Psychol Res (1987) 49: 23–29

Psychological Research

Intersensory facilitation in the motor component?

A reaction time analysis

Adele Diederich[1] **and Hans Colonius**[2]

[1] Universität Hamburg, Psychologisches Institut I, Von Melle-Park 6, D-2000 Hamburg 13, Federal Republic of Germany
[2] Universität Oldenburg, Institut für Kognitionsforschung, Postfach 2503, D-2900 Oldenburg, Federal Republic of Germany

Summary. In the bimodal detection task the observer must respond as soon as a signal is presented in either of two modalities (e.g., a tone or a flash). A typical finding is a facilitation of reaction time for redundant signal trials, that is, when both signals are presented simultaneously or with a short delay. Models advanced for this effect imply either *statistical facilitation* (separate activation) or *intersensory facilitation* (coactivation). This paper reports a study investigating whether part of the facilitation can be accounted for by coactivation in the motor component. An analysis of the distributions of reaction time differences between left and right hand responses from a double response paradigm gave some evidence in favor of this hypothesis. In particular, our data suggest a u-shaped functional dependence of the amount of facilitation in the motor component on the interstimulus interval.

In the bimodal detection task considered in this paper the observer must respond to a signal presented well above threshold in either of two modalities, that is, a flash or a tone. On *single* signal trials only one signal is present, while on *redundant* signal trials both signals are presented simultaneously or with a brief delay. Since the pioneering work of Todd (1912) it has been generally found that first, for medium intensity levels, reaction time (RT) to auditory stimuli is faster than RT to visual stimuli; second, RT in the redundant signal situation is facilitated when both signals are presented simultaneously; moreover, RT to a visual stimulus followed by an auditory stimulus *d* ms later ($d \leq 100$ ms) is shorter than RT to the auditory stimulus alone plus the delay between the two stimuli.

This evidence has been taken to rule out the hypothesis that the subject simply responds to the (often faster) auditory stimulus channel. Rather, there seems to exist some interaction among the sensory modalities leading to a faster RT. The term "*intersensory facilitation*" has been used to describe such results. Two types of models have been advanced to account for intersensory facilitation: (a) those postulating the summation of stimulus energy across sensory modalities ('energy summation') and (b) those that conceive of the auditory stimulus as an alerting cue ('preparation enhancement'). There has been considerable debate over these alternative views, for an excellent review see Nickerson (1973).

Moreover, the issue was whether or not faster RTs in redundant signal situations should be interpreted as 'true' intersensory facilitation effects at all. Raab (1962) demonstrated that because of the variabilities in processing times of the stimuli in peripheral stages of processing, there could be a kind of *statistical facilitation* with the subject responding to whichever of the two stimulus modalities occurred in a particular trial first. Predictions of this 'race' model are based on the fact (true for arbitrary random variables) that the mean of the minimum of two processing times is always smaller or equal to the minimum of the means of either single processing time. Miller (1982) proposed a simple distribution inequality (see below) which, if violated, purports to rule out any explanation of the facilitation effect based solely on a race mechanism. Moreover, recent investigations by Gielen, Schmidt and van den Heuvel (1983) suggest that, while such a mechanism may in fact be operating in the redundant signal situation, some portion of the decrease in RT cannot be accounted for by statistical facilitation. For a discussion of the assumptions underlying the race model see Colonius (1986).

Within the class of models for intersensory facilitation, the question of the locus of the facilitating mechanism has been the focus of much interest recently. We have no intention to review the various arguments here. Suffice it to say that the energy summation view places the locus of intersensory facilitation in early stages, those dealing with sensory information processing. On the other hand, the preparation enhancement view has at least part of the facilitation effect in later stages of processing, such as response selection or response programming. Schmidt, Gielen, and van den Heuvel (1984), using Sternberg's (1969) additive-factors logic, found data arguing for a rather broad role of the stimulus as an alerting cue in a number of late stages of processing, in particular those of response programming, which they interpreted as evidence for the preparation enhancement view. However, it seems fair to say that the issue is far from being settled.

