low semantic salience. Semantic saliency was manipulated by comparing taboo versus neutral cue words. Taboo words are emotional words defined by their high arousal (versus valence, Anderson, 2005; Janschewitz, 2008) and have strong social and emotional salience. In our task, a taboo or neutral word was presented as a brief irrelevant peripheral cue either to the left or right of fixation. Following a variable SOA, a central arrow signalled a speeded saccade to be made to either the cued or uncued locations, left or right of fixation, or to a location straight above or below fixation (to provide a measure of saccade deviation in response to left versus right cues). Participants were instructed to ignore the cues which were unpredictive of saccade target location.

The semantic value of exogenous cues has been shown to influence covert attention (e.g., Fox, Russo, Bowels, & Dutton, 2001; Stolz, 1996) and previous research has shown taboo words to receive preferential attentional processing over less arousing neutral words (Anderson, 2005; Mathewson, Arnell, & Mansfield, 2008; and see Bertels, Kolinsky, & Morais, 2010, for evidence in spatial orienting of auditory attention). Accordingly, we expected taboo (versus neutral) words to receive more covert attentional allocation, thus requiring greater inhibition which should result in a larger saccade deviation away from the location.

2. Method

2.1. Participants

Nineteen students of the Vrije Universiteit completed the experiment for course credit or payment. Participation was voluntary and informed consent was given. The native language of all participants was Dutch, all had normal or corrected-to-normal vision and were naïve to the specific experimental hypotheses. Data from four participants were excluded from primary analyses; three due to excessive errors (at least half of trials removed from conditions involved in saccade deviation analysis, cf. criteria below), and one due to reported dyslexia. The remaining 15 participants (11 female) were all right-handed with a mean age of 20.6 years.

2.2. Apparatus, stimuli and procedure

The experiment was programmed using SR Research Experiment Builder (version 1.6.1). Participants were seated approximately 70 cm from a 21 in. display. Eye movements were tracked using the EyeLink® 1000 (SR Research, Ltd.). Cues were Dutch words, consisting of eight neutral non-taboo words (taken from Hermans & De Houwer, 1994) and eight taboo words (taken from Tibboel, De Houwer, & Crombez, 2007), and are presented in the Appendix A. Taboo words were a mixture of positive and negative sexually vulgar terms rated highly on arousal and 'taboo-ness' measures. Both categories were matched for word length, written frequency, and affective valence (although variances differed for valence).

See Fig. 1 for illustration of the task sequence. Trials consisted of a central fixation cross ($0.5° \times 0.5°$) and three empty boxes ($1.5° \times 3.9°$) all in either the upper or lower hemifield, presented on a white background. One box was positioned 5.5° straight above or below fixation (middle box), and one on either side of fixation, halfway between the middle box and central fixation (left and right boxes). Trials began by fixating the central cross for 500 ms. A cue word (lowercase 28-point black Arial font, four to six letters subtending $1.0° \times 1.5$–$3.6°$) then appeared for 100 ms inside either the left or right box. After a variable SOA of 100, 400, or 800 ms, a central arrow ($1.6° \times 0.5°$) was used as a saccade cue to any one of the three boxes. Participants were instructed to ignore the cue, maintain fixation until the arrow appeared, and then make a speeded saccade to the indicated box. A warning tone sounded if gaze strayed further than 1.5° from central fixation before the arrow appeared. Eight experimental blocks of 144 trials followed 20 practice trials, giving 1152 analyzable trials. Trials were self-paced.

