Contemporary developments inspired by the research of Charles W. Eriksen

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The papers in this special issue document significant progress relevant to the research of Charles W. Eriksen. Erik clarified fundamental issues concerning the selective nature of human perception and awareness, pioneered methods for investigating those issues, and discovered basic aspects of perceptual selection. The present papers attest to the continuing impact of Erik's research.

Erik enabled us to see farther, and he illuminated paths for continued discovery. The large literature encompassed by the following papers substantially update theory, methods, evidence, and unsolved problems pertinent to basic themes in Erik's research. We hope the contributions to this special issue will stimulate further progress. That certainly would be Erik's wish as well.

The order of papers roughly represents a chronology of themes in Erik's research. More information about his research career, his scientific interests and methods, and Erik as a compelling character may be found in several biographical accounts: Fournier et al. (2019); Kramer et al. (1994); and Lappin et al. (2018). An edited book of research articles inspired by his research is also useful: Kramer et al. (1996).

To begin, Randolph Blake recounts the influence of "Eriksen's seminal essay on discrimination, performance, and learning without awareness." His review reminds us that Erik's early work was motivated by questions about *consciousness* and how it should be investigated. Blake connects Erik's work to contemporary research on conscious vs unconscious perceptual processes. A growing part of this contemporary research comes from cognitive neuroscience. Maier and Tsuchiya also review a related part of the cognitive

neuroscience literature that suggests a functional distinction between *neural mechanisms for attention and consciousness*. Questions about attention and consciousness underlie most of the papers in this issue.

Another major focus of Erik's research, reflected in most papers in this issue, involved the *temporal processes* of vision. Erik was skeptical of the once-popular idea that visual masking constitutes an interruption of perceptual processing. Many of his experiments in the 1960s tested a simpler alternative hypothesis that vision integrates visual images over time. Two papers by Eriksen and Collins (1967, 1968) were classic demonstrations of such *temporal integration*. A substantially expanded conception of *spatiotemporal integration* is now provided by Norman, Dukes, Shapiro, Sanders, and Elder, who demonstrate that spatially separate images of boundary contours of solid objects rotating in depth can be visually integrated to perceive *3D shapes and depths* of solid objects. They did this by using "anorthoscopic" displays, where only separate object parts are simultaneously visible through slits in an occluder.

The next four papers address processes revealed by studies of *visual search*—extending Erik's many studies of visual search beginning in the 1950s. Westerberg and Schall review behavioral and neurophysiological evidence about "Neural mechanisms of *priming* in visual search." The authors offer three rival hypotheses about these neural mechanisms—a bottom-up mechanism, a top-down mechanism, and a selection switching process. These hypotheses identify issues for future investigation. Gibson, Pauszek, Trost, and Wenger report results of a novel study of *probabilistic cues* for locating search targets. Their results emphasize the importance of information theory for understanding visual *spatial uncertainty*. A complementary role of *statistical learning* in visual search is examined by Ivanov and Theeuwes, who found that statistical information suppresses interference from response-incongruent distractors. Proctor and Healy summarize a large set of experiments to clarify the influence of spatial information for visual target selection and for selection and control of responses. They

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conclude that spatial information processing is functionally distinct for *visual target selection vs response control*.

Not surprisingly, many contributions to this issue focus on phenomena revealed by the *Eriksen flanker paradigm*. One set of issues concerns the *spatial structure of image information* that facilitates or interferes with target discriminations. A series of experiments by Moore, He, Zheng, and Mordkoff tested rival hypotheses for the effects of target-flanker similarity, based on “group selection” vs “image segmentation.” Multiple results supported the role of *image segmentation*, prior to target selection. Weichart and Sederberg used a 2-dimensional flanker task to evaluate the *shape of the spotlight of attention*, based on relative inhibitory influence of distractors in horizontal and vertical directions from the target. For most observers, the attentional spotlight was elliptical rather than circular, and usually was horizontally biased. But individuals differed in the extent and direction of bias. Michael Pratte compared the impact of stimulus organization on the *temporal process of response conflict* in the Stroop, Simon, and Eriksen flanker tasks. Response conflict affected different parts of the RT distributions in these three paradigms, and these differences are attributed to the timing of different forms of interfering information in the visual cortex.

An important idea developed in a series of studies by Eriksen and colleagues was that competing response processes operate concurrently with visual target identification. Erik proposed that concurrent perceptual and response processes exert a *continuous flow* of interactive influence. Research on the concept of continuous flow has been sparse, but four papers here investigate and support this idea. Ridderinkhof, Wylie, van den Wildenberg, Bashore, and van der Molen focus on the *arrows version of the flanker task* to provide an insightful review of the evidence and broad applications of the continuous flow concept. Mordkoff and Chen point out that a basic idea implicit in Erik’s concepts of continuous flow and response competition is that spatially selective attention is a *two-phase process*. The first phase is non-selective, but involves pro-active response inhibition to suppress erroneous responses. Spatially selective attention to the target occurs in the second phase. After replicating and extending evidence for this two-phase model, Mordkoff and Chen verified further predictions using the lateralized readiness potential, EMG activity, and response force. Erb, Smith, and Moher review *direct evidence* for continuous flow provided by the *dynamics of continuous 2D response movements* toward selected targets. The method is straightforward and powerful. Townsend and Wenger offer a general framework for quantitative analysis and classification of *continuous flow dynamics* in which subprocesses communicate with one another. Their taxonomy clarifies fundamental characteristics of alternative systems. They illustrate the approach by simulating the classic target-flanker congruency effect in the Eriksen flanker paradigm.

