ACTA NEUROBIOLOGIAE EXPERIMENTALIS

Acta Neurobiol. Exp. 1995, 55: 57-64

The effect of stimulus intensity on force output in simple reaction time task in humans

Piotr Jaśkowski, Krzysztof Rybarczyk, Feliks Jaroszyk and **Dariusz Lemański**

Department of Biophysics, Medical Academy, 10 Fredry St., 61-701 Poznań, Poland

Abstract. The force needed to press the key in a simple reaction time task was measured as a function of stimulus intensity for visual and auditory stimuli in three experiments using a total 45 male and female human subjects. Intensity ranged from 0.316 to 1995 cd/m^2 for visual stimuli and from ranged from 47 to 102 dB for auditory stimuli. We found, in agreement with Angel's (1973) original study, that for auditory stimuli higher intensity is accompanied by a larger force. Surprisingly, in the case of visual stimuli the intensity does not influence the force. These findings are explained by the assumption that the changes of force reflect the changes of unspecific activation level evoked by immediate arousal. Thus, the different behaviour of force for these two modalities is in agreement with the common view that loud auditory stimuli are arousing while intense visual ones are not.

Key words: simple reaction time, intensity, response force, immediate arousal, activation, human subjects

INTRODUCTION

There is no agreement among researchers of perceptual latency whether the motor part of simple reaction time (RT) depends upon stimulus intensity. Advocates of the idea that only those processes that occur early in stimulus processing depend on stimulus intensity, refer to electrophysiological studies carried out by Vaughan et al. (1966) and by Wilson and Lit (1981)) (see also Williamson et al. 1978, Jaśkowski et al. 1990). These authors measured the RT and latency of the visual evoked potential (VEP) as a function of stimulus intensity. If the motor part of RT depends on intensity, the curve relating reaction time to intensity is steeper (or flatter) than the curve for the evoked potentials. The direct comparison of both curves clearly revealed that they are parallel, which means that the processes operating subsequently to the processes represented by the visual evoked potential are independent of intensity.

On the other hand, there are some methods to investigate relative sensory latency, like temporal order judgement, the Pulfrich effect or the Hess effect[1] (for a review see Roufs, 1974). In some of them, no motor component is involved. Direct comparison of the results obtained by such methods with RT findings suggests that the motor delay is intensity-dependent. Indeed, in those experiments, in which both the changes of sensory latency and the changes of RT were measured as a function of intensity by one of these methods, it was commonly found that the changes of RT are larger than those of relative latency measured by the other methods (Roufs 1974, Brauner and Lit 1976, Menendez and Lit 1976, Williams and Lit 1983). This observation seems to indicate that there is an intensity-dependent component of RT which starts after the detection is completed.

One can question these interpretations, by arguing that it is not sufficiently well known which processes exactly underlie these methods, and that it is, therefore, not certain whether the results obtained by these methods can be compared with the results obtained from RT studies (see Morgan 1977, for an alternative explanation of the Pulfrich effect and Collyer 1976, Jaśkowski 1991, for two examples of paradoxical behaviour of temporal order judgement). However, Angel (1973) offered another argument. Although Angel's paper does not provide an evidence for an effect of intensity on motor delay, it strongly supports the claim that intensity can affect the motor system. He measured the force needed by subjects to press a key in an RT task and found that the force depends on stimulus intensity: the higher the intensity, the stronger the force.

As far as we know, this important result has never been replicated. Unfortunately, it was obtained under conditions which are not typical of RT experiments. First of all, after the subject's response a kind of feedback is usually delivered informing the subject that the response has been executed, e.g., the commonly used telegraph-like keys can bend under the finger's force within a limited range of several mm and the abrupt resistance of the key gives such feedback information. In Angel's experiment, the force was measured under isometric conditions and no feedback was delivered. Due to the lack of such feedback, it is not known what amount of force was used by the subjects. In typical RT experiments, very sensitive keys needing only little force are employed.

