Commentary

Microsaccades Are an Index of Covert Attention

Commentary on Horowitz, Fine, Fencsik, Yurgenson, and Wolfe (2007)

Jochen Laubrock, Ralf Engbert, Martin Rolfs, and Reinhold Kliegl

University of Potsdam, Potsdam, Germany

Horowitz, Fine, Fencsik, Yurgenson, and Wolfe (2007, this issue) investigated the relation between microsaccade congruency (MC, the congruency between the direction of the microsaccade and the location of the target) and reaction time (RT) in a spatial cuing paradigm and concluded that "fixational eye movements are not an index of covert attention." We show that microsaccade direction is a reliable on-line measure of attention that potentially indexes effects beyond those reflected in RT.

In Posner's (1980) task, the spatial cue is the only objective marker of attention. Therefore, a cue-validity effect is a necessary property of any index of attention. Such an effect has been established for both RT (i.e., the RT cue-validity effect) and microsaccades (i.e., the MC effect; Engbert & Kliegl, 2003; Galfano, Betta, & Turatto, 2004; Hafed & Clark, 2002; Rolfs, Engbert, & Kliegl, 2004, 2005). Directional biases in microsaccades are not just an oculomotor reflex: If a task requires shifts in spatial attention, directional biases are elicited by circular color cues; if the task does not require attentional shifts, directional biases are not elicited even by arrow cues (Engbert & Kliegl, 2003; Laubrock, Engbert, & Kliegl, 2005).

Horowitz et al. compared (a) RTs from validly cued trials with microsaccades oriented away from the target and (b) RTs from invalidly cued trials with target-congruent microsaccades, arguing that if microsaccades are useful as measures of attention, then RTs in the latter trials should be faster than RTs in the former trials. Here we show that this result can be obtained even if microsaccades and attention are substantially correlated. Let us assume that microsaccade direction is a valid but imperfect measure of attention and that the probability of a microsaccade being oriented toward the location where attention is deployed, p(microsaccade direction|attention), is .75. Pitting MC against cue validity assumes that attention does not always follow the cue (e.g., because subjects match probabilities; Brunswik, 1939). Let us therefore further assume that the probability that attention does follow the cue, p(attention|cue), is .8.

Given these assumptions, attention and microsaccades will both be directed opposite the target on 15% of the valid-cue trials (.2 × .75 of all valid-cue trials), but attention will follow the cue toward the target despite a target-incongruent microsaccade on 20% of the valid-cue trials (.8 × .25). Similarly, invalidly cued trials with target-congruent microsaccades will be a mixture containing "attentional error" trials on which microsaccades follow attention toward the target (.2 × .75 = .15 of all invalid-cue trials) and trials on which microsaccades are directed toward the target but attention is not (.8 × .25 = .20). Hence, the cue-validity effect on RT (i.e., benefits and costs of valid and invalid cues, respectively) will dominate the MC effect in the conditions that Horowitz et al. compared. Even if microsaccades are well correlated with attention,[1] this selection of conditions imposes prior odds of 4:1 against finding a benefit of MC in RT. Therefore, showing that RT is slower for trials with valid cues and target-incongruent microsaccades than for trials with invalid cues and target-congruent microsaccades is not evidence against the direction of the microsaccade reflecting covert attention, but a consequence of the cue controlling attention.

EFFECTS OF SPATIAL ATTENTION ON MICROSACCADES

We propose that both microsaccade direction and RT are reliable indicators of covert attention. To this end, we investigated

[1]We chose p(microsaccade direction|attention) = .75 for illustrative purposes here. However, this value appears not to be too far off: Our data (see Fig. 1b) suggest that the true value is somewhere between .69 and .82, depending on whether we assume perfect attention shifts or probability matching, respectively.

Address correspondence to Jochen Laubrock, Institut für Psychologie, Universität Potsdam, Karl-Liebknecht-Str. 24/25, DE-14476 Potsdam, Germany, e-mail: laubrock@uni-potsdam.de.

