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THE LOCUS OF INTERSENSORY FACILITATION OF REACTION TIME *

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When an imperative visual stimulus is paired with an auditory (accessory) stimulus, RT is generally faster than with the imperative stimulus alone. Three experiments using additive-factors logic tested an energy-summation view of the accessory, where effects are due to increased rate of information build-up in sensory stages, and a preparation-enhancement view which holds that the accessory serves an alerting function. Experiment 1 found no interaction between the accessory presence and (visual) stimulus brightness, suggesting no role of the accessory in stimulus identification. Experiment 2 found no interaction between accessory presence and spatial S-R compatibility, arguing that the accessory operated in stage(s) other than response selection. Experiment 3 produced an interaction between the accessory and movement complexity, arguing for accessory effects in a response-programming stage. The data generally favored preparation-enhancement, and offered no support for an energy-summation view.

Considerable research in the past decade, stemming from the early work of Todd (1912), has shown that the reaction time (RT) to visual stimuli is faster if the visual imperative stimulus is paired with a preceding or simultaneous auditory stimulus (called an accessory), even if the accessory is delayed by as much as 100 msec and even if the subject is told not to respond to it. The phenomenon is quite general. It is found in simple- and choice-RT paradigms (Bernstein et al. 1969a;

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Bernstein and Edelstein 1971; Morrell 1968b; Simon and Craft 1970; Van der Molen and Keuss 1979), the reduction in visual RT decreases if the interval between the imperative and accessory stimuli increases (Erkelens 1981; Bernstein et al. 1969b; Bernstein et al. 1969a; Keuss 1972; Michie et al. 1976; Morrell 1967, 1968a, 1968b; Posner et al. 1976; Wadman et al. 1980), the facilitation holds for auditory accessories as well as other modalities such as shock (Todd 1912; Michie et al. 1976; Semjen et al. 1973) or torques (Erkelens 1981; Gielen et al. 1983; Gurfinkel and Pal'tsev 1965; Wadman et al. 1980), and for visual accessories shortening auditory RT (Posner et al. 1976; Morrell 1968a). The RT to the combined-stimulus events is generally shorter than the RT to the accessory stimulus alone plus the delay between the imperative and accessory, which tends to rule out the hypothesis that the subject simply responds to the (often faster) accessory stimulus channel. Such evidence has been taken to mean that there is some interaction among the sensory modalities, leading to a more rapid RT. Such an effect is usually referred to as an *intersensory facilitation* of RT.

There has been debate over whether or not such speeded RTs in combined-stimulus situations should be interpreted as "true" intersensory-facilitation effects (e.g., Nickerson 1973; Raab 1962; Gielen et al. 1983). A leading alternative explanation was presented by Raab, who showed that because of the variabilities in processing times of the imperative and accessory stimuli in peripheral stages of processing, there could be a kind of *statistical facilitation*, in which the subject responded to whichever of the two stimulus modalities happened, on a particular trial, to be processed first. However, recent analyses of the problem by Nickerson (1973) and Gielen et al. (1983) suggest that, while such a mechanism may, indeed, be operating in these situations, there appears to be some portion of the decrease in RT that cannot be accounted for by statistical facilitation. The present understanding, then, is that there is some additional intersensory effect, in which the accessory stimulus combines in some fashion with the imperative stimulus to decrease RT.

Two such models of this intersensory facilitation were outlined by Bernstein et al. (1973) and Nickerson (1973). An early view of the phenomenon was that of energy summation. Here, the energy from the two stimulus modalities is assumed to combine, or summate, in some early peripheral stage(s) of processing, leading to the earlier termination of the processing in the early stages and thus to more rapid RT. Such a view places the locus of the intersensory facilitation in early stages, those dealing with sensory information processing. Such energy-summation processes may be involved in what Sanders (1980) has called the *preprocessing* stage, where many have argued that the speed of information processing is based on the *amount* of stimulus energy delivered to some neural system. But it is also possible that such energy-summation effects may be involved in a later stage of sensory processing, in this case what Sanders (1980) has termed the *feature-extraction* stage. In any case, the point is that the energy-summation hypothesis has the locus of an intersensory facilitation effect as being early in the stages of processing, certainly not in stages having to do with response selection or response programming.

A rival to this energy-summation view is the preparation-enhancement model discussed by Bernstein et al. (1973) and Nickerson (1973). Here, the accessory stimulus is assumed to provide an "alerting" or arousing role on many of the stages of processing, so that the affected stages are terminated more quickly and the response comes earlier. This preparation view has at least part of the locus of the facilitation in later stages of processing, such as response selection or response programming, although the hypothesis does not rule out the possibility of alerting effects in early stages as well. Thus, the preparation hypothesis has at least part of the intersensory facilitation effect in later stages of processing, while the energy-summation view does not.

A specific version of this preparation view is the alerting hypothesis discussed by Posner (1978). In this view, the accessory stimulus causes the subject to respond earlier to the build-up of information in a stage involving stimulus identification. The quality of the information at any time after the stimulus is presented is not changed, unlike the energy-summation view which holds that information quality is increased, but the subject responds as if the criterion is lowered. This lowered criterion is one way to account for the tendency for the accessory to speed RT but to increase errors as it does. Posner's view differs from the preparation-enhancement view of Nickerson in that the locus of the effect seems limited to stimulus identification, whereas it can be located in any of a number of later stages in Nickerson's view.

