Perceptual deficits and inattention in schizophrenia

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Abstract

A number of investigators have found perceptual deficits in schizophrenic subjects. It has also been indicated that those with schizophrenia suffer from reduced attention. This raises the possibility that their perceptual deficits may wholly or in part reflect attentional effects. The present study used computer simulations to examine the potential effects of inattention on performance measures determined with three psychophysical methods: the Two Alternative Forced Choice (2-AFC) Staircase Method, the Two Alternative Forced Choice (2-AFC) Fixed Stimuli Method, and the Yes/No Method. It is shown that both 2-AFC methods are susceptible to attentional effects but, in contrast, the Yes/No Method may allow for the differentiation of attentional effects from sensory sensitivity and subjective criterion effects. The simulations indicate that it may be possible to control for attention effects by using Yes/No Method in combination to a 2AFC method.

Key words; Attention; schizophrenia; vision; psychophysics; 2-AFC methods; Yes/No methods.

1. Introduction

It is widely accepted that schizophrenia is associated with cognitive abnormalities. However, a number of investigators have suggested that schizophrenia is also associated with sensory deficits, particularly with deficiencies in the area of visual perception (Schwartz et al., 1999; Keri et al., 2000; Butler et al., 2001, 2005; Doninger et al., 2002; Foxe et al., 2001; Schechter et al., 2003; Slaghuis, 2004; Kim et al., 2006; Kurylo et al., 2007; Kimhy et al., 2007; Viertio et al., 2007). This could have important implications for our understanding of schizophrenia and its etiology.

There are also, however, indications that schizophrenia is associated with attentional problems (Schwartz et al., 2001; Keri & Janka, 2004; Keri et al., 2005; Laycock et al., 2007). This is important since deficits in attention have the potential to affect performance on sensory tests (Peli and Marcia-Perez 1997; Stuart et al 2001; Davis et al 2001; Roach et al 2004). This, therefore, raises the question of if, or to what extent, the observed sensory deficits might reflect underlying attentional problems^{1, 2}.

An attentional deficit would be expected to manifest itself in threshold elevations that occur more or less uniformly across a stimulus dimension (Skottun & Skoyles, 2007b). In the case of contrast sensitivity, a number of studies have indeed found schizophrenic individuals to have contrast sensitivity deficits which are more or less uniform across spatial and temporal frequencies (Slaghuis, 1998; Slaghuis & Bishop, 2001; Keri et al., 2002; Slaghuis, 2004; O'Donnell et al., 2006; see Skottun & Skoyles, 2007c for a review). This would be consistent with an underlying attentional problem (Skottun & Skoyles, 2007c). Also, some investigators have found sensory abnormalities on different types of task. For instance, Schechter et al. (2003) found that schizophrenic subjects have abnormal sensitivity to visual masking as well as abnormalities associated with temporal integration of visual stimuli. This would also be consistent with a generalized attentional deficiency.

¹ It has been proposed that the attentional problems associated with schizophrenia reflect deficits in the magnocellular portion of the visual system (Laycock et al., 2007). To link attention to the magnocellular system is, however, problematic (Skottun & Skoyles, 2006a, 2006b, 2006c, 2007a, 2007d).

² There is also evidence to indicate that attentional factors have the ability to affect Visually Evoked Potentials (e.g. Casco et al., 2005).

On the other hand, other investigators have found reduced performances on some tasks but not on other ones. For instance, Keri et al. (2000) found abnormal visual masking in schizophrenic subjects without finding abnormalities in contrast sensitivity. This would seem to argue against the notion that the sensory deficiencies found in these studies are due to underlying attentional factors. However, there are at least two important observations that need to be made: First, it is not at all clear that different sensory tasks are equally susceptible to the influence of attention. And, second, different psychophysical methods may differ with regard to the degree to which they are affected by attentional factors. In the present investigation we explore this latter issue by modeling the effect of lapses of attention on stimulus detection threshold in three different commonly used psychophysical research methods: (1), the Two Alternative Forced Choice (2-AFC) Staircase Method, (2), the Method of Two Alternative Forced Choice (2-AFC) Fixed Stimuli, and (3), the Yes/No Method. The simulations were carried out within the general framework of signal detection theory.