The practice of combining the evidence from various experimental results is marred by the fact that investigations often differ in their experimental setup. For example, data from an experiment with catch trials – where the auditory stimulus is occasionally presented alone, and the subject must *not* respond if it is – are not directly comparable to those from an experiment without catch trials since

---

Offprint requests to: H. Colonius

the subjects' strategies may be quite different. Moreover, it is not obvious to us that evidence for intersensory facilitation from an experiment dealing with letters as stimuli is directly relevant to the way of looking at mechanisms involved with much simpler visual and/or auditory signals.

Further discussion is to be seen in the following framework.

Figure 1 depicts the common serial stages view of processing, where peripheral sensory channel processing is followed by a central stimulus processing stage ending up with response preparation and a motor delay component leading to the observable response. There has been some controversy about the assumption of strict seriality of stages implied by this model (cf. McClelland, 1979; Ashby, 1982; Miller, 1982; Meyer, Yantis, Osman, & Smith, 1984). The following development, however, only rests upon the assumption of separability of an additive motor component from the observable response time.

A general finding in simple RT studies is a speeding up of responses with increasing stimulus intensity. While this is commonly attributed to facilitation of processing in early stages of stimulus encoding (e.g., Burbeck & Luce, 1982; Kohfeld, Santee, & Wallace, 1981), Ulrich and Stapf (1984) present evidence for a speeding up of the motor processes by increasing stimulus intensity as well. The experiment reported below aims at looking at that very late stage of processing. It is conjectured that intersensory facilitation, if it occurs, is also present – at least partially – in the motor component. This is not to say that the mechanisms involved in processing intensity variations and those of intersensory facilitation are identical. It is conceivable, however, that varying the time delay between visual and auditory stimulus may have an effect on the motor system comparable to varying stimulus intensity.

Before stating our hypotheses in more detail, the main conceptual tool for studying motor component effects is to be made explicit. As noted above, it is assumed here that observable response times consist of two additive random components:

$$\mathrm{RT} = S + M \tag{1}$$

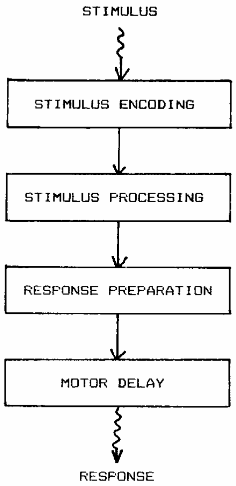

Fig. 1. The serial-stages model of processing

with S denoting the time needed to detect and process the stimulus and to prepare the motor command for movement execution, while M refers to the motor delay. In the *double response paradigm* (cf. Ulrich & Stapf, 1984), the subject is requested to respond to a stimulus with both hands simultaneously. The response times for the right and the left hand then are

$$\mathrm{RT}^{(r)} = S + M^{(r)} \text{ and } \mathrm{RT}^{(l)} = S + M^{(l)} \tag{2}$$

with $M^{(r)}$ and $M^{(l)}$ denoting the hand-specific motor delays. On any given trial, the random variables S, $M^{(r)}$, and $M^{(l)}$ take on values according to some (unknown) probability law. Whenever $M^{(r)}$ is smaller than $M^{(l)}$, the response of the right hand precedes the response of the left and vice versa. The point of using this double response paradigm is the fact that by taking differences

$$D = \mathrm{RT}^{(r)} - \mathrm{RT}^{(l)} = M^{(r)} - M^{(l)} \tag{3}$$

the common component S is dropped, that is, D depends only on those stages that follow the central motor command. Consequently, if facilitation only occurs in stages preceding the motor delay, the distribution of D should be unaffected by any experimental manipulation varying the amount of facilitation.

The empirical investigation was guided by the following questions:

1. Is the decrease of RT in the redundant signal situation, if it occurs, explainable entirely in terms of statistical facilitation (separate activation) or is it necessary to postulate some coactivation mechanism?

2. If coactivation is to be assumed, can part of the effect be located in a very late stage of processing, that is, the motor delay?

To replicate the facilitation effect simple visual and auditory stimuli of medium intensity were applied. The time delay between the stimuli in the redundant signal situation is used as the main independent variable presumably affecting the amount of facilitation.

