Psychophysical scaling based on the perception of the form of continuous stimulus increment with time: A preliminary study

KLAS M. BRENK and ANJA POLJANŠEK

A direct psychophysical scaling method of perceived form of stimulus increment with time has been lately studied mostly by psychologists from the Department of psychology in Zagreb. In experiment on brightness perception (Bujas, Rohaček, Mayer, Vodanović, 1984) discontinuous slide-projection through filters of different grays was used. Stimulus intensity function producing the linear impression was inverted to estimate the psychophysical function. The method has not been used often, presumably because it was time-consuming and demanding.
A computer application, which provides a continuous intensity change, was written to resemble the conditions in natural environment better. Preliminary measurements were done and a comparison with the study of Bujas et al. (1984) was made. Higher power-function exponents were obtained consistently (0.82 to 1.05). The results were also much more interpersonally variable. Some feasible explanations are discussed, including differences in room illumination, shape of presented stimulus functions, background colour, display characteristics and continuity of stimulus change.

Among the many existing psychophysical scaling procedures we are still searching for one that would be reliable and valid enough. In the last forty years the direct approaches to scaling have been popular. One of them is based on the perception of the form of stimulus increment with time (a shorter name for the psychophysical method is thus PFSI). The method was used in studies of different sensory modalities (Bujas, Rohaček, Mayer & Vodanović, 1984; Bujas, Ajduković, Szabo, Mayer & Matutinović, 1997; Marks & Slawson, 1966; Rohaček, 1983).

In PFSI stimulus intensity is not judged isolated from other intensities. Instead, stimulus intensity changes as some function of time. The forms of the presented functions vary. Usually, the presented functions are power functions with various exponents. After each presented intensity-time function observer assesses the form of intensity changes, i.e., he/she gives the global judgement on the entire stimulus. This can be done either by reporting the numerical estimation of the degree of nonlinearity (Marks & Slawson, 1966) or by categorising the form as 'decelerated, accelerated or linear' (Bujas et al., 1984; Bujas et al., 1997; Rohaček, 1983; Vukosav, 1988). It is hypothesised that there will be one intensity-time function that gives rise to a sensation whose magnitude appears to increase linearly with time (Marks & Slawson, 1966).

The power of the intensity-time function, that provokes linear increment in sensation, is called the exponent of subjective linearity. It can be determined in various ways. One of them is analogous to the determination of the point of subjective equality in the method of constant stimuli. After the logarithmic transformation of exponents in geometric progression is done, Spearman's summation method (described in Guilford, 1954) can be used on obtained arithmetic progression of values. Exponent of subjective linearity is determined as antilogarithm of the average of upper and lower limens, found at proportion 0.5 of answers 'accelerated' and 'decelerated', respectively. As was mathematically proven for power functions (Bujas et al., 1984; Bujas et al., 1997; Vukosav, 1988), the inverse of the exponent of subjective linearity represents the psychophysical function exponent.

Bujas and co-workers (1984) analysed the metric characteristics of PFSI. They investigated brightness perception. Light was projected through filters of different greys and transduced through a frost-glass screen. Intensities were presented discontinuously, in series of six stimuli,

Klas M. Brenk, Department of Psychology, University of Ljubljana, Aškerčeva 2, 1000 Ljubljana, Slovenia. E-mail: Klas.Brenk@uni-lj.si; Anja Poljanšek, Department of Psychology, University of Ljubljana, Aškerčeva 2, 1000 Ljubljana, Slovenia. E-mail: anja.poljansek@uni-lj.si (Correspondence concernig this article should be sent to this address).

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from one with the lowest reflectance to that one with the highest. The exponents of presented intensity-time functions were in geometric progression (0.769, 1.00, 1.3, 1.69, 2.197, 2.856, 3.713 and 4.827). Subjects rated increments as decelerated, linear or accelerated. The psychophysical function for transduced luminance was found to be 0.434, variation coefficient 8.77 %, with extreme-values ratio of 1 : 1.47.