Furthermore, Angel's paper contains only limited information on the details of procedure and data analysis:

1. The absolute values of intensities used are unknown. Instead Angel gave only the range of the intensity changes.

2. He used two different foreperiod characteristics (constant or exponentially distributed) and

[1]The Pulfrich effect is a simple observable visual illusion. Wearing a neutral filter in front of one eye and watching binocularly a pendulum which moves to-and-fro in a plane perpendicular to the line of sight, one can find that the pendulum bob seems to follow an ellipse-like path being once closer and once further from the observer. This illusion has been explained after Pulfrich (1922) in terms of different latencies between both eyes due to different intensities of stimulation. The Hess effect is a one-dimensional version of the Pulfrich effect (Williams and Lit 1983).

two types of intensity variation (blocked and mixed). However, it is unclear whether the results obtained under those conditions differed in any way.

3. No RT data were presented.

4. Two methods of data analysis were mentioned in the methods section. The first used sweep averaging, in which the EMG signals were summed over all trials for a given intensity and divided by the number of trials. Then the amplitude of the resulting signal was measured. In the second method, amplitude averaging, the amplitude was measured for every trial and then the averaged amplitude was calculated. Although he mentioned that in several cases both methods were applied and no differences were noticed, this agreement is plausible only if the time dispersion of responses (i.e., RT) would be the same for all stimulus intensities. It is well known that the dispersion of RT is higher for low intensity. Therefore, we can expect that mean of response force obtained by using sweep-averaging could depend on intensity even if individual responses have the same amplitudes. In other words, it is possible that sweep-averaging can show a relationship between response force (higher response force for higher intensities) and intensity due to different blur of RTs. These methodological weaknesses led us to replicate Angel's experiment under conditions typical of RT studies.

EXPERIMENT I

Method

SUBJECT

Fifteen subjects (5 males and 10 females) whose age were between 19 and 23 participated in the experiment. They were mainly recruited from students of different faculties of Adam Mickiewicz University in Poznań. They were not informed that force would be measured in the experiment. Some of them had previous experience in psychophysical experiments.

APPARATUS

The visual stimulus was a flash lasting 800 ms generated by a yellow light-emitting diode. The stimulus had the shape of a circle 0.19 deg of arc. in diameter with a sharply defined border. Ten intensity levels were used, ranging from -0.5 to 3.3 log cd/m^2. The target LED was surrounded by four red LEDs, which were displayed to facilitate fixation.

The subjects were lying on a couch with their forearms stretching along their body. The LED panel containing the target LED and the four red LEDs was mounted 1.5 m above the subject's head. The subject's straight index finger was resting on the response key. A telegraph-like key with built-in mechano-electrical converter was used. The key did not bend under the depression. Therefore, the muscle contraction was nearly isometric, as in Angel's study. Unlike in his experiment, however, a force higher than 1.5 N caused the generation of a tone. The output from the key was connected to an A/D converter. The signal from the key was sampled for 800 ms starting just after stimulus onset. The sampling interval was 4 ms.

PROCEDURE

The experiment was performed in a dark laboratory room. Each subject participated in one session. Before starting the main session, an initial block of 20 practice trials was performed. The subjects' task was to respond as fast as possible to each stimulus. They were informed that the buzzing heard after pressing the key meant that the response had been executed.

During one session 250 stimuli were presented, 25 for each intensity level. The stimuli were presented in blocks. In one block, the stimuli of only one intensity were presented. We chose the blocked arrangement of stimuli to avoid the interference of consecutive trials (i.e. after-effects). This arrangement is often used by researchers when intensity is manipulated, particularly for visual stimuli (e.g. Roufs 1974, Menendez and Lit 1983).

Results

A typical force record is presented in Fig. 1 (record A). The horizontal line marks a level at which the key buzzer started to generate a pitch. RT is defined as the time from stimulus onset to the moment at which the force signal crosses the marked level.

Sometimes, atypical waveforms were recorded. Three representative examples of such abnormal records are presented in Fig. 1 (records B, C and D). The first type (record B) of abnormality is a very slow increase of tension. This type was rare compared to the second one (records C and D): the biphasic waveform. Both types were mentioned by Angel, too. He excluded such abnormal records from analysis, as we did. The problem is, however, which criterion should be applied to eliminate these atypical records. After some attempts, we decided to do it off-line by visual inspection using rather restrictive criteria. In spite of this, only about 3% of records were rejected. In the following, we show the results only for all the accepted records.