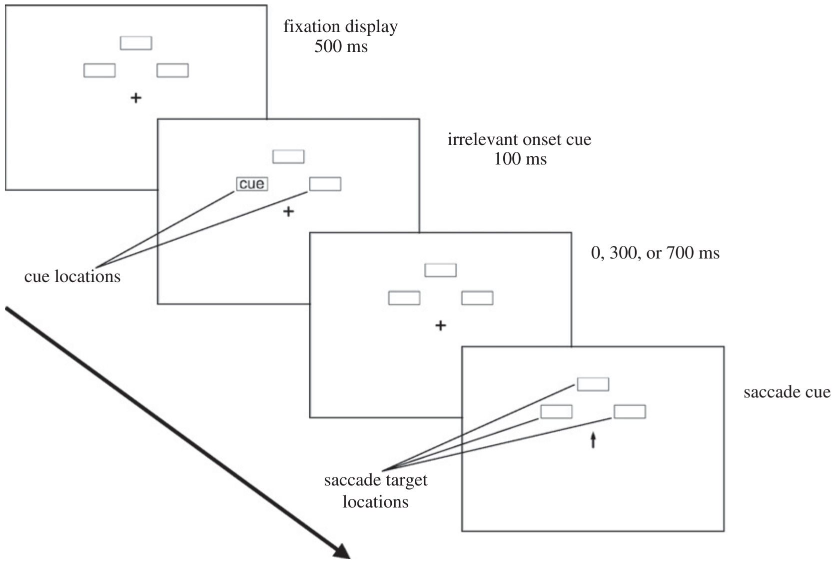

Fig. 1. Task sequence. After the central cross was fixated for 500 ms, a word cue was presented for 100 ms inside either the left or right box. Following a variable delay of 0, 300, or 700 ms following cue offset, a central arrow (saccade cue) pointed to one of the three boxes. Participants executed a speeded saccade to the box indicated by the arrow.

2.3. Design

The primary dependent variable was trajectory deviation of correct saccades to the middle target box only. Within-participants factors included three SOA latencies (100, 400 and 800 ms) × two semantic cue values (taboo and neutral) × three saccade target locations (left, right and middle boxes). Cues appeared in either the left or right box with equal probability. Similarly, saccades were equally likely to be indicated to any of the three target locations.

Trials were presented in a pseudorandom order, constrained by having no more than five of the same cue validity or semantic value conditions (and three of any specific cue therein), or three SOA conditions presented successively. Two visual hemifield presentations (upper and lower) × two trial orders (one reversed) were counterbalanced across participants.

3. Results

A saccade was defined when eye movement velocity surpassed 30°/s or acceleration surpassed 8000°/s^2. Trials were removed from subsequent analyses if fixation was not maintained until the central arrow appeared, if saccades were initiated before 100 ms or after 600 ms, were small (<2°), or contained an eyeblink. Saccades were defined as correct if the starting point was within 1.5° of central fixation, and ending within an angular deviation of 25°, and a distance of 2°, from the target centre. Using these criteria, 16.7% of trials were excluded from trajectory deviation analyses.

Saccade trajectory deviations were measured only for correct saccades to the middle target. They were determined by calculating the mean of angular deviations between a straight line from saccade starting point to the centre of the target box and straight lines from saccade starting point to each 1-ms sample of the actual saccade path (see Van der Stigchel et al., 2006, for an overview of saccade deviation analysis). Positive and negative deviations refer to saccade trajectory deviations to the right and left of the saccade target respectively.

Cue influence on saccade trajectory deviations was determined by examining the difference in mean deviation between trials where the cue was presented to the left versus the right-side (i.e., subtracting the mean deviation in response to right cues from that in response to left cues). For example, if trajectories deviated 3° to the right in response to a left-side cue, and deviated 2° to the left (and thus assigned a value of −2°) in response to a right-side cue, the difference value would be 5°, that is, 3° − [−2]°. *Positive* deviation difference values would thus indicate an overall deviation *away* from the cued location. Fig. 2 presents an illustration of mean saccade trajectory deviation across participants as a function of semantic cue value, separately for both left and right cues, while Fig. 3 shows means and standard errors for saccade tra-

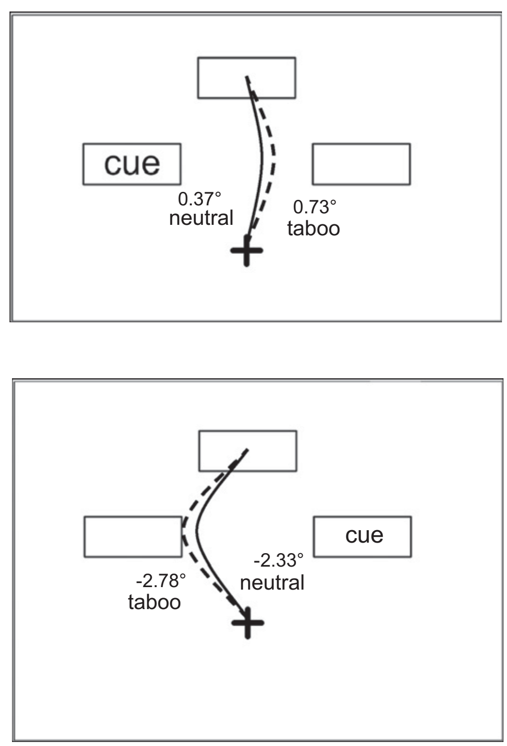

Fig. 2. An illustration of the mean saccade trajectory deviation (degrees of visual angle) across participants as a function of semantic cue value, in response to left cues (top panel) and right cues (bottom panel). Positive and negative deviations refer to saccade trajectory deviations to the right and left of the saccade target respectively. Note figure not drawn to scale.