Some other authors also found low variability of individual psychophysical function exponents (Bujas, Rohaček & Mayer, 1981, after Rohaček, 1983; Bujas et al., 1997; Rohaček, 1983) and stressed this as an implication of better metric characteristics of PFSI compared to Stevens' magnitude estimation method, which is more frequently used today. The PFSI method was found to yield reliable and valid results (Rohaček, 1983; Bujas et al., 1984; Vukosav, 1988). Compared to magnitude estimation, in PFSI the psychophysical relation was also less affected by stimulus-intensity range (Rohaček, 1983) and by irrelevant factors (Vukosav, 1988). None of the critics concerning the use of numbers for estimating psychological intensity (Banks & Coleman, 1981; Banks & Hill, 1974; Curtis, 1970) can be applied to PFSI. An important feature of PFSI is a dynamic stimulation, which makes the experimental situation similar to the natural conditions (Rohaček, 1983; Bujas et al., 1997).

Despite all the potential advantages of PFSI the method has not been applied often. The procedure, used by Bujas et al. (1984), takes a lot of effort to prepare materials and to present stimuli to subjects. It is tiring to follow all the series and to pass a judgement. Experiments were performed in groups to obtain more results in a shorter period, but the same experimental conditions for every participant were not achieved, since slides were observed at different visual angles by different participants. Slide-projection resulted in variable room illumination, which led to constant adjusting of pupila. Discontinuous presentation of (isolated) stimuli did not reflect reality best. The continuous change in stimulus intensity was suggested for future studies, but at that time technical limitations were admitted (Rohaček, 1983; Vukosav, 1988).

To improve the procedure and fulfil the aspirations of previous authors for continuous presentation of stimulus increment, we have developed a computer application in MS Visual Basic 4.0, called 'GPM'. 'GPM' is an abbreviation for 'global-perception method'. The name is trying to reveal that perception is considered in a more global sense, i.e., not being based on isolated stimuli, but positioned in time. With GPM much shorter time is needed to execute the experiment. Computers also assure perfect repetitions of giving instructions, presenting experimental material and following experimental procedure.

This paper reports about the preliminary study that was done to see whether the computerised procedure functions well. An indication of that could be given by a comparison with the results of the procedure used by Bujas et al. (1984), where related physical continuum was studied.

It was noticed soon that the experimental situation with the use of computers cannot be a perfect repetition of the study of Bujas and associates. Some adjustments considering the forms of presented intensity-time functions were necessary. That is why we wanted to check whether small changes in stimulus range can influence the outcome.

Since most of our everyday judging of brightness takes place not in a dark surround, but under rather different (daylight) conditions, we also wanted to see how other spatial luminances influence the results. Hence, room illumination was varied.

METHOD

Participants

Eighty-three students of psychology at University of Ljubljana participated. All of them followed a course on global perception method. Some examples of the continuous stimuli (e.g. the sound of a howling siren, the car that decelerates and stops in front of the traffic-lights) were given and the concepts 'accelerated, decelerated and linear' were explained. However, participants were not introduced to exact experimental characteristics, because we believed that their estimations could be shaped beforehand if a certain brightness intensity-time was explained with a certain concept. Fifty participants were regular second-year students and constituted Groups 1 and 2. Thirty-three students of nonregular psychology course at the same university constituted Group 3.

Apparati

Sixteen different PCs 486 with Windows 95 and 15" RGB monitors Sony Trinitron (with 16-bit colours and 800x600 resolution) were accessible in a student computer-room at our university. Screens were switched on half of an hour prior to the experiment for pictures to be stabilised, and carefully calibrated for contrast and brightness (set to medium contrast and medium brightness). However some inequalities could not be eliminated.

Using ELVOS LM-1010 luxmeter stimulus intensities were measured. Luxmeter was placed closely to the screen, facing its centre.

Stimuli

GPM application operated with visual stimuli. In the centre of a constant middle-level grey screen (RGB(142, 142, 142)) was a square with the area of 7x7 cm. The colour of the centre square changed from black to white, i.e., from stimulus intensity 0 lx to the one of 210-230 lx (depending on the screen). Such a transition we called a relevant stimulus. An irrelevant stimulus was the one where stimulus intensity did not only increase but also decreased. Five different irrelevant stimuli were presented in order to maintain observers' motivation and control their concentration (that is, to make observers follow the whole stimulus, not just the beginning).

Changes in stimulus intensities were presented in such a rapid manner, that observers could not register any leaps. Each presentation was about 6.4 seconds long.

Ten series of eight stimuli, seven relevant and one irrelevant, were shown. Within a series the stimuli were presented in random order.

