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The effects of stimulus context on components of simple reaction time

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Simple reaction time (RT) depends not only on stimulus intensity but also on the context in which that stimulus intensity is presented. We investigate contextual effects of neutral, weak and strong stimulus intensities on simple RT and its premotor and motor components in response to auditory stimuli of three different intensities. We find that the context of weak stimulus intensities lengthens the premotor RT compared to neural context. The implications of these findings for the accounts of contextual effects in simple RT are discussed

Key words: simple reaction time (RT), premotor RT, motor RT, stimulus context, stimulus intensity

Arguably, latency characteristics have been one of the most extensively investigated behavioural aspects in areas of psychological research ranging from psychophysics and neurophysiology to cognitive psychology. The investigations of simple reaction time (RT) in various sensory and motor modalities can be traced to the very origins of experimental psychology and continue to be an active area of investigation to the present day.

One of the main reasons for the prominent status of simple RT in many areas of experimental psychology has been its established inverse relationship with stimulus intensity. In all sensory modalities, response latency decreases, often as a negative acceleration, as stimulus intensity increases (Cattell, 1886; Berger, 1886; Pieron, 1952). While in traditional psychophysics this has led to the frequent use of simple RT as an objective measure of perceived intensity, in modern approaches to stimulus intensity effects one of the main emphases has been their locus, i.e. whether they are related to stimulus detection or response evocation phases of simple RT.

A number of authors have proposed that stimulus intensity only affects the earliest stages of processing and a decrease in RT with stimulus intensity has been thought to reflect directly differences in early peripheral processing of weak and strong sensory stimuli (Sternberg, 1969; Vaughan & Hull, 1965). Although there seems to be ample evidence indicating reliable effects of intensity on neural processing from periphery to cortical level, it has also been clearly established that stimulus intensity effects cannot be explained on the grounds of stimulus energy alone.

Wundt was among the first to suggest that peripheral, or encoding stage related influences were not a major contributors to the large intensity effects in simple RT, and considered the role of attentional factors (Nissen, 1977). In his experiments, Wundt used two auditory stimuli of different intensities and presented them either randomly interspersed, or in the regular order in which subjects knew which intensity would be presented on each trial. When subjects knew the intensity on each trial, the difference in RT to the high and low intensity tones was 11 msec. Surprisingly, when subjects did not know which intensity will be used on each trial, the overall RT increased 137 ms compared to the predictable condition, and the difference in RT between high and low intensity stimuli was 109 msec. Wundt argued for

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an attentional explanation and suggested that RT increase in the random condition was because subjects were unable to direct attention to the particular tone intensity.

Wundt's original observations have been consistently replicated and point to the crucial role of the overall stimulus context in the relationship between stimulus intensity and simple RT. For example, Grice & Hunter (1964) have reported larger intensity differences in simple RT when two different stimulus intensities are randomly presented to the same group of subjects, compared to when two different groups of subjects were exposed only to one intensity in isolation. Also, Kohfeld (1968) found that pre-exposing subjects to various stimulus intensities prior to experimental measurements, significantly modifies the relationship between stimulus intensity and simple RT. His results showed that for the same stimulus intensity, subjects who were pre-exposed to higher stimulus intensities displayed longer RT than subjects who were pre-exposed to lower stimulus intensities.

The first theoretical explanation for these contextual effects was proposed by Grice & Hunter (1964) in terms of adaptation level theory (Helson, 1964). According to this approach, the stimulus experience, and all behavioural aspects of that experience, including RT, can be described in terms of its difference to a reference level that corresponds to an average intensity level of overall stimulation. Low intensity stimuli in the context of high intensity stimuli (and in relationship to the higher adaptation level formed by their presence) will be experienced as of comparatively even lower intensity then if subjects were exposed only to the low intensity level.

However, the adaptation level approach to the intensity effects in simple RT was replaced by more cognitively oriented models which consider intensity effects in simple RT as an interaction between encoding and decision making stages. These models propose that although following stimulus presentation, sensory information grows in strength that is proportional to stimulus intensity, this sensory output is evaluated by the central decision mechanism and the response is given only when the internally adopted criterion is met (Luce & Green, 1972; McGill, 1963; Grice, 1968). The decision mechanism is thought to consist of two "neural monitors", one monitoring and accumulating neural evidence in the absence of sensory signal (noise), and one accumulating neural evidence of the expected signal. Similar to the signal detection theory framework, a decision to respond is made as soon as the activity in one of these monitors reaches a specified criterion, resulting in either a correct response (Hit) or a false alarm. The assumed type of monitored neural evidence can include for example, a number of neural pulses (neural count model, McGill, 1963), or inter arrival times of interspike intervals (neural timing model, Luce & Green, 1972).