Experiment

Subjects. Four right-handed subjets *(MJ, AD, HC, HE)*, two female and two male, associated with the psychology department of Oldenburg University, participated in the experiment (*AD* and *HC* refer to the authors.) All have some experience with RT tasks.

Apparatus. The visual stimulus was a flash (250 Lux) of $^{1}/_{16}$ s duration generated by a flashlight (SUNPAK auto 36DX, Thyristor) and projected onto a projection screen at a distance of 3.5 m. The subject was seated in a sound-attenuated, darkened room 2.5 m in front of the screen. The auditory stimulus was an 80 db SPL sinusoidal tone of 1000 Hz presented binaurally over headphones (Sennheiser HD 414). Signal presentation and RT registration were controlled by a PDP 11/34 processor. Two Morse keys in front of the subject served as response buttons for each hand separately.

Procedure. The beginning of each trial was signaled to the subject by a small warning lamp in front of the screen. After a random foreperiod, the visual stimulus (Condition *V*), the auditory stimulus (Condition *A*), or the visual stimulus followed by the auditory d ms later (Condition *VA(d)*) were presented. The subject was instructed to press the response buttons with the index fingers as fast as possible upon detecting either signal (no catch trials). The reaction time was recorded from stimulus onset to keypress for each hand separately. After the last response there was a 3-s pause before the beginning of the next trial was signaled. The first response in each trial terminated the auditory signal.

The purpose of the random foreperiod was to avoid anticipatory responses. The random foreperiod was never less than 1 s. In every trial, an exponentially distributed random duration (mean 1 s) was added to a 1-s base time. If a response occurred prior to stimulus onset, a rattle indicated a false alarm followed by a repetition of the trial. Only very few anticipatory responses actually occurred.

The interstimulus interval (ISI) *d* ranged from 0 to 90 ms in steps of 10 ms. In each block of 20 trials, a specific stimulus condition (*V, A*, or *VA(d)*) was held constant. A single experimental session consisted of 12 blocks with a random, balanced order of conditions except that the first block always consisted of 20 trials of the *VA*(90) condition. This block functioned as a warming-up period and was not used in later data analysis. After four blocks, there was a 10-min rest period. Each session took about 1 h. All subjects participated in four training and ten experimental sessions resulting in a sample of 200 responses for each subject in each of the 11 conditions taken for data analysis.

Results. Means and standard deviations of RTs under all experimental conditions can be found in Table A1 in Appendix 1 with each subject and hand listed separately. While there are some interindividual speed differences, the overall picture is about the same for all subjects. The reaction time to the auditory signal is about 40 ms shorter than RT to the visual signal. There is a small but consistent laterality effect with the left hand responses being 5–10 ms faster than the right hand responses, which is in accordance with a finding of Annett and Annett (1979) with respect to right-handed subjects. The best way to check for facilitation effects is to plot mean RT as a function of the ISI *d*. Figure 2 (a–d) depicts these data for each subject separately. The triangles (Δ) refer to measured mean RTs, while the solid line represents the RT expected if no facilitation is assumed to occur. The area in between may be taken as indicative for the amount of facilitation present in the data. For all subjects, an ISI about equal to the difference between the mean RT in Condition *V* and Condition *A* generates maximal facilitation. This ISI corresponds to maximal overlap between the processing time distributions of the visual and auditory signal and is to be expected if statistical facilitation is at work (for details, see Raab, 1962; Gielen et al., 1983). It presents, of course, no evidence against any form of intersensory facilitation. In the next section, it is checked whether the observed decrease in RT can be explained by statistical facilitation alone.

Testing for statistical facilitation

Let RT_V, RT_A, and $RT_{VA(d)}$ denote the reaction time random variable in the visual, auditory, and combined stimu-

