

Temporal Integration in Sensorimotor Synchronization

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Abstract

■ The concept of a temporal integration process in the timing mechanisms in the brain, postulated on the basis of experimental observations from various paradigms (for a review see Pöppel, 1978), has been explored in a sensorimotor synchronization task. Subjects synchronized their finger taps to sequences of auditory stimuli with interstimulus-onset intervals (ISIs) between 300 and 4800 msec in different trials. Each tonal sequence consisted of 110 stimuli; the tones had a frequency of 500 Hz and a duration of 100 msec. As observed previously, response onsets preceded onsets of the stimuli by some tens of milliseconds for ISIs in the range from about 600 to 1800 msec. For ISIs longer than or equal to 2400 msec, the ability

to time the response sequence in such a way that the responses were placed right ahead of the stimuli started to break down, i.e., the task was fulfilled by reactions to the stimuli rather than by advanced responses. This observation can be understood within the general framework of a temporal integration process that is supposed to have a maximal capacity (integration interval) of approximately 3 sec. Only if successive stimuli fall within one integration period, can motor programs be initiated properly by a prior stimulus and thus lead to an appropriate synchronization between the stimulus sequence and corresponding motor acts. ■

INTRODUCTION

In various experimental paradigms, integration limitations of central timing mechanisms, as well as temporal segmentation of different human activities, have been observed many times (for an earlier review see Pöppel, 1978). The findings suggest that the ability of the central nervous system to integrate temporally external events and/or own acts is limited to a *temporal integration interval*, which provides an automatic binding across time. The duration of this interval is supposed to be a few seconds (Pöppel, 1988; Pöppel & Schwender, 1993).

Historically, the problem of temporal binding may be related to the phenomenon of a "subjective present." James (1890), Stern (1897), Wundt (1911), and Boring (1942) pointed out that the "feeling of oneness," the subjective present, is limited to a few seconds. "The practically cognized present is no knife-edge, but a saddle-back, with a certain breadth of its own on which we sit perched, and from which we look in two directions into time" (James, 1890, p. 574). It has been suggested that this special temporal interval is, within certain limits,

determined by what is perceived (e.g., Fraisse, 1984). There is, however, overwhelming evidence, if one takes together observations from different areas of research, that an interval up to about 2 or 3 sec can be considered as a time window, within which information is integrated and which is provided automatically by central mechanisms of the nervous system.

In experiments on temporal reproduction, it has, for instance, been shown that intervals up to approximately 3 sec are reproduced veridically; intervals longer than this are usually reproduced considerably shorter than their real duration (Pöppel, 1971; Richards, 1964). This observation corresponds with other studies, which indicate that information transmission is optimal for such an interval (Bechinger, Kongehl, & Kornhuber, 1969), or that Weber's law applies only to intervals up to such a temporal limit (Getty, 1975). In studies on spontaneous reversal rates of ambiguous visual or auditory patterns, a similar time constant for the different perspectives of the Necker cube and for reversible verbal interpretations (like KU-BA, BA-KU) has been observed (Radilová & Pöppel, 1990; Radilová, Pöppel, & Ilmberger, 1990). If one

looks at the duration of spontaneous utterances, again a preference for intervals up to 2 or 3 sec has been found (Kowal, O'Connell, & Sabin, 1975; Pöppel, 1988; Vollrath, Kazenwadel, & Krüger, 1992). The duration of intentional acts, which in different cultures has been demonstrated to last preferentially up to 3 sec (Schleidt, Eibl-Eibesfeldt, & Pöppel, 1987), suggests that automatic temporal binding determines also gross motor behavior. Also for short-term memory a similar temporal constraint has been observed; using a particular paradigm preventing rehearsal Peterson and Peterson (1959) found that information can accurately be kept for only a few seconds. Thus, temporal integration (Hearnshaw, 1956) appears to be a general phenomenon characterizing sensory, motor, and central processes and may therefore be of logistical importance for all cognition.

The question is whether automatic temporal integration limited to approximately 3 sec also plays a role in sensorimotor synchronization. Synchronization of finger tapping with repetitive sensory events (stimuli) is an experimental paradigm that has been used many times for studying various aspects of timing of sensorimotor behavior (e.g., Bartlett & Bartlett, 1959; Fraisse, 1978; Franěk, Mates, Radil, Beck, & Pöppel, 1991a,b; Kolers & Brewster, 1985; Michon, 1967; Najenson, Ron, & Behroozi, 1989; Peters, 1989; Woodrow, 1932). In the synchronization paradigm, one phenomenon of interest is the systematic temporal asynchrony between stimulus onsets and corresponding tap onsets (further called synchronization error, SE). Most often a lead of tap onsets is observed without the subject being aware of it (Fraisse, 1978; Kolers & Brewster, 1985; Mates, Radil, & Pöppel, 1992; Müller, Ilmberger, Pöppel, Mates, & Radil, 1990; Peters, 1989; Woodrow, 1932). It has already been established that SEs are influenced by various external factors, like the rhythmic structure, lateralization, or the sensory modality of stimuli (Fraisse, 1982; Ilmberger, Müller, Pöppel, Mates, & Radil, 1990; Kolers & Brewster, 1985; Najenson et al., 1989). Influence of the interstimulus-onset interval duration (further shortly interstimulus interval, ISI) on performance was observed by Bartlett and Bartlett (1959), MacDorman (1962), and Peters (1989). They supposed that the influence of internal factors (motor, sensory, and central), which restrict the accuracy of synchronization, varies with the rate of stimulus presentation. For rapid rates (ISIs shorter than approx. 300 msec), sensory and/or motor limits were thought to be of primary importance. At slow stimulus repetition rates (ISIs longer than approx. 1000 msec), central limits (especially "memory") were hypothesized to be the crucial factors influencing timing in a synchronization task and, thus, the resulting synchronization accuracy.