Various lines of argument bear on these two views, as discussed by Bernstein et al. (1973), Nickerson (1973), and Posner (1978). In simple RT situations, where the imperative stimulus and the accessory are redundant, it seems logical that some kind of energy-summation effects could be occurring. But, in choice RT, where the accessory stimulus carries no information about the upcoming response, it is difficult to imagine how any attention devoted to the accessory channel would not be expected to *slow* RT to the imperative stimulus, and yet evidence clearly indicates that the accessory *speeds* RT. Such findings suggest that the effects of the accessory are largely automatic in nature. Second, the accessory generally increases errors, consistent with the idea that various stages of processing could be affected, such as stimulus identification as Posner suggests, or other later stages such as response selection or reponse programming as Nickerson (1973) would suggest. Such findings tend to favor one of the alerting views. Third, the fact that the accessory affects visual RTs even when delayed by as much as 100 msec raises doubts about an energy-summation view; in this case, peripheral visual preprocessing would be expected to have been completed by the time the accessory was presented, suggesting that the accessory affects somewhat later stages of processing. Finally, it is possible that both views could be correct, with each operating at a different place in the information processing system, and perhaps under different conditions (e.g., simple versus choice RT).

The present experiments were designed to provide evidence, converging from a different perspective and paradigm than has been used before, bearing on the energy-summation and preparation (or alerting) views. We have utilized the basic assumptions and methodology of the additive-factors method (Sternberg 1969) to indicate which of the stages are or are not affected by the presence of an auditory stimulus. If evidence can be provided that the accessory affects later stages of processing, and that it does not affect early stages of processing, then support would be provided for a preparation-enhancement view of intersensory facilitation. Predictions from the energy-summation hypothesis would be contradicted at the same time.

Three stages of processing that have been widely discussed (e.g., Keele 1973; Sanders 1980; Schmidt 1982) are stimulus identification, response selection, and response programming. During stimulus identification, various analyses of the incoming stimulus input are done, with the end of this stage representing the proper identification of the stimulus that was presented. Variables that affect the nature of the stimulus presumably affect this stage, such as stimulus intensity, clarity, and contrast. During response selection, the proper action is chosen out of many possible actions, with variables such as S-R compatibility and number of S-R alternatives thought to be determiners of the duration of processing in this stage. In response programming, the motor apparatus is prepared for the action that has been selected, and variables such as movement complexity and movement duration are thought to be determiners of the duration of this stage. Many have argued that these stages are serial and independent (see Klapp 1977, Sanders 1980, or Schmidt 1982, for reviews and evidence), but recent arguments have raised serious doubts as to this strict view of processing stages (e.g., McClelland 1979).

In the present paper, we used these ideas in relation to the following assumption from additive factors logic: If some variable A interacts with a variable B known to affect a certain stage, then variable A has at least part of its effect in this stage; on the other hand, if variables A and B do not interact, then we can say that variable A does not affect the same stage that variable B does. In our case, the variable of interest was the presence or absence of an accessory stimulus, and experiment 1 investigated whether or not there is an interaction of accessory presence with imperative stimulus intensity; if there is, then accessory presence has some of its effect in the stimulus-identification stage. Experiment 2 investigated whether or not the effect is in the response-selection stage, and the presence or absence of the accessory was crossed with spatial S-R compatibility in this experiment. If these variables interact, then the accessory has at least part of its effect in response selection. Finally, experiment 3 investigated whether or not there is an interaction between accessory presence and movement complexity; if there is, then at least part of the accessory's effect lies in the response-programming stage. An energy-summation hypothesis would predict that interactions would be found for experiment 1 (which deals with a very early stage), with no interactions predicted for experiments 2 and 3 which deal with later stages of processing.

Experiment 1

In this experiment, the possible interaction between imperative (visual) stimulus intensity and the presence or absence of an auditory accessory was studied. Thus, the study involved the role of the accessory in the stimulus-identification stage of processing. Interactions between these two variables have been found earlier by Bernstein et al. (1970, 1973), where the bright–dim difference is generally about 25 msec larger for the no-accessory condition than for the accessory condition (an overadditive interaction).

However, these experiments have all used "go/no-go" paradigms, and for reasons we have discussed elsewhere (i.e., Gielen et al. 1983), we wanted to conduct this experiment with a choice-RT paradigm.

Method

Subjects

Eight volunteers from the Department of Medical Physics, Rijksuniversiteit Utrecht, participated in the study. Seven were male, and all had received considerable practice in RT situations in general, and with the apparatus used in particular.

Apparatus

The movement apparatus involved a 110 cm high metal frame that supported two ball-bearing mounted v-pulleys at either end; a continuous cable was strung horizontally between them. The cable supported a metal wrist cuff padded with rubber, allowing horizontal movement of the cuff. To one of the v-pulleys was attached a potentiometer, together with torque motors that could be activated to provide resistance to movement (not used in the present experiments). A more complete description of the apparatus can be found in Wadman et al. (1980).