In both of these models, the effect of the intensity of a stimulus on the subject's response *to that stimulus* is mediated by the rate of buildup of information, with the buildup of information for a strong stimulus accumulating more steeply than that for a weak stimulus. In summary, the subjects' RT reflects the time required for the impulse count to reach the criterion value (see Figure 1). While McGill (1963) viewed the response criterion as being generally constant, Grice (1968) proposed that a criterion could vary as a function of a number of experimental factors such as contextual and motivational variables. According to Grice (1968) RT can be viewed as a decreasing function of stimulus intensity and an increasing function of criterion level and any experimental manipulation that raises or lowers the criterion should correspondingly enhance or reduce the difference in RT to weak and strong stimulus intensity as schematically depicted in Figure 1.

A number of studies have experimentally confirmed RT contextual dependencies that are seemingly consistent with the assumed corresponding shifts in subjects' decision criterion. Speiss (1973) showed that RT to two auditory intensities is longer when the two are randomly intermixed compared to being presented in two separate blocks. Interestingly, when the two stimuli were randomly presented but subjects were told which intensity was to be presented on each trial, RT to two stimuli is identical to when they are presented in separate blocks. Speiss (1973) argued that the longest RT with random and unpredictable presentation of two intensities is consistent with the assumed higher decision criterion in such experimental situation. In blocked presentation, subject can utilize knowledge of both the

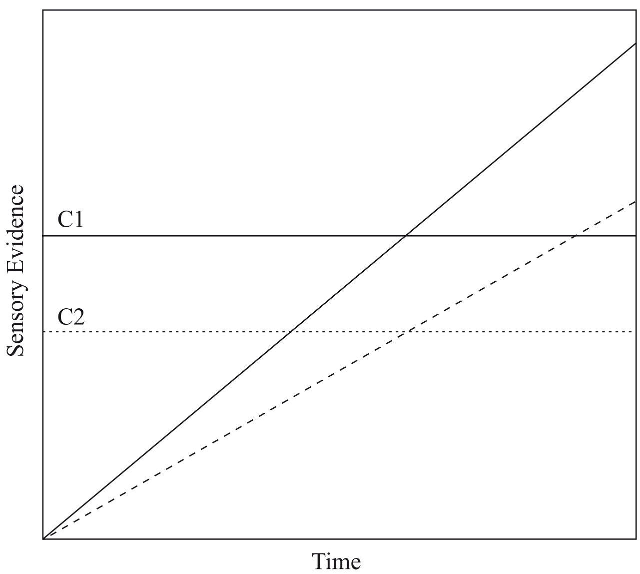

Figure 1. Schematic representation of Groce's (1968) decision criterion model of simple RT. Criterion is a threshold neural activation that needs to be accumulated during the stimulus duration. Criterion can be set at different levels resulting in corresponding changes in RT at the same intensity level.

expected excitation from the signal and the internal noise characteristics of their sensory system and use relatively low decision criterion for both weak and strong signals. The general stimulus uncertainty in mixed intensity blocks, presumably leads to use of a criterion higher than that used in the pure block trials, leading to longer RT.

In additional support for the notion of a flexible and variable decision criterion, Murray (1970) showed that RT for a given intensity varies as a function of the intensity of the immediately preceding stimulus. For example, RT to an auditory tone of 40 db is significantly longer when immediately preceded by a tone of 100 db, compared to tones of 70 and 40 db. Also, in his experiment, Murray (1970) varied the presentation frequency of three auditory tones (40,70, and 100db) and experimentally compared the following distributions: 1:1:1, 1:1:6, 1:6:1, and 6:1:1. His results clearly showed that the frequency distribution in which the most frequent stimulus was of the highest intensity (1:1:6) resulted in longest RT for all three stimuli, consistent with the higher decision criterion in this condition. The shortest RT was obtained with the frequency distribution with the highest frequency of low intensity stimuli (6:1:1), consistent with the presumed lower decision criterion adopted by subjects in this stimulus context. Identical effects of the stimulus context in the domain or RT to electrical tactile stimulation, were reported by Babkoff, Bergman, & Brandeis (1974).

