

## Theoretical Issues in Stimulus-Response Compatibility: Editors' Introduction

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It all began in the mid-1950s. Although the term *stimulus-response compatibility* had been coined and already introduced by Small in 1951 (see Small, 1990), the real spark for compatibility research were the now classic papers by Fitts and Seeger (1953) and Fitts and Deininger (1954). The important finding of Fitts and colleagues was that human performance is not only affected by characteristics of the stimulus set and the response set used in a task, but by the combination of the sets as well. In particular, performance was shown to be systematically affected by (a) whether or not a set of stimuli shares one or more features with the response set and (b) the way in which the particular stimuli and responses are mapped onto each other (cf., Alluisi & Warm, 1990; Kornblum, Hasbroucq, & Osman, 1990). Since then, the effect of stimulus-response (S-R) mapping with feature-overlapping stimulus and response sets has been called the *S-R compatibility effect*.

During the late 1950s and 1960s, S-R compatibility research flourished, not least due to the increasing interest in human factors and the design of man-machine interfaces (for an overview see Kantowitz, Triggs, & Barnes, 1990; Wickens, 1992). Yet, there was little interest in theorizing about compatibility phenomena, at least not over and above attempts to rephrase empirical results in the language of information theory, which was at its heyday at this time. A major historical reason for this theoretical ignorance may lie in the fact that the transition from behaviorism to the information-processing approach as the leading theoretical paradigm was less radical than has often been assumed. In fact, the behavioristic belief that each and every S-R association can be learned in the same way is well taken care of in the information-theoretical presupposition that each and every stimulus code can be easily transformed into each and every response code. In focusing on the information transmitted, but not on the system

transmitting it, information theory has little to offer for a deeper theoretical understanding of obviously privileged S-R relationships if the respective stimuli and responses do not differ from those less privileged in terms of uncertainty reduction.

In the late 1960s, these simple learning and information transmission approaches started to disappear slowly from the scene, which is indicated by two parallel and independent developments. On the one hand, human-performance approaches were increasingly replaced by more cognitively oriented approaches, such as those advocated by Neisser (1967), that consider how processes operate on, and are constrained by, cognitive structures, hence the processing system. On the other hand, even within the S-R-oriented learning theory, it became more and more apparent that learning does not happen in a bodily vacuum, but inside a biological system the structure of which puts important constraints on what is and can be learned and how (Seligman & Hager, 1972). Both of these developments may be viewed as paving the way for theorizing about the interaction of information-transmitting processes with the structure of the information-processing system, producing theories that later proved extremely fruitful in advancing our insights in S-R compatibility phenomena.

The year 1967 saw a further milestone in compatibility research: the accidental discovery by Simon and Rudell that the (spatial) S-R relationship impacts performance even if it is completely irrelevant to the task. Like the observations of Fitts and coworkers, the outcome of Simon and Rudell's study, meanwhile familiar as the *Simon effect*, has been replicated several times and has shown to be very robust across many task variations (for overviews see Lu & Proctor, 1995; Simon, 1990). The theoretical importance of the Simon effect lies in that it is very difficult to describe and even more difficult to understand in information-theoretical terms—after all, the "transmitted stimulus information" is task-irrelevant, hence neither useful nor welcome. Therefore, other theoretical approaches were required and in fact developed—approaches that proved to be very stimulating in many respects.

The first account of the effect of irrelevant spatial S-R relationships—hence for faster responses to spatially corresponding stimuli—was suggested by Simon (1969), who referred to a "natural tendency to react towards the stimulus". Although later research by Simon and by others led to theoretical refinements and changes, this approach can be regarded as the precursor of current attentional approaches to S-R compatibility as represented by Stoffer and Umiltà's chapter in this volume. The second account of the Simon effect was presented by Wallace (1971, 1972), who suggested something that has since been called the coding view. Different from Simon's "attentional" perspective, Wallace's approach considered the way stimuli and responses are cognitively represented and how these representations (codes) may interact during the process of S-R translation. During the 1970s and later, the coding view continuously gained

attraction and set the stage for current approaches such as those presented by Proctor and Wang, Barber and O'Leary, Lu, Prinz, or Hommel in this book.

While the 1970s and 1980s saw theoretical issues becoming more and more important in the compatibility field (which is nicely documented in the contributions to Proctor & Reeves, 1990), the 1990s have seen several major changes that are comprehensively captured in the present contributions:

First, the theoretical focus has shifted from merely "localizing" compatibility effects at one or another information-processing stage—mostly following Sternberg's (1969) additive-factors logic—to attempting to specify the mechanisms involved in, or responsible for, compatibility phenomena. This attempt has led to the formulation of more general principles, such as the salient-feature principle of Reeve and Proctor (1990) and more or less full-fledged information-processing models such as those of Kornblum et al. (1990) or Barber and O'Leary (this volume)—models that not only picture particular effects but allow for a number of new and interesting predictions.