jectory deviation *differences* as a function of SOA and semantic cue value. The effect of semantic cue value on saccade trajectory deviations was determined by submitting the deviation difference to a two-way repeated measures analysis of variance (ANOVA), using SOA and semantic cue value as within-participant factors.

A main effect of SOA ($F(2, 28) = 15.73$, MSE = 6.62, $p < .001$) was characterised by trajectory deviation differences which reduced as SOA increased. A significant main effect of semantic value was revealed, $F(1, 14) = 5.39$, MSE = 2.45, $p < .05$, where saccade trajectories deviated further away from taboo ($M = 3.48°$) compared to neutral cues ($M = 2.71°$). An interaction between SOA and semantic cue value failed to approach significance ($F < 1.9$). Post-hoc analyses revealed saccade deviation differences at 100 ms SOAs ($M = 4.98°$) were significantly larger than at 400 ms SOAs ($M = 3.05°$), SE = 0.60, $p < .05$, which, in turn, were significantly larger when compared to 800 ms SOAs ($M = 1.26°$), SE = 0.66, $p < .05$. Furthermore, the saccade deviation differences at SOAs of 100 ms ($t(14) = 11.68$, $p < .001$), and 400 ms ($t(14) = 6.00$, $p < .001$), were significantly different from zero, indicating saccades deviated away from the cued location, whereas at 800 ms they were not ($t < 1.7$). Planned contrasts using two-way paired *t*-tests revealed that deviation differences were significantly larger for taboo versus neutral cues at the 800 ms SOA, $t(14) = -2.55$, $SE = 0.84$, $p < .05$, but not at SOAs of 400 ms ($t < -0.5$) or 100 ms ($t < 0.3$).

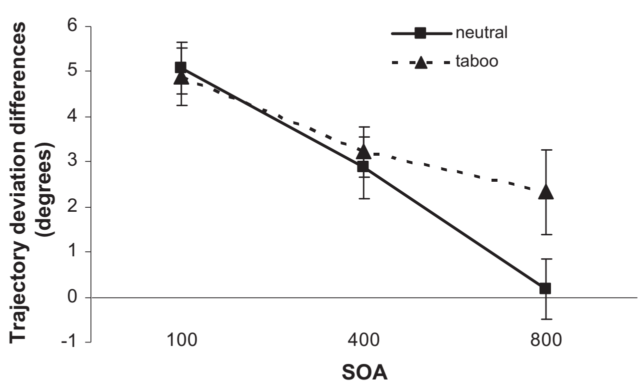

Fig. 3. Saccade trajectory deviation differences and standard errors for taboo and neutral cue trials as a function of stimulus onset asynchrony (SOA; ms).

4. Discussion

The present study is the first to demonstrate that linguistic content of words has an effect on saccade trajectory deviations. Our study shows that at the longer SOA, the eyes curve away stronger from taboo words than from neutral words. Notably, these words were completely irrelevant for the task (both in their content and location) and as such this effect is completely exogenous. Even though participants were not required to process the content of the words, they did so anyway, as evidenced by the effect of semantic content on saccade deviations.

Our findings indicate that the semantic content of the irrelevant words presented at 5.5° in the periphery is processed up to a level at which the meaning becomes available. Because the word cue is presented with abrupt onset we assume that attention is initially exogenously captured towards the location of the word cue (Theeuwes, 1991). Following the initial capture, the content of the word is processed. When a saccade has to be generated immediately following the presentation of the irrelevant word cue (i.e., at SOA 100 ms) there is a strong deviation away from the distractor word which is not yet influenced by the linguistic content. This initial saccade deviation away is completely driven by the exogenous bottom-up activation caused by the abrupt onset (Theeuwes, Kramer, Hahn, & Irwin, 1998). However at the later SOA (i.e., at 800 ms) there is a clear effect of the semantic content on saccade deviation: the neutral word no longer causes a saccade deviation while at the same time the taboo words still cause a significant deviation away.