However, some studies of contextual effects in simple RT have not yielded identical results. For example, Grice, Nullmayer, & Schnizlein (1979) failed to observe any significant effects of context with simple visual stimuli varying in brightness. On the other hand, Rohaček & Kolesarić (1983) obtained results in an apparent contradiction with predictions of both adaptation level and decision criteria models of intensity effects in simple RT. In their study, they used two different contexts, which shared one, critical stimulus intensity. The critical shared intensity was the strongest stimulus intensity in the weak context and the lowest intensity in the strong contextual series. The stimuli used were electrical phosphenes and it was found that RT to the critical stimulus intensity was significantly longer when in context of weak, compared to a strong stimulus context. They postulated that obtained results can be accommodated by assuming that stimulus context facilitated formation of spontaneous “sensory’ or “motor” sets. Rohaček & Kolesarić (1983) reasoned that in a context of weak surrounding stimuli, subjects had to orient themselves more towards the detection of weak stimuli, resulting in a formation of a “sensory” set which leads to longer RT compared to the acquired “motor’ set in the context of higher stimulus intensities. These concepts are quite analogous with the traditional concepts of sensory and motor preparatory sets first introduced by Lange (1888).

However, when there was a large temporal gap between RT measurements in two contextual situations, RT to the critical shared stimulus intensity did not differ between weak and strong contexts when stimuli of different intensities were presented in random order (Kolesarić, Komar, & Rohaček, 1983). When the uncertainty regarding stimulus intensity was reduced, by presenting each intensity level in groups of five stimuli (also preceded by an explicit instruction as to which stimulus intensity will be presented), Kolesarić et al. found that RT to the critical stimulus was longer in the context stronger stimuli than in the context of weaker stimuli. In a subsequent study, Kolesarić, Rohaček, & Komar (1984) have found no significant contextual effects with a blocked presentation of various stimulus intensities, consistent with an earlier finding reported by Speiss (1973).

It is clear that the findings on the role of stimulus context on simple RT are heterogeneous and only partially consistent with the predictions of Grice’s variable decision criterion (Grice et al., 1979). Information processing theoretical approaches continue to debate whether stimulus intensity affects only perceptual processes or whether the speed of response activation and execution is affected as well (Miller, Urlich, & Rinkenauer, 1999). The role of stimulus context in simple RT can be considered in relation to the entire sensory-motor process, as evident in an attempt to suggest an interactive effect of stimulus context on the formation of corresponding stimulus- or motor reaction-induced sets (Rohaček & Kolesarić, 1983). Such sensory or motor sets (usually induced by explicit experimental instructions) have been found to affect simple RT even in the absence of any stimulus intensity related experimental manipulations (Vidaković, 1983).

One way to facilitate our understanding of the locus and nature of contextual effects in simple RT is to consider their effects not only on the overall RT, but also on its component phases ranging from stimulus detection to response preparation and execution. Within this approach, RT measurements are accompanied by some physiological indicator, which marks either the end of perceptual processing or the beginning of motor responding. For example, Bartlett (1963) measured the time between the onset of electromyographic (EMG) activity and movement, and found that this time interval was independent of stimulus intensity. Similarly, Botwinick & Thompson (1966) divided RT into premotor and motor components RT by defining the time between stimulus presentation and the beginning of the recorded EMG-activity as premotor component. The motor RT component was defined as time form the beginning of the recorded EMG-activity till the end of response. Botwinick & Thompson (1966) investigated the effects of varying duration of preparatory intervals (from 0.5s to 15 sec) and found that premotor time and RT were highly correlated and showed similar dependencies as a function of duration of preparatory interval. On the other hand, motor time was poorly correlated with RT and was independent of variations in duration of preparatory intervals. Meijers

& Eijkman (1974) also shared the view that the variability of the motor component does not contribute to the overall simple RT.

