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NOTE

S–R COMPATIBILITY EFFECT OR CEREBRAL LATERALITY EFFECT? COMMENTS ON A CONTROVERSY

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Abstract—This article investigates the role played by misleading terminology in the origins of a recent controversy about the nature of stimulus–response compatibility effects.

SINCE the work of FITTS and SEEGER [7], we know that the reaction time to stimuli whose relative spatial localization corresponds to the relative position of response is shorter than if these do not correspond (e.g. it is shorter if one uses the right hand to react to a light onset in the right rather than in the left visual field). This phenomenon, which also occurs when the localization of stimuli is not relevant to the task in the sense that it is not the position of the stimulus on which the subjects have to decide in their response (but, for example, its symbolic content), see [17], is generally referred to as the stimulus (S)-response (R) compatibility effect. Recently, COTTON *et al.* [6] carried out two experiments to investigate theories of S–R compatibility but concluded that the results of these experiments require an "explanation in terms of cerebral laterality factors" ([6], p. 13). This claim has gained much critical attention in the literature [2, 4, 11, 13, 14, 20], its tenor being that Cotton *et al.*'s results are standard S–R compatibility effects and that no new (neuronal) theory is necessary to explain them.

Besides the kind of S–R compatibility where (relevant or irrelevant) spatial relations are involved, several other types of S–R compatibility have been detected and investigated (for discussion see [14] and [18]). In the following we only deal with S–R compatibility effects which are due to spatial correspondence; so when speaking of S–R compatibility we always mean *spatial* S–R compatibility ("spatial" here used in the wider sense capturing both relevant and irrelevant stimulus locations as in [18], not in the narrower sense including only relevant stimulus locations as in [14]).

Much research has been carried out to distinguish the S–R compatibility effect from an effect which is due to neuroanatomical pathways. Both explanations predict the same asymmetry pattern if one assumes that the stimulus is processed in the hemisphere where it directly arrives (e.g. stimuli from the right visual field first reach the left hemisphere where also the right-hand response is initiated). WALLACE [19] offered an experimental design to distinguish the S–R compatibility effect from a pathway effect. He employed an arrangement where the subjects responded with crossed hands. By comparing the results of crossed and uncrossed hands he could eliminate the confusion between hand and position of hand and show that for the standard S–R compatibility effect not a correspondence between stimulus position and responding hand (as for the pathway effect) but a correspondence between stimulus position and position of responding hand is required. ANZOLA *et al.* [1] used this technique to show that S–R compatibility is present only in choice reaction times whereas in simple reaction times neuroanatomical pathways play the determining role (cf. also [3]). NICOLETTI *et al.* [14], also using the crossing-hands-technique, were able to show that the S–R compatibility effect even obtains when both right and left stimuli are localized on one side of the body midline and right and left responses are localized either on different sides or on one side too; therefore it is the *relative* spatial localization of stimulus and response cues which governs S–R compatibility and not their relation to the body midline.

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The methods and results employed in these investigations suggest the following definition of "S-R compatibility": For an experimental result to be called an S-R compatibility effect two conditions must be met: (I) The experimental design must be such that stimulus and response positions correspond in at least one dimension (e.g. left/right); (II) there is a reaction time advantage for compatible vs incompatible conditions which can be attributed to the different response positions and which is not due to the neuroanatomical or anatomical difference between the possible responses. This definition covers the notions of S-R compatibility as employed in the studies cited above. In a simple reaction time task of the kind studied in [1], for example, condition I is met but not condition II as shown by the crossing-hands-test.

Two main types of explanation have been offered for S-R compatibility effects which according to NICOLETTI *et al.* [14] may be called *attentional* and *coding* hypotheses. The most widespread one of the former type is SIMON's [15, 16] hypothesis according to which S-R compatibility results from a "reaction toward the source of stimulation" which is conceived of as a "stereotype" based on an "orienting reflex" ([15], p. 344). The latter hypothesis goes back to WALLACE [19] who assumed that the possible positions of the stimulus and the response are related to a "spatial code" and credits the S-R compatibility effect to "the outcome of a comparison between their representations in this code" ([19], p. 354). This assumption can also explain the crucial role of *relative* spatial localization of stimulus and response cues (cf. [14]), whereas according to the attentional hypotheses only the position with respect to the body midline can be important. The coding hypothesis is a genuinely cognitive explanation; Bradshaw and Umiltá speak of the "higher-order cognitive processes involved in the spatial encoding of the relative positions of stimuli and responses" ([4], p. 100). The attentional hypotheses, on the contrary, though also formulated in non-neural terms, can be given an interpretation in terms of hemispheric activation (see [14]).

COTTON *et al.* [6] introduced a new type of explanation into the debate on S-R compatibility effects. They assumed "that laterality effects play a major role in producing the S-R compatibility effect" ([6], p. 16). By "laterality effects" they mean effects which have to do with specialized hemispheric processing, not simple neuroanatomical pathway effects. We shall try to show that, in view of the definition of "S-R compatibility effect" as proposed above, the controversy about the explanation of Cotton *et al.*'s results was provoked by Cotton *et al.*'s conceptual unclarity about the notion of S-R compatibility, which was, however, taken over also by their critics.