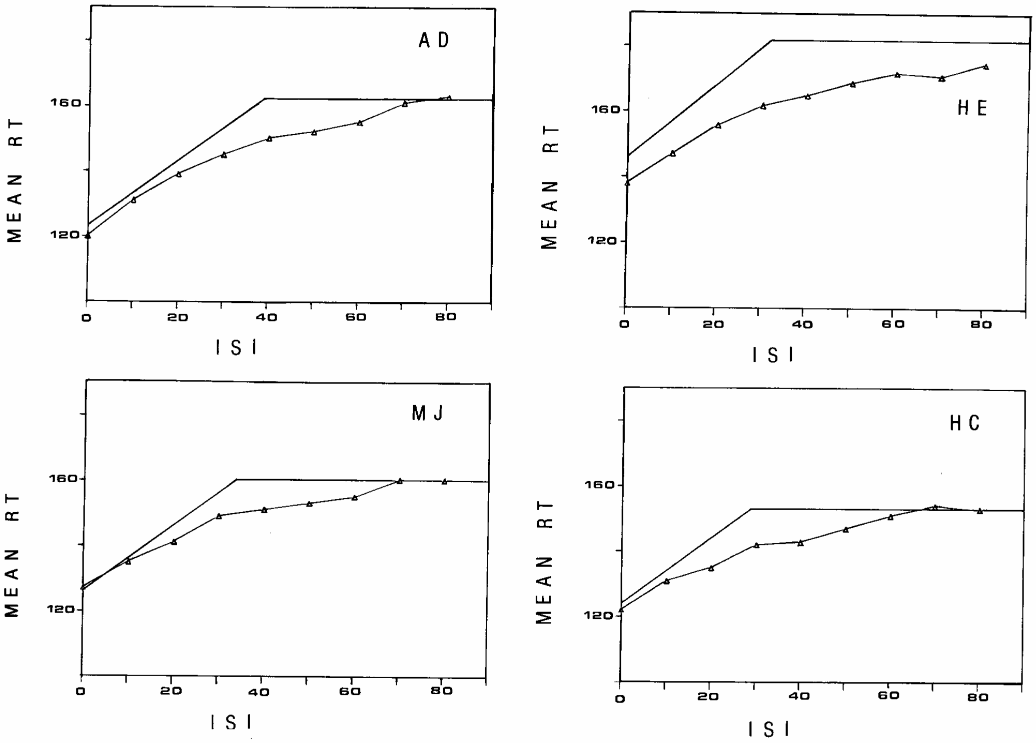

Fig. 2. Observed mean RT as a function of the interstimulus interval (the solid line represents RT if no facilitation is present)

lus condition, respectively. Equation (1), postulating an additive decomposition of RT into a detection and motor delay part then implies

$$\mathrm{RT}_V = S_V + M \text{ and } \mathrm{RT}_A = S_A + M \qquad (4)$$

with S_V and S_A denoting the (random) detection time in the visual and auditory condition, respectively. Moreover, the race mechanism in the model of statistical facilitation postulates that in the redundant signal situation, detection time is determined by the minimum of the two stimulus processes, that is,

$$\begin{aligned}\mathrm{RT}_{VA(d)} &= \min(S_V, S_A + d) + M \\ &= \min(\mathrm{RT}_V, \mathrm{RT}_A + d) \qquad (5)\end{aligned}$$

for $d = 0, 10, \ldots, 90$. From elementary probability theory, it follows that

$$P(\mathrm{RT}_{VA(d)} \leq t) \leq P(\mathrm{RT}_V \leq t) + P(\mathrm{RT}_A \leq t-d) \qquad (6)$$

for any t.

Estimates for the above probabilities are obtainable from the empirical (cumulative) distribution functions in the corresponding experimental conditions. As observed by Miller (1982), Inequality (6) provides a test for statistical facilitation. If (6) is violated for any t, facilitation is greater than a model of separate activation is able to predict, no matter what specific distributional assumptions about S_V, S_A, and M are made. On the other hand, nonviolation of (6) does not represent evidence in favor of separate activation models since coactivation mechanisms satisfying (6) are conceivable (cf. Miller, 1982).

In testing Inequality (6) for our data, it should first be observed that violations are to be expected only for values of t that are not too large. The reason is that for large values of t, all cumulative distribution functions in (6) approach an upper boundary of 1 yielding the inequality $1 < 1 + 1$ in the limit. Second, a null hypothesis of the form of Inequality (6) involving the sum of two probabilities is not amenable to standard nonparametric testing procedures. Miller (1982) applied paired t-tests at the various percentile points of the empirical cumulative distributions corresponding to the left and right hand sides of Inequality (6) and, seeing the need for justification of this approach, performed extensive simulations to back his conclusions. Lacking convincing alternatives at this time, we settle for a descriptive evaluation of the data.

For all subjects, violations of Inequality (6) can be observed. Moreover, the degree of violation, that is, by how much the inequality is reversed, depends on the size of the ISI in the following way. For $d = 0$, there is small (Subject *AD*) or no violation (Subjects *MJ* and *HC*). Then, violation increases as d increases until $d = 40$ and decreases again reaching about the starting level at $d = 80$. For Subject *HE*, violation is more salient throughout, but the same trend as above is discernable. Some illustrative data from Subject *HC* are depicted in Figure 3 below (The complete data set is available from the authors upon request).

In conclusion, violation of Inequality (6) appears quite regularly for all subjects. Maximum violation around an ISI of 40 ms parallels the maximal facilitation found above in the analysis of mean RTs.

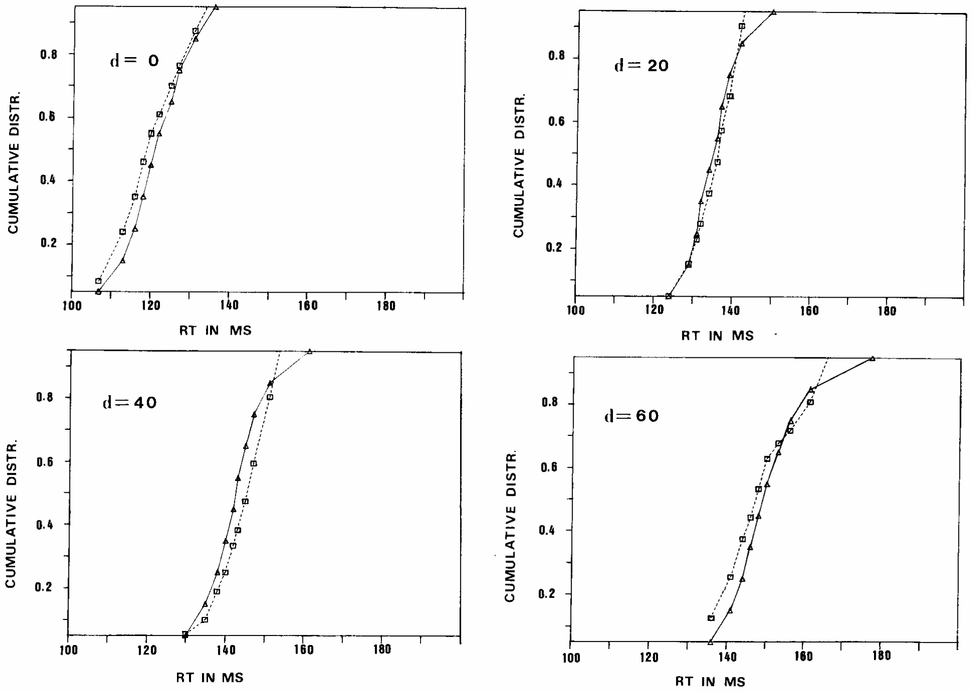

Fig. 3. Cumulated RT distributions: triangles refer to double stimulus condition, squares to the sum of auditory and visual single stimulus condition

Testing for facilitation in the motor component

Since violation of Inequality (6) suggests that some coactivation mechanism is operating, we take up the question whether (at least) part of this coactivation may be located in the motor component. As pointed out in the first section, the distribution of RT differences between the left and the right hand may be revealing in this respect. Note that:

$$\begin{aligned} D_{\mathrm{VA(d)}} &= \mathrm{RT}_{\mathrm{VA(d)}}^{(\mathrm{r})} - \mathrm{RT}_{\mathrm{VA(d)}}^{(\mathrm{l})} \\ &= M_{\mathrm{VA(d)}}^{(\mathrm{r})} - M_{\mathrm{VA(d)}}^{(\mathrm{l})}, \end{aligned} \tag{7}$$

that is, the difference between left and right hand RT in the redundant signal situation with an ISI of d ms only depends on the motor delay part of the RT. If, as is commonly presumed, varying d affects the amount of facilitation only in stages preceding the motor delay, the random variables $D_{\mathrm{VA(d)}}$ ($d = 0, \ldots, 90$) should be identically distributed for different values of d. This null hypothesis was tested applying a generalization of the Kolmogorov-Smirnov test by Kiefer (1959). The corresponding test statistic was significant ($p \leq 0.01$) for Subjects *MJ, HE,* and *AD* (for details of the test procedure and the results, see Appendix 2).