The signal from the potentiometer was fed to amplifiers, and resulting position and velocity signals were delivered to a 7-channel FM tape recorder and to an oscilloscope visible only to the experimenter. The position of the handle in the horizontal plane was indicated as a small mark on a large oscilloscope screen (P4 phosphor, rise time to 90% of maximum intensity of about 0.5 msec) placed 30 cm from the center of the metal frame, visible to the seated *S* on the opposite side of the frame. A 10 mm square patch could be made to "jump" 12.5 cm to the left or right from its center position under the experimenter's control, and by moving the wrist cuff, the *S* could position the small mark on the screen under any of the positions of the patch.

Procedures and design

A choice-RT paradigm was used in which the *S* would move either to the left or right a distance of 15 cm when the patch on the screen jumped from its center position. The sequence of right and left stimuli was determined randomly, and four trials in a 25-trial block were catch trials in which the accessory was presented (as described below), but the stimulus-patch did not move. *S*s heard a ready signal (*Klaar* in Dutch), and then either 1, 2, or 3 sec later the stimulus patch moved (except on catch trials). Emphasis in instructions was placed on moving quickly, and no emphasis was placed on target accuracy, except the *S*s were told to move to the approximate location of the target patch on each trial.

Two variables were used in a 2 × 2 design. The first variable was accessory presence. In the no-accessory condition, only the visual stimulus as described above was presented, and *S*s made use of only visual information. In the accessory condition, the visual stimulus was paired with a loud (93-dB) "pop" from a speaker placed atop the oscilloscope 1.3 m from, and directly in front of, the *S*. The duration of the sound stimulus was 10 msec, and it was presented simultaneously with the visual stimulus.

The sound stimulus did not provide any indication of movement direction, being the same for both right and left visual stimuli.

The second experimental variable was stimulus intensity, a variable known to affect a stimulus-identification stage. In the high-intensity condition, the intensity of the stimulus patch was 600 cd/m^2, whereas the intensity was 30 cd/m^2 for the low-intensity condition. These intensities were presented for both the initial position of the patch and the target position to which it "jumped", and were given against a background illumination of 10 cd/m^2.

*S*s were tested in a blocked order, in which each combination of stimulus intensity and accessory presence was constant for 25 trials. Two complete replications of the experiment were provided, such that each *S* received 50 trials at each of the treatment combinations. Each *S* received the treatments in a randomized order, and a 15-trial "warm-up" was given before each 25-trial block.

Measurement of RT

The velocity records differentiated from the positional traces were played onto a storage oscilloscope (50 msec/division) for analysis, and the time from stimulus until first break of the velocity trace was taken as the RT for that trial (Gielen et al. 1983). Thus, the measured RTs were somewhat (about 40 msec) shorter than they would have been if the time to first movement had been measured, and thus somewhat shorter than are usually found in RT studies. The within-*S* mean, median, and *SD* were computed for each *S*, using all 50 correct trials; errors, where the movement occurred in the incorrect direction, were recorded but not included in the analysis of RTs. Error trials were repeated at the end of a block in a random order.

Results

Means

The across-*S*s averages of the within-*S* mean RTs for each condition are shown in fig. 1. Overall, there was an effect of stimulus intensity, with the high-intensity stimulus resulting in RTs approximately 15 msec shorter than the low-intensity stimulus. Every *S* showed this trend, and the effect was significant in a repeated-measures ANOVA, $F(1,7) = 83.6$, $p < 0.05$. Also, there was a main effect of accessory presence, with the accessory signal reducing RTs by approximately 30 msec. Again, this trend was present for all *S*s, and was significant, $F(1,7) = 198.4$, $p < 0.05$. There appeared to be a slight interaction, with the stimulus-intensity effect being slightly larger for the no-sound condition (18 msec) than for the sound condition (13 msec), but this effect was inconsistent across *S*s, and failed significance, $F(1,7) = 1.1$, $p > 0.05$. This lack of significant interaction indicated that the accessory did not act within the stimulus-identification stage, and was contrary to the predictions of the energy-summation hypothesis.

Medians

The across-*S*s averages of the within-*S* medians revealed a trend nearly identical to that shown in fig. 1 for the means. There was a significant effect of stimulus intensity,

$F(1,7) = 99.9$, and of accessory presence, $F(1,7) = 236.0$, $p < 0.05$. However, the interaction effect was again small and inconsistent across *S*s, with the intensity effect being 18 msec when the sound was absent and 13 msec when it was present; and the interaction failed significance, $F(1,7) = 0.9$, $p > 0.05$. As with the analysis of mean RT, the medians provided no support for the hypothesis that the accessory stimulus was acting in the stimulus-identification stage.

Errors

Error responses, on which the *S* moved initially in the incorrect direction, numbered 48 for the entire experiment, representing a relatively small overall error rate (3%). However, the errors did not appear to be distributed uniformly across the various treatment conditions, with the majority (42 errors) being associated with the accessory condition. The effect was significant, with $\chi^2(1) = 27.0$, $p < 0.05$. On the other hand, the errors appeared to be affected only slightly by the stimulus-intensity variable, with the high-intensity stimulus resulting in an error rate (3.5%) slightly larger than the dim stimulus (2.5%), but this effect was not significant, $\chi^2(1) = 1.3$, $p > 0.05$. Also, the effects of these variables appeared to be roughly independent, and this was supported by a nonsignificant $\chi^2(1) = 1.8$, $p > 0.05$. Finally, in terms of errors produced on catch trials, no *S* under any of the conditions produced a response to the accessory stimulus when presented alone (i.e., on catch trials).