The results indicate that at SOA 800 ms the pure exogenous effect of the cue on saccade deviation is no longer present, a result consistent with Godijn and Theeuwes (2004). In line with the competitive integration model of Godijn and Theeuwes (2002b), this implies that the exogenous activation within the saccade map caused by the presentation of the cue has died out by the time a saccade is required. However, when the word has a taboo meaning, there is still activation within the saccade map which requires inhibition causing the eyes to curve away from the taboo word. We assume that it is the semantic content of the taboo word that holds attention longer at the distractor location. Consistent with Nummenmaa et al.'s (2009) conclusions regarding emotional scenes, we conclude that taboo words may have a higher semantic salience causing attention to 'hold on' longer, such that it affects saccade trajectories relativity late in time.

The holding of attention at the taboo word is comparable to the holding of attention that is often reported with emotional pictorial stimuli such as spiders or angry faces. For example, Fox, Russo, and Dutton (2002) showed that observers had trouble disengaging attention from angry faces (see also Georgiou et al., 2005). Recently, Belopolsky, Devue, and Theeuwes (2011) showed that observers were slower to make a saccade away from the central fixation point when an angry (versus a neutral) face was presented at fixation.

Beyond the oculomotor system, the present findings can be more broadly compared to research of linguistic influences on manual reaching movements. For example, Finkbeiner, Song, Nakayama, and Caramazza (2008) demonstrated greater deviations of reach trajectories in response to colour distractor locations which had been made more salient by a masked semantic word prime. Our study extends the emerging wealth of research utilising continuous movements to explore higher-level cognitive processes, by showing that, like manual reaching movements, saccade trajectories also demonstrate considerable utility as a continuous and dynamic measure to investigate the role of higher-order information on lower-level structures.

In summary, the present study shows that semantic linguistic content affects saccade trajectory deviations. We assume that this effect of high level semantics on the relatively low level eye movement structures is gated by attentional processes.

Acknowledgments

We thank Sebastiaan Mathôt for his assistance with data analyses. This research was made possible thanks to a New Zealand Tertiary Education Commission Top Achiever Doctoral Scholarship and a JL Stewart Postgraduate Scholarship to M.D.W.

Appendix A. Taboo and neutral words (in Dutch) which were used as cues

Taboo words
Teef
Hoer
Orgie
Incest
Piemel

(*continued on next page*)

Appendix A. (*continued*)

Neuken
Beffen
Pijpen

Neutral words
Gist
Klei
Stoep
Cirkel
Schaar
Takken
Parade
Streep

References

Aizawa, H., & Wurtz, R. H. (1998). Reversible inactivation of monkey superior colliculus: I. Curvature of saccadic trajectory. *Journal of Neurophysiology, 79*, 2082–2096.

Anderson, A. K. (2005). Affective influences on the attentional dynamics supporting awareness. *Journal of Experimental Psychology: General, 134*, 258–281.

Antes, J. R. (1974). The time course of picture viewing. *Journal of Experimental Psychology, 103*, 62–70.

Belopolsky, A. V., Devue, C., & Theeuwes, J. (2011). Angry faces hold the eyes. *Visual Cognition, 19*, 17–36.

Bertels, J., Kolinsky, R., & Morais, J. (2010). Emotional valence of spoken words influences the spatial orienting of attention. *Acta Psychologica (Amsterdam), 134*, 264–278.

Boulenger, V., Roy, A. C., Paulignan, Y., Deprez, V., Jeannerod, M., & Nazir, T. A. (2006). Cross-talk between language processes and overt motor behaviour in the first 200 msec of processing. *Journal of Cognitive Neuroscience, 18*, 1607–1615.

Buswell, G. T. (1935). *How people look at pictures: A study of the psychology of perception in art*. Chicago, IL: University of Chicago Press.

Cerf, M., Frady, E. P., & Koch, C. (2009). Faces and text attract gaze independent of the task: Experimental data and computer model. *Journal of Vision, 9*, 1–15.

Dale, R., Kehoe, C., & Spivey, M. J. (2007). Graded motor responses in the time course of categorising atypical exemplars. *Memory and Cognition, 35*, 15–28.

De Graef, P., Christiaens, D., & d'Ydewalle, G. (1990). Perceptual effects of scene context on object identification. *Psychological Research, 52*, 317–329.