Procedure

Groups 1, 2 and 3 participated under different experimental conditions. The experiment was performed in smaller groups of 10-16 people, with one participants working on one PC. Observers were brought to an indirectly illuminated room (Ne-lights) and took their sits in front of screens, approximately 1 m away. Groups 1 and 2 remained light-adapted and the application was run with lights switched on. In Group 3 lights were switched off, and participants ran the application in dark (they were dark-adapted for about 10 minutes before beginning the experiment).

Observers first read instructions on computers, where they were introduced to the application, the basis of global-perception method and an example. Their questions were answered. When they were ready, they started the experiment with centre-square transitions by clicking the mouse.

After each stimulus series ended, a choice among preset answer options was made by the observer. Options were given in writing, with pictures showing extremely decelerated, (moderately) decelerated, linear, (moderately) accelerated and extremely accelerated changes, as Figure1 shows (see Appendix)

If subjects found no option accurate, they could click the option 'different' and choose among five different pictures of irrelevant stimuli. Experimental part was usually completed in approximately 25 min.

When developing GPM it was discovered that the exponents, which were used in the study of Bujas et al. (1984), cannot be efficiently used in the computerised procedure, because not all estimations were 'decelerated' at the lowest exponent 0.769. To follow the method of constant stimuli and Spearman's summation method, the exponents had to be chosen in such a way that every answer to the smallest exponent would be 'decelerated', and to the highest exponent 'accelerated'. Exponents not only had to be shifted downwards, but their range had to be expanded in order to satisfy the demand for the upper bound of the exponent series.

With Groups 1 and 3 the following exponents of intensity-time functions were used: 0.356, 0.533, 0.8, 1.2, 1.8, 2.7 and 4.05. The basic exponent (the central one in the geometric series) was thus 1.2, and the geometric-progression coefficient (the multiplier of the preceding exponent in a row to get the next one) was 1.5.

To see whether the change in the exponents could alter the psychophysical function, another condition was set with a shift in the basic exponent. To satisfy the demands for the use of Spearman's summation method a shift had to be small enough and, at the same time, the geometric-progression coefficient had to be changed. Group 2 participated in the experiment under modified conditions, with basic exponent 0.8 and geometric-progression coefficient 2, that is, with exponents 0.1, 0.2, 0.4, 0.8, 1.6, 3.2, 6.4.

Data analysis

The calculations excluded first sixteen stimuli. Two observers in Group 3 were eliminated from further analysis since their answers were completely confused or showed no understanding of the concepts 'accelerated' and 'decelerated'.

The proportion of specific estimate category at each exponent was determined. Spearman's summation method was used with logarithms of exponents of intensity-time functions to obtain the exponent of subjective linearity.

Although a relatively large range of exponents of intensity-time functions was chosen to provide proportion of answers 'accelerated' and 'decelerated' equal 1.0 at the highest and the smallest exponent, respectively, some observers' failed to give answers accordingly. For them computations were done with corrections. For example, if the proportion of answers 'accelerated' was lower than 1.0 at the highest exponent presented, it was assumed that at the first exponent even higher all the observer's answers would be 'accelerated'. This exponent, obtained by multiplying the highest presented exponent by the geometric-progression coefficient, served to calculate the upper limen. All further calculations to determine the exponent of the psychophysical function were applied as in Bujas et al. (1984).

RESULTS

Individual psychophysical exponents were distributed normally (Shapiro-Wilk's W was found statistically non-significant in all our groups). As can be seen from Table 1 the average exponents of psychophysical function varied from 0.82 to 1.05, thus the psychophysical relation for brightness was shown to be close to linear. The intensity-time functions, resulting in linear increase in sensation, were linear or only slightly accelerated (average exponents of subjective linearity varied from 0.95 to 1.22). The highest psychophysical function exponent was obtained in Group 2 (where the range of exponents was changed). The difference between the results of our study and those of Bujas et al. (1984) was very large. Our results showed two times aboveor even higher exponents than they obtained (0.434).

The extreme-values ratios were quite large, from 1 : 1.79 to 1 : 2.49 (Table 1). Bujas et al. obtained much lower ratio, i.e., 1 : 1.47. Also the coefficients of variation were very large in our case (see *V* in Table 1), and about two times larger than that obtained by Bujas et al. ($V = 8.77$ %). However, our results showed no more variability than some other studies of PFSI (Rohaček, 1983; Vukosav, 1988), and they showed less absolute variability around the average than results of some studies on magnitude estimation (Rohaček, 1983; Bujas et al., 1984).

Groups 1 and 3, which performed the experiment under different room illumination but were presented equal intensity-time functions, were compared by Kolmogorov-Smirnov test. The groups did not differ significantly ($|D_{max}| = 0.31$; $p > 0.05$, two-tailed) and were afterwards merged into a single one ($N = 66$) for a comparison with Group 2. This comparison by Kolmogorov-Smirnov test showed that the change of exponents influenced the value of average exponent of psychophysical function ($|D_{max}| = 0.54$, $p < .01$, two-tailed). Changing the basic exponent (from 1.2 to 0.8) and geometric-progression coefficient (from 1.5 to 2) significantly influenced the outcome.

Subjects reported that they found the task to be very interesting. They were motivated by irrelevant stimuli included. Some problems occurred with the first few stimuli. First sixteen estimations were excluded from data anyway when determining the psychophysical function. We believe that after the sixteenth presented stimulus subjects were well acquainted to their task, since they also reported that they had no more problems thereafter. It was reported that some answers were based only on parts of stimuli.

Table 1

Descriptive statistics of the distribution of the individual psychophysical-function exponents in three groups, where brightness perception was measured with GPM.

	Group 1	Group 2	Group 3
N	35	15	31
M	0.89	1.05	0.82
SD	0.135	0.178	0.174
V (%)	15.17	17.45	21.48
Min	0.647	0.712	0.515
Max	1.159	1.422	1.281
Max/min	1.79	2.00	2.49

Note. The experimental conditions in the three groups varied. Group 1 - light-adapted, default intensity-time functions. Group 2 - light-adapted, modified intensity-time functions. Group 3 - dark-adapted, default intensity-time functions. *V* stands for coefficient of variation (in %), *Min* for the smallest individual psychophysical-function exponent, and *Max* for the largest individual psychophysical-function exponent. *Max/min* represents ratio of the largest to the smallest individual exponent (extreme-values ratio).

DISCUSSION

Many authors report on decelerated psychophysical relation in the brightness modality (Bujas, 1981, after Rohaček, 1983; Bujas et al. 1984; Plateau, 1872, after Rohaček, 1983; Stevens & Galanter, 1957). Yet, the psychophysical relation obtained in our study is almost linear. It lies in between the results obtained in the modality of light reflectance and the results obtained with brightness. In some CRT studies (Catode Ray Tube) on brightness (Arend, 1993; Arend & Spehar, 1993; Schirillo, Reeves & Arend, 1990), it was found that observers are able to identify two distinct sensory modalities for greys on the screen - lightness and brightness. The first refers to apparent reflectance, while the second refers to perceived luminance (Schirillo et al., 1990). Our stimuli could thus resemble the reflectance of neutral grey surfaces, especially in lighted conditions. For reflectance of grey papers, Stevens & Galanter (1957) obtained the exponent 1.2 with magnitude estimation. If some notions, e.g. that with numerical scales open upwards the numerical continuum is perceived as compressive (Banks & Coleman, 1981), are taken under consideration, ours and Stevens' (compressed) exponents become alike. It is possible that our observers' judgements did not concern brightness only.

The unexpectedly high individual psychophysical function exponents and their variability in GPM, as compared to the study of Bujas et al. (1984), asked for a closer look at experimental characteristics in both studies to find some other feasible explanations.

Greater variability of results in our study could be the result of using 16 different monitors with unequal characteristics (contrast, brightness, highest intensity presented, colour nuance, glaring). Presumably the calibration of monitors was not exact enough. Computers could differ in their configurations (system devices, display adapters). The consequences were slightly different processing speed and hence different time intervals of stimulus presentation, and perhaps the presented intensity-time functions. In future, studies have to be done on a single PC.

It is questionable whether a frost-glass screen gives stimuli similar to those produced by a computer monitor. In the study of Bujas et al. the light was transduced, while with computers light is emitted by phosphor triads on the screen. Some differences in the nature of light should be irrelevant as long as the spatial distribution of light at the eye is kept the same (Agostini & Bruno, 1996). We were not able to control this.

The visual angle in the study of Bujas et al. was 5°, whereas in our study it was approx. 4°. This could be one of important procedure differences, since comparability of studies is affected by control of visual angles (Agostini & Bruno, 1996). Space is an important context factor (Lockhead, 1992) and stimulus size influences brightness (Allik, 1989; Stevens & Galanter, 1957). Our results are consistent with conclusion of Stevens (1957) that smaller targets give larger exponent.

What we consider a major context effect, is the background colour. Bujas et al. used a black surround, while in our study medium grey surround was displayed on the screen around the target. A bright surround inhibits the subjective brightness of a target and its exponent jumps to a higher value (Stevens, 1960). This is what had to happen in our experiment, since the background was brighter.

Although we measured stimulus intensities with luxmeter, intensity ranges of both studies are comparable, since, as Adlešič (1957) stated, "...a completely white surface, illuminated with 1 lux, has a brightness of 1 apostilb" (p.259). Both screens were secondary emitters illuminated by primary lighting bodies (slide-projector in one case and phosphor triads in another). If measurements were taken with apparati placed in the centre of the screen in both studies, the measures would be directly comparable. In the study of Bujas et al. the intensity varied from 0.5 to 525 apostilbs and in our study from 0 to 230 apostilbs (1 lx equalled 1 asb). Our smaller range of presented intensities was due to the monitors' limitations to produce greys (whites) of higher intensities. Even the brightest stimulus seemed light grey compared to the colour of a white paper. Since in some studies of PFSI the psychophysical function exponents were slightly higher (however non-significantly) when stimulus range was smaller (Bujas, 1984; Rohaček, 1983), the higher exponent, obtained in our study, can be attributable to the effect of stimulus range. Perhaps if we reached a more intensive white, intensity-time functions would seem more decelerated.

Since the relationship of stimulus range and response range is of great importance (Teghtsoonian & Teghtsoonian, 1989), we should provide equal stimulus range before making any judgements about other contextual effects.

The ratios of accelerated to decelerated exponents presented were different in both studies. Bujas et al. used the ratio 6 to 1, ours was 4 to 3. That could be the reason for different results as well. The point of subjective equality tends to be the mid-point of the presented range of stimuli (Garner, 1954). Criterion shift occurs (Warren, 1989). Suppose that subjects in both studies tended to locate the exponent of subjective linearity as the mid-point of presented exponents. If so, in experiment of Bujas et al. it would tend to be around 1.927 and in our study it would tend to be around 1.2 in Groups 1 and 3, and around 0.8 in Group 2. The exponent of psychophysical function would therefore tend to be around 0.519 in the other study, and 0.833 (Groups 1, 3) and 1.25 (Group 2) in ours. That is very close to what was actually found. The chosen physical exponents themselves could thus be the reason for the results obtained. To be more sure about such an effect, both of our experimental settings should use equal geometric-progression coefficient. If the effect existed, that would certainly mean a disadvantage to the method.

Room illumination was not equal in both studies. In the one of Bujas et al. it was dark, except for the flashes of the projector light. Light-adaptation increases the contrast effects (Stevens, 1960; Murray, 1989) and the slope of the brightness function (Curtis & Rule, 1972; Stevens, 1957; Stevens & Galanter, 1957). However, spatial distribution of luminance beyond basic experimental stimuli and other luminance in the visual field seem to have opposite side-effects in CRT (i.e. computer & monitor) studies and reduce contrast effects (Agostini & Bruno, 1996). Anyway, in our Group 3, which performed experiment in a dark room, the obtained exponent was not significantly lower, which indicates that the global-perception method is resistant to influences of room illumination.

Another important factor could be the time of stimulus-series exposition. In the study of Bujas et al. stimulus lasted 22 seconds (one slide shown for 2 sec, break 2 sec, next slide more intense 2 sec, etc.), while in GPM it lasted approximately 6.4 seconds. It was found previously that brightness is a function of flash duration (Lockhead, 1992) or time duration (Allik, 1989) and it is still a question how continuous changes influence perceived brightness. Continuous presentation is closer to real-life situation, more consistent with underlying theory (Rohaček, 1983; Bujas et al., 1984). Vision is the result of intensity differences (Lockhead, 1992) and should be treated like that in experiments. However, to be sure that the difference in presentation form influenced psychophysical relation, all other factors, mentioned before, should be controlled.

According to some findings in literature, the above-mentioned factors mostly suggest the right direction of explaining our higher psychophysical function exponents.

Further investigations will have to be carried out with better controlled experimental settings. The study of Bujas et al. should be repeated with a PC if one would want to obtain the same physical continuum. In future we intend to make an application similar to GPM, that will present stimuli discontinuously. In such a way equality of stimulus modalities in both procedures will be assured, and spatial distribution of luminance, visual angle and intensity range will be controlled better. We will try to answer whether the form of stimulus presentation (continuous vs. discontinuous) affects psychophysical relation. Difficulties will remain in determining the optimal time interval. However, temporal dimension of stimulation remains GPM's major advantage.

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APPENDIX

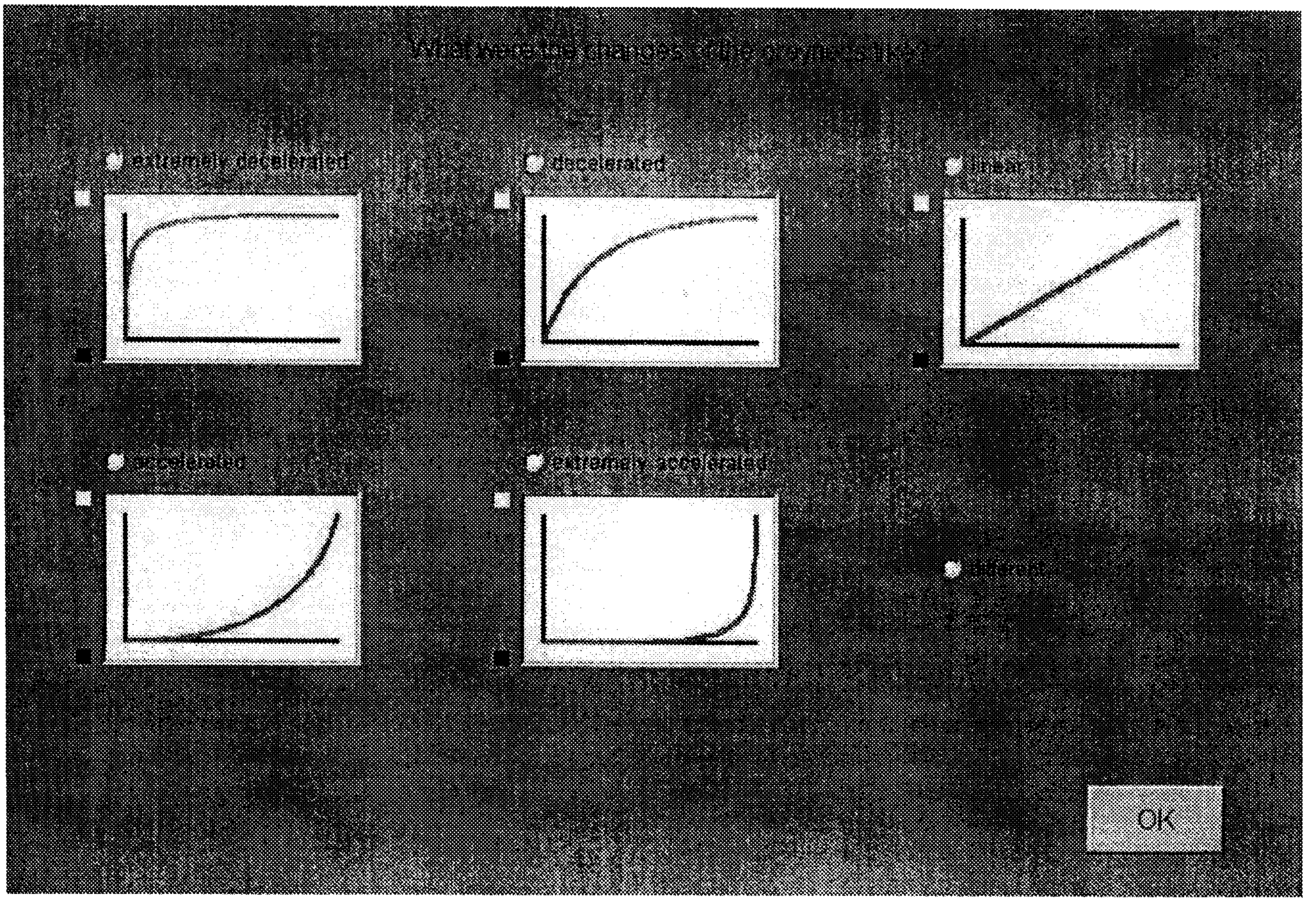

Figure 1. Five options, describing relevant stimulus intensity increments, were displayed on the screen. Subjects had to click one of them.