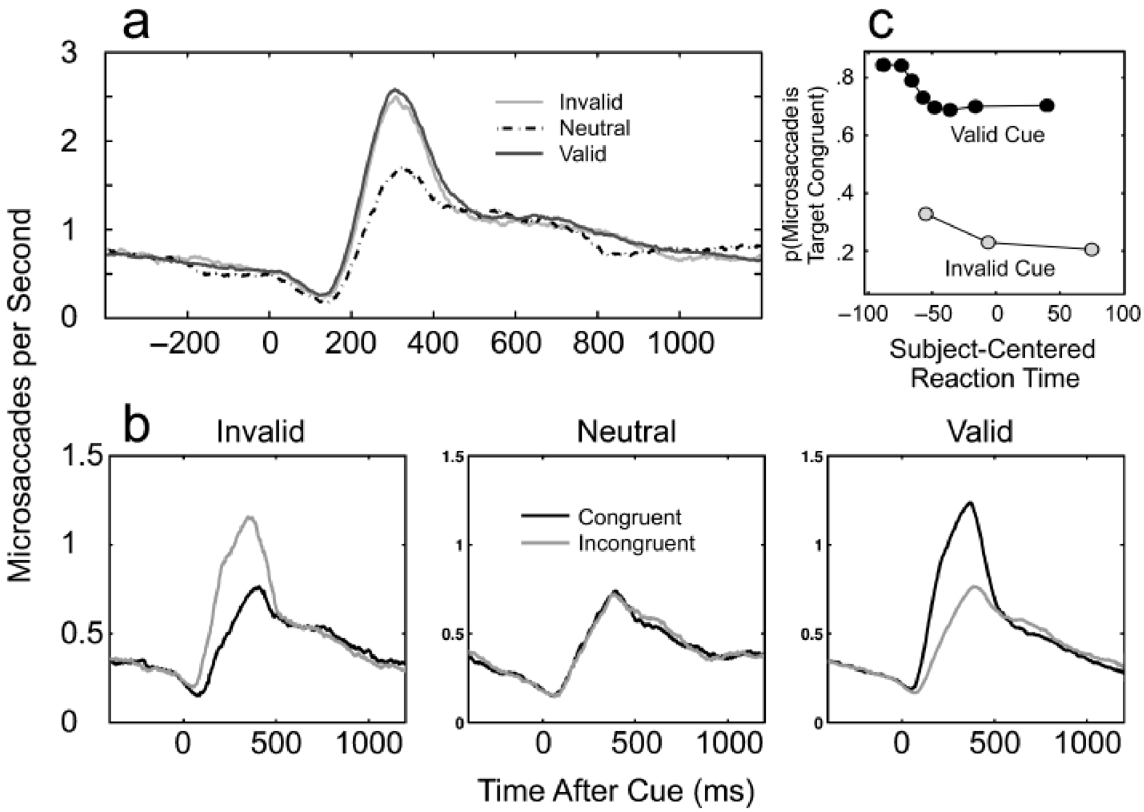

Fig. 1. Results: (a) microsaccade frequency (unweighted moving-average filter, width = 150 ms) as a function of time and cue validity, averaged across the saccadic and manual tasks; (b) microsaccade frequency as a function of time, microsaccade-target congruency, and cue validity (separate graphs for invalid, neutral, and valid cues); and (c) probability of target-congruent microsaccades in the saccadic task as a function of cue validity and reaction time (centered around individual subjects' means). Reaction times were binned for visual presentation in this figure but were used as a continuous predictor in the generalized linear mixed models.

the contribution of MC to the RT cue-validity effect and tested whether RT is sufficient to explain the MC effect. That is, we examined whether MC uncovers aspects of covert attention that are not already contained in RT and vice versa.

Method

In a Posner cuing task, each of 6 subjects contributed 312 trials (156 each from a saccadic localization task and a manual localization task; proportion of valid:invalid:neutral cues = 4:1:1) in each of six sessions. The temporal and most spatial aspects of the tasks were the same as in the experiment by Horowitz et al. Our analyses are based on 90% of the trials; we excluded trials containing blinks and trials with incorrect or excessively slow responses. The MC analyses are based on 3,406 microsaccades occurring 150 to 500 ms after cue onset on validly or invalidly cued trials.

We analyzed effects on RT with linear mixed-effects models and effects on MC with generalized linear mixed models (with a logit link), using the lme4 package (Bates & Sarkar, 2006) in the R environment (R Development Core Team, 2006). In both models, subjects were specified as a random factor to control for their associated intraclass correlation (i.e., random intercept models—Pinheiro & Bates, 2000; for an application, see Oberauer & Kliegl, 2006); these kinds of models also tolerate the necessarily unequal number of validly and invalidly cued responses.

Results

Figure 1a shows the microsaccade rate as a function of time from the cue. The change in microsaccade frequency over time qualitatively replicates our previous result (Engbert & Kliegl, 2003); there was a temporal correlation between the cue and the microsaccade rate. Figure 1b shows that there was also a spatial correlation, as most microsaccades in a critical interval pointed toward the later target on valid-cue trials, and away from the target on invalid-cue trials.

Does MC have an effect on RT independent of the effects of spatial cue and task? In an lme model, MC (b = 6 ms, SE = 1.7 ms), cue validity (b = 81 ms, SE = 2 ms), task (b = 95 ms, SE = 2 ms), and the interaction of cue validity and task (a larger cue-validity effect in the manual task than in the saccadic task; b = 72 ms, SE = 4 ms) were significant (all $ps \leq .001$). Removing MC or cue validity from the model significantly decreased the goodness of fit, as indicated by likelihood ratio tests—effect of

MC: $\chi^2(1) = 10.9$, $p = .0009$; effect of cue validity: $\chi^2(2) = 1{,}442$, $p < 2.2e^{-16}$. The standard deviation of average RTs across subjects was estimated as 25 ms, and the standard deviation of residuals was estimated as 42 ms, yielding a substantial intraclass correlation of .26. Although the MC effect was 13.5 times smaller than the cue-validity effect (and less consistent across subjects), there was a reliable effect of MC on RT.