While this result indicates that something is in fact going on in the motor component, evidence for coactivation there would be more persuading if a functional dependence on the ISI could be demonstrated. Assuming, for the present, that facilitation in the motor component is proportional to overall observed facilitation (see Figure 2) a U-shaped dependence is to be expected. Specifically, for medium ISI values (20–50 ms), facilitation should be largest, decreasing for smaller or larger ISIs. Unfortunately, there is no way to directly assess this hypothetical effect since the motor delays are unobservable. One may, however, take advantage of the fact, true for most RT studies, that there is a positive correlation between observed variance and mean RT (see also the discussion in Ulrich and Stapf, 1984). Consequently, a shortening of the motor delays for certain ISI values ought to show up in smaller corresponding motor delay variances. The point now is that an estimate of the latter ones is obtainable from the distribution of RT differences as follows:

$$\begin{aligned} \mathrm{var}(D_{\mathrm{VA}}) &= \mathrm{var}(\mathrm{RT}_{\mathrm{VA}}^{(\mathrm{r})} - \mathrm{RT}_{\mathrm{VA}}^{(\mathrm{l})}) \\ &= \mathrm{var}(M_{\mathrm{VA}}^{(\mathrm{r})} - M_{\mathrm{VA}}^{(\mathrm{l})}) \\ &= \mathrm{var}(M_{\mathrm{VA}}^{(\mathrm{r})}) + \mathrm{var}(M_{\mathrm{VA}}^{(\mathrm{l})}) \\ &\quad - 2 * \mathrm{cov}(M_{\mathrm{VA}}^{(\mathrm{r})}, M_{\mathrm{VA}}^{(\mathrm{l})}) \end{aligned} \tag{8}$$

Defining average motor delay variance by

$$\mathrm{var}(M_{\mathrm{VA}}) = (\mathrm{var}(M_{\mathrm{VA}}^{(\mathrm{r})}) + \mathrm{var}(M_{\mathrm{VA}}^{(\mathrm{l})}))/2$$

this yields

$$\mathrm{var}(M_{\mathrm{VA}}) = \mathrm{var}(D_{\mathrm{VA}})/2 + \mathrm{cov}(M_{\mathrm{VA}}^{(\mathrm{r})}, M_{\mathrm{VA}}^{(\mathrm{l})}) \tag{9}$$

Estimating this average motor delay variance from the observable $\mathrm{var}(D_{\mathrm{VA}})/2$ term in the above equation will underestimate (overestimate) the true value whenever the covariance between left and right hand motor delay is positive (negative). In any case, assuming this covariance to be about constant for different ISI values a functional dependence of $\mathrm{var}(M_{\mathrm{VA}})$ on the ISI should be reflected in $\mathrm{var}(D_{\mathrm{VA}})/2$. Given high positive correlations between standard deviation (SD) and mean RT in our data, we tentatively checked this hypothesis for all four subjects. A nonlinear (quadratic) regression analysis of $\mathrm{SD}(D_{\mathrm{VA}})/(2)^{1/2}$ on ISI was performed separately for each subject. For subjects *MJ* and *HC* a significant ($P \leq 0.01$) improvement of quadratic vs. linear regression of $\mathrm{SD}(D_{\mathrm{VA}})/(2)^{1/2}$ on ISI was found. Moreover, combining data from *MJ, HC,* and *AD* (after standardization) revealed a significant ($P \leq 0.05$) quadratic trend in the expected direction. To sum up, our data suggest a U-shaped functional dependence of the amount of facilitation in the motor component on the ISI but, obviously, more research is needed to allow for any strong conclusions about the nature of this dependence.