In our study we analyze simple RT and its premotor and motor components to auditory stimuli presented in contexts of weaker and stronger stimulus intensities. Grice's variable decision criterion model predicts that RT should increase in the context of stronger stimulus intensities and decrease in the context of weaker stimulus intensities. It would be informative to investigate whether these changes in overall RT are accompanied by the corresponding changes in its premotor and motor components. It seems intuitive to expect that assumed lowering of the decision criterion (assumed to be responsible for overall decrease in RT in the context of weaker stimulus intensities) might be evident in the corresponding shortening of the premotor components of the simple RT. Likewise, the assumed increase in the decision criterion in the context of higher stimulus intensities might correspond to the accompanying increase in the duration of the premotor component. Interestingly, Rohaček & Kolesarić's (1983) suggestion that weak stimulus context facilitates spontaneous formation of a sensory preparatory set can be used to make prediction that weak stimulus context would lengthen the duration of premotor component of simple RT time due to its presumed emphasis on sensory detection and/or discrimination.

METHODS

Participants

11 first year psychology students participated in exchange for course credit. All were right-handed, female, and between 18-20 years of age. In addition, all subjects had prior experience in participating in RT measurements and were nad've to the aims of the experiment.

Design

There were two independent variables in our study: stimulus intensity (low, intermediate and high: 55, 75 and 95dB respectively) and stimulus context (neutral, weak and strong). All three intensities were clearly suprathreshold and easily discriminable from each other. In the neutral context condition the frequency of all three intensities was equal (1:1:1). Each of the three intensities was presented 50 times, amounting to a total of 150 trials. In the weak context condition the lowest intensity was presented three times more compared to intermediate and high intensities (3:1:1). The lowest intensity was presented 120 times compared to two other intensities that were presented 40 times each. In the high context condition, the highest intensity was presented 120 times with the intermediate and low intensities presented 40 times each. The weak and strong context conditions each resulted in 200 trials.

Dependent variables in our study were overall RT, premotor RT and motor RT. The overall RT was defined as the time from the onset of auditory stimulus till the response button press. The premotor RT was defined as the time from the onset of auditory stimulus till the beginning for EMG activity, while the time between the beginning of EMG activity and the response button press was defined as the motor RT.

Apparatus

RT measurements

RT measurements were performed by reaction time meter (Laboratorij Mjerne Elektronike, Zagreb), which recorded the time between stimulus presentation and a simple manual button press response. The precision of obtained response times was +/-0.5 ms. Auditory stimuli were delivered by earphones (Koss, K6) worn by subjects which were seated in a custom built chair that allowed for a comfortable but fixed and precise position of the dominant arm which was used for responding.

EMG measurement and analysis

EMG measurements were performed by a polygraph set up (POLI 80, Laboratorij Mjerne Elektronike, Zagreb). It consisted of a universal EMG amplifier with input and output resistance of 90 mOhm and 10 mOhm respectively. The time constant was 300 ms and lower and upper filter frequencies from 0.5 Hz to 5000 Hz. The EEG signals were recorded by a four-channel recorder (Hewlett Packard, 3964A) and continuously monitored via visual presentation on a video display and a printout. Ag-AgCl electrodes (Beckman) were used to record EMG activity.

EMG signals were analyzed via computer controlled 12-channel AD converter and MIOTEST software for EMG analysis. AD converter's sampling rate was 1ms, with a12 Bit (1bit= 1mV) resolution. MIOTEST software performed simultaneous analysis of two analogue channels: channel one contained information regarding timing of preparatory and actual stimulus and channel two contained integrated EMG activity. The software performed A/D conversion in the period of three seconds from the detection of preparatory signal. The analysis establishes time period between the preparatory and actual signal. The recorded duration of the actual signal is equivalent to RT, which was allowed to vary between 100ms and 300 ms. RT outside those boundaries were not analyzed. These cut offs resulted in an exclusion of 2.1% of total number of response times.

Premotor time was determined in the following way: during the first 50 ms after the onset of the actual signal an average EMG activity was calculated and 100 mV was added to that activity. The time from the onset of the actual signal until that threshold EMG activity was reached was defined as premotor RT. The remaining time till the end of signal duration (and RT termination) was defined as motor RT.

Procedure

Every subject participated in three experimental situations and for each participant these measurements were performed at the same time of the day. The order of three experimental conditions varied randomly between subjects.

After arrival, subjects were prepared for EEG recordings by placing the electrodes over flexor digitorum superficialis, which controls and is associated with the movement of middle finger (Masuda & Sadoyama, 1987). The exact positioning of the electrodes was marked and used in subsequent measurements. After electrodes were put in place, the subjects were taken to the dimly illuminated measurement room. Subjects were placed in a chair with a specially constructed armrest with a response button at its end. The armrest length could be adjusted to match that of subject's forearm. Subjects wore earphones and sat opposite the signal box used to deliver warning visual signals. Auditory stimuli followed visual warning signals at randomly presented variable intervals of 0.5s, 1s, 1.5s and 2 s. In each experimental condition, three different stimulus intensities were presented in random order. The duration of auditory stimulus was until subject's response, or 500 ms maximum duration. Inter trial intervals varied randomly between 10 and 15 s. The duration of one experimental condition too approximately between 40 and 50 minutes.

