On differentiating sensory and attentional contributions to psychophysical performance

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Short Heading: Attentional vs. sensory contributions

ABSTRACT

Both sensory and attentional factors have the ability to influence psychophysical performance. To be able to differentiate these factors is important in relation to conditions such as, e.g., dyslexia and schizophrenia. A generalized expression of the psychometric function takes account of the "Lapse Rate". By assuming the Lapse Rate corresponds to "lapses of attention", i.e. to inattention so as to make $\text{attention} = 1.0 - \text{Lapse Rate}$, it is possible to generate a simple method for distinguishing attentional and sensory contributions to psychophysical performance. Psychometric functions increase with stimulus intensity, or the magnitude of stimulus difference, up to an upper asymptote. From the level of this asymptote it is possible to determine the Lapse Rate and consequently the level of attention. Sensory capabilities, on the other hand, can be deduced from noting where the psychometric function crosses the level halfway between chance performance and the upper asymptote.

Key words: Psychometric function; 2-AFC; Lapse Rate; attention; perception; dyslexia; schizophrenia.

INTRODUCTION

It seems quite obvious that attentional factors have the ability to influence performance on perceptual tasks. In many instances it is desirable to be able differentiate the effects of attention from perceptual capabilities. This may be particularly important when testing perceptual capabilities in groups of individuals which are known, or assumed, to suffer from attention deficits. Examples of such groups would be dyslexic readers (e.g., Hari & Renvall, 2001; Bosse et al., 2007; Krause, 2015) [FOOTNOTE 1] and schizophrenic patients (Bortolon et al., 2015; Graticelli et al., 2015). In the case of schizophrenic patients, for instance, it has been proposed that the more or less uniform contrast sensitivity reductions shown by these patients may reflect lack of attention (Skottun & Skoyles, 2007b). In the present report is described a simple method for distinguishing the roles of attention and sensory factors in determining psychophysical performance.

THE PSYCHOMETRIC FUNCTION

The m-Alternative Forced Choice (m-AFC) method is an objective technique. By this is meant that the results obtained with this technique are independent of the subjective criteria the subject may have adopted. With this method the subject is presented with m stimulus alternatives and is required to make a decision in regard to these alternatives. Critical for the method is that the responses may be characterized as correct or incorrect. The fraction of correct responses as a function of the stimulus intensity (or the magnitude of the difference between stimuli) is given by the psychometric function.

A general expression of the psychometric function takes the form (see e.g., Eqn. 1b of Prins, 2013):

$$\Psi(x, \gamma, \lambda) = \gamma + (1.0 - \gamma - \lambda)f(x) \quad \text{Eqn. 1}$$

where γ denotes the "Guess Rate", λ the "Lapse Rate", and $f(x)$ represents a function reflecting sensory capabilities where x denotes the stimulus (either stimulus strength in the case of a detection experiment or the magnitude of stimulus difference in the case of a discrimination task). An example of such a function would be:

$$f(x) = 1 - \exp(-x/\alpha) \quad \text{Eqn. 2}$$

where x is the stimulus strength and α is a constant. The exact nature of $f(x)$ is not important in the present context. All that is required is that the function returns 0.0 for 0.0 stimulation, increases monotonically with stimulus intensity and has an upper asymptote of 1.0. A number of functions fulfill these requirements.

Equation 2 represents a simple example of such a function. A graph generated from Eqn. 2 is shown in Fig. 1A.

Equation 1 is intended to describe responses in a Yes/No experiment. (A "Yes/No" experiment is one in which a subject is presented with a stimulus and asked if he/she sees it. The answers will then be either "Yes I see it" or "No I don't".) In order to apply Equation 1 to m-Alternative Forced Choice (m-AFC) data one has to also add the responses on which a correct response is given by guessing: (An m-AFC experiment is one in which the subject is presented with m different presentations one of which contains the stimulus or a stimulus which differ from the other(s) in some regard. The subject has to identify the presentation with the relevant stimulus. The response will then be either correct or incorrect.) The correct guesses are given by:

$$(\Psi(x, \gamma, 0.0) - \Psi(x, \gamma, \lambda))\gamma = (\gamma + (1.0 - \gamma - 0.0)f(x) - (\gamma + (1.0 - \gamma - \lambda)f(x)))\gamma = \gamma\lambda f(x)$$

By adding this to Eqn. 1 we get the psychometric function for a Forced Choice experiment:

$$\Psi(x, \gamma, \lambda) = \gamma + (1.0 - \gamma - \lambda)f(x) + \gamma\lambda f(x) = \gamma + (1.0 - \gamma - \lambda + \gamma\lambda)f(x) \quad \text{Eqn. 3}$$

where γ , (i.e. the Guess Rate) is $1/m$ with m denoting the number of possible response choices in the Forced Choice experiment. [FOOTNOTE 2]

THE LAPSE RATE

Although there can be no question as to the role of the Lapse Rate (i.e., λ) in the above equations it is unclear what exactly this constant corresponds to outside of the equations. Different authors have varied considerably in their characterization of this constant. Cohen and Maunsell (2011, p. 15805) characterized Lapse Rate as "sloppiness" and wrote "... 'lapse rate' is often used to quantify a subjects motivation or arousal". Romeijn and Van Someren (2011, p. 75) stated that "lapses have to be attributed to fluctuations in information processing in the brain". Van Driel et al., (2014, p. 406) wrote "we do not claim per se that the lapse rate unambiguously reflects 'lapses of attention'" and that Lapse Rate is "... the tendency of the subject to make an uninformed random decision". Mutt et al. (2005, p. 479) characterized a lapse as making "a random choice independent of the stimulus".

On the other hand, several authors have linked the Lapse Rate explicitly to attention, or lack thereof. Tipper et al. (2013, p. 11) wrote that "lapse rate" is a "a putative measure of attentional engagement".

Shen et al., 2015, p.14) wrote "The λ parameter is referred to as the 'lapse rate', indicating the proportion of times that the listeners attention has lapsed". Treutwein (1995, p. 2405) in connection with "lapsing rate" describes a "tendency not to notice the stimulus, i.e. to have lapses". Statements to similar effects have also been made by Dai and Micheyl (2011), Gibson et al. (2011), and Shen and Richards (2012).

Since the level of the upper asymptote of the psychometric function depends heavily upon the Lapse Rate it is also relevant that Manny and Klein (1985) and Treutwein and Strasburger (1999) have pointed out that attention has the ability to influence this level.

It will be shown below that if we take the "Lapse Rate" to be the rate of lapses of attention then it is possible to create a method which separates attention and sensory influences to psychophysical performance. In which case Lapse Rate will be a measure of inattention making attention correspond to $1.0 - \text{Lapse Rate}$ (i.e., $1 - \lambda$). This gives us a measure of attention which varies between 0.0 and 1.0 and with which a higher level of attention corresponds to higher performance.

SEPARATING ATTENTIONAL AND SENSORY INFLUENCES

Since $f(x)$ has an upper asymptote of 1.0 we can calculate the actual asymptote for given values of γ and λ by inserting 1.0 for $f(x)$ in Eqn. 3. If we call the response level of the asymptote r we can write:

$$r = \gamma + (1.0 - \gamma - \lambda + \gamma\lambda)$$

Since the asymptote is reached with a high value for x it can be determined empirically by selecting a sufficiently large stimulus, or stimulus difference. (r is represented with a horizontal dashed line marked r in Fig. 1B.) The Lapse Rate, which indicates inattention, can then be obtained by solving the above equation for λ which gives us:

$$\lambda = (1 - r)/(1 - \gamma) \quad \text{Eqn. 5.}$$

Since γ is known as it is determined by the experimental design (i.e., by the number of choices in the Forced Choice experiment) we may calculate λ provided we are able to obtain a measure of r . Thus, provided we accept λ as a measure of inattention we can determine the level of attention as $1 - \lambda$ by using the value of λ determined from Eqn. 5.

Fig. 1

FIGURE LEGEND

Fig. 1. (A) Example of a basic psychometric function generated from Eqn. 2 with $\alpha = 0.5$ (i.e., a function generated from Eqn. 3 in which both $\gamma = 0.0$, and $\lambda = 0.0$) is shown with solid line. The dashed horizontal line indicates the upper asymptote (at 1.0) and the dotted horizontal line (at 0.5) indicates the response level halfway between 0.0 and 1.0. The vertical dotted line indicates the threshold which is marked with T_a . (B) Psychometric functions generated from Eqn. 3. In both functions $\gamma = 0.5$ ($\gamma = 0.5$ means that it models a 2-AFC experiment), and $\lambda = 0.2$. The upper solid line depicts a psychometric function generated with $\alpha = 0.5$ and the lower solid line gives a function obtained with $\alpha = 1.0$. The thresholds for the two functions are given by T_b and T_c , respectively. The upper line depicts a function reflecting the same sensory performance as the one in A since $f(x)$ have an $\alpha = 0.5$ in both cases. Thus, $T_a = T_b$. The lower function has the same γ and λ as the upper curve but a larger α . This is reflected in a higher threshold, i.e., $T_c > T_b$. The dashed horizontal line (indicated with r) marks the upper asymptote for $\gamma = 0.5$ and $\lambda = 0.2$. The response level for this line is 0.9 which, using Eqn.5, gives $\lambda = 0.2$ for $\gamma = 0.5$. The fact that the upper asymptote is the same for both functions demonstrates that the attention level in the two cases is the same (although the sensory capabilities are different).

Sensory Performance. Once we have determined a value for λ , and since γ is given by the experimental design, determining the sensory performance is straight forward. Sensory performance is conventionally held to be the stimulus intensity (or magnitude of stimulus difference) at which the psychometric function crosses some predetermined level. In the absence of any inattention (i.e., when $\lambda = 0$) this level is conventionally halfway between chance performance and a performance of 1.0. In order to determine this criterion level in the presence of inattention (i.e., when $\lambda > 0.0$) the criterion needs to be adjusted. This can be done simply by inserting the value for the criterion level in the place of $f(x)$ in Equation 3. Thus we get:

$$c_a = \gamma + (1.0 - \gamma - \lambda + \gamma\lambda)c_u \quad \text{Eqn. 6}$$

Where the adjusted criterion is given by c_a and the unadjusted criterion by c_u . Note that the unadjusted criterion level (c_u) needs to be given in relation to $f(x)$. Thus, in order to obtain a criterion level half way between guessing level and always correct one needs to insert 0.5 for c_u in Eqn. 6.

Sensory performance will then be the stimulus magnitude (or difference in stimulus magnitude) at which the psychometric function crosses c_a .

DISCUSSION

A number of authors have described the effect of Lapse Rate upon the psychometric function (e.g., Treutwein, 1995; Treutwein & Strasburger, 1999; Strassburger, 2001; Wichmann & Hill, 2001; Cohen & Maunsell, 2011; Prins, 2012, 2013; Shen, 2013. See also Watson & Pelli, 1983). And many have characterized the Lapse Rate in terms of lapse of attention (Dai & Micheyl, 2011; Gibson et al., 2011; Tipper et al., 2013; Shen et al., 2015). Yet, it appears no one has proposed that a method for separating attentional factors from sensory capabilities can be based on this concept. The present report shows that if we accept the Lapse Rate as a measure of lack of attention (i.e., lapse of attention) this can be done quite easily.

The present measure of attention is $1.0 - \lambda$ where λ denotes inattention which is defined as the number of presentations on which the stimuli are not detected and, consequently, on which performance is determined by guessing. In order to determine λ the present method requires that the upper asymptote, i.e., r in Equation 5, can be determined. As was pointed out above, this should not represent a substantial difficulty given that the asymptote can be determined using a large stimulus value (or in the case of a discrimination task, a large stimulus difference).

An advantage of the present method is that attention and sensory performance are assessed under the same conditions. If one were to test attention with one method under one set of conditions (e.g., using a cueing paradigm) and test sensory performance with a different method and under other conditions (e.g., by measuring contrast sensitivity) one not only runs the risk that the different conditions affect attention and sensory capabilities differently but this would also open for the possibility that the kind of attention assessed is different from the one that is relevant for the assessment of sensory capabilities.

Although the emphasis in the present report has been on the ability to assess attention, it should not be overlooked that the method also allows for assessing sensory capabilities as these would appear absent the influence of attention. It is common to treat the psychometric function as an expression of only sensory capabilities. The present exposition shows that this is only appropriate when the level of the upper asymptote is 1.0.

FOOTNOTES

1. However, at least some of the visual deficits linked to dyslexia are hard to attribute to attention since they are specific to certain stimulus conditions (Skottun & Skoyles, 2007a).
2. The present description focuses on m-AFC data. It may be possible to adapt the present approach to data obtained with a Yes/No method. In that case the analysis would have to be based on Equation 1 rather than Equation 3. The advantage of Forced Choice data is that these are not dependent upon what subjective criteria the subjects may have adopted.

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