Discussion

The experiment reported here replicated the facilitation effect observed in many previous investigations. Specifically, we found a U-shaped functional relationship between the amount of facilitation and the interstimulus interval. While this is compatible with both separate and coactivation mechanisms for facilitation, a test of Inequality (6) provided evidence that the amount of facilitation was larger than any separate activation model could predict. However, there is one – possibly serious – argument against using the above inequality for testing recapitulated recently in Luce (1986, p. 129). In applying Equality (5) it is implicitly assumed that the detection time distribution of S_{V} (or S_{A}) in the single signal situation can be equated with the (marginal) detection time distribution of S_{V} (or S_{A}) in the redundant signal situation. This assumption may be plausible in the experimental setup but, when there is reason to doubt it, it is not clear how to test it empirically. One alternative approach is to dispense with the single signal situation entirely and to study the effect on RT of an additional variable, for example stimulus intensity. It may then be possible to develop simple models for coactivation that could serve as plausible alternatives to separate activation models.

This study tried to check in particular whether part of the facilitation effect can be located in the motor component of RT. An analysis of the distributions of RT differences between left- and right-hand responses provided some positive evidence for this hypothesis. Although an effect of the ISI on the motor delay analogous to that on observable RT could not be proven in a direct fashion, our results suggest further research in that direction to be promising. Of course, the method of analysis based on RT differences rests upon the disputable assumption that the motor delay constitutes an additive component of the entire observable RT (see e.g., McClelland, 1979). Note, however, that additivity of prior processing stages is not presupposed here. While this study was not directed at testing this assumption, the overall regularity of our data does not provide any evidence against additivity, either.

Acknowledgements. We thank Arno Schilling for assistance in conducting the experiment.

Appendix 1

	Subject *MJ* Mean RT	SD	Subject *HE* Mean RT	SD
d	*r* *l*	*r* *l*	*r* *l*	*r* *l*
A	125.79/123.81	8.03/ 8.66	145.71/140.74	11.08/11.81
0	126.71/124.95	8.34/ 8.55	137.93/137.38	8.02/ 9.00
10	134.99/133.55	8.84/ 8.80	146.61/145.44	8.80/ 9.67
20	141.43/140.74	7.61/ 8.33	155.58/155.42	11.54/12.58
30	148.69/147.92	7.86/ 7.94	162.35/160.21	10.31/11.14
40	151.37/150.46	10.57/10.67	164.55/162.37	11.16/12.08
50	153.67/150.77	14.19/13.71	168.90/164.46	13.56/13.98
60	154.94/151.44	11.13/ 9.93	172.39/170.08	14.67/16.83
70	160.37/156.88	13.96/14.67	170.59/167.87	12.90/13.82
80	160.17/155.89	14.93/15.23	174.85/170.54	14.46/14.92
V	160.36/157.54	17.05/17.26	181.88/176.76	17.66/17.18

	Subject *AD* Mean RT	SD	Subject *HC* Mean RT	SD
d	*r* *l*	*R* *l*	*r* *l*	*r* *l*
A	123.70/116.87	10.50/ 9.91	123.64/117.81	19.66/17.60
0	120.48/113.41	7.63/ 7.50	121.58/116.13	10.89/10.76
10	131.10/123.40	8.24/ 6.90	130.93/125.36	12.99/11.74
20	139.24/131.52	7.47/ 6.94	135.49/130.33	11.20/11.48
30	145.00/138.26	7.89/ 8.10	141.61/136.51	9.74/10.11
40	149.55/141.40	9.62/ 8.74	142.87/137.08	9.63/ 9.56
50	152.48/144.93	11.02/11.59	147.35/142.48	12.49/12.85
60	155.29/146.55	12.90/11.91	151.04/144.71	12.36/11.72
70	160.51/153.55	13.41/13.47	154.15/148.64	17.30/16.49
80	163.41/155.63	15.36/15.02	152.80/147.13	18.37/17.12
V	161.87/154.61	16.57/16.44	153.04/146.36	21.60/20.73