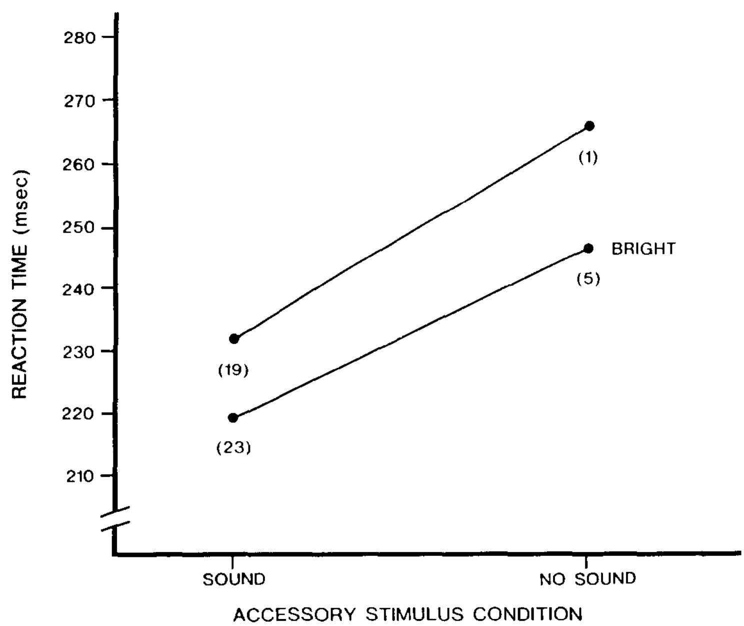

Fig. 1. Mean RT in experiment 1 as a function of visual stimulus brightness and presence of an accessory sound stimulus (total errors in parentheses).

Discussion

This experiment provided no support for the hypothesis that the effect of the accessory stimulus in choice-RT situations is involved in a stimulus-identification stage of processing. The separate effects of the variables of stimulus intensity and accessory presence were relatively large (15 and 30 msec, respectively) and statistically reliable, yet the slight tendency for an overadditive interaction shown in the descriptive statistics (a difference of only 5 msec between the intensity effects at the two accessory conditions) was inconsistent across *S*s and was not statistically reliable. This evidence suggested that the effect of the accessory stimulus was in some stage other than that associated with stimulus intensity. These findings provide difficulties for an energy-summation hypothesis, which holds that the accessory effects should interact with intensity effects, since the accessory is argued to operate in this early stage of processing.

It is still possible that the accessory stimulus could be operating in a part of the stimulus-identification stage, however, as Sanders (1980) has argued that this stage is logically separable into three substages, probably two of which are sensitive to our manipulations of stimulus intensity. These three substages are termed *preprocessing* (with signal contrast being a variable), *feature extraction* (with signal quality being relevant), and *stimulus identification* (with variables like word frequency being relevant). It is not clear as to which of the substages our stimulus-intensity variable affected, because our manipulations of intensity affected both intensity of the stimulus (feature extraction) as well as its contrast with the background (preprocessing). Either or both of these first stages within stimulus identification are where energy-summation effects would be expected, and the lack of interaction of stimulus brightness with accessory presence contradicts predictions from the energy-summation hypothesis. But, it is possible that the accessory acts in Sanders' (1980) third substage, perhaps through increased alerting and a lowered criterion. The tendency for the accessory to increase errors is also consistent with this hypothesis.

The results from experiment 1 also speak to the locus of stimulus-brightness effects in RT experiments. Posner (1978: 113) has entertained the possibility that a bright imperative stimulus and/or an accessory stimulus both act, in addition to other effects, to produce an alerting change which results in more rapid stimulus identification and increased errors. Such a view predicts that stimulus brightness and accessory presence should interact, as they affect a common stage. The failure of such an interaction to occur here suggests that this hypothesis might be incorrect, although acceptance of a null interaction is required for this conclusion.

This analysis is complicated, however, by the fact that Bernstein et al. (1973) have shown interactions between stimulus brightness and accessory presence, but in go/no-go paradigms, and these results tend to support Posner's expectation. We (Gielen et al. 1983) have argued before that these paradigms may produce complicated strategies by *S*s dealing with the various combinations of stimulus events. And, these methods provide other difficulties, most important of which is very high error rates on catch trials. Indeed, Bernstein et al. (1973) found error rates as high as 41% for accessory-only trials, whereas on comparable trials in our experiment the *S*s made no errors at all. Also, the size of the interaction in Bernstein's experiments was 25 msec, whereas ours was only about 5 msec (and nonsignificant). These marked differences in results tend to suggest that rather different processes may be occurring in go/no-go and choice-RT paradigms, at least when accessories are involved.