COTTON *et al.* ([5], experiment 2) performed an experiment with response buttons above and below a start key in the mid-sagittal plane, both buttons being equidistant from the stimuli on the right and left. They used a stimulus pattern in which four light-emitting diodes (LEDs) were mounted 1.5° to the right or left and 1° above or below a fixation point. The subjects had to press the top key if a stimulus onset occurred above the fixation point (regardless of whether it was right or left) and the bottom key if it occurred below the fixation point. The results showed that responses were quickest when an upper stimulus was presented in the visual field corresponding to the response hand and when a lower stimulus appeared in the opposite visual field to the hand. The result remained the same when the presentation time was reduced in order to preclude eye movement to ensure that right field stimuli reached the left hemisphere and left field stimuli the right hemisphere (see [6]) and even when, instead of top and bottom LEDs, symbols with the meaning "above" and "below" were presented to the left or right of the fixation point at the horizontal midline.

COTTON *et al.* [6] suppose that this result must be explained on the basis of the assumption of differences in hemisphere function. Since none of the classical static dichotomous models of hemispheric specialization (verbal vs spatial, analytic vs holistic, etc.) are sufficient to explain this effect—they would predict the same field superiority for right- and left-hand reactions—Cotton *et al.* adopt (referring to KINSBOURNE [12]) the assumption that the responding hand causes a higher arousal in the contralateral hemisphere. This "primed" hemisphere—and that is the second assumption processes, in the authors' opinion, the "more salient" aspects of a stimulus, whereas the other hemisphere processes the "less salient" aspects. As for "more salient" aspects in the pairs of opposites above/below and right/left, Cotton *et al.* refer to the linguistic concept of markedness.

As has been argued by all of Cotton *et al.*'s critics, this explanation is rather speculative, in particular the use of the terms "salient" and "marked" and the hypothesis of the preference in processing of such stimuli by the primed hemisphere [see 20] (however, recent results on intrahemispheric cognitive/motor interference [8–10] support some aspects of Cotton *et al.*'s hypotheses). Yet, Cotton *et al.*'s explanation of their own effect would probably not have had this strong critical resonance had it not been called an explanation of S-R compatibility by the authors, thus calling into question earlier explanations of S-R compatibility. It is exactly this thesis which is mistaken. According to the proposed definition of S-R compatibility, COTTON *et al.*'s [6] experimental result is not an S-R compatibility effect because condition I is not fulfilled. There is no right/left dimension of possible response positions which could correspond to the right/left dimension of stimulus positions. What suggested calling their effect an S-R compatibility effect was probably that their experimental design resulted from an other experimental design which actually produced an S-R compatibility effect ([5], experiment 1) just by rotating the response key. However, this rotation markedly changes the experimental situation in so far as the spatial relationships usually seen as crucial for S-R compatibility are destroyed. So from the point of view of our definition of S-R compatibility, Cotton *et al.*'s result cannot principally challenge any theories of S-R compatibility effects exactly because no compatible or incompatible right/left S-R relation exists. There is, of course, a correspondence in the above/below dimension which could possibly produce an above/below S-R compatibility effect. But in order to consider Cotton *et al.*'s "diagonal" effect as an S-R compatibility effect, one needs an additional right/left difference in response positions.

(Aside from that it can be questioned whether "above/below" for stimuli in the vertical plane does correspond to "above/below" for responses in the horizontal plane which is in fact a "farther/nearer" difference.)

Furthermore, in several places Cotton *et al.* confound the levels of the phenomenon to be explained ("explanandum") and the theory explaining the phenomenon ("explanans"). This confusion is already present in the titles of their papers [5, 6]: [5] bears the subtitle "S–R compatibility effect or ?", thus suggesting that "S–R compatibility" and "?" (i.e. cerebral laterality) are concurrent theoretical *explanations* of a certain phenomenon, whereas the title of [6] speaks of the "role of cerebral hemispheric processing in the visual half-field stimulus–response compatibility effect", thus supposing that the S–R compatibility effect is just the *phenomenon* (i.e. the experimental result) for whose explanation a theory of cerebral laterality is offered. This leads to the contradiction that on the one hand a certain experimental result is *denoted* as an S–R compatibility effect but on the other hand *explained* by a theory which by assumption is incompatible with S–R compatibility.

Unfortunately, Cotton *et al.*'s critics took it for granted that Cotton *et al.*'s interpretation of their results were a challenge to traditional theories of S–R compatibility. (LUPKER and KATZ [13], for example, consider it "a very new and different view of S–R compatibility effects" ([13], p. 97).) Their aim was then to retain these theories by showing that Cotton *et al.*'s effect can in fact be considered as an S–R compatibility effect to which these theories are applicable. In order to show that clause I in the definition of S–R compatibility is fulfilled one has to demonstrate that not only an above/below but also a right/left difference is contained in the possible responses. For this purpose LUPKER and KATZ [13] and NICOLETTI *et al.* [14] argue that to press the top and bottom keys abduction or adduction movements, respectively, are required; these contain rightward or leftward movements, respectively, when responding with the right hand, and leftward or rightward movements, respectively, when responding with the left hand. So according to these authors there is a correspondence between right/left stimuli and abduction/adduction (right hand) or adduction/abduction (left hand) movements which created an S–R compatibility effect leading exactly to Cotton *et al.*'s results (i.e. the preference of the left below/right above diagonal line for the right hand and left above/right below diagonal line for the left hand) which therefore can be accounted for along the traditional lines of S–R compatibility.

COTTON *et al.* [6], however, being aware of this possible explanation, found with a few further subjects that no different result was obtained when response was performed with the forearm held parallel to the body, which means that no rightward/leftward movements are contained in the movements toward the response buttons. This result is treated by LUPKER and KATZ [13] and NICOLETTI *et al.* [14] by arguing that the correspondence between right/left and abduction/adduction (right hand) or adduction/abduction (left hand) movements need not be an actual one. For LUPKER and KATZ [13] "not the actual movement but the entire set of components making up the response" ([13], p. 98) is relevant; they speak of "the natural association between the two forms of movement (i.e. away and right or toward and left for right-handed responders)" (p. 98). NICOLETTI *et al.* [14] similarly use the notion of "*intrinsic* lateral biases" (p.672, our italics) in that case.

However, such a theory does not justify calling Cotton *et al.*'s result an S–R compatibility effect. Although condition I of our definition is now met (there is a right/left difference in response positions), condition II no longer holds because according to these explanations it is not only the *position* of the response which is effective but also an *anatomical* difference between certain movements. This anatomical difference is of course associated with a certain spatial right/left difference; but this difference is actual only under the condition that the forearm is held in the normal non-parallel position with respect to the body and not under the condition where the forearm is held parallel to the body. Something similar holds for BAUER and MILLER's [2] explanation of Cotton *et al.*'s effect: these authors speak of "implicit movement commands" toward the stimulus location which are "similar in nature to movements which are actually executed" ([2], p. 369) and where "the subsequent movement to the response key will be made as if it were composed of the implicit movement plus the actual movement" ([2], p. 370), yielding an implicit circular movement which is different in direction for both hands. The difference between right and left hand is then explained by reference to different preferential movement directions for the two hands (right hand prefers counter-clockwise, left hand prefers clockwise movements). Here again (in spite of the differences to the models of LUPKER and KATZ [13] and NICOLETTI *et al.* [14]) stimulus and response positions are effective not alone, but only together with certain anatomical preferences.

One could object that this analysis is due to our narrow notion of S–R compatibility, and that a wider notion also capturing anatomical differences which are naturally associated with spatial differences would be more adequate. It seems to us, however, that under such an extension the notion of S–R compatibility would lose much of its specific content. If one also admits intrinsic anatomically based differences in direction as a basis of S–R compatibility, one could, for example, argue that there is a natural association between right hand and right position and between left hand and left position, and that this association is effective also if it is not actual (e.g. when the hands are crossed). But if this were correct, the crossing-hands-technique would entirely lose its significance, since this would predict the same result for crossed and uncrossed hands, as in the case of a pathway effect.

In conclusion: neither Cotton *et al.* nor their critics are right in that the 'diagonal' effect Cotton *et al.* found is an S–R compatibility effect. Both parties widen the standard concept of S–R compatibility in an inappropriate way: Cotton *et al.* by denoting a result an S–R compatibility effect for which the terms "compatible/incompatible" do not immediately apply, and the critics by introducing anatomical differences which are intrinsically associated with spatial (right/left) differences instead of considering actual spatial differences only. This conclusion does not

solve the controversy about the explanation of Cotton *et al.*'s effect, but it lessens at least some of the emphasis given to the positions held by showing that their subject are not the established theories of S–R compatibility.

Concerning the explanation of Cotton *et al.*'s effect (which we have argued has nothing to do with S–R compatibility), we doubt that Bauer and Miller's, Lupker and Katz's and Nicoletti *et al.*'s proposals, in particular their introduction of "implicit" or "intrinsic" movements or biases is less speculative than Cotton *et al.*'s own theorizing. Whereas Cotton *et al.*'s explanation is speculative in the sense of not having much empirical support though being empirically falsifiable, the theories referring to these intrinsic factors seem to us to be speculative in the sense of not even being empirically testable. Implicit, i.e. not directly observable, entities can be admitted in scientific discourse only if there is an operationalization relating them somehow to empirical investigation. However, we do not see how this could be done, i.e. how it can be empirically tested whether "implicit movement commands" (Bauer and Miller), "natural associations" different from "actual movements" (Lupker and Katz) or "intrinsic lateral biases" (Nicoletti *et al.*) exist or not.

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