The results of Experiment I are presented in Fig. 2. In Figure 2C the mean of RT averaged over subjects is plotted versus stimulus intensity. In Figure 2A the mean of force amplitude is presented for all intensities. It was calculated by amplitude averaging rather than by sweep averaging. The RT data replicate previous results, namely, RT significantly depended on intensity ($F(9,126)=10.42$, $P<0.001$), while in contrast, force amplitude did not.

To show that the force-intensity curves are also flat for individual subjects we calculated the regression coefficient assuming that $F=F_o + b \log I$, where

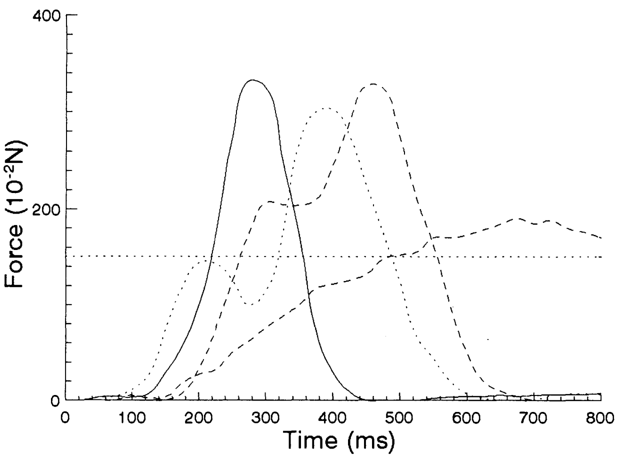

Fig. 1. Four examples of force records obtained in Experiment I.

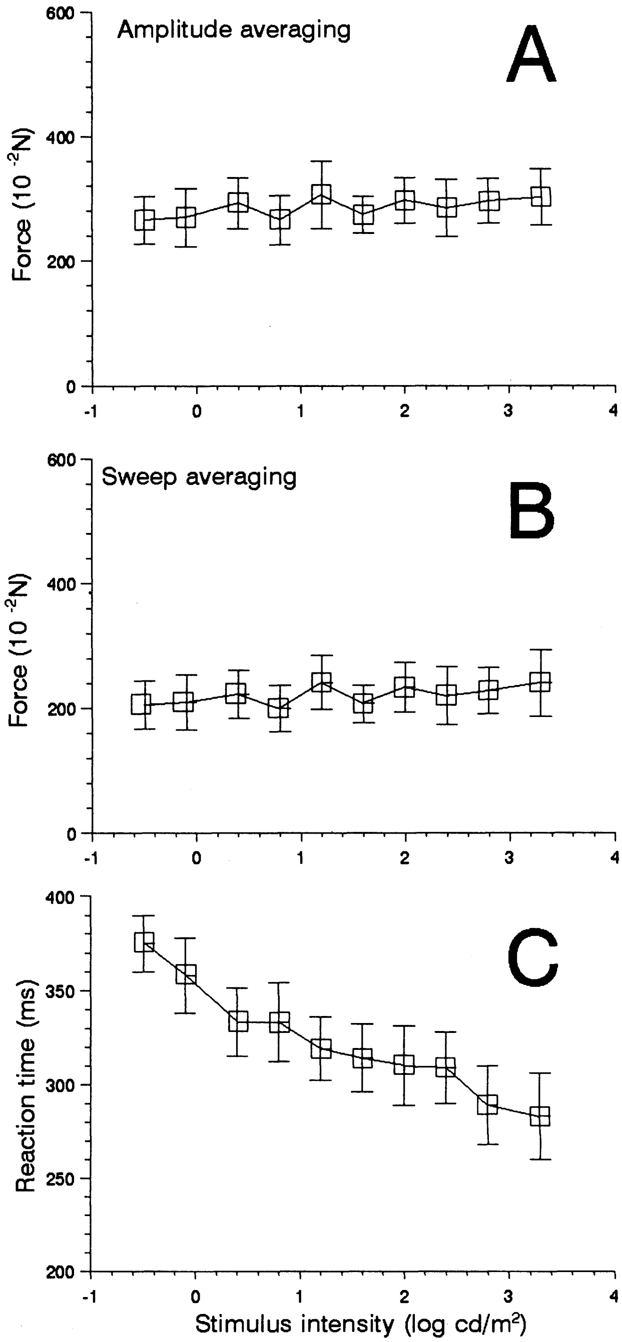

Fig. 2. Force amplitude evaluated by amplitude averaging (A), sweep averaging (B), and reaction time (C) as a function of stimulus intensity.

