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50TH ANNIVERSARY ARTICLE

The Birth of Flow: Why Coles et al. (1985) Is Important

Bernhard Hommel
Department of Psychology, Shandong Normal University

This perspective article explains why the article of Coles et al. (1985) must be considered a milestone in research on human cognition: Because it was the first convincing demonstration that Eriksen's theoretical flow idea can be tested and confirmed, because it foreshadowed systematic modeling attempts to capture the dynamics of decision making and response conflicts, and because its findings provided one of the strongest arguments against the back then dominating stage-analytical approach, which opened the door for more dynamic, interactive models of human cognition.

Public Significance Statement
This article highlights the scientific importance of the article by Coles et al. (1985).

Keywords: continuous flow, stage analysis, dynamic models, diffusion models, theory of event coding

In the 1970–1980s, cognitive psychology was strongly dominated by the stage-analytical approach to human cognition advocated by the influential Sternberg's (1969) article. I even owe my first published article in the *Journal of Experimental Psychology: Human Perception and Performance* to this dominance: I originally submitted it as a single-experiment article to *Acta Psychologica*, where it was rejected for the sole reason of not having included a Sternbergian stage analysis of my findings. Being a student of Wolfgang Prinz, who was the first to openly criticize the stage approach (Prinz, 1972), I was obviously reluctant to oblige, and therefore added some experiments and (successfully, as it turned out) submitted to the *Journal of Experimental Psychology: Human Perception and Performance* (Hommel, 1995).

One of the key assumptions of stage analysis was the existence of separable, identifiable processing stages that would be dedicated to a particular psychological function and that would operate in a particular, typically fixed sequence. What made the stage approach so popular, up to this very day, is that it comes with a straightforward analysis of variance-based methodology to identify and disentangle processing stages (Sternberg, 1969), which has inspired thousands of articles devoted to stage analyses. And yet, to increasingly many, and especially those who were interested in physiology and the human brain, the assumption of strictly sequential and unidirectional processing seemed rather implausible. Not only because the identification and labeling of hypothetical stages were based on armchair reasoning and semantic distinctions that were uninformed by considerations about the functioning of the human brain but also because neural activities are known to interact heavily, which renders the idea of a unidirectional processing chain not overly plausible. Colleagues at the Max Planck Institute for Psychological Research and I were working on (apparently rather continuous) interactions between perception and action in the 1990s, and we found lots of evidence for the impact of both perception and memorizing on action planning and acting and action planning on perception (e.g., Müsseler & Hommel, 1997). Trying to understand the continuity of such effects and especially of action/perception "backward" effects from a stage view did not seem to make much sense.

Accordingly, the suggestion of Charles Eriksen and collaborators (Eriksen & Schultz, 1979) that there may be a continuous flow from perception to decision making and action control was a theoretical breakthrough for us and many other perception–action researchers. This concept also jibed well with first interactive approaches in language processing (one of the domains showing an interesting interplay of perception and action processes), like the interactive activation model of McClelland and Rumelhart (1981). The key problem, however, was that direct empirical evidence for continuous flow was hard to obtain, especially given that stage theorists became pretty inventive in (post hoc) defending their approach. And here came Coles et al. (1985) with a brilliant combination of behavioral experimentation and psychophysiological measurements to make continuous flow visible. This made it possible to demonstrate that task-irrelevant flankers can activate responses in a "subliminal" fashion, in the sense that response-incompatible flankers activate "their" (i.e., the incorrect) response to a certain degree, as indicated by electroencephalographic measures related to stimulus evaluation and subthreshold electromyographic activity. Hence, it was clear that

Jelena Ristic served as action editor.
Bernhard Hommel https://orcid.org/0000-0003-4731-5125
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Correspondence concerning this article should be addressed to Bernhard Hommel, Department of Psychology, Shandong Normal University, No. 88 East Wenhua Road, Jinan, 250014, Shandong Province, China. Email: bh@bhommel.onmicrosoft.com

some degree of information can reach the motor cortex before decision making is complete.

Later studies have improved the methodology (e.g., by employing mouse-tracking responses), and the use of functional magnetic resonance imaging and transcranial magnetic stimulation has meanwhile strongly enriched the opportunities to tap into continuous flow. Nevertheless, the study of Coles et al. (1985) will remain a milestone in cognitive psychology for at least three reasons. First, because it was the first convincing demonstration that Eriksen's theoretical flow idea can be tested and confirmed, which opened many doors to study the cognitive and neural underpinnings of action planning and execution. In particular, the clever use of physiological/neuroscientific measures to more closely and more continuously monitor cognitive processes over time has encouraged many researchers (like me) interested in a closer connection between the cognitive sciences and the cognitive neurosciences. Second, this approach foreshadowed systematic modeling attempts to capture the dynamics of decision making and response conflicts, like in drift-diffusion models of general decision making (Ratcliff, 1988) or behavior in conflict tasks (Servant et al., 2014). Third, the findings of Coles et al. (1985) provided one of the strongest arguments against the back then dominating stage-analytical approach, and therefore opened the door for more dynamic, interactive models of human cognition. The theory of event coding (Hommel et al., 2001), which even denies that perception and action are different processes or stages, is just one concrete example, Ratcliffe's diffusion model is another.

Accordingly, the article of Coles et al. (1985) had a strong impact on experimenting and theorizing in cognitive psychology. I consider it a true milestone of our discipline, and one of the best combinations of theoretical thinking, clever experimentation, and the use of neuroscientific techniques. It did change my mind and stimulated me very strongly both empirically and theoretically.

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