Can the later-occurring RT account for the earlier MC effect? In a generalized linear mixed model with binary MC as the dependent variable, task ($b = 1.9$, $SE = 0.3$, $z = 5.4$, $p < .001$) and the task-by-cue-validity interaction ($b = 4.0$, $SE = 0.7$, $z = 5.6$, $p < .001$) were significant; the cue-validity effect was larger in the saccadic task ($.75 - .25 = .50$) than in the manual task ($.68 - .33 = .35$). Linear and quadratic components of RT (centered separately for each subject), specified as nested within each of the four design cells,[2] were significant for all cells except for the combination of invalid cues in the manual task; the probability of a target-congruent microsaccade always decreased as reaction time increased (Fig. 1c depicts this relationship for validly cued and invalidly cued trials in the saccadic task, using a quantile representation of RT), but cue validity had a larger effect. Removing RT components or cue validity significantly decreased the goodness of fit, as indicated by likelihood ratio tests—effect of cue validity: $\chi^2(2) = 220.3$, $p < 2.2e^{-16}$; effect of RT: $\chi^2(6) = 75.6$, $p < 2.9e^{-14}$. In summary, MC indicates effects of covert attention induced by spatial cues, and it carries some information that is not contained in subsequent RT.

CONCLUSION

Microsaccade direction is an implicit but reliable indicator of spatial attention. Both RT and microsaccade direction are more directly related to the cue than to each other, but microsaccades also carry on-line information about the time course of attention (e.g., Betta & Turatto, 2006). They represent attentional dynamics, in addition to attention-unrelated processes of fixation control (Engbert & Kliegl, 2004) and enhancement of retinal image slip (Engbert & Mergenthaler, 2006). Their measurement contributes to research on oculomotor control, visual perception, and, last but not least, covert attention.

Acknowledgments—This work was supported by Deutsche Forschungsgemeinschaft (DFG, KL955/3). We thank James Cutting, Todd Horowitz, Michele Nathan, and an anonymous reviewer for helpful comments.

[2]The neutral-cue conditions were not included in this analysis because there is little incentive for observers to spatially shift attention to a random location on neutral trials, as their performance, on average, will not benefit.

REFERENCES

Bates, D., & Sarkar, D. (2006). lme4: Linear mixed-effect models using S4 classes (R package Version 0.995-2) [Computer software]. Retrieved February 2006 from http://cran.r-project.org/src/contrib/Descriptions/lme4.html

Betta, E., & Turatto, M. (2006). Are you ready? I can tell by looking at your microsaccades. *NeuroReport*, *17*, 1001–1004.

Brunswik, E. (1939). Probability as a determiner of rat behavior. *Journal of Experimental Psychology*, *25*, 175–197.

Engbert, R., & Kliegl, R. (2003). Microsaccades uncover the orientation of covert attention. *Vision Research*, *43*, 1035–1045.

Engbert, R., & Kliegl, R. (2004). Microsaccades keep the eyes' balance during fixation. *Psychological Science*, *15*, 431–436.

Engbert, R., & Mergenthaler, K. (2006). Microsaccades are triggered by low retinal image slip. *Proceedings of the National Academy of Sciences, USA*, *103*, 7192–7197.

Galfano, G., Betta, E., & Turatto, M. (2004). Inhibition of return in microsaccades. *Experimental Brain Research*, *159*, 400–404.

Hafed, Z.M., & Clark, J.J. (2002). Microsaccades as an overt measure of covert attention shifts. *Vision Research*, *42*, 2533–2545.

Horowitz, T.S., Fine, E.M., Fencsik, D.E., Yurgenson, S., & Wolfe, J.M. (2007). Fixational eye movements are not an index of covert attention. *Psychological Science*, *18*, 356–363.

Laubrock, J., Engbert, R., & Kliegl, R. (2005). Microsaccade dynamics during covert attention. *Vision Research*, *45*, 721–730.

Oberauer, K., & Kliegl, R. (2006). A formal model of capacity limits in working memory. *Journal of Memory and Language*, *55*, 601–626.

Pinheiro, J., & Bates, D. (2000). *Mixed-effects models in S and S-PLUS*. New York: Springer.

Posner, M.I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, *32*, 3–25.

R Development Core Team. (2006). R: A language and environment for statistical computing (Version 2.3.1) [Computer software]. Vienna: R Foundation for Statistical Computing.

Rolfs, M., Engbert, R., & Kliegl, R. (2004). Microsaccade orientation supports attentional enhancement opposite a peripheral cue: Commentary on Tse, Sheinberg, and Logothetis (2003). *Psychological Science*, *15*, 705–707.

Rolfs, M., Engbert, R., & Kliegl, R. (2005). Crossmodal coupling of oculomotor control and spatial attention in vision and audition. *Experimental Brain Research*, *166*, 427–439.

(Received 7/31/06; Revision accepted 9/15/06; Final materials received 10/2/06)