F force amplitude, I is luminance expressed in cd/m^2 and F_o,, and b are constants. With $t_{crit}(8)=2.30$, the coefficient b reached significance only for one subject.

The pattern of results was very similar when sweep averaging instead of amplitude averaging was applied, $F(9,126)=1.87$, $P>0.05$. In Figure 2B, force amplitude calculated according to the sweep averaging procedure is plotted against stimulus intensity. As with amplitude averaging, it was independent of intensity. The only difference between the two ways of averaging was that the amplitude for sweep averaging was smaller than that for amplitude averaging ($t=9.38$, $P<0.001$).

The result of the experiment seems to be clear. Luminance does not affect the force used by subjects to press the key. Moreover, there is little if any effect of the averaging procedure on the relationship between amplitude and intensity: clearly, the differences of RT dispersion for different intensities are too small.

EXPERIMENT II

In Experiments II and III we investigated the force-intensity relationship for auditory stimuli. The experiments differ from one another only in the way in which the stimuli of different intensities were presented: while the intensity varied from trial to trial in Experiment II, the intensities were changed blockwise in Experiment III, as was done in Experiment I.

Method

SUBJECT

Another fifteen persons (7 males and 8 females) whose age were between 19 and 24 participated in the experiment. They were mainly recruited from students of different faculties of Adam Mickiewicz University in Poznań. They were not informed that force would be measured in the experiment. Some of them had previous experience in psychophysical experiments.

APPARATUS

The stimuli were 1,000 Hz tones of 50 ms duration, with rise and fall times of 20 ms. Intensity levels of the stimuli were controlled by an 8-bit D/A converter. Since the experiment was not performed in a sound-proof room, stimuli were presented against a 40 dB(A) white-noise background. Both the stimuli and the background noise were delivered by earphones. Ten intensities were used, ranging from 47 to 102 dB(A).

The remaining details of the apparatus were identical to those used in Experiment I.

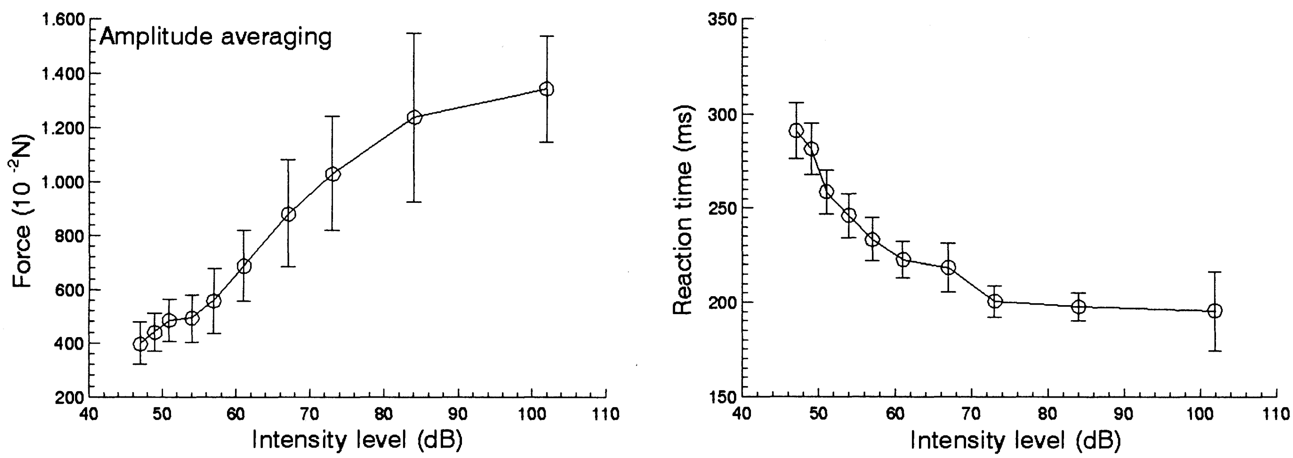

Fig. 3. Force amplitude and reaction time as a function of stimulus intensity (random presentation).