Appendix 2

The Kiefer test (Kiefer, 1959), generalizes the Kolmogorov-Smirnov two-sample test to k independent samples. It checks the null hypothesis that k samples have been drawn from the same population. The test statistic is

$$T = \sup_{\mathrm{x}} \sum_{j=1}^{k} n_{\mathrm{j}} (S_{n_j}^{(\mathrm{j})}(x) - \overline{S}_n(\mathrm{x}))^2$$

with

n_{j} number of observations in the j-th sample

$S_{n_j}^{(\mathrm{j})}$ the empirical distribution function of the j-th sample

$\overline{S}_n \quad = \sum_j n_{\mathrm{j}} S_{n_j}^{(\mathrm{j})} / \sum_j n_{\mathrm{j}}.$

The critical region is $K \geq K_\alpha$ with $K = T^{1/2}$. Since tables of K_α are available for $k \leq 6$ only, we decided to test the following null hypothesis:

H_0: $D_{\mathrm{VA(d)}} = D_{\mathrm{VA}}$ for $d = 0, 20, 30, 40, 60, 80$ (ms)

Computing statistic T for all subjects involves evaluating the empirical distribution functions in all experimental conditions *VA(d)*. This yields for $K = T^{1/2}$

MJ: $K = 4.7198$
HE: $K = 4.4539$
AD: $K = 2.9688$
HC: $K = 1.6700$

Given a value of $K_{0.01} = 2.25$, the null hypothesis is rejected for three of the four subjects.

References

Annett, M., & Annett, J. (1979). Individual differences in right and left reaction times. *British Journal of Psychology, 70,* 393–404.

Ashby, F. G. (1982). Deriving exact predictions from the cascade model. *Psychological Review, 89,* 599–607.

Burbeck, S. L., & Luce, R. D. (1982). Evidence from auditory simple reaction times for both change and level detectors. *Perception & Psychophysics, 32,* 117–133.

Colonius, H. (1986). Measuring channel dependence in separate activation models. *Perception & Psychophysics, 40,* 251–255.

Gielen, S. C. A. M., Schmidt, R. A., & van den Heuvel, P. J. M. (1983). On the nature of intersensory facilitation of reaction time. *Perception & Psychophysics, 34,* 161–168.

Kiefer, J. (1959). K-sample analogues of the Kolmogorov-Smirnov and Cramer-v. Mises test. *The Annals of Mathematical Statistics, 30,* 420–447.

Kohfeld, D. L., Santee, J. L., & Wallace, N. D. (1981). Loudness and reaction times: II. Identification of detection components at different intensities and frequencies. *Perception & Psychophysics, 29,* 550–562.

Luce, R. D. (1986). *Response times. Their role in inferring elementary mental organization.* New York: Oxford University Press.

McClelland, J. L. (1979). On the time relations of mental processes: An examination of systems of processes in cascade. *Psychological Review, 86,* 287–330.

Meyer, D. E., Yantis, S., Osman, A., & Smith, J. E. K. (1984). Discrete versus continuous models of response: A reaction time analysis. In S. Kornblum, & J. Requin (Eds.), *Preparatory States and Processes: Proceedings of the Franco-American Conference,* Ann Arbor, MI, August, 1982. Hillsdale, NJ: Erlbaum.

Miller, J. (1982). Divided attention: Evidence for coactivation with redundant signals. *Cognitive Psychology, 14,* 247–279.

Nickerson, R. S. (1973). Intersensory facilitation of reaction time: Energy summation or preparation enhancement? *Psychological Review, 80,* 489–509.

Raab, D. H. (1962). Statistical facilitation of simple reaction times. *Transactions of the New York Academy of Sciences, 24,* 574–590.

Schmidt, R. A., Gielen, S. C. A. M., & van den Heuvel, P. J. M. (1984). The locus of intersensory facilitation of reaction time. *Acta Psychologica, 57,* 145–164.

Sternberg, S. (1969). The discovery of processing stages: Extensions of Donders' method. In W. G. Koster (Ed.), Attention & Performance II. *Acta Psychologica, 30,* 276–315.

Todd, J. W. (1912). Reaction to multiple stimuli. *Archives of Psychology, 25,* 1–65.

Ulrich, R., & Stapf, K. H. (1984). A double response paradigm to study stimulus intensity effects upon the motor system in simple reaction time experiments. *Perception & Psychophysics, 36,* 545–558.

Received September 26, 1986/December 9, 1986