Subjects task was to respond as fast as possible to the presentation of an auditory stimulus by pressing a response button with their middle finger. First five trials in each experimental condition were considered practice trials and were not used in data analysis.

RESULTS

Preliminary analyses

Three dependent variables in our study were the overall, premotor and motor RT. The average response times for 11 participants in three experimental conditions are presented in Table 1 and graphically depicted in Figure 1????. Preliminary analyses included three two-way repeated measures ANOVAs for each of the dependent variables.

The analysis for the overall RT revealed the significant main effect of stimulus intensity ($F(11,2)=14.91$, $p<0.0001$) and no other significant effects or interactions. The analysis for the premotor RT revealed significant main effects of both stimulus intensity ($F(11,2)=13.50$, $p<0.0001$) and stimulus context ($F(11,2)=5.34$, $p<0.007$). With the motor RT, there was a significant effect of stimulus context ($F(11,2)=4.81$, $p<0.01$), while the main effect of stimulus intensity was not significant.

The analysis of the effect of stimulus context

The preliminary analyses revealed significant main effect of stimulus context only on premotor RT. In order to further evaluate the nature of this effect we performed further analysis where the effects of weak and strong stimulus context were examined only on a selected range of appropriate stimulus intensities. In these comparisons, the premotor RT to three different stimulus intensities was used as a baseline.

As a reminder, in the neutral context each of the three stimulus intensities was presented with equal frequency (50 times). In the weak context, the presentation frequency of the lowest intensity was increased to 120, while the presentation frequency of other two intensities remained simi-

Table 1
Average overall, premotor and motor reaction time (ms) for 11 subjects in neutral, weak and strong stimulus context

		Overall RT		Premotor RT		Motor RT	
	Intensity	*M*	*SD*	*M*	*SD*	*M*	*SD*
Neutral Context	Weak	191.9	19.60	119.1	21.07	72.8	18.99
	Intermediate	158.6	15.46	93.5	12.07	65.1	16.46
	Strong	153.2	13.03	90.7	11.64	62.4	15.35
Weak Context	Weak	189.6	22.72	123.6	18.39	66.0	22.08
	Intermediate	161.8	17.62	101.6	12.36	60.1	16.37
	Strong	156.0	17.59	98.6	11.29	57.3	14.63
Strong Context	Weak	196.2	23.94	127.4	23.28	68.8	20.02
	Intermediate	161.0	19.87	97.0	14.16	64.0	16.29
	Strong	152.9	17.01	93.0	13.59	59.9	15.04

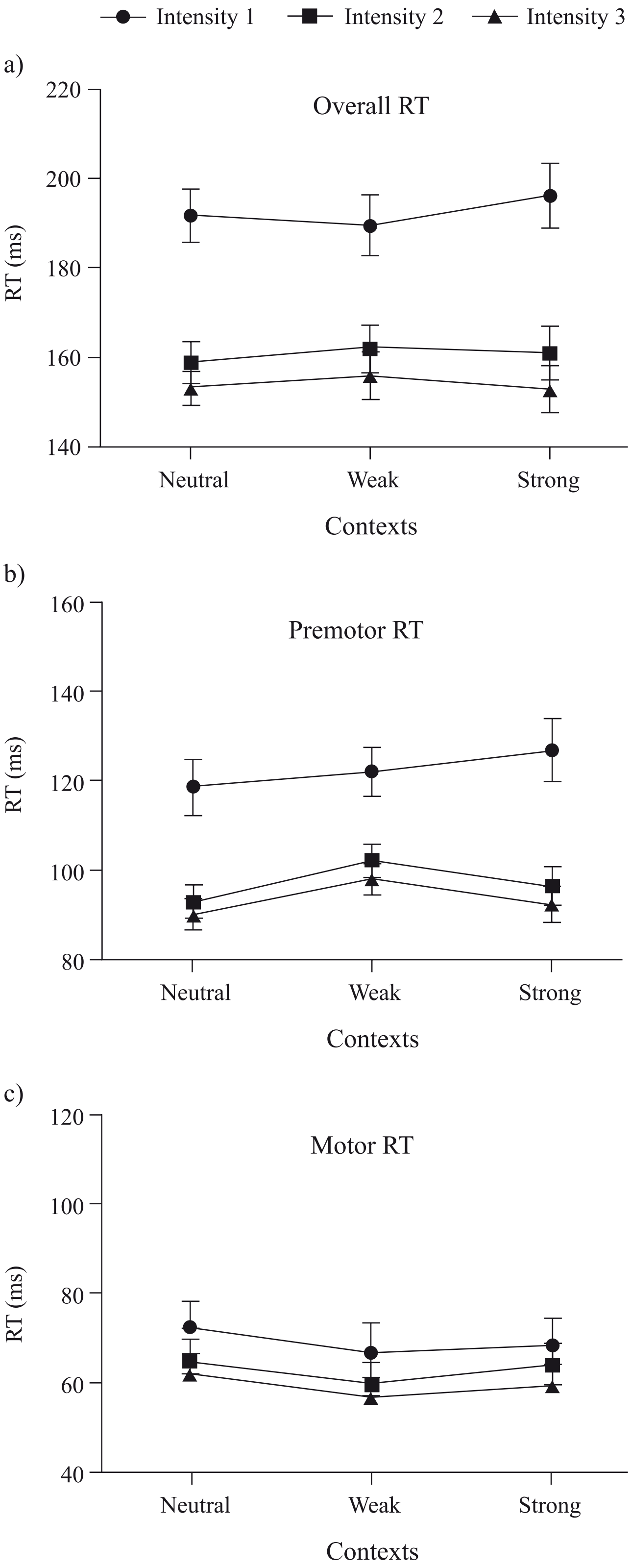

Figure 2. Simple RT in neutral, weak and strong context: (a) overall RT; (b) premotor RT; and (c) motor RT. Error bars represent the standard error of the mean.

lar to that in the neutral, baseline context (40 times each). Conversely, in the strong context the presentation frequency of the highest intensity was three times that of the two remaining intensities. We chose to evaluate the effect of each context type by making comparison for the two stimulus intensities that had similar presentation frequencies to that of the neutral context type. Correspondingly, the effect of weak context was examined for the intermediate and strong intensities, while the effect of strong context was examined

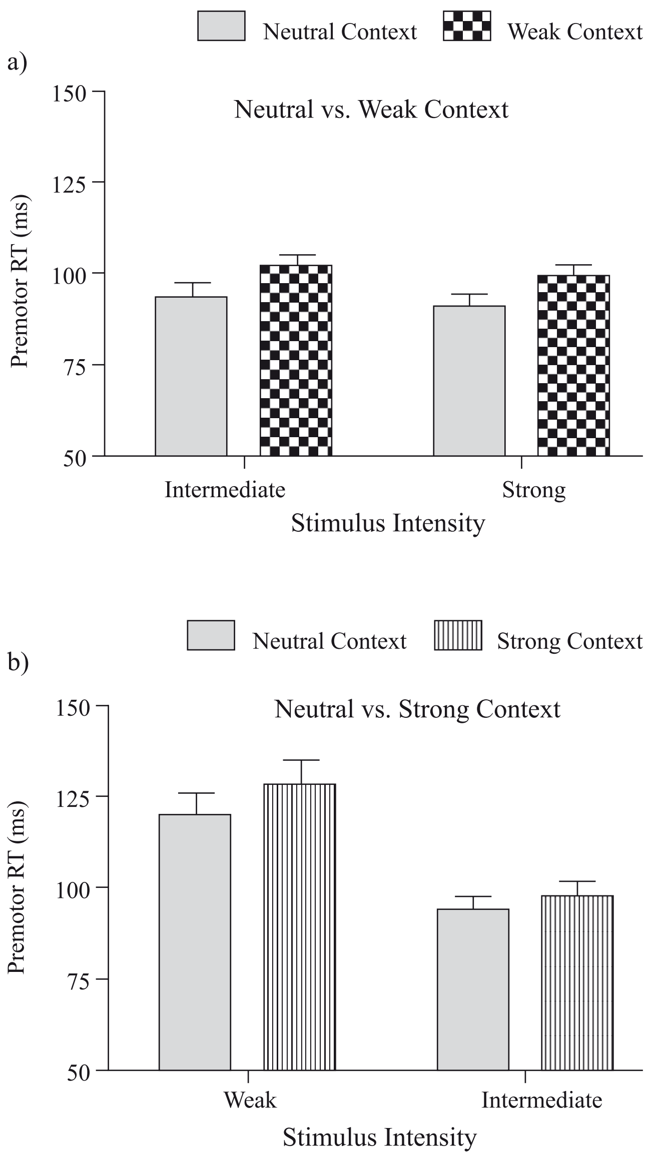

Figure 3. Premotor RT in neutral, weak and strong context: (a) comparison between neutral and weak context conditions for the intermediate and strong stimulus intensity levels; (b) comparison between neutral and strong context conditions for weak and intermediate stimulus intensity levels. Error bars represent the standard error of the mean.

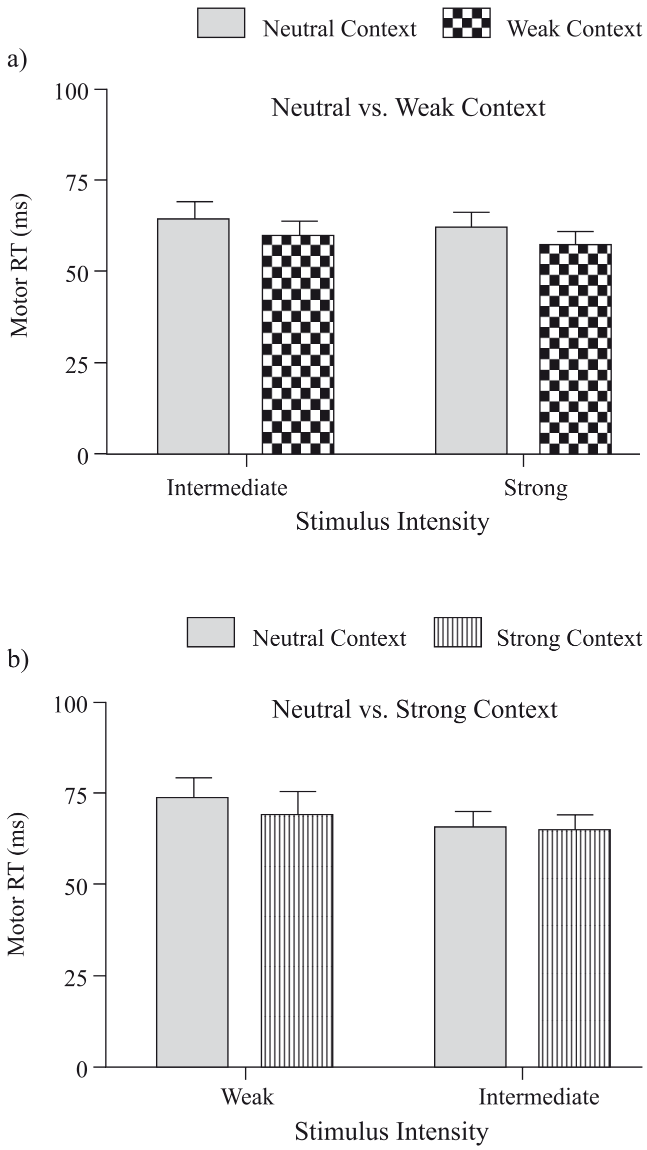

Figure 4. Motor RT in neutral, weak and strong context: (a) comparison between neutral and weak context conditions for the intermediate and strong stimulus intensity levels. (b) comparison between neutral and strong context conditions for weak and intermediate stimulus intensity levels. Error bars represent the standard error of the mean.

for the weak and intermediate intensities. The average premotor RT and motor RT for these selected comparisons are presented in Figures 3 & 4 respectively.

Comparison between Neutral and Weak Context

A two-way repeated measures ANOVA for premotor RT revealed the significant main effect of Context ($F(1,20)=16.03$, $p<0.0007$) such that premotor RT was longer in the condition of Weak compared to Neutral Context. The main effect of Intensity was not significant. Bonferroni posttests revealed significant difference at both intermediate and strong intensity levels ($t(10)=2.87$, $p<0.05$; and $t(10)=2.79$, $p<0.05$ respectively).

The analysis of motor RT revealed no significant main effect of Intensity and only marginally significant main effect of Context ($F(1,20)=5.26$, $p<0.033$). Bonferroni posttests revealed no significant difference at either intermediate or strong intensity level.