PROCEDURE

The same procedure was applied as in Experiment I except for the order of stimulus presentation. The intensities were randomised so subjects were not aware of the intensity of incoming stimulus. This procedure could be used with auditory stimuli, because after-effects are minimal with these stimuli, in contrast to intense visual stimuli.

Results

In Figure 3 (right panel) RT is plotted over stimulus intensity levels. As expected, RT increased with intensity: $F(9,126)=26.01$, $P<0.001$. In Figure 3 (left panel) the mean of force amplitudes is plotted over the same intensity levels. Evidently the pattern of results was quite different from that obtained in Experiment I for visual stimuli. Force amplitude increased nonlinearly with stimulus intensity in a similar fashion as in Angel's study ($F(9,126)=16.58$, $P<0.001$).

However, the force-intensity relationship can not be described by a simple power law, as was suggested by Angel, because when I approached 0, force amplitude approached a constant value. This finding is probably a consequence of the feedback informing subjects that their force crossed the critical value. Therefore, subjects did not stop pressing the key unless they had heard the buzzer.

A second observation of interest is that in the auditory experiment the forces developed by the subjects were generally higher ($t(8)=10.78$, $P<0.001$) than in the visual experiment, although the force value needed to generate the sound from the feedback buzzer was the same.

The further interesting question is whether there were any correlations between individual reaction times and response forces. Correlation coefficients were calculated separately for every intensity and for every subject. The mean over subjects ranged from -0.05 to 0.29, never reaching the significant level similar to the results reported in Angel's (1973) and Giray's (1990) studies.

EXPERIMENT III

The surprising differences between Experiment I and II suggests that intensity is processed differently in the auditory and the visual systems. However, it can be also argued that this difference was due to different orders in which intensities were presented in both experiments. To eliminate this possibility an experiment was perform in which the auditory stimuli were used again but the order of intensity presentation was as in Experiment I, i.e., the intensities were blocked.

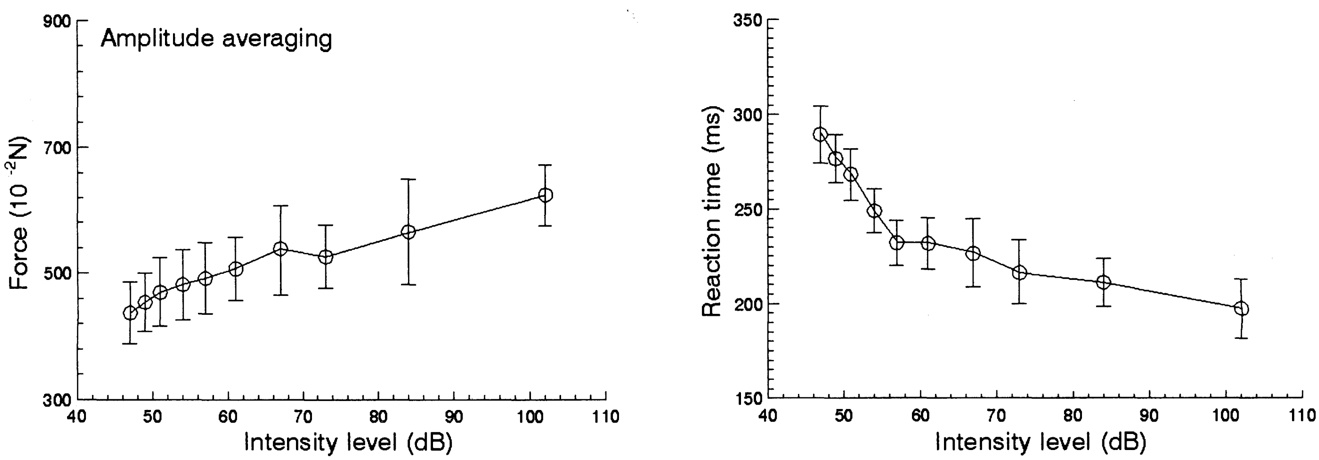

Fig. 4. Force amplitude and reaction time as a function of stimulus intensity (blocked presentation).