Woodrow (1932) observed that the variability of synchronization errors for an ISI of 4 sec was almost three times larger than the variability for an ISI of 2 sec, and six times larger than that for an ISI of 1 sec; while for various ISIs that were shorter than 1 sec, the variabilities

were of similar magnitude. Woodrow defined an "upper limit of synchronization" as the stimulus repetition rate, at which the average absolute synchronization error and the average reaction time to each tone in a sequence with the same ISI would be identical. By means of a linear interpolation from the data at an ISI of 2 and 4 sec he estimated the limit to be equal to 3.34 sec. This duration "represents the vanishing point of the capacity for synchronization, and (if taken as the duration of a single foot) for experiencing rhythm" (Woodrow, 1932, p. 377). MacDorman (1962) reported a breakdown in synchronization when the ISI reached 1.8 sec; when it reached 2.4 sec, the subjects reacted to stimuli rather than placed responses in advance of them. Also Najenson and co-workers (1989) assumed that for a stimulus sequence with ISIs longer than 3 or 4 sec "the subjects could not remember the interval duration and might have switched their strategy to that similar to the one used for randomly spaced stimuli" (p. 177). While for isochronous sequences (and thus predictable stimuli) with ISIs up to 2 sec, Najenson and co-workers observed predictive responses, the responses for ISIs longer than 2 sec and for randomly spaced stimuli suggested a reaction-type strategy. It should, however, be noted that Najenson and co-workers observed in their group of subjects no responses in advance of stimuli at all, and they considered even delayed responses with synchronization errors up to about 150 msec as predictive.

In the synchronization paradigm, the temporal distance between two successive motor acts (i.e., intertap-onset interval; further shortly intertap interval, ITI) must mimic the corresponding interstimulus interval. It has already been mentioned that the mutual temporal relationship between single stimulus and the associated motor act (synchronization error) is determined by various aspects of the stimulus sequence. Consequently, intertap intervals might be influenced by the same factors. The dependence of the overall variability of ITIs on the stimulus repetition rate (i.e., on the ISI duration), as well as on the stimulus modality, has been observed by several authors (Bartlett & Bartlett, 1959; Fraisse, 1982; Kolers & Brewster, 1985). Michon (1967) reported differences in the variability of ITIs that were of the same order as were the differences in the variability of SEs found by Woodrow (1932) in analogous conditions, and discussed in the previous paragraph. Peters (1989) has asked whether it is possible that in the synchronization paradigm different mechanisms operated at different stimulus repetition rates. He focused, however, on the change of performance at ISIs near 300 msec. For ISIs longer than about 2 sec Vos and Ellermann (1989) claim that "the temporal coherence between successive events is progressively lost, and the sequence is perceived more and more as a number of independent events" (p. 181) (see also Fraisse, 1982; Michon, 1967; cf. further subjects' introspective reports collected by Woodrow, 1932). The loss of perceived coherence of a stimulus sequence re-

sults in the loss of internal coherence in a stream of responses.

Despite the experimental observations above, nobody has investigated the transition in subjects' synchronization performance strategy mentioned and the process of strategy alternation in more detail, neither have there been attempts to postulate a hypothesis about the responsible underlying mechanism. In this investigation, the changes of a subject's ability to synchronize tapping to periodic stimulus sequences were explored in dependence on the stimulus repetition rate (i.e., on the duration of ISI) in a wider range of interstimulus interval durations. The aim was to specify whether or not the mechanism of temporal integration, observed in other experimental paradigms, could also be responsible for some performance limitations in a synchronization task. Given the experimental findings above and considering the hypothesis of central integration mechanisms of the brain, that provide temporal processing windows of up to 3 sec duration, we expected a usual pattern of sensorimotor synchronization, accompanied by the phenomenon of slightly advanced responses, only in sequences with ISIs shorter than 2 or 3 sec.

RESULTS

The results confirmed the influence of the length of interstimulus-onset intervals (ISIs) on the time differences between tap onsets and stimulus onsets (synchronization errors, SEs), as well as on the intertap-onset intervals (ITIs). Examples of the time series of synchronization errors in two trials for two subjects are depicted in Figure 1.

Synchronization Error Distributions

In the sequences with ISIs up to 1800 msec, the hypothesis about the normality of individual distributions of synchronization errors, according to the Kolmogorov-Smirnov test, could not be rejected.¹ The distributions were strictly unimodal, with interindividually different parameters. The distributions substantially changed their shape in the sequences with ISIs between 2400 and 4800 msec: the subjects produced both delayed and advanced responses with high variability. Examples of the SE distributions of two subjects are shown in Figure 2. The alternation between advanced and delayed responses for ISI durations that were longer than or equal to 2400 msec led to bimodal SE distributions, for which the hypothesis about normality of distribution was rejected. This effect started for different subjects at different ISI durations.

Due to the bimodality of distributions observed for some ISI durations, where individual sets of SEs were distributed not according to a Gaussian distribution law, they were inspected for multiple distribution components. Mixture distributions (i.e., standardized sums of

several single-distribution density functions weighted by different proportion factors) were fitted to grouped data (binwidth = 10 msec) by a maximum-likelihood method (Ling & Tolhurst, 1983). The lowest number of normal distribution components were used, for which the hypothesis about the consonance between the empirical distribution and the theoretical mixture distribution could not be rejected. For several data sets, a better fit was obtained by a mixture of two distribution components. The parameters (means and standard deviations) of the best-fitted single or mixture distributions are depicted for every subject and every ISI duration separately in Figure 3. The weighting factors of the distribution components in the best-fitted distributions are shown in Figure 4.

The parameters of the best-fitted distributions of SEs demonstrate that in the sequences with a high stimulus repetition rate (i.e., $ISI \leq 450$ msec), the measured time difference was minimal or even absent, with small absolute variability (see Fig. 3). This is in accordance with previous findings by Peters (1989) and Müller and co-workers (1990).

As expected on the basis of previous observations in synchronization tasks (Fraisse, 1978; Peters, 1989), tap onsets usually preceded stimulus onsets in the sequences with medial durations of ISIs. In our experiment this held true for the sequences with ISIs from 600 up to 1800 msec (see Fig. 3).

In the sequences with ISIs between 2400 and 4800 msec, a gradual transition from advanced toward delayed (reactive) responses can be seen from Figure 2. Under these conditions, two distribution components were detected (cf. Fig. 3), one comprehending highly variable advanced responses and the other representing responses delayed with respect to the stimuli. Delays of about 150 msec correspond to normal simple reaction times to auditory stimuli (e.g., Jaśkowski, Jaroszyk, & Hojan-Jeziarska, 1990; Pöppel, Schill, & von Steinbüchel, 1990b).

In the sequences with ISIs of 4800 msec the distributions showed higher concentration of delayed responses, the distributions "moved" to another location. This transition is obvious from the proportion factor, by which the distribution component representing reactive responses contributes to the global empirical distribution of SEs. An increase (with only one exception) of this proportion factor, while lengthening the ISI, can be observed (see Fig. 4, cf. Fig. 2).

Individual Intervals of Transition

The determination of critical ISI durations, that is of the intervals where the transition in synchronization strategy above described took place, was based on results of the Kolmogorov-Smirnov test of normality. As soon as the shape of SE distribution changed substantially (i.e., the hypothesis of normality of the distribution was rejected),

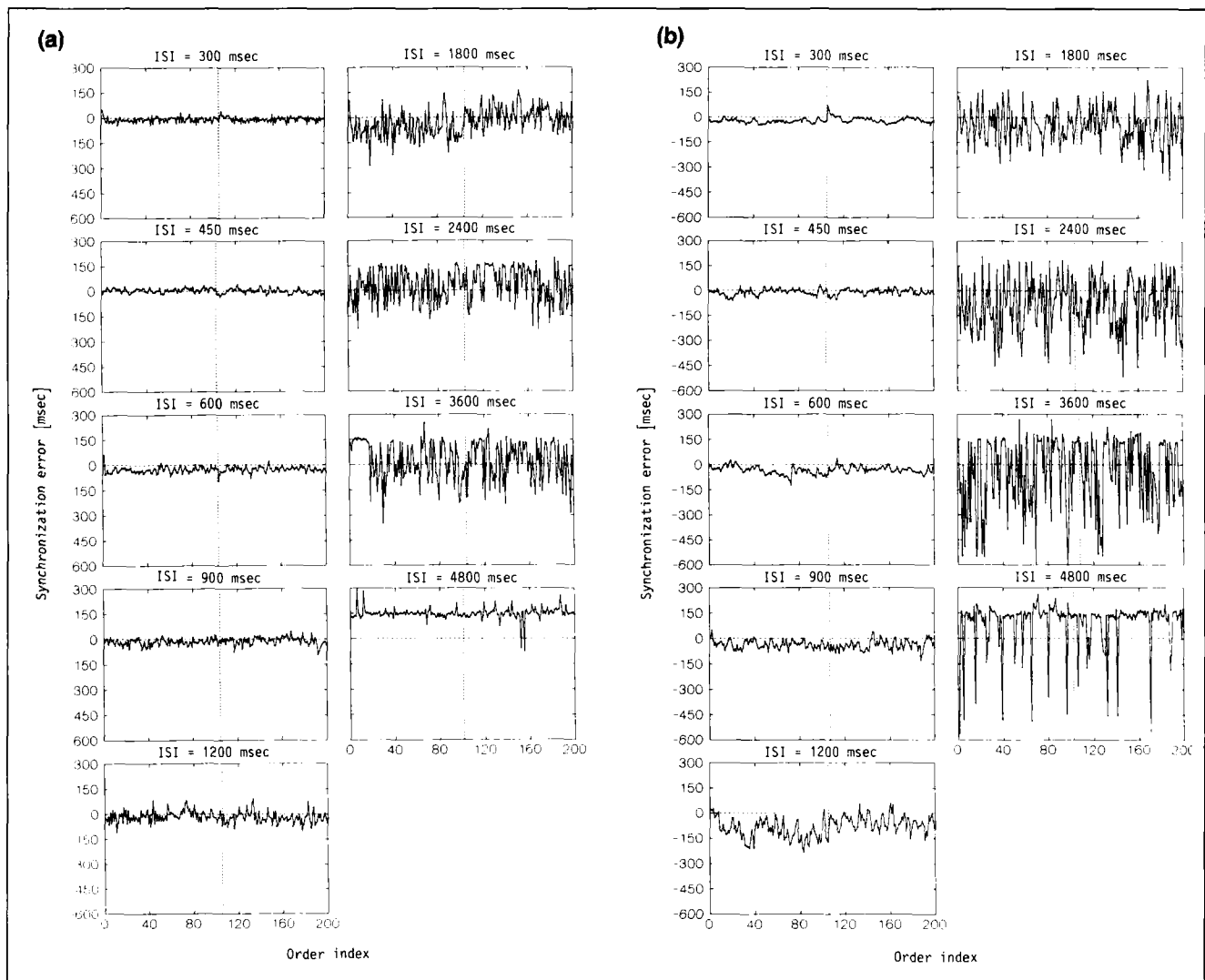


Figure 1. Examples of time series of synchronization errors in a trial for every interstimulus-onset interval duration separately (indicated on the top of each subpanel). Data (200 values) from the first and the second trial of two subjects are presented. (a) Subject 1; (b) Subject 2. The horizontal dashed line represents the onset of stimuli, the zero level means perfect synchronization, negative values correspond to responses in advance of the stimuli. The vertical dashed line depicts the end of the set of data from the first trial. (Tick marks on the abscissas are not a scale; points are connected with lines to aid the eye.)

it was obvious that the synchronization behavior was not generated by application of a unique performance strategy. This critical ISI duration varied interindividually between 2400 and 3600 msec (see Figs. 3 and 4).

Intertap-Onset Intervals

The individual standard deviations (SD) of ITI durations are shown in Figure 5, upper panel. An increase of SD with increasing ISI durations for almost all subjects is apparent. For comparable ISIs, the SD values are very similar to those reported by Michon (1967). The striking decrease of the SD for subject 1 reflects the fact that this subject, for ISI = 4800 msec, had already changed his strategy to an almost purely reactive one. The SD reflects therefore the small variability of his reaction time to acoustical stimuli (cf. Figs. 3 and 4). If the SD is expressed

as a relative portion of the corresponding average ITI duration (i.e., as the variation coefficient; Fig. 5, lower panel), a change of the dependence trend for the ISI duration between 2000 and 3000 msec can be observed. The increase in variability for the ISI shorter than 450 msec corresponds to the findings by Peters (1989), and it probably reflects an increasing influence of motor limitations.

DISCUSSION

In this experiment it was confirmed that the deviations from the exactly timed template, observed in a synchronization paradigm, are not determined by the precision (i.e., stability against random errors) of the involved sensory, motor, and central control systems only. The results

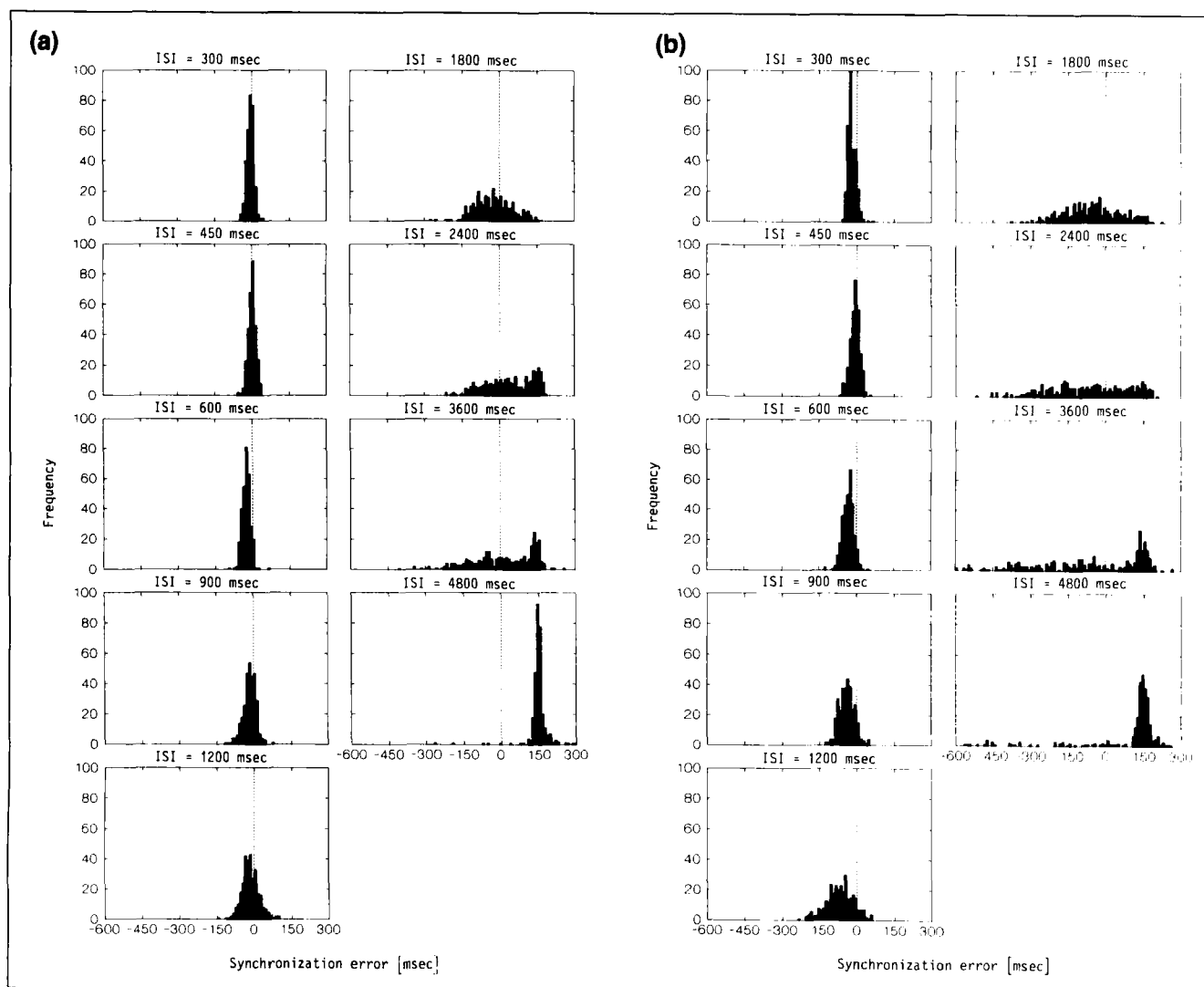


Figure 2. Examples of synchronization error distributions for the same subjects as in Figure 1 for every interstimulus-onset interval duration separately (indicated on the top of each subpanel). (a) Subject 1; (b) Subject 2. Data from all three respective trials were pooled. The other empirical distributions, divided according to the number of distribution components that follows from Figure 3 into two classes, were of similar appearance as the class representatives shown in the figure. The dashed line represents the onset of stimuli, the zero level means perfect synchronization, negative values correspond to responses in advance of the stimuli.

suggest that synchronization performance is also characterized by some systematic temporal constraints.

Sufficient objective synchronization was observed for very fast sequences only (ISI down to 300 msec; for ISIs shorter than 300 msec see, e.g., Müller et al., 1990; Peters, 1989). Although motor behavior, in this case, looks superficially like perfect synchronization, the subjects reported subjectively insufficient synchronization. Due to performance (mainly motor) limitations for very fast sequences, even the independence of a series of stimuli and a series of responses was hypothesized, since there is relatively little freedom to make any corrections (Peters, 1989).

A subjective impression of proper synchronization was reported only within a limited range of ISI durations from about 450 to about 1800 msec (cf. Fraisse, 1982; MacDorman, 1962; Najenson et al., 1989). Synchroniza-

tion behavior in this case was characterized by objectively advanced responses. The mechanism behind the phenomenon of negative synchronization errors (responses in advance of stimuli) is still unknown. A possible partial explanation is as follows. Let us assume that some internal events, which are related to the objectively detected asynchronous occurrence of the stimulus and the motor response, are synchronous. It is obvious that the temporal availability of the internal representations of the sensory stimulus and that of some (feedback) aspect of the already executed response is delayed with respect to the physical moment of their occurrence. The subjective synchronization is then given, if the two internal representations are not judged as internally asynchronous. If the transduction time (or perception latency; Fraisse, 1978) of a response feedback aspect is longer than the transduction time of the auditory stimulus, then in the

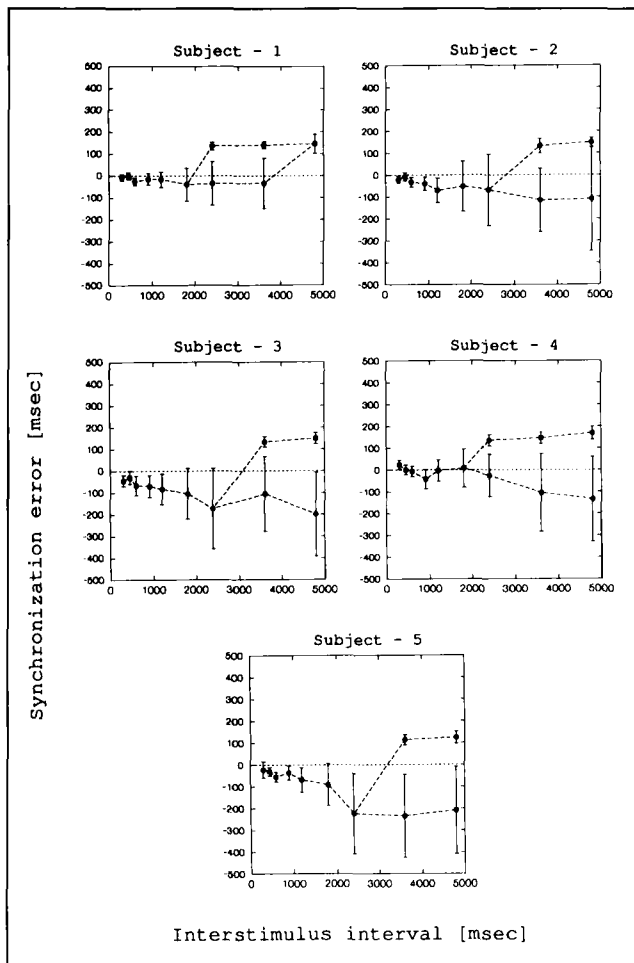


Figure 3. Means and standard deviations of the best-fitted single or mixture distributions of synchronization errors for every subject (S1–S5) at every interstimulus-onset interval duration separately. The dashed line represents the onset of stimuli, the zero level means perfect synchronization, negative values correspond to responses in advance of the stimuli.

case of external stimulus–response synchrony, the internal representation of the response would be delayed in comparison with the internal representation of the stimulus. Therefore, the objectively measured response onset has to be in advance of the stimulus onset. This hypothesis has been investigated theoretically by several authors (e.g., Mates, 1994a,b; Pöppel, Müller, & Mates, 1990a; Prinz, 1992) and it also met an empirical support in the data by Aschersleben (1994).

For ISIs longer than 1800 msec, the subjects started to realize their inability to synchronize their responses with the presented sequences, i.e., they did not report a feeling of synchronization. In this case, two distribution components were detected in the empirical distributions of synchronization errors. The components represent two different sources of variability of SEs—two qualitatively different strategies of performance: (1) advanced responses with interindividually different averages and high, interindividually different variabilities; and (2) de-

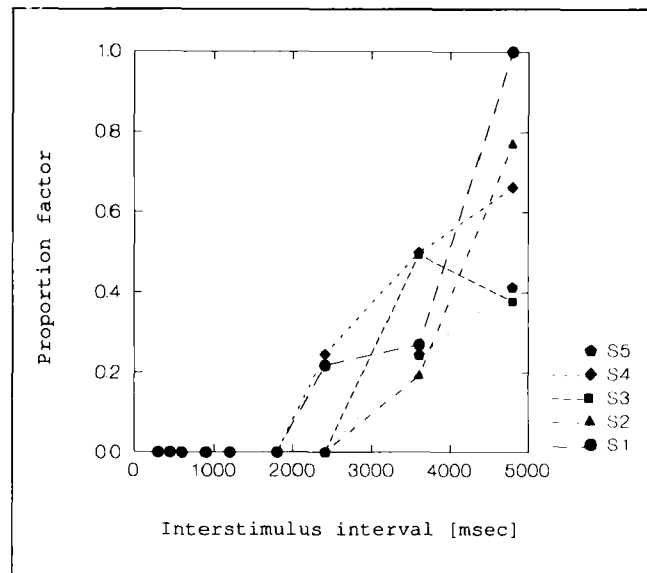


Figure 4. Single- or mixture-distribution function was fitted to the global empirical distribution of synchronization errors for every subject (S1–S5) at every interstimulus-onset interval duration separately. Depicted are values of the proportion factor a (i.e., the weighting factor) of the second distribution component that represents reactive responses. Zero value of a thus means that only one distribution component (single distribution) was fitted. The proportion factor of the other distribution component is $b = 1 - a$.

layed responses with interindividually almost stable averages and very small variabilities, interindividually almost stable as well (see Fig. 3).

Successful synchronization necessitates as a basic requirement the ability to form an internal temporal template shifted properly ahead of the stimulus sequence and revealing subjectively acceptable variability (a model of hypothetical control mechanisms underlying synchronization performance has been developed by Mates, 1994a,b). This ability enables the subject to predict the moment of occurrence of the next stimulus with sufficient precision, and thus to time the initiation of the respective motor programs adequately by a prior stimulus to get a subjective response–stimulus synchrony. Insufficient stability of intertap interval duration to be produced for an interstimulus interval longer than a critical duration caused the synchronization strategy to be changed. While lengthening ISIs, the strategy passes from slightly advanced responses to an alternation between highly advanced and variable responses and reactive ones, and occasionally to pure reactions. That is, if the duration of interstimulus interval reached some limit, an alternative response strategy (giving less response variance, but being not reported as successful synchronization) became superior.

In Figure 3 the means of the distribution components representing advanced responses scale with the ISI in some cases. Such a dependence (in a narrower range of ISIs already observed, e.g., by Peters, 1989, and Woodrow, 1932) could be tentatively explained in terms of a

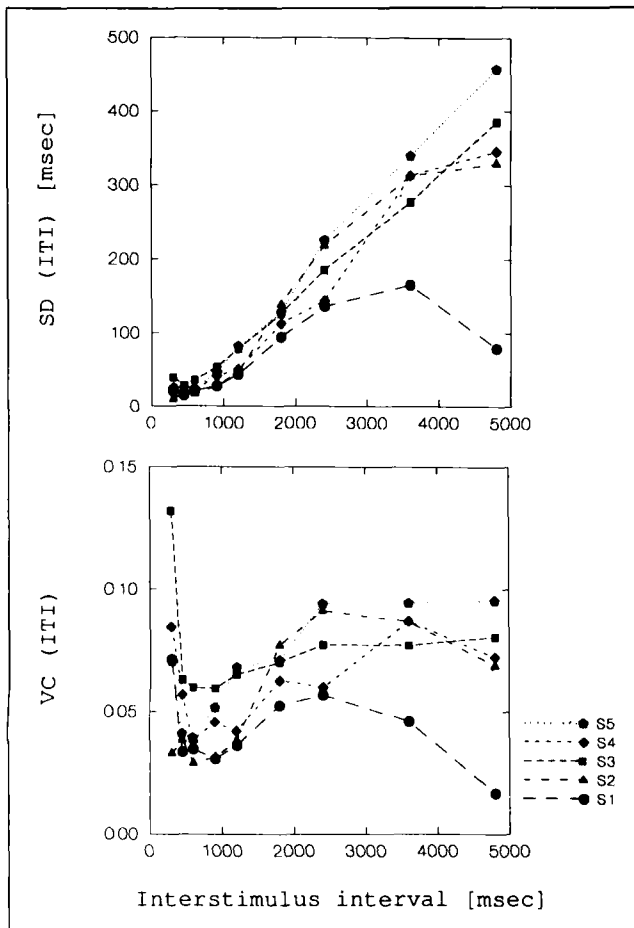


Figure 5. Upper panel: standard deviations of intertap-onset intervals; lower panel: variation coefficients of intertap-onset intervals (standard deviations expressed as a relative portion of the corresponding average intertap-onset interval). Individual values (subjects S1–S5) are shown in relation to the corresponding interstimulus-onset interval duration.

subjective cost function for synchronization errors that is asymmetric with respect to the error's sign (this hypothesis was elaborated, e.g., by Koch, 1992). Since the variability of intertap intervals produced increases for longer ISI durations (cf. Fig. 5), also the spread of the synchronization error distributions grows. Under such circumstances, the mean of the distribution would have to be shifted toward more negative values (more advanced responses with respect to the stimuli) in order to reduce the "costs" due to an increasing occurrence of more progressively penalized positive synchronization errors, or in order to maintain a constant percentage of positive errors. Not enough evidence, however, has been collected yet to confirm this hypothesis.

A dependence of variability in time production on the interstimulus interval duration was already mentioned in the introduction. Further, it is obvious that a subject would not delay his/her responses more than to his/her simple reaction. Thus, a possible spread of distribution of synchronization errors toward greater positive values,

resulting from a continuous increase of response variability, is restricted by simple reaction time. One could, therefore, argue that the change of performance strategy reflected the above restriction on a continuous increase of variability of intertap intervals (and consequently of SEs). Another possible interpretation could be that an alternative performance strategy is used whenever it minimizes the expected synchronization error or its variability or some other kind of a "cost criterion." None of these interpretations, however, answers the question why did the alternative strategy appear in the 2–3 sec range (and not at 1 or 4 sec)? Even if there is a continuous increase in variability in time production, one should ask why does the increasing variability produced become unsatisfactory for the subject (and thus cause him/her to select another optimal strategy) just in the range of 2–3 sec?