The Eriksen flanker paradigm has also proved effective in studying selective attention to *multisensory patterns*. Charles Spence and Merz, Frings, and Spence review evidence from a substantial area of research on target-flanker relations in *auditory, tactile, and cross-modal spatial patterns*. Experimental results emphasize the importance of a multisensory perspective for gaining a general understanding of selective filtering, perception of non-visual spatial information, and perceptual capacity limitations. Ulrich, Prislán, and Miller investigated the temporal characteristics of *bimodal congruence effects* for visual target letters accompanied by irrelevant auditory letters. Bimodal congruence effects occurred when targets and flankers shared the same letter name, but not when different letters were assigned the same response. When the auditory letters preceded the visual targets, the RT distributions for congruent and incongruent auditory flankers indicated that the auditory flankers influenced the speed of visual target recognition but did not directly activate the associated responses. Salagovic and Leonard studied effects of a *preceding nonspatial auditory tone* on responses to visual target and flanker letters, with stimulus-congruent, response-congruent, incongruent, or neutral flankers. The tone produced faster and less variable responses overall, consistent with an alerting effect, but a more interesting finding was that the tone modified the congruency effect, with greater speeding for congruent than incongruent flankers.

A set of basic issues associated with the Eriksen flanker task concerns how *experience and statistical learning* of target and flanker patterns may influence target selection and response competition. Such effects of experience on image segregation and response control have been studied in several ways, often by manipulating the probabilities of different flanker types. (Note that studies of stimulus probability effects on the flanker task overlap with studies of such effects in visual search.) Bausenhardt, Ulrich, and Miller evaluate *adaptive reductions of response conflicts* caused by competing letter classifications in the flanker task in comparison with adaptations to conflicts caused by competing spatial responses in the Simon task. Adaptations to incompatible stimuli and responses were observed in both tasks, but those effects did not transfer between tasks. Evidently, behavioral adaptations were task-specific, without higher-order cognitive control. Related results were found in experiments by Cochrane, Simmering, and Green. They report a study of the *proportion compatibility effect*, in which the effects of incompatible flankers are reduced when those flankers are more probable. Their experiments found robust effects of the compatibility proportions, involving response compatibility on the preceding trial or preceding block. But these effects evidently did not involve statistical learning in which effects emerged gradually over trials within a block. Learning is also

examined by Gao and Gozli, who evaluated distracting effects of incompatible *flankers with features contingent on previous responses*. When the response-contingent distractor features were simple (color, spatial location), the cost in response times from incompatible flankers was reduced. But when target-distractor compatibility depended on previous responses, the distractor cost was unaffected. The authors conclude that associative learning affects the allocation of attention to task-irrelevant events. Bulger, Shinn-Cunningham, and Noyce describe a detailed evaluation of the effects of the probabilities of particular flanker configurations, using both left/right pointing chevrons and letters. They found a close relationship between the probability of a given flanker configuration and the accuracy of speeded left/right target responses. Two main conclusions are that (a) statistical regularities drive distractor expectations at multiple time scales, and (b) effects are strongest when targets and flankers are geometrically similar and when observers respond rapidly.

Gutchess, Ksander, Millar, Uzundag, Sekuler, and Boduroglu offer new research relevant to Erik's early interest in effects of personality on perception. Using Eriksen's flanker task with varied spatial separations and relative contrasts of targets and flankers, the authors tested whether the breadth and resolution of attention are influenced by an observer's *cultural background*. Flanker effects were compared for observers from Eastern (Turkish) and Western (American) cultures. Mathematical analyses of RT distributions and accuracies indicated that Turks accumulated visual evidence faster and required more evidence for a decision than did Americans.

Erik's research career exhibited a persistent concern for methods for distinguishing the influence of perception from that of response criteria and strategies (e.g., Garner et al. 1956). Questions about such distinctions can arise in identifying the causes of differences in RTs, pertinent to many studies in this special issue. Manipulations of stimulus probabilities, for example, might influence either perceptual or response processes or both. Methods for mitigating such ambiguities

are illustrated by analyses of RT distributions in the studies of Bulger et al., Ulrich et al., and Pratte.

Related problems in identifying the stimulus information that controls perception as distinct from strategic responses to a particular subset of available cues also arise in many experiments with complex stimulus patterns. Such issues appear in most studies in this issue, many of which were specifically designed to identify the controlling stimulus information. A general research problem that may be motivated by the contributions to this special issue is to identify stimulus information that controls perception, attention, and action, and identify the processes that use this information to enact the control.

Erik certainly would have been stimulated by both the progress and issues exhibited by the research in this special issue. We hope that others will be as well.

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