Finally, the analysis of directional errors (not associated with catch trials) showed that the accessory presence tended to increase errors in movement direction. This finding is consistent with both Posner's (1978) and Nickerson's (1973) views, where errors are produced via a lower criterion, and seem inconsistent with an energy-summation view that argues for increased rate of information acrual in a peripheral stage. It is tempting to argue that the roughly additive effects of the brightness and accessory variables on errors implies that they act in separate stages, but the test is weak since the effect of brightness on errors was not statistically reliable. Finally, it is interesting that, in contrast to the go/no-go paradigms (e.g., Bernstein et al. 1973), *S*s here had no difficulty in inhibiting responses on accessory-alone trials, suggesting that these two RT paradigms might be acting in fundamentally different ways, at least in relation to accessory stimuli.

Experiment 2

This experiment involved the factorial manipulation of the accessory presence with spatial S-R compatibility. Thus, the study involved the role of the accessory in the response-selection stage.

Method

Subjects

Eight people associated with the Department of Medical Physics at Utrecht were used in this study. All were male, and all had received considerable practice in RT situations, and with the particular apparatus used here. Six of the *S*s were also involved in experiment 1.

Apparatus, procedures, and design

The physical apparatus was exactly as in experiment 1. Other procedural details such as testing methods, measurement of RTs, etc. were identical as well.

The variables of interest in this study were accessory presence, manipulated exactly as in experiment 1, and spatial S-R compatibility – a variable usually argued to affect a response-selection stage of processing (e.g., Klapp 1977; Sanders 1980; Schmidt 1982), during which the *S* is presumably selecting the appropriate action (given the stimulus that was presented) from a number of possible actions. In the low-compatibility situation, the *S* was to make a movement opposite in direction to the movement of the stimulus patch. Thus, if the patch "jumped" to the right, a leftward movement would be necessary in order that the small mark indicating hand position would be aligned with the stimulus patch. In the high-compatibility condition, a rightward stimulus indicated a rightward response. Again, a two-choice RT paradigm was used, with the treatment conditions being presented in separate blocks of 25 trials, with two complete replications of the experiment for a total of 50 trials per S for each condition. Catch trials, where no visual stimulus was given, but the accessory stimulus was given, occurred on eight of the 50 trials per condition as before. Error responses were recorded, and repeated at the end of a 25-trial block.

Results

Means

The across-Ss averages of the within-S mean RTs for each condition are plotted in fig. 2. Overall, there was a main effect of S-R compatibility, with the low-compatability condition having approximately 36 msec longer RTs than the high-compatability condition. Every S showed this general trend, and the effect was significant with $F(1,7) = 148.1$, $p < 0.05$. Also, there was a main effect of accessory presence, with the dual-stimulus condition producing a 23 msec reduction in RT relative to the vision-alone condition. Again, every S showed this effect, and it was significant with $F(1,7) = 77.0$, $p < 0.05$. There appeared to be an underadditive interaction, with the difference between the compatibility conditions under the sound condition being 41 msec and the no sound condition being 31 msec; however, this effect was inconsistent across Ss, and failed significance, $F(1,7) = 2.09$, $p > 0.05$. This lack of significant interaction failed to support the hypothesis that the accessory stimulus was active in a response-selection stage.

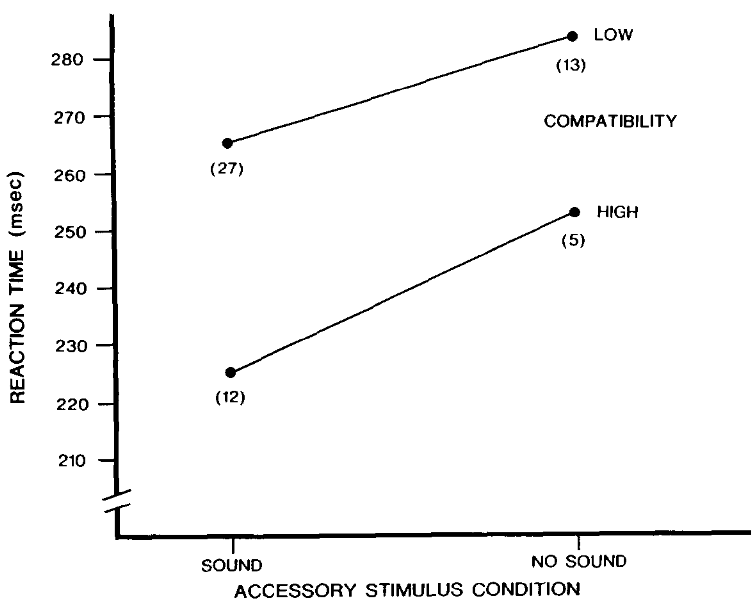

Fig. 2. Mean RT in experiment 2 as a function of S-R compatability and presence of an accessory sound stimulus (total errors in parentheses).

Medians

The across-*S*s average of the within-*S* medians revealed a trend virtually identical to that shown in fig. 1 for the means. Again, there was a significant main effect of compatibility, $F(1,7) = 153.6$, $p < 0.05$, and of accessory presence, $F(1,7) = 48.6$, $p < 0.05$. And, the trend of an interaction between compatability and accessory presence was present, with the compatibility difference being 47 msec when the accessory was present and 32 msec when it was not. But the effect was inconsistent across *S*s and was not statistically significant, $F(1,7) = 2.3$, $p > 0.05$. Like the analysis of means, the median data failed to support the hypothesis that the accessory effect was located in the response-selection stage.