Method

APPARATUS AND PROCEDURE

They were the same as in Experiment II.

SUBJECTS

Another fifteen persons with normal hearing (by self-report) and unaware of the purposes of the experiment were used as subjects.

Results

The analyses of variance indicated the significant effects of intensity both on force amplitude ($F(9,126)=54.63$, $P<0.001$) and on reaction time ($F(9,126)=54.60$, $P<0.001$). Force amplitudes and mean RT averaged over subjects are plotted over intensity levels in Fig. 4. In Experiment II, the changes of force amplitude were, in this experiment even larger than in Experiment III, excluding the possibility that the discrepancy between Experiment I and II is due to the different order in which intensities were presented.

GENERAL DISCUSSION

Different patterns of results for visual and auditory systems is not a new finding. (Bertelson and Tisseyere 1969, Sanders and Wertheim 1973; for a review see Nissen 1977). For example, in an S1-S2 experiment (warning signal followed by imperative stimulus) Sanders and Wertheim found that the usual increase of RT from short to long foreperiods occurred only for visual stimuli, whereas for loud (70 dB) auditory stimuli the effect was very small if at all. Moreover, Niemi (1979) has shown that the effect of visual intensity of the imperative stimulus was additive with the effect of foreperiod, while auditory intensity interacted with foreperiod duration. Referring to Bertelson and Tisseyere (1969), Sanders and Wertheim attributed the asymmetry they found to the immediate arousal caused by intense auditory stimuli but not by visual stimuli, an idea elaborated later by Sanders (1983) in his general model of stress. He assumed that every incoming stimulus starts a sequence of active or controlled processes like detection, recognition, and response choice which take place in the so-called computational channel. This processing relies on three interrelated types of energetical supplies: arousal, activation, and effort. Arousal can affect activation which is connected directly to the motor-preparation stage. According to this model, loud auditory stimuli produce more arousal which leads to an extra shortening of RT. This way the model can explain both the interaction in Sanders and Wertheim's and Niemi's data. Sanders provided, additionally, some other lines of evidences supporting his model.

It seems that subjects respond more strongly if their motor preparation stage is more activated. According to Sanders' model higher activation can be produced by increases of the level of arousal. The model explains why the louder auditory signals make subjects press more strongly. On the other hand, visual stimuli are regarded to be non-arousal, which is probably the reason we found no effect of intensity on force.

The hypothesis that the changes of force are due to the excitation of the arousal/activation system was recently supported by Giray (1990). He measured response force as a function of foreperiod duration in an S1-S2 paradigm and found that response force was largest for the shortest foreperiod and decreased when duration of foreperiod increased. In his double-stimulation experiment the force was found to be significantly higher when two modalities were stimulated at the same time than when they were stimulated separately. To explain his findings Giray (1990) presented a model (which, in some aspects, is very similar to Sanders') in which each stimulus, besides starting the sequence of processing aimed to prepare the response, activates temporarily the unspecific channel (=energetical supplies), which is able to influence the dynamic of motor response. Furthermore, he assumed that the higher the activation of the unspecific channel, the larger the force used by subjects. The model explain his data very well. It is also consistent with our data if the assumption is accepted that auditory stimuli can activate the unspecific/energetical channel while visual stimulus cannot.

The results obtained in our study replicate Angel's findings only partially. There might be several reasons for the discrepant results. Unfortunately, it will be rather difficult to discover which of them is responsible for the difference because of the incomplete description of the procedure provided by Angel. However, let us look closer at two of them.

1. Although Angel's subjects were informed of the aim of the experiment after it was over, two facts would seem to indicate that they may not have been entirely unaware of its purpose. EMG electrodes were placed on the subject's forearm. Further, subjects were drawn from among "scientific or technological staff of the departments of physiology and psychology or from the student population" (p. 194). For people selected this way, the experiment's aim may be somewhat predictable, so some kind of unintended manipulation may have taken place.