Finkbeiner, M., Song, J. H., Nakayama, K., & Caramazza, A. (2008). Engaging the motor system with masked orthographic primes: A kinematic analysis. *Visual Cognition, 16*, 11–22.

Fox, E., Russo, R., Bowels, R., & Dutton, K. (2001). Do threatening stimuli draw or hold visual attention in subclinical anxiety? *Journal of Experimental Psychology: General, 130*, 681–700.

Fox, E., Russo, R., & Dutton, K. (2002). Attentional bias for threat: Evidence for delayed disengagement from emotional faces. *Cognition Emotion, 16*, 355–379.

Georgiou, G., Bleakley, C., Hayward, J., Russo, R., Dutton, K., Eltiti, S., et al. (2005). Focusing on fear: Attentional disengagement from emotional faces. *Visual Cognition, 12*, 145–158.

Godijn, R., & Theeuwes, J. (2002a). Oculomotor capture and inhibition of return. *Psychological Research, 66*, 234–246.

Godijn, R., & Theeuwes, J. (2002b). Programming of endogenous and exogenous saccades: Evidence for a competitive integration model. *Journal of Experimental Psychology: Human Perception and Performance, 28*, 1039–1054.

Godijn, R., & Theeuwes, J. (2004). The relationship between inhibition of return and saccade trajectory deviations. *Journal of Experimental Psychology: Human Perception and Performance, 30*, 538–554.

Hanes, D. P., & Wurtz, R. H. (2001). Interaction of the frontal eye field and superior colliculus for saccade generation. *Journal of Neurophysiology, 85*, 804–815.

Henderson, J. M., Weeks, P. A., Jr., & Hollingworth, A. (1999). The effects of semantic consistency on eye movements during complex scene viewing. *Journal of Experimental Psychology: Human Perception and Performance, 25*, 210–228.

Hermans, D., & De Houwer, J. (1994). Affective and subjective familiarity ratings of 740 Dutch words. *Psychologica Belgica, 34*, 115–140.

Howard, L. A., & Tipper, S. P. (1997). Hand deviations away from visual cues: Indirect evidence for inhibition. *Experimental Brain Research, 113*, 144–152.

Janschewitz, K. (2008). Taboo, emotionally valenced, and emotionally neutral word norms. *Behaviour Research Methods, 40*, 1065–1074.

Loftus, G. R., & Mackworth, N. H. (1978). Cognitive determinants of fixation location during picture viewing. *Journal of Experimental Psychology: Human Perception and Performance, 4*, 565–572.

Ludwig, C. J. H., & Gilchrist, I. D. (2003). Target similarity affects saccade curvature away from irrelevant onsets. *Experimental Brain Research, 152*, 60–69.

Mackworth, N. H., & Morandi, A. J. (1967). The gaze selects informative details within pictures. *Perception and Psychophysics, 2*, 547–552.

Mathewson, K. J., Arnell, K. M., & Mansfield, C. A. (2008). Capturing and holding attention: The impact of emotional words in rapid serial visual presentation. *Memory and Cognition, 36*, 182–200.

McKinstry, C., Dale, R., & Spivey, M. J. (2008). Action dynamics reveal parallel competition in decision making. *Psychological Science, 19*, 22–24.

McPeek, R. M. (2006). Incomplete suppression of distractor-related activity in the frontal eye fields results in curved saccades. *Journal of Neurophysiology, 96*, 2699–2711.

McPeek, R. M., Han, J. H., & Keller, E. L. (2003). Competition between saccade goals in the superior colliculus produces saccade curvature. *Journal of Neurophysiology, 89*, 2577–2590.

McSorley, E., Haggard, P., & Walker, R. (2004). Distractor modulation of saccade trajectories: Spatial separation and symmetry effects. *Experimental Brain Research, 155*, 320–333.

Mulckhuyse, M., Van der Stigchel, S., & Theeuwes, J. (2009). Early and late modulation of saccade deviations by target distractor similarity. *Journal of Neurophysiology, 102*, 1451–1458.

Nummenmaa, L., Hyönä, J., & Calvo, M. G. (2009). Emotional scene content drives the saccade generation system reflexively. *Journal of Experimental Psychology: Human Perception and Performance, 35*, 305–323.