Errors

The total number of responses in which the movement was in the incorrect direction are given in parentheses in fig. 1 below the data points for each condition mean. The rate of errors overall was quite low, with 57 total errors across eight *S*s and 200 trials per *S*, yielding a percentage error rate of only 3.6%. The number of errors tended to be somewhat larger for the low-compatibility condition (40) as compared to the high-compatibility condition (17), an effect which is usual in two-choice RT experiments; it was significant, with $\chi^2(1) = 9.28$, $p < 0.05$. As in experiment 1, the accessory stimulus appeared to cause increased errors, with the accessory condition showing 39 errors, and the vision-alone condition showing 18 errors; this was significant, $\chi^2(1) = 7.73$, $p < 0.05$. These effects appeared to be nearly additive, and were independent statistically, with $\chi^2(1) = 0.05$, $p > 0.05$. Both trends have been reported previously (e.g., Posner et al. 1976; Posner 1978), but the apparent additivity between them, to our knowledge, has not. As with experiment 1, no *S* under any of the conditions responded on a catch trial where the accessory stimulus was presented alone.

Discussion

Generally, the analysis of means and medians in experiment 2 provided no support for the hypothesis that the effect of the accessory stimulus was acting in a response-selection stage of processing. The effect of both independent variables was large (36 and 23 msec for S-R compatibility and accessory presence, respectively) and significant, providing a situation where an interaction, if it was present, could manifest itself. Yet the interaction effects examined for each *S* separately were quite inconsistent; two *S*s showed no interaction, four showed a small underadditive interaction, and two showed a small overadditive interaction. If one can argue that the effect of S-R compatibility seems confidently placed in a response-selection stage (e.g., Sanders 1980), these data offered no convincing support for the hypothesis that the accessory stimulus had effects in this stage of processing.

As with experiment 1, the error analysis supports the results from the analysis of means and medians. Both of the factors in this experiment contributed to errors, with each contributing about 11 errors as it was manipulated. That these errors tended to be additive, with the smallest number of errors being 5 in the high-compatibility/no-accessory condition, and the largest number being 27 in the low-compatibility accessory condition, suggested that the sources of these errors were in different stages of processing. If this analysis of error data can be accepted, it provides additional evidence that spatial S-R compatibility and the accessory stimulus had their effects in separate stages.

Experiment 3

In this experiment, the focus was on the possibility that the accessory stimulus would act in a response-programming stage. Thus, the variables studied were accessory presence and movement complexity. Earlier evidence has tended to link accessory presence with this stage of processing, but the logical links are not particular strong. For example, Bernstein et al. (1970, 1973) and Sanders (1980) have found that foreperiod duration interacts with accessory presence. Because foreperiod duration is thought to affect alerting, and because alerting is thought to operate in stimulus identification (Posner 1978) or in somewhat later stages of processing, this evidence can be seen as favoring an alerting role for the accessory. Furthermore, Sanders (1980) has found that foreperiod duration interacts with instructed muscle tension, again placing foreperiod effects and the accessory in a late stage of processing. But because of the tenuousness of these logical links, we wanted to determine more directly whether the accessory was operating in a response-programming stage by examining the accessory's interaction with a variable known to affect this stage – movement complexity.

Method

Subjects

Eight people associated with the Department of Medical Physics at Utrecht served in this experiment. Seven were male and one was female, and all had also served either in experiment 1 or 2. All eight *S*s had considerable experience on the apparatus.

Apparatus, procedures, and design

The physical apparatus was exactly as before. The testing procedures, measurement of RTs, instructions, and orders of testing were similar as well.

The variables of interest in this experiment were accessory presence, manipulated exactly as before, and movement complexity. This latter variable is thought to affect a stage of processing associated with the programming of a response (e.g., Klapp 1977; Sanders 1980; Schmidt 1982), during which the selection of the appropriate patterns of muscular action is established. We manipulated movement complexity by having either a simple response, in which the *S* moved 15 cm to a target, or a complex response, in which the *S* made a 15 cm movement to the target and then reversed direction to return to the starting position. Movements were to be as rapid as possible.

The procedures involved a choice-RT response as in experiments 1 and 2, where the movement could be either to the right or left, randomly determined across trials. The four experimental conditions were done in a blocked fashion, with constant levels of the independent variables for 25 trials, and two replications, for 50 trials/*S* in each condition. Ss completed all four conditions in a separate order determined randomly. In the complex-movement trials, a leftward movement of the stimulus patch implied that the S should move leftward first, and then return to the starting position; in the simple-movement trials, a leftward single movement was required. All trials were two-choice, with the uncertainty being the direction of the upcoming stimulus movement. Catch trials, in which no visual stimulus was presented, were given on eight trials in each condition, as before.