Comparison between Neutral and Strong Context

A two-way repeated measures ANOVA revealed the significant main effect of Intensity ($F(1,20)=16.06$, $p<0.0007$) such that premotor RT was longer at the intermediate compared to strong intensity level. The main effect of Context was not significant. Bonferroni posttests revealed no significant differences at both intermediate and strong intensity levels.

There were no significant man effects or posttest comparisons resulting from the analysis of motor RT.

DISCUSSION

In this study we investigate the effects of stimulus context on components of simple RT to auditory stimuli. The premotor and motor components of simple RT were determined in relation to the onset of the response related EMG activity. The time between stimulus onset and the beginning of the recorded EMG-activity was defined as premotor component while motor RT was defined as time form the onset of the EMG-activity till the end of response. We presented three different stimulus intensities in either neutral context or in contexts of weaker and stronger stimulus intensities.

Our preliminary analysis revealed significant effects of stimulus intensity on both overall and premotor RT but no such effect on the motor component of simple RT. These results are consistent with previous findings that the effects of stimulus intensity affect phases of simple RT that precede the final execution of motor response (Bartlett, 1963: Botwinick & Thompson, 1966). Although on the base of EMG based physiological measure alone, it cannot be ruled out that intensity could affect motor processes preceding EMG onset, without affecting the final execution, some recent studies utilizing different physiological markers do not seem consistent with such a hypothesis. For example, Miller et al. (1999) used lateralized readiness potential, the difference in EEG activity at the left and right sensorimotor cortical areas responsible for initiation of hand movements, and supported conclusion that the characteristics of the motor component of RT seem to be unaffected by stimulus intensity.

The main analysis focused on the effect of stimulus context on simple RT and its premotor and motor components. The neutral context consisted of equal number of weak, intermediate and strong intensities. The frequencies of weakest and the strongest stimulus intensity were increased in the weak and strong contexts respectively. While there was no significant effect on the overall and motor RT, the premotor RT showed significant effect of stimulus context such that premotor RT at intermediate and strong stimulus intensity levels was longer in the context of weaker stimulus intensities. This finding seems to some extent inconsistent with the assumption of lower decision criterion in the context of weak stimulus intensities (Grice, 1968). We think that it is plausible to assume that lower decision criterion could be expected to decrease, not increase premotor component of simple RT.

On the other hand, this finding seems consistent with the notion of spontaneously induced sensory preparatory set in simple RT, as suggested by Rohaček & Kolesarić (1983) and Kolesarić et al. (1894). As evident from Figure 2(b), for two out of three tested intensity levels, premotor RT is longer in weaker stimulus context compared to both neutral and strong stimulus contexts. The observed smaller difference in premotor RT between neutral and strong stimulus contexts is also consistent with the assumption that the preparatory set induced, or perhaps a default set, in neutral context coincides with motor preparatory set. The increased frequency of weaker stimulus intensities seems to facilitate the adoption of sensory set.

One possible cautionary note in regard to our suggestion is that the significant effects were only evident in the case of premotor RT and not with the overall RT as well. Our view is that by utilizing the physiological measure of the onset of EMG activity, we have perhaps succeeded in operationalizing a more sensitive measure of contextual effects in simple RT, than it is possible with purely behavioural techniques (such as overall RT). Also, another reason why the effects of contextual manipulations were not observed for overall RT is that our context manipulations were not of the type, and possibly as strong, as some used in the previous studies (Speiss, 1973; Babkoff et al., 1974). In these studies, contextual effects were estimated by comparing the simple RT to a stimulus intensity presented in isolation to that presented in a context of weaker or stronger stimulus intensities.

Given that all three intensity levels were presented together even in the condition of neutral context, our manipulations of stimulus context can perhaps be better described as variations in contextual strength (rather than type). However, this way of operationalizing contextual effects is consistent with the traditional manipulations of frequency of component elements that differ in stimulus intensity. The contextual dependencies in this situation presumably depend on the interrelations and the relative differences between component elements. It is possible that some other contextual manipulations, for example the presence of noise of varying intensity could yield different results as in this situation the contextual information concerns the relation between a given intensity and its temporally contiguous background. In summary, while our manipulations did not produce observable effects at the level of overall RT, we found significant and consistent effects on the premotor RT component.

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