A possible explanation is that the phenomenon observed reflects more specific features of temporal constraints of brain activity. The short-term memory trace on temporal dating of the preceding stimulus and/or tap in the sequence fades out approximately after 2–3 sec and, thus, provides apparently no longer a sufficiently precise cue for triggering the following motor act in the right time. Thus, the system adapts to one of the two possible strategies described. We suppose that the transition in behavior strategies observed reflects the constraints of central timing mechanisms in the brain, and that the transition zone corresponds to the limit of temporal integration capacity of those mechanisms. This integration capacity has an individually slightly different span; the interindividual differences might be an explanation for why a change of performance strategy has been reported in the literature at slightly different interstimulus interval durations, as reviewed in the introduction (cf. Fraisse, 1982; MacDorman, 1962; Najenson et al., 1989; Vos & Ellermmann, 1989).

Automatic temporal integration independent of what is represented seems to be a universal phenomenon determining mental processes on several levels. As mentioned in the introduction, temporal segmentation as defined by temporal integration can be observed on the perceptual, motor, and also more cognitive level. The question then is whether such a universal phenomenon with similar time constants (approximately 3 sec) in all tasks is dependent on a unique neuronal mechanism or whether each functional domain is characterized by its own temporal integration mechanism. In the first case, some "master clock" would have to be hypothesized; in the second case, synchronization mechanisms between different functional domains would have to be suspected. Insight into this question can probably be gained by neuropsychological observations with brain-injured patients. Preliminary evidence, in particular on patients with aphasic problems, suggests independent temporal integration mechanisms for the different functional domains (von Steinbüchel & Pöppel, 1993).

METHOD

Stimuli

Sequences consisting of 110 tonal stimuli were used. The intervals between tone onsets (interstimulus-onset intervals, ISIs) in a sequence were constant (isochronous sequence). Nine different durations of ISI were used in different trials: 300, 450, 600, 900, 1200, 1800, 2400, 3600, and 4800 msec. Tones had a frequency of 500 Hz and a duration of 100 msec in a rectangular envelope.

Procedure

The stimulus sequences were presented to the subjects through headphones. The subject's task was to synchronize his/her tap onsets with stimulus onsets as precisely as possible; the reproduction of tone duration was not explicitly required. In order to collect enough experimental data, but to avoid trials being too long for longer ISI durations, the number of stimuli in one trial was kept constant and each sequence was applied three times. The shortest trials lasted 33 sec, the longest ones almost 9 min. Short rest periods were introduced between trials. The presentation order of the sequences with different ISIs was randomized between subjects. All factors possibly influencing synchronization performance (see introduction) were kept constant over trials. Individual data records show (see Fig. 1) that subjects performed in stationary experimental conditions, that is they did not change their strategy during trials or fatigue while doing the experiment.

Rhythmic stimulus templates presented are acquired quite fast by the subjects, according to Fraisse (1982) synchronization with repetitive rhythmic patterns is usually established from the third pattern on. Therefore, the subjects were asked to listen to several tones at the beginning of each trial to become familiar with the ISI before they started tapping. More than 100 responses were recorded from each trial, the first tap in a sequence was discarded from the analysis. Since the focus of our interest was on the steady-state performance of the subjects, an incidental transient phase at the beginning of the trials was not analyzed.

The measured response parameters were (1) the time difference between tap onset and stimulus onset (synchronization error, SE); and (2) the time interval between successive tap onsets (intertap-onset interval, ITI). If the tap onset preceded the stimulus onset, we assigned a negative value to the measured time gap. Positive values of this time difference stand for delayed responses (analogously as done by Peters, 1989).

Apparatus

The stimulus sequences were controlled and subject's responses recorded by a program described by Mates (1990) and implemented on an IBM compatible com-

puter. The temporal resolution was 250 μ sec. Tones were generated by triggering a rectangular signal of the internal sound generator of the computer. The signal was amplified to a comfortable level of loudness for each subject. The response key was similar to those used on computer keyboards. A possible multiple event detection, which might result from mechanical switch bouncing, was thus eliminated. The key produced no additional sound when pressed.

Subjects

Three female and two male, right-handed, neurologically unimpaired subjects (S1: 50, S2: 26, S3: 40, S4: 28, S5: 33 years old) took part in the experiment. They all had former experience in tapping tasks, having participated previously in similar experiments.

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Note

1. The time series of SEs and ITIs in a synchronization task are usually not series of independent random samples. Strictly speaking, any statistical description of such series by means of distributions and distribution parameters (averages and standard deviations) is then not exhaustive. Nevertheless, we use an analogous type of description as that mostly adopted in the literature on synchronization.

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