Results

Means

The average of the within-S mean RTs are given in fig. 3. As before, the presence of the accessory reduced RTs, here by about 31 msec. This effect was present for all Ss, and was significant in a repeated-measures ANOVA, $F(1,7) = 58.0$, $p < 0.05$. The complex movement resulted in a 13 msec longer RT than the simple movement. This effect was present in all but one S, and was significant in the analysis, $F(1,7) = 10.9$, $p < 0.05$. The two variables appeared to interact slightly, with the simple-complex difference being 10 msec under the accessory condition, and 17 msec under the no-accessory condition. This interaction was at least weakly present in all of the Ss, and was statistically significant in the repeated-measures ANOVA, $F(1,7) = 15.4$,

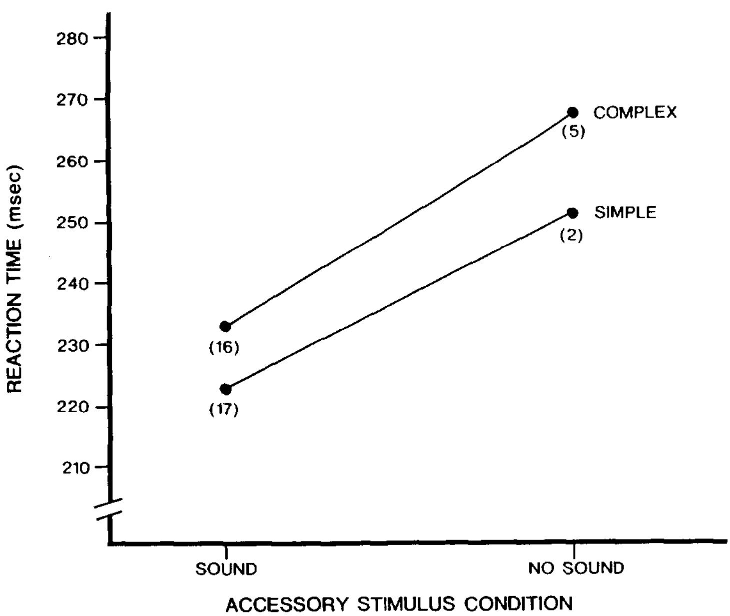

Fig. 3. Mean RT in experiment 3 as a function of movement complexity and presence of an accessory sound stimulus (total errors in parentheses).

$p < 0.05$. This analysis of means provided support for the view that the presence of the accessory was influencing some response-programming stage of processing.

Medians

The analysis just described was also conducted with the within-*S* medians as the dependent variable. The presence of the accessory reduced median RT by 29 msec, which was significant, $F(1,7) = 41.8$, $p < 0.05$. And, the complex movement produced a 14 msec longer median RT than the simple response, $F(1,7) = 7.3$, $p < 0.05$. Both of these effects were essentially as in the analysis of the mean RTs. The interaction effect, which was nearly identical to that in the analysis of mean RT, was however not significant, $F(1,7) = 1.2$, $p > 0.05$. Thus, in the analysis of median RTs, the data did not support the hypothesis that the effect of the accessory stimulus was in some response-programming stage of processing.

Errors

The total number of errors for each condition are provided below the corresponding data points in fig. 3. Again, the error rates were small, overall being about 2.5%. But an examination of these error patterns shows that the incidence of movement in the wrong direction was far larger in the accessory conditions (about 4%) than in the no-accessory condition (about 1%), producing effects essentially like those found in experiments 1 and 2. The effect of the accessory on errors was significant, with $\chi^2(1) = 16.9$, $p < 0.05$. The complex and simple movements resulted in about the same error rate (2.6 and 2.4%), and the effect of movement complexity on errors was not significant, $\chi^2(1) = 0.1$, $p > 0.05$. And, the two variables appeared to be independent, $\chi^2(1) = 1.2$, $p > 0.05$, indicating that the effects of the two variables were roughly additive. Again, no *S* under any condition in this experiment responded on a catch trial when the accessory was presented alone.

Discussion

This experiment was apparently successful in manipulating the duration of the response-programming stage. The reversal movement resulted in a 13-msec longer RT than the unidirectional movement and, while this difference was not particularly large, it was consistent across *S*s and statistically reliable. Manipulations of movement "complexity" in the past have been inconsistent in their effects from study to study, and have not been particularly consistent across *S*s. And, our methods seem to minimize one additional previous difficulty, in which certain manipulations of complexity (e.g., target size) were confounded with the velocity of the initial portions of the movement. When target size, for example, is increased, movement velocity increases, making the interval from initial muscle contraction until switch closure (a distance of only 2 mm or so) longer, perhaps increasing RT artificially. It is difficult to see how, using the tasks and methods we did, this criticism could be leveled here, and the present methods can be recommended for future studies of response programming.

Again, presence of the accessory had strong effects on RT and, togehter with the effects of movement complexity, provided a reasonable basis to examine the possible interaction effects. The interactions provided a somewhat confusing picture, with the somewhat inconsistent effect (for different *S*) being significant in the analysis of mean values) using the median RTs. However, an examination of the patterns of interaction for the individual *S*s revealed that the overadditive effect was always present at least to some degree using mean RT. Using medians, however, a single *S* showed a marked deviation from the overall pattern of other *S*s, apparently sufficiently that the error mean square for the interaction was too large for statistical reliability. On balance, we argue that the analysis of means is to be preferred to that for medians here, because the data are more consistent from *S* to *S*. If this interaction is considered reliable, then the interpretation is that the accessory stimulus had some effect on a response programming stage.