Quaia, C., Optican, L. M., & Goldberg, J. H. (1998). The maintenance of spatial accuracy by the perisaccadic remapping of visual receptive fields. *Neural Networks, 11*, 1229–1240.

Schall, J. D. (1991). Neuronal basis of saccadic eye movements. In A. G. Leventhal (Ed.). *Vision and visual dysfunction: The neural basis of visual function* (vol. 4, pp. 388–442). London: Macmillan Press.

Schall, J. D., & Hanes, D. P. (1993). Neural basis of saccade target selection in frontal eye field during visual search. *Nature, 366*, 467–469.

Song, J. H., & Nakayama, K. (2009). Hidden cognitive states revealed in choice reaching tasks. *Trends in Cognitive Sciences, 13*, 360–366.

Sparks, D. L., & Hartwich-Young, R. (1989). The deeper layers of the superior colliculus. In R. H. Wurtz & M. E. Goldberg (Eds.), *The neurobiology of saccadic eye movements* (pp. 213–255). Amsterdam: Elsevier Science Publishers.

Spivey, M. J. (2007). *The continuity of mind*. Oxford, NY: Oxford University Press.

Spivey, M. J., Grosjean, M., & Knoblich, G. (2005). Continuous attraction toward phonological competitors. *Proceedings of the National Academy of Sciences of The United States of America, 102*, 10393–10398.

Stolz, J. A. (1996). Exogenous orienting does not reflect an encapsulated set of processes. *Journal of Experimental Psychology: Human Perception and Performance, 22*, 187–201.

Theeuwes, J. (1991). Cross-dimensional perceptual selectivity. *Perception and Psychophysics, 50*, 184–193.

Theeuwes, J. (1994). Bottom-up capture and attentional set: Selective search for colour and visual abrupt onsets. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 799–806.

Theeuwes, J., & Godijn, R. (2004). Inhibition-of-return and oculomotor interference. *Vision Research, 44*, 1485–1492.

Theeuwes, J., Kramer, A. F., Hahn, S., & Irwin, D. E. (1998). Our eyes do not always go where we want them to go: Capture of the eyes by new objects. *Psychological Science, 9*, 379–385.

Theeuwes, J., & Van der Stigchel, S. (2009). Saccade trajectory deviations and inhibition-of-return: Measuring the amount of attentional processing. *Vision Research, 49*, 1307–1315.

Tibboel, H., De Houwer, J., & Crombez, G. (2007). *The emotional modulation of the attentional blink: Effects of taboo and non-taboo arousing stimuli in a dual and single task paradigm*. Unpublished manuscript. Department of Experimental Clinical and Health Psychology, Ghent University.

Tipper, S. P., Howard, L. A., & Houghton, G. (2000). Behavioral consequences of selection from population codes. In S. Monsell & J. Driver (Eds.), *Control of cognitive processes: Attention and performance XVIII* (pp. 223–245). Cambridge, MA: MIT Press.

Tipper, S. P., Howard, L. A., & Paul, M. A. (2001). Reaching affects saccade trajectories. *Experimental Brain Research, 136*, 241–249.

Van der Stigchel, S. (2010). Recent advances in the study of saccade trajectory deviations. *Vision Research, 50*, 1619–1627.

Van der Stigchel, S., Meeter, M., & Theeuwes, J. (2006). Eye movement trajectories and what they tell us. *Neuroscience and Biobehavioral Reviews, 30*, 666–679.

Van der Stigchel, S., & Theeuwes, J. (2005). Relation between saccade trajectories and spatial distractor locations. *Cognitive Brain Research, 25*, 579–582.

Van der Stigchel, S., & Theeuwes, J. (2007). The relationship between covert and overt attention in endogenous cueing. *Perception and Psychophysics, 69*, 719–731.

Walker, R., McSorley, E., & Haggard, P. (2006). The control of saccade trajectories: Direction of curvature depends upon prior knowledge of target location and saccade latency. *Perception and Psychophysics, 68*, 129–138.

Weaver, M. D., & Lauwereyns, J. (2011). Attentional capture and hold: The oculomotor correlates of the change detection advantage for faces. *Psychological Research, 75*, 10–23.

Welsh, T. N., & Elliot, D. (2005). The effects of response priming on the planning and execution of goal-directed movements in the presence of a distracting stimulus. *Acta Psychologica (Amsterdam), 119*, 123–142.

Yarbus, A. L. (1967). *Eye movements and vision*. New York, NY: Plenum.