Second, the models proposed not only become more complex and specific, they also allow more (often parallel) ways for stimulus information to access response-related processes and, in particular, to affect response selection. Minimally, stimuli sharing features with one member of the response set are allowed to access the response stage automatically, in parallel to voluntary S-R translation processes (see chapters by Eimer, Lu, Hommel, or Barber & O'Leary). Moreover, the work Proctor and Wang present in this volume strongly suggests that even in the absence of (or at least independent from) feature overlap, learned S-R associations may also affect the manner or the ease of S-R translation.

Third, besides specifying mechanisms and processing routes, the temporal dynamics of information processing, that is, the changes in the activation of cognitive codes over time, has increasingly gained attention. As discussed in the chapters by Eimer, Lu, and Hommel, the Simon task in particular has proved to be a suitable tool for investigating the waxing and waning of code activation, although Lu convincingly shows that other tasks can be used as well to provide converging evidence.

Fourth, compatibility theory becomes more and more sensitive to the fundamental insight that what is compatible or incompatible is not so much a sensory and a motor pattern, but a perceived event and an intentional action. This has a number of implications that the present contributions work out in several ways.

One implication is that the focus of psychological research is on observing actors, a fact that is not always fully acknowledged in the predominant information-processing view. Rather than merely responding, human actors behave in an intentional, goal-directed and adaptive fashion, as is most strongly emphasized in the chapters by De Jong, Michaels and Stins, Prinz, and Chua and Weeks. Consequently, our experimental and theoretical analyses must not start

with stimulus presentation, but with the presentation of the task. Actually, a great deal is going on in the human information-processing system long before the first trial starts: The instruction must be understood and used to prepare and adjust the system to the task; action goals need to be determined and action conditions defined; strategies are worked out and implemented; and much more. There is ample evidence that all these processes matter—or at least may matter, depending on the particular task and the effect investigated. Yet, our theorizing has only begun to grant them the status of a basic theoretical ingredient.

A further and related implication of a theoretical focus on acting observers is that stimulus and response must not (only) be viewed as cause and effect, but as information in the environment that must be actively extracted and used to produce a coordinated movement pattern. In one way or another, and expressed in sometimes rather different theoretical languages, this insight is an issue in many chapters: Both De Jong and Prinz point out that without the intention to act, presenting a stimulus to a subject would not have much effect; Stoffer and Umiltà highlight that stimuli are not simply registered but actively attended, this having consequences for action preparation; Michaels and Stins (and, in a way, Hommel, too) suggest that perceiving a stimulus always means perceiving the action it affords, while acting means realizing this affordance; and so forth.

A final important implication of a more action-oriented approach is that it invites the investigations of more complex actions than pressing one of two buttons or uttering one of two single-syllabic words. Of course, there are obvious practical advantages of simple actions, and many theoretical questions can, have been, and will be solved based on these. Yet, as nicely demonstrated in the chapters by Michaels and Stins and Chua and Weeks, exploring compatibility effects on complex movements not only confronts us with new methodological challenges, it may also provide us with new and exciting theoretical insights.

Altogether, we feel that the theory of S-R compatibility has become mature now in an important sense. In contrast to the early years of compatibility research, theorizing has become more than translating the (often accidental) empirical findings in some theoretical language, which meant little more than (re-)describing them without gaining further, generalizable insights. Moreover, and this we believe is of greatest importance, current theorizing is no longer restricted to accounting for the empirical data at hand, but aims at a deeper, fundamental understanding of the architecture of the human information-processing system, the relationship between perception and action, and between the intentional human being and his or her environment. In other words, theories in the field of S-R compatibility now make active and creative use of the phenomena rather than remaining slaves to them, often using the phenomena and effects as a mere investigation tool rather than as the ultimate goal of explanation. In our view, this a most promising direction that will strongly foster the impact of compatibility research on other psychological fields.

The contributions to this book are the fruits of a "symposium on the theory of S-R compatibility." The symposium, organized by Bernhard Hommel and supported by the Max Planck Society, was held in the abbey of Benediktbeuern, a small Bavarian village south of Munich, on June 13—15, 1995. Fortunately, many were able and willing to accept our invitation, so that the list of participants (see pp. ix-x) reads as a nearly complete inventory of the currently most influential compatibility researchers representing many different, and often contradictory, theoretical perspectives. We would like to emphasize that the authors were strongly encouraged to present not only a review of their current work, but a broad overview of their theoretical opinions and guidelines as well—empirically based speculation, if you will. Consequently, what the chapters of this book make available to the reader are not so much final conclusions but work in progress: fresh theoretical views based on lively, exciting, ongoing research programs.

The 10 chapters are based on the 10 talks held at the symposium. But there were not only talks. In fact, to foster the free flow of opinions, ample time was available at the meeting for broadly discussing, criticizing, and defending the theoretical approaches represented in and through the presentations. In order to transfer some of the spirit of these discussions and controversies to the book, and thus to the reader, we decided to add to each of the main articles one or two commentaries, thus providing the other participants with the opportunity to express their agreement or disagreement directly. We very much hope that the resulting mixture of, in our view, highly stimulating papers and sharp comments grants the reader the same intellectual pleasure as we had in listening to and rereading them.

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