Again, as has been found earlier, the accessory increased errors. Although the errors for the movement complexity and accessory presence were statistically independent, the apparent additivity has far less importance here than in experiment 2 because one of the variables (movement complexity) did not affect errors. And, it is again interesting that *S*s had no difficulty in suppressing responses on catch trials when the accessory was presented alone, contrary to findings in earlier studies using go/no-go paradigms.

General discussion

These experiments used the additive-factors logic of Sternberg (1969) in an attempt to infer the locus of accessory effects in choice-RT situations. Of course, the use of this research style, and the acceptance of the interpretations presented here, depend heavily on the viability of the assumption that processing stages are serial and independent. If this cannot be accepted, then some (e.g., McClelland 1979) have argued that additive-factors interpretation of interactions, or lack of interactions, among certain independent variables may not be valid. However, others have continued to argue that the assumptions and logic of the additive-factors method are valid, and the method has continued to be a useful one in studies of this type (e.g., Sanders 1979, 1980; Sanders et al. 1982; Simon 1982). The issue is clearly unsettled, but at least some of the interpretations of the present experiments should be viewed cautiously until arguments concerning the assumptions of the additive-factors method are more clearly resolved.

Within these limitations, the results from our experiments provided no support for an energy-summation view of accessory effects. In experiment 1, no interaction was found between accessory presence and (visual) stimulus intensity, which argued that these variables operate in different stages of processing. The brightness variable we used is probably located in either a preprocessing or feature-extraction substage of the stimulus-identification stage (Sanders 1980), just where an accessory would operate under an energy-summation view. Indeed, most statements of the energy-summation view (e.g., see Nickerson 1973 for one description) emphasize that the accessory speeds the build-up of information in the most peripheral stages, so that decisions are made earlier, and RT is shortened. This view does not predict an increase in errors from the accessory, because the *quality* of information at any time after the imperative stimulus is increased. And, this prediction was contradicted in all three experiments (and in the previous literature), as the accessory increased errors systematically.

As we discussed earlier, it is possible that the accessory acts in the stimulus-identification stage, not through an energy-summation effect, but through increased alerting in Sanders' (1980) third substage of stimulus identification. Our stimulus-brightness variable probably did not tap this stage, and thus the accessory could have acted there without interacting with brightness. And, this suggestion is consistent with the general finding of increased errors with the accessory, which would be expected with a lowered criterion associated with increased alertness.

At the same time, experiment 1 argued against Posner's (1978: 113) suggestion that making an imperative stimulus brighter acts to increase alerting in the same way as (in the same stage as) the accessory stimulus does. If so, then we should have found that brightness and accessory presence interact. It seems more consistent with the existing data to suggest that stimulus brightness acts in the very earliest stages, and that the accessory acts in either a late substage of identification and/or later processing stages dealing with motor programming. In any case, the accessory and brightness appear not to act in the same stage.

Experiment 2 provided no support that the accessory acted in a response-selection stage, as the interaction between accessory presence and spatial S-R compatibility was very inconsistent and not statistically reliable. And, the finding that the errors produced by these two variables tended to be additive also suggested that the accessory was acting in a stage separate from response selection.

Our experiment 3 suggests that the accessory also acts in response programming, a conclusion stemming from the interaction of accessory presence with movement complexity. This finding favors Nickerson's (1973) view of the accessory, in which the preparation for the response is enhanced as a form of alerting. Thse findings would suggest that some late stage of processing involving the "tuning" of the segmental apparatus (e.g., Kots 1977), the generation of movement commands (or programming), or other motor processes, are enhanced by the accessory stimulus, leading to more rapid movement planning. Our data do not speak to the possibility that errors in movement direction are created at this state, rather than at a stimulus-identification stage as Posner (1978) suggests, as the movement-complexity variable did not affect errors sufficiently that the interaction of these sources of variability could be evaluated. But, these two locations for error production are certainly possible.

Various views of the effect of the accessory stimulus in the response-programming stage are possible. One is that the accessory acted to speed the "assembly" of movement programs, as our movement complexity variable is thought to manipulate the amount of such processing that must be done to create the action. But Sanders (1980) views the response-programming stage as consisting of two substages, one to "assemble" the movement commands, and another termed *response adjustment* that seems sensitive to the preparation-like effects of the length and regularity of the fore-period and instructed muscle tension. With our data seeming to argue for the accessory acting in a stage associated with the assembly of the program, and Sanders (1980) and Van der Molen and Keuss (1979) arguing that the accessory is associated with motor adjustment, the evidence suggests that the accessory increases alerting, thereby affecting *both* late substages in response programming.

Finally, the results of experiment 3 tend to argue against Posner's (1978) view that *all* of the alerting effects of the accessory act to terminate the processing in stimulus-identification more quickly. Such a strong view of alerting would not predict that the accessory would interact with a movement-complexity variable that almost certainly has its locus in a late stage of processing. Thus, while we cannot rule out Posner's view that the accessory operates in a stimulus-identification stage, our data argue for a broader role of the accessory in a number of stages of processing – here, stimulus identification and/or response programming. Of course, this view of accessory activity is what Nickerson (1973) called the preparation-enhancement view, although he could not be specific at the time about which stages were involved. In general, then, our data seem to argue for an alerting or arousing role for these accessory stimuli that may alter processing in a number of stages, and at the same time provide no support for an energy-summation view.

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