2. Methods

Computer simulations using *Mathematica* (Wolfram Research) were employed to simulate the effect of lapses of attention on three psychophysical methods. In the case of 2-AFC experiments, responses were modeled by drawing pairs of random values from an underlying Gaussian distribution (i.e. the probability of extracting a given value conformed to a Gaussian distribution). To one of these values was added a positive value, delta, corresponding to the average signal strength. The program was made to identify as the signal the highest of the two values. A correct response would then occur if the identified value were the one to which delta had been added. In the case of the 2-AFC Staircase Method, the magnitude of delta was adjusted based on the response (see below for further details). In the case of 2-AFC Fixed Stimuli Method, responses were obtained for a series of fixed values of delta. Again, the program was made to identify the stimulus as the one with the highest response. The proportion of correct responses, i.e. the percentage of presentations on which the highest response was the one to which delta had been added,

was calculated for each value of delta (see below for further details).

In the case of the Yes/No Method single values were drawn from the Gaussian distribution. In order to increase the average stimulus strength a value, delta, (of different magnitudes, see below), was added to the random number. The program was made to give a "Yes" response whenever the value exceeded a give threshold (for more details, see below).

In both the 2-AFC methods and the Yes/No Method the Gaussian distribution was centered at 0.0 and had a standard deviation of 1.0.

Inattention was modeled by assuming that lapses of attention caused the stimuli not to be seen so as to force the subject to resort to guessing. In order to model various levels of inattention, the proportion of stimulus presentations afflicted by inattention (i.e. the proportion of presentations in which the result was generated by guessing) was varied and was, on any given presentation, determined by chance. The level of inattention was the probability of a chance response (e.g., 0.1 level of inattention meant that the response was determined by guessing on average on 10% of the presentations). Guessing was determined by generating a random number between 0.0 and 1.0, and by taking one output if the value of the random number was above 0.5 and another if it was below this value (this is equivalent to the flipping of a coin).

3. Results

3.1 Two Alternative Forced Choice (2-AFC) staircase

Staircase methods are frequently used in psychophysical tests of clinically defined subject groups because they are fast and make it possible to obtain threshold measures in the course of a few minutes. In the case of the 2-AFC Staircase, the subject is provided with two response alternatives in which one is correct and the other incorrect. The staircase starts out with a relatively easy task. The task is then made gradually more challenging as long as the subject makes correct responses. In the case where the subject makes a mistake, the task is made easier. Typically the staircase is constructed so that three consecutive correct responses make the task harder whereas one error causes the task to be easier. This makes the staircase converge to the level where the probability of three correct responses

equals the probability of making one error. Since the probability of three correct responses equal the probability of one incorrect response, they both are 0.5 since their sum has to be 1.0. This makes the probability of one correct response the cube root of 0.5 which is 0.794 (i.e. $x^3 = 0.5$ which gives $x = 0.794$) (Levitt, 1971). The staircase can also be carried out by making the task easier after only two correct responses. In this case the staircase converges to 0.707, i.e. the square root of 0.5 (i.e. $x^2 = 0.5$ which gives $x = 0.707$). We have simulated the effect of inattention on both of these staircases.

In a 2-AFC method, the task is to differentiate two stimuli in which one is the noise and the other is the signal plus noise. The 2-AFC staircase was modeled by drawing two numbers from a random distribution with a mean of 0.0 and a standard deviation of 1.0 (see Methods). In the case of the signal, a positive value, delta, was added to the random value. In the case of the noise, the random value was used directly. The program identified as the signal the largest of the two values. In the case of very large values of delta the program correctly identified the signal. As the staircase made the task more difficult, by making delta smaller, the two distributions began to overlap and the program would start to make mistakes on some fraction of the presentations. As the delta became even smaller, the distributions became even more overlapping, further increasing the number of errors. (In the case where $\delta = 0.0$, the distributions would be identical, and the performance would be pure guessing with probability of a correct response of 0.5). The presence of an error caused the task to become easier (i.e. caused delta to become larger) until consecutive correct responses were produced at which point the staircase reversed so as to make the task harder. This in turn, caused the staircase to again reverse direction so as to become easier upon which the whole cycle was repeated.

A lapse of attention was modeled by assuming that this prevents the stimuli from being perceived with sufficient accuracy to allow the subject to base the response on them, and in the absence of stimulus information, the subject has to resort to making a guess. In our simulations, guessing was simulated by the use of a random number (equivalent to the flipping of a coin; see Methods). In order to simulate various degrees of inattention, the proportion of stimulus presentations which were determined by a random number was varied. The proportions used in our simulations were 0.0, 0.1, 0.2, 0.3. Examples of

Fig. 1. (A) Examples of simulated 2-AFC staircