

**THE PERCEPTION OF DIFFICULTY AND EXERTION IN MOTOR TASKS:
WHAT CAN BE KNOWN ABOUT PERCEPTIVE CONTINUA
THROUGH INDIVIDUAL PSYCHOPHYSICAL EXPONENTS?**

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Abstract: In a recent experiment, Delignières and Famose (1994) have shown that the individual exponent for the perception of difficulty was invariant for four different perceptual-motor tasks. The aim of the present paper was to determine whether this invariance was related to a response bias, concerning the way by which each individual used numbers, or reflected a global sensitivity to difficulty, independent of the nature of the task and of the relative expertise of the subject. The goal of this experiment was to analyze the samples of individual exponents obtained by magnitude estimation in five different situations: perception of difficulty in manual tapping tasks, in reaction time tasks, in reasoning tasks, perception of exertion during running tasks, and circle areas estimation. Exponents samples from the situations of perception of difficulty and effort were strongly intercorrelated, but the exponents from area estimation did not correlate with any other sample. These results suggest that whatever the nature of the task, the perception of difficulty or exertion is managed by the same invariant process. This hypothesis is discussed in relation with the psychophysical models which suggest a link between exponent and stimulus dynamic range.

Key words: Perceived difficulty, perceived exertion, psychophysical functions, individual exponents.

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Traditionally psychophysical investigations have focused on well-defined sensory dimensions, which could each be identified by a stimulus, a receptor and a specific nervous circuit. These dimensions are characterized by an invariant process, which relate beyond the diversity of the situations, the stimulus and the corresponding sensation. Notably, a sensory dimension is characterized by the exponent of the psychophysical function (Stevens, 1957).

Psychophysicists have diversified their field of investigation toward dimensions where the identification of the stimulus and of the processes of perception are less evident. This is especially the case for the perception of difficulty or for the perception of exertion. The psychophysical status of these dimensions remains problematical. In particular, the legitimacy of the concept of perceived difficulty is *a priori* more phenomenological rather than psychophysical. Could perceived difficulty be considered as a sensory dimension, as, for example, loudness or brightness?

We think that perceived difficulty has to satisfy several requirements to attain to this status. Firstly, it must be possible to describe stable mathematical relationships between the objective characteristics of tasks and the magnitude of the sensation of difficulty. In a series of experiments, Borg and his collaborators failed to evidence such relations (Borg, Bratfisch & Dornic, 1971a, 1971b, 1971c; Borg & Forsling, 1964; Bratfisch, Borg & Dornic, 1972; Bratfisch, Dornic & Borg, 1972): from one experiment to another, perceived difficulty seemed predominantly related either to the characteristics of the task, or to the level of performance, and a stable type of relation could not be described. This inconsistency in results led Dornic, Sarnecki and Svensson (1973) to doubt of the existence of a genuine sensation of difficulty. According to the authors, perceived difficulty must be conceived as a mediate experience, contaminated by the more salient aspects of task or performance.

Nevertheless we think that this inconsistency in the results could be attributed to a lack of rigor in the choice of the objective descriptors of the tasks. From one experiment to another, Borg and his collaborators used either performance data (sometimes the performances of the experimental group, and sometimes data collected in a larger group, distinct from the experimental one), or objective descriptors of the tasks, without any theoretical frame to justify their use. The choice of a pertinent model of the stimulus is essential for the validity of a psychophysical approach (Bonnet, 1986). With the aim of proposing a measurement model adaptable for a large variety of simple tasks, we suggested using the average amount of information to be processed by trial as a measure of objective difficulty (Delignières & Famose, 1992).

Thus we have shown that it was possible to describe, in simple tasks of manual tapping or visual search, an exponential relationship between the average amount of information to be processed and perceived difficulty, assessed by magnitude estimation method (Delignières, 1993; Delignières & Famose, 1992). These close fits were obtained for group data as well as for individual data. These experiments have also shown that it was possible to describe a power relation between average performance and perceived difficulty.

These results, which have been repeated successfully several times, allowed the first requirement to be satisfied. However, if they allowed affirmation that between tasks, the perception of the difficulty follows the same logic, it could not be concluded that this referred to the same process in all cases. In other terms, is difficulty perception a task-specific process, dependent on the nature of the requested resources, or does it correspond to a general, non specific process, independent of the nature of the tasks? According to this second hypothesis, a stimulus-sensation relationship ought to be described, whatever the task, by a unique psychophysical function, with an invariant exponent.

In our previous works on difficulty perception we have obtained relatively similar psychophysical functions for different tasks. The relation between the average amount of information and perceived difficulty could be described according to an exponential function, with an exponent of .402 for a reciprocal tapping task, .462 for a visual search task, and .402 for a visual search task under temporal pressure (Delignières, 1993; Delignières & Famose, 1992). The corresponding relations between performance and perceived difficulty could be fitted by power functions, with respective exponents of 1.649, 1.987 and 1.608. These similarities did not allow for a definite conclusion, as these experiments were performed with different subjects. Nevertheless, these results suggested that these exponents could represent three consecutive measurements of the same values. This hypothesis was also advanced by Gopher and Braune (1984), who showed that the relation between objective and subjective difficulty, for 21 different tasks (related to perceptual motor control, short-term memory, verbal and spatial abilities, selective and divided attention, and time-sharing capabilities), could be fitted by a unique power function, with an exponent of 1.317. These results suggested that the psychophysical function for perceived difficulty could not be specific to a particular task, but could constitute a general, non-specific subject characteristics, independent of the nature of the task and of the requested processes.

To test this hypothesis the analysis of individual exponents is required. We have to obtain the same average exponent between tasks, but furthermore the samples of individual exponents must be correlated between tasks. In a recent investigation, we have analyzed the individual exponents obtained for four perceptual-motor tasks, each with five levels of difficulty (Delignières & Famose, 1994). The first one was a visual search task, the second a reaction time task, the third a reciprocal tapping task, and the fourth a fine motor control task, in which the subject had to transfer rings along a metallic stick from beginning to end. For each task and each level of difficulty, the average amount of information to be processed by trial was measured and served as an index of objective difficulty. Perceived difficulty was assessed by magnitude estimation method. At the individual level, exponential relationships were evidenced between average amount of information and perceived difficulty. Within each task, individual exponents were extremely variable between subjects. Significant positive correlations (from .527 to .815) were found between the four samples of individual exponents. Furthermore, an analysis of variance showed that the exponent of the function objective-subjective difficulty did not significantly vary between tasks. This experiment showed that in different perceptual-motor tasks, requesting clearly differentiated resources (e.g. decisional or fine motor control resources), the relations between average amount of

information and perceived difficulty could be described by a unique psychophysical function.

These findings raise the question, whether this invariance of exponents reflects a genuine general sensitivity to difficulty, or some kind of response bias. The existence of a response bias, related in particular to the fact that each subject uses a characteristic range of numbers in magnitude estimation, has been clearly established (Ekman, Hosman, Lindman, Ljungberg & Åkesson, 1968; Jones & Marcus, 1961; Jones & Woskow, 1962; Rule, 1966).

Nevertheless Ekman *et al.* (1968) suggested that this response bias accounted for a relatively moderate amount of variance in exponent, and proposed a two-factor hypothesis, according to which individual differences in scaling behavior reflect both a genuine perceptual variability, and differences in response bias. So the results of Delignières and Famose (1994), which put forward significant intercorrelations between exponents samples, and no between-tasks effect on average values, cannot be entirely explained by a response bias, and suggest the presence of a general sensitivity to difficulty, independent of the nature of the tasks and of the requested processes.

The question then arises about the range of relevance of such a proposition. Is this sensitivity only characteristic of the perception of difficulty in perceptual-motor tasks, or does it also concern strictly mental tasks? Does it work only with information processing related tasks, or is it relevant for the whole range of goal-oriented tasks, including physical exertion tasks?

The aim of the present experiment was to analyze individual exponents obtained in diverse psychophysical situations. Firstly, our goal was to partially replicate the experiment by Delignières and Famose (1994), by using two simple perceptual-motor tasks. We expected to find, as previously, no significant differences between group exponents, and a significant correlation between the samples of individual exponents.

Two other situations were added, with the aim of verifying if the invariance in exponent was a characteristic of perceptual-motor tasks, or was concerned more generally with the perception of difficulty and exertion: for this we used a difficulty assessment in reasoning tasks, and an exertion assessment in a running task on a treadmill.

The introduction of such tasks, with which a measurement of objective difficulty through information theory was not possible, raised some theoretical problems. The main problem with which researchers have faced in the domain of the perception of difficulty or exertion was the identification of the stimulus really taken into account by subjects. Concerning the perception of difficulty, most authors generally believed that this stimulus is the amount of mental effort that the subject invests in the task (Delignières, 1993, Delignières, Brisswalter & Legros, 1994; Dornic, 1977, Gopher & Braune, 1983). In the domain of physical effort, the authors have mainly search at the physiological level the antecedents of perceived exertion (Borg *et al.*, 1987, Seip *et al.*, 1991). The use of task's descriptors such as entropy or mechanical power allows to

obtain extremely accurate relationships between objective difficulty and perceived difficulty (or exertion), but nothing proves that these relations are *true* psychophysical relations between a stimulus and a sensation. Nevertheless, one could suppose that the obtained relation between objective difficulty and perceived difficulty is mediated by the stimulus (Delignières, 1993).

When identical descriptors are used, from a task to another (for example entropy), one could suppose that this descriptor had equivalent relation with the stimulus, from a task to another. Then similar exponents could be expected between tasks for the relations between this descriptor and perceived difficulty. Such a result was obtained in the experiment by Delignières and Famose (1994).

On the contrary if descriptors differs in nature, similar exponent could not be expected. Then, we did not expect similar exponent between the two former situations (tapping and reaction time) and the two latter (reasoning and running). Nevertheless correlation analysis between individual exponent samples remained valid. Significant correlations between individual exponents samples obtained in the two former situations and those obtained in the two latter would support the hypothesis of the existence of a common process underlying the perception of difficulty among all kinds of tasks.

Finally, with the aim of assessing whether this invariance was related to a specific sensitivity to difficulty, or to a response bias, a fifth situation was added, the estimation of circle areas. As this situation was not related to difficulty assessment, we supposed that if the sample of individual exponents obtained in this situation correlated with the samples obtained in the other situations, this implied the existence of a general response bias. On the contrary, if significant correlations were obtained among the four difficulty assessment tasks, and no correlations between these situations and the estimation of areas, it could be possible to conclude to the existence of a global sensitivity to difficulty.

From a methodological point of view, the analysis of individual exponents raises some specific problems. Generally, psychophysicists have been more interested in average data, and have centered their analyses on the searching of a power fitting. In actual fact, very few experimental data could be accurately fitted by the simplest form of the power function,

$$R = aS^b$$

which supposes an intersection at the origin for the two scales. Generally data suggested an intersection with the y axis different from zero, and some alternative power equations have been proposed, as:

$$R = a + cS^b \quad (\text{Ekman \& \AA kesson, 1965})$$

or
$$R = a + c(S-d)^b \quad (\text{Borg, 1962})$$

It seems that the use of these complex forms of fitting, although permitting a more accurate description of the relation between stimulus and numerical response, leads to an uncertainty at the level of the exponent value. In particular, Bonnet (1969) noted that the interindividual variability in exponents was partially related to the choice of the a constant. We think that the use of more simple fittings, by the least squares method, is more relevant for the comparison of individual functions. It is not certain that the more accurate fitting obtained by this method was the power one. In our previous experiments on perceived difficulty, because of the positive intercept with the y axis and because of the positive acceleration of the curve, the exponential fitting was frequently the best. It is obvious that in accordance with the main assumption of Stevens, psychophysicists are mainly looking for power fittings. But insofar as the aim is not to evidence the average exponent characterizing a perceptual dimension, but to compare between subjects the acceleration of the stimulus-response relation, the exclusive use of the power fitting does not appear to be justified.

An analysis of the data from Ekman and Åkesson (1965) could illustrate our point. In this experiment individual scales were constructed for saltness and for sweetness. Power functions, with additive constant, were computed. Individual exponents ranged from 1.11 to 1.97 for saltness, and from 1.33 to 1.98 for sweetness. The correlation between the two samples of exponents (taking into account the seven subjects who took part in the whole experiment) was conclusively non significant ($r=.014$). An *a posteriori* analysis of Ekman and Åkesson's data, according to the least squares method, shows that a simple exponential function, as

$$R = a * e^{bS}$$

allows an accurate fitting, either for saltness or for sweetness. At the individual level, the average correlation coefficient is .980 for saltness, and .992 for sweetness. The correlation between the two samples of exponents is very high ($r=.944$).

These two methods of fitting provide opposite results. The use of the simplest forms of function, providing less uncertainty on the value of the exponent, seems more appropriate for an approach focusing on interindividual comparisons.

METHOD

Subjects

14 subjects, 9 males and 5 females (mean age: 20.8 yrs, S.D.: 3.4) were involved in this experiment.

Experimental devices

The subjects had to perform five psychophysical situations. Each situations included five levels of the stimulus, labelled A to E. The first two situations were previously used in the study by Delignières and Famose (1994).

Estimation of difficulty in tapping tasks.- We used the reciprocal tapping tasks of Fitts (1954). Subjects have to tap alternatively two rectangular targets with a stylus. The index of objective difficulty (I) was computed according to the equation proposed by Fitts (1954):

$$I = \log_2 (2a/w)$$

where a represents the center-to-center distance between the targets, and w the width of each target (Figure 1).

The characteristics of the five levels of difficulty were as follows:

level A	a= 5 cm	w= 4 cm	I= 1.32 bits/resp.
level B	a= 5 cm	w= 2 cm	I= 2.32 bits/resp.
level C	a= 10 cm	w= 2 cm	I= 3.32 bits/resp.
level D	a= 20 cm	w= 2 cm	I= 4.32 bits/resp.
level E	a= 20 cm	w= 1 cm	I= 5.32 bits/resp.

A CTCS chronometer (EAP) was used to measure the inter-target movement time. For each level of difficulty, the subjects had to perform five blocks of 10 tappings.

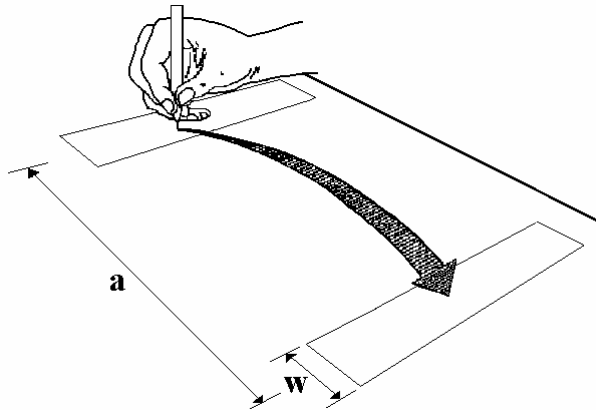


Figure 1: Reciprocal tapping task

Estimation of difficulty in reaction time tasks.- The task was presented on a personal computer, connected to two joysticks. The response signal was given by the highlighting of one square among a certain number of squares drawn on the screen. Subjects had to respond by tilting one of the joysticks in the appropriate direction. Objective difficulty varied with the number (n) of squares initially drawn on the screen, and was measured according to the equation proposed by Hick (1952):

$$I = \log(n) \text{ bits/trial}$$

The following values were obtained:

level A	n=1	I= 0.00 bits/trial
level B	n=2	I= 1.00 bits/trial
level C	n=4	I= 2.00 bits/trial
level D	n=6	I= 2.58 bits/trial
level E	n=8	I= 3.00 bits/trial

The arrangement of the squares, for each level of difficulty, was conceived to maximize the compatibility between stimulus and response (Figure 2). Subjects performed two blocks of 10 trials at each level of difficulty.

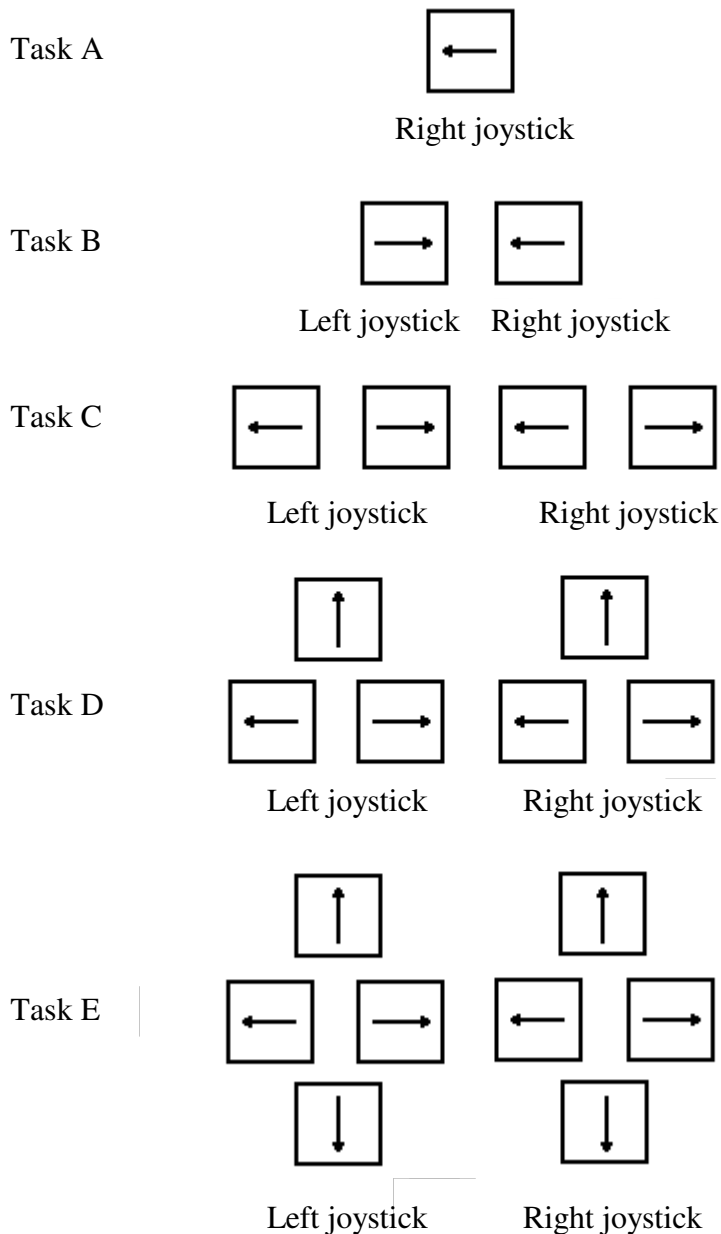


Figure 2: Stimulus-response coding in the reaction time tasks. The squares are displayed as they appeared on the screen of the computer. The arrows indicate the

direction in which the left or right joystick had to be tilted, when the corresponding square highlighted.

Estimation of difficulty in reasoning tasks.- We used a part of the "S.B.R. II" test, previously employed by Borg and Forsling (1964) and Hallsten and Borg (1975) in their experiments on the perception of difficulty. The task was to point out the picture that in some way deviated from the others. We retained 5 items with increasing difficulty (items 25, 29, 4, 24, 26, cf. Figure 2). Objective difficulty was estimated according to performance data from a group of 200 subjects, provided by Borg and Forsling (1964). The following values were obtained, expressed in failure proportion (p):

Item A	p=0.110
Item B	p=0.275
Item C	p=0.495
Item D	p=0.565
Item E	p=0.830

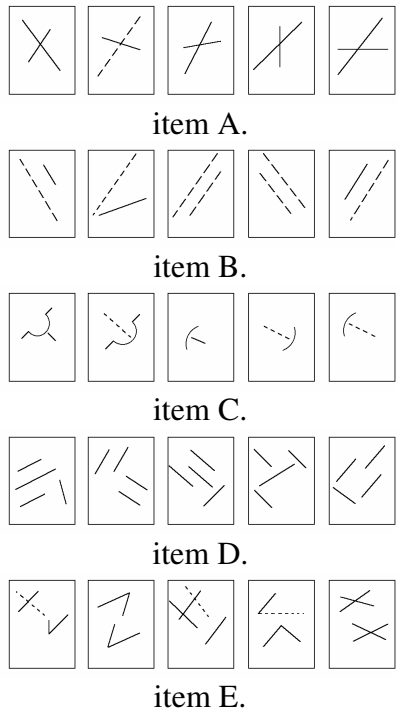


Figure 3: "SBR test" items used for the perception of difficulty of reasoning tasks.

For each item the subject had one minute to find and explain the solution. Within this minute, in case of failure, the error was briefly explained and the subject could try again.

Estimation of exertion in a running task.- The task was performed on a treadmill, with a constant slope of 3%. The maximal oxygen uptake of each subject was preliminary assessed during a triangular protocol on the treadmill. During the

experiment, the subjects began by a 6 minute warm-up session, at a speed corresponding to 40% of the speed at which they reached their maximal oxygen uptake. This speed was about 7 km.h⁻¹ for one subject, 8 km.h⁻¹ for 7 subjects, and 10 km.h⁻¹ for the last six subjects.

Then subjects performed 5 sessions of 4 minutes, with one minute of recovery between the sessions. The first session was performed at the warm-up speed. Then the speed was progressively increased by 2 km.h⁻¹ by session. Heart rate was continuously recorded.

Estimation of circle areas.- Filled circles were printed in black on white paper. Their dimensions were as follows:

circle A	area: 15 cm ²	(diameter: 4.37 cm)
circle B	area: 30 cm ²	(diameter: 6.18 cm)
circle C	area: 45 cm ²	(diameter: 7.57 cm)
circle D	area: 60 cm ²	(diameter: 8.74 cm)
circle E	area: 75 cm ²	(diameter: 9.77 cm)

Each circle was presented for five seconds.

Procedure

The order of presentation of the five situations was systematically varied between subjects. For each situation, the A level served as modulus and received the arbitrary rating of 10. The other levels were rated according to the magnitude estimation method. As our goal was not to find "genuine" psychophysical functions, but to analyze individual differences, we decided to systemized the order within each situation. The diverse levels were presented systematically from A to E, in alphabetical order. This methodological precaution was aimed at standardizing the sequential effects traditionally reported in the literature (Baird, Berglund, Berglund & Lindberg, 1991).

Data analysis

We took as objective descriptors of the stimulus (1) for the tapping tasks and the reaction time tasks, the indexes of difficulty (I) computed as previously mentioned; (2) for the reasoning tasks, the proportion of failure (p) computed from the data by Borg et Forsling (1964); (3) for running tasks, the speed (s) of the treadmill, and (4) for the estimation of areas, the objective areas (oa) of the circles.

Linear, logarithmic, exponential and power fittings were computed by the least squares method, both for average and individual data. The choice of the final fitting, for statistical treatments, was based on several criteria (most accurate fitting of the average data, most accurate fitting on average, at the individual level).

RESULTS

The coefficients of correlation obtained for each subjects and each situation, for the linear, exponential, logarithmic and power fittings are reported in table 1. We have also mentioned the coefficient obtained for averaged data.

Estimation of difficulty in tapping tasks.- The relationship between the index of difficulty and performance, at the individual level, could be accurately fitted to exponential functions. The average correlation coefficient¹ was about .972. This result was consistent with those previously reported for this kind of task (Delignières & Famose, 1992; 1994). The best fitting for group data between index of difficulty (I) and perceived difficulty (PD) was exponential:

$$PD = 5.268 * e^{(0.408)I} \quad (r=.991)$$

For individual data, the exponential fitting was the most accurate for 11 subjects. The average correlation coefficient was .985 for the exponential fitting, against .959 for the linear and .951 for the power one.

Estimation of difficulty in reaction time tasks.- The relationship between index of difficulty and performance, at the individual level, could be accurately fitted to exponential functions. The average correlation coefficient was about .982. This result was consistent with those previously reported for similar tasks (Delignières, 1993; Delignières & Famose, 1994).

As the x scale contained a zero value, only the linear and exponential fitting could be computed. The best fitting for group data between index of difficulty (I) and perceived difficulty (PD) was exponential:

$$PD = 9.672 * e^{(0.349)I} \quad (r=.997)$$

For individual data, the exponential fitting was the most accurate for all subjects. The average correlation coefficient was .990 for the exponential fitting, against .959 for the linear one.

Estimation of the difficulty in reasoning tasks.- The best fitting for group data between proportion of failure (p) and perceived difficulty (PD) was exponential:

$$PD = 7.435 * e^{(2.042)p} \quad (r=.966)$$

For individual data, the exponential fitting was the most accurate for 11 subjects. The average correlation coefficient was .948 for the exponential fitting, against .925 for the linear one.

¹ All average correlation coefficients were computed from Fisher' z -transformations.

Table 1: Correlation coefficients of the linear, exponential, logarithmic and power individual fittings, among the 5 experimental situations. The correlation coefficients of the fitting functions computed from mean data are also included.

Subj.	Reciprocal tapping				Reaction time		SBR test			
	lin.	exp.	log.	power	lin.	exp.	lin.	exp.	log.	power
1	0.915	0.994	0.830	0.970	0.964	0.997	0.933	0.990	0.794	0.912
2	0.976	0.995	0.914	0.958	0.951	0.974	0.912	0.960	0.761	0.840
3	0.980	0.994	0.921	0.980	0.984	0.998	0.907	0.951	0.756	0.835
4	0.974	0.995	0.910	0.960	0.942	0.993	0.853	0.870	0.747	0.826
5	0.941	0.978	0.856	0.921	0.981	0.982	0.900	0.915	0.821	0.886
6	0.990	0.993	0.951	0.985	0.949	0.987	0.923	0.962	0.807	0.892
7	0.965	0.953	0.971	0.979	0.991	0.992	0.791	0.768	0.625	0.603
8	0.910	0.897	0.812	0.805	0.969	0.977	0.893	0.921	0.768	0.820
9	0.931	0.885	0.854	0.814	0.889	0.921	0.993	0.983	0.963	0.986
10	0.988	0.991	0.941	0.970	0.992	0.995	0.862	0.891	0.795	0.838
11	0.944	0.988	0.868	0.943	0.990	0.999	0.791	0.845	0.721	0.784
12	0.940	0.976	0.855	0.912	0.918	0.950	0.919	0.961	0.783	0.862
13	0.954	0.990	0.884	0.948	0.978	0.994	0.995	0.989	0.958	0.982
14	0.865	0.986	0.763	0.935	0.970	0.984	0.887	0.954	0.743	0.887
Group	0.941	0.991	0.860	0.944	0.978	0.997	0.935	0.966	0.815	0.892

Table 1 (continued)

Subjects	Running				Area estimation			
	lin.	exp.	log.	power	lin.	exp.	log.	power
1	0.980	0.994	0.960	0.994	0.993	0.986	0.953	0.989
2	0.892	0.979	0.840	0.951	0.981	0.967	0.973	0.983
3	0.986	0.995	0.968	0.997	0.980	0.994	0.909	0.974
4	0.974	0.995	0.951	0.986	0.894	0.988	0.788	0.947
5	0.953	0.996	0.924	0.988	0.993	0.987	0.942	0.997
6	0.943	0.994	0.907	0.981	0.962	0.993	0.891	0.969
7	0.987	0.998	0.967	0.989	1.000	0.987	0.973	0.997
8	0.985	0.995	0.963	0.981	0.978	0.996	0.906	0.951
9	0.993	1.000	0.980	0.996	1.000	0.987	0.973	0.997
10	0.989	0.981	0.983	0.992	0.967	0.989	0.894	0.976
11	0.962	0.999	0.930	0.992	0.985	0.958	0.994	0.997
12	0.950	0.987	0.916	0.966	0.992	0.951	0.970	0.996
13	0.996	0.986	0.996	0.994	0.958	0.926	0.997	0.987
14	0.927	0.996	0.885	0.982	0.985	0.998	0.922	0.979
Group	0.960	0.998	0.930	0.987	0.988	0.996	0.929	0.989

Estimation of exertion in a running task.- The relation between speed and heart rate, for individual data, could be accurately linearly fitted. The average correlation coefficient was .990. This result was consistent with those reported in the literature, and showed that for each subject the progressive increase in speed led to a proportional increase in the demands made on the organism.

The best fitting for group data between speed (s) and perceived exertion (PE) was exponential:

$$PE = 1.625 * e^{(0.201)s} \quad (r=.998)$$

For individual data, the exponential fitting was the most accurate for 10 subjects. The average correlation coefficient was .995 for the exponential fitting, against .988 for the power one.

Estimation of circle areas.- The best fitting for group data between objective area (OA) and perceived area (PA) was exponential:

$$PA = 7.104 * e^{(0.405)OA} \quad (r=.996)$$

For individual data, the exponential fitting was the most accurate for 6 subjects, the linear fitting for 4, and the power one for 4. The average correlation coefficient was .988 for the power fitting, .986 for the exponential fitting, and .987 for the linear fitting.

As the exponential fitting appeared in most cases to be the more appropriate, as well as for group data than for individual data, we decided to select it for further treatments. The individual exponents of the exponential fittings for each situation are indicated in table 2.

A Shapiro-Wilk test indicated that the samples of exponents did not significantly differ from the normal distribution. Product-moment Pearson correlations were calculated among the five samples of exponents (Table 1). Significant correlations were observed among the exponents of the four situations of perception of difficulty and exertion. But there was no significant correlation between the exponents of area estimation and the four other samples.

A one-factor analysis of variance with four levels of repeated measurement showed that the mean exponents significantly differed ($F=49.11$, $p<.001$). Nevertheless a Sheffé a posteriori test showed that there was no significant differences between the exponents obtained in the tasks of reciprocal tapping and in the tasks of reaction time.

Table 2: Individual exponents of the exponential fitting functions, among the 5 experimental situations.

Subjects	Tapping	Reaction time	SBR test	Running	Area estimation
1	0.571	0.503	2.940	0.255	0.347
2	0.285	0.264	2.003	0.257	0.236
3	0.510	0.355	2.357	0.151	0.510
4	0.324	0.526	1.595	0.162	0.589
5	0.457	0.463	1.345	0.268	0.481
6	0.327	0.352	1.393	0.200	0.328
7	0.132	0.164	0.653	0.092	0.271
8	0.201	0.119	0.861	0.074	0.242
9	0.288	0.222	0.940	0.099	0.271
10	0.293	0.204	1.731	0.190	0.565
11	0.303	0.444	3.469	0.236	0.222
12	0.280	0.220	1.723	0.135	0.538
13	0.267	0.225	0.963	0.078	0.162
14	0.717	0.464	3.005	0.318	0.347

Table 3: Correlation matrix among the individual exponents obtained in the five experimental situations.

	1.	2.	3.	4.
1. Reciprocal tapping				
2. Reaction time	.709*			
3. SBR test	.666*	.657*		
4. Running	.719*	.714*	.733*	
5. Area estimation	.250	.303	.083	.158

*: $p < .01$

DISCUSSION

On the whole the best fitting of our data was exponential, either at the individual or at the group level. This result was obviously related to our method of fitting. This could be surprising for the reader, as psychophysical data were commonly described through power functions. This result does not really challenge the general validity of Stevens' power law. In particular, an exponential function could only fit positively accelerated relations between stimuli and numerical responses, that is, the relations which could be fitted by power functions with exponents above to 1. But our goal was only to characterize accurately individual relationships between "stimuli" and numerical responses, for intersubject comparisons. In this case, is it interesting to search complex

power fittings, with evident error risks on the value of the exponent, when a simple exponential function, comprising a single multiplicative constant and an exponent, allows an accurate fitting of the data?

Our results indicated high intercorrelations among the exponents obtained in the situations of perception of difficulty and effort. In the experiment by Delignières and Famose (1994), not only were similar correlations obtained, but also an analysis of variance showed that the value of the exponent did not significantly vary among tasks. In the present experiment, the exponents do not significantly differ between tapping and reaction time tasks, but are lower for the perception of exertion, and higher for the perception of difficulty in reasoning tasks. As stated previously, it seems difficult to take these differences into consideration. It is impossible to affirm that the exponents obtained are the "true exponents". Nevertheless, the exponents obtained are proportional to these "true exponents", as the relation between the objective descriptor of the task and perceived difficulty is mediated by the relation between stimulus and perceived difficulty (Delignières & Famose, 1992).

Generally, the authors who have found significant correlations between exponents among different perceptive continua suggested the existence of response bias, related to the manner by which individuals use numbers in magnitude estimation (Ekman *et al.*, 1968; Jones & Marcus, 1961; Jones & Woskow, 1962; Rule, 1966). The significant correlations among our four first situations could be interpreted following such hypothesis. But as the individual exponents for area estimation did not correlate with any of the other exponents, we could conclude that the correlation among the first situations did not reflect a response bias, but a specific sensitivity to difficulty and effort.

The invariance in exponents between the tapping and reaction time tasks was an expected replication of the results reported by Delignières and Famose (1994). The significant correlations found between these two situations and the reasoning tasks indicate that the invariance in exponent does not concern exclusively perceptual-motor tasks, but more generally all cognitive related tasks. These results are consistent with those reported by Gopher and Braune (1984), concerning 21 perceptual-motor and cognitive tasks. The correlations described between perception of difficulty and perception of exertion are more surprising.

Some psychophysical models, particularly developed by Teghtsoonian (1971) and Borg (1970, 1972), could provide some hypotheses of interpretation. According to these models, the differences in exponent among continua are related to differences in the stimulus dynamic range: the narrower the dynamic range, the higher the exponent. More precisely, the ratio between the exponents of two continua is inversely proportional to the ratio between the logarithms of the correspondent stimulus dynamic ranges. Borg (1970) suggested a second hypothesis according to which for a given continuum the range of subjective magnitudes is identical between subjects, even if the individual stimulus dynamic range might vary largely. So, differences in exponents for individual functions could be related to individual differences in stimulus dynamic range. The empirical test of these hypotheses, which requires the experience of extreme

intensities, is often impossible. Some dimensions, as, for example, the perception of exertion could nevertheless permit such an approach. However some experiments performed under this aim gave ambiguous results (Borg & Karlsson, 1976; Teghtsoonian, Teghtsoonian & Karlsson, 1981).

If this model is considered as valid, our results suggest that for each subject, the stimulus dynamic range is identical among tasks, for the perception of difficulty as well as for the perception of exertion. This hypothesis remains hardly sustainable, following the classical definition of stimulus dynamic range. For example Borg and Karlsson (1976) and Teghtsoonian, Teghtsoonian and Karlsson (1981) based their measure of stimulus dynamic range on the one hand on a determination of the absolute threshold by the method of limits and on the other hand on an assessment of the maximal threshold by a measure of the maximal working capacity. The authors made the assumption that the perceived effort associated with maximum load is itself a maximum value, and stimulus dynamic range was clearly related to the expertise of each subject in the task.

Delignières and Famose (1994) have clearly shown that exponent invariance appeared despite evident differences among tasks in subjects' expertise. So stimulus dynamic range does not appear directly related to subjects' expertise in the task, and especially to their actual maximal capacity. Some experimental results suggested that the stimulus range taken into account by each subject could be related to personality factors: for example Dornic and Birbaumer (1974) have shown that the exponent for perceived difficulty in a task under time pressure was higher in neurotics rather than in normal subjects. Chung, Seong, Hong and Kim (1993) reported higher ratings of exertion in introverts rather than in extraverts. Some results also suggested an influence of sex-role identity on perceived exertion (Hochstetler, Rejeski & Best, 1985; Rejeski, Best, Griffith, & Kenney, 1987). Delignières (1993) found that expert rock-climbers had significantly lower exponents for perceived difficulty in tapping tasks rather than sedentary subjects. This suggested that the experience of extreme difficulty could modify the stimulus range effectively taken into account by subjects in all assessment of difficulty situations.

We suggest that in these situations of perception of difficulty or effort, the stimulus dynamic range is limited, for each individual, by two hypothetical demand levels, corresponding to minimal and maximal sensations of difficulty. These two limits might not be determined by the actual capacities of the subject, but by more general factors of personality, whose nature remains unknown. We could suggest that self-esteem, self-confidence and aspiration level play a determinant role. Stimulus dynamic range (i.e. the ratio between the intensities corresponding to these two limits), would then be identical among situations, whatever the nature of the task.

Are these hypotheses compatible with the previous statements on the perception of exertion and difficulty? Several works suggest that the perception of difficulty is based on the magnitude of the resources investment that the subject must allocate to realize a given level of performance (Delignières, 1993; Delignières, Brisswalter & Legros, 1994; Dornic, Sarnecki, Larsson & Svensson, 1974; Gopher & Braune, 1984; Vidulich, 1988; Yeh & Wickens, 1983). So perceived difficulty would not be based on

an assessment of the objective characteristics of the tasks, nor on a judgement of actual performance, but on the amount of effort thought necessary to obtain a satisfying performance. Perceived difficulty would refer to the investment of a central pool of resources, a concept which appears for example in the models of Sanders (1983) or Pribram and McGuinness (1975). Such a model could explain the invariance of exponents among the situations of perception of difficulty (Delignières & Famose, 1994). Our current results suggest that perceived exertion refers to the same phenomenon.

Generally, the origins of perceived exertion have been researched at the physiological level (Borg, 1962; Borg, van den Burg, Hassmen, Kaijser & Tanaka, 1987; Ekblom & Goldbarg, 1971; Hetzler, Seip, Boutcher, Pierce, Snead & Weltman, 1991; Seip, Snaed, Pierce, Stein & Weltman, 1991). But if high correlations could be expected between physiological variables (heart rate, lactatemy) and perceived exertion, nothing permits *a priori* the supposition of a causal relationship between them. Several works have shown the importance of psychological variables in the perception of exertion (Rejeski, 1981, 1985). The level of exertion that subjects expect would especially be a central determinant of the exertion effectively perceived (Rejeski & Ribisl, 1980; Rejeski & Sanford, 1984). Generally, authors suggest that psychological factors could have a secondary influence, but that the determinant source was the physiological cues deriving from the production of exertion. Our results suggest, on the contrary, that the sensitivity to exertion refers to a deeper dimension, independent of the nature of the invested resources.

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