2. The absolute values of luminance in Angel's study are unknown. It might be, therefore, that he used much higher intensities than we did. This possibility to be a reasonable suspicion because Angel used a discharge gas tube as his light source. Sanders (1975) and Niemi and Lehtonen (1982) found that some arousal effect of visual stimuli can occur for large and relatively intense visual stimuli, rather rarely used in RT experiments. So, the dependence of force on luminance might become manifest when intensity is higher than 1,000 cd/m^2.

ACKNOWLEDGEMENTS

The subject of this paper was inspired by Rolf Ulrich during the first author's stay in the Institut für Psychologie in Tübingen. The authors are very indebted to him for his helpful discussion of the methodology of force measurements and suggestions concerning possible mechanisms involved. Helpful discussion and suggestion on an earlier manuscript were received from Rolf Verleger.

REFERENCES

Angel A. (1973) Input-output relations in simple reaction time experiments. Q. J. Exp. Psychol. 25: 193-200.

Bertelson P., Tisseyere F. (1969) The time-course of preparation with regular and irregular foreperiods. Q. J. Exp. Psychol. 20: 297-300.

Brauner J. D., Lit A. (1976) The Pulfrich effect, simple reaction time, and intensity discrimination. Am. J. Psychol. 89: 105-114.

Collyer C. E. (1976) The induced asynchrony effect: Its role in visual judgment of temporal order and its relation to other dynamic perceptual phenomena. Percept. Psychophys. 18: 47-54.

Giray M. (1990) Über die Aktivierung der menschlichen Motorik: Theoretische und experimentelle Analysen bei Reaktionsaufgaben. Ph. D. Thesis (Institut für Psychologie), Tübingen.

Jaśkowski P. (1991) Perceived onset simultaneity of stimuli with unequal durations. Perception 20: 715-726.

Jaśkowski P., Pruszewicz A., Świdziński P. (1990) VEP latency and some properties of simple motor reaction time distribution. Psychol. Res. 52: 28-34.

Menendez A., Lit A. (1983) Effects of test flash and steady background luminance on simple visual reaction time and perceived simultaneity. Invest. Ophthal. Visual Sci. 24: 95.

Morgan M. J. (1977) Differential visual perisistence between the two eyes: A model for the Fertch-Pulfrich effect. J. Exp. Psychol.: Hum. Percept. Perform. 3: 484-495.

Niemi P. (1979) Stimulus intensity effects on auditory and visual reaction processes. Acta Psychol. 43: 299-312.

Niemi P., Lehtonen E. (1982) Foreperiod and visual stimulus intensity: a reappraisal. Acta Psychol. 50: 73-82.

Nissen M. J. (1977) Stimulus intensity and information processing. Percept. Psychophys. 22: 338-352.

Roufs J. A. J. (1974) Dynamic properties of vision. V: Perception lag and reaction time in relation to flicker and flash threshold. Vision Res. 14: 853-869.

Sanders A. F. (1975) The forceperiod effect revisited. Quart. J. Exp. Psychol. 27: 591-598.

Sanders A. F. (1983) Towards a model of stress and human performance. Acta Psychol. 53: 61-97.

Sanders A. F., Wertheim M. (1973) The relation between physical stimulus properties and the effect of foreperiod on reaction time. Quart. J. Exp. Psychol. 25: 201-206.

Vaughan H. G. jr., Costa L. D., Gilden L. (1966) The functional relation of visual response and reaction time to stimulus intensity. Vision Res. 6: 645-656.

Williamson S. J., Kaufman L., Brenner D. (1978) Latency of the neuromagnetic response of the human visual cortex. Vision Res. 18: 107-110.

Williams J. M., Lit A. (1983) Luminance-dependent visual latency for the Hess effect, Pulrich effect and simple reaction time. Vision Res. 23: 171-179.

Wilson A., Lit A. (1981) Effects of photopic annulus luminance level on reaction time and on the latency of evoked cortical potentials responses to target flashes. J. Opt. Soc. Am. 71: 1481-1486.

Received 1 March 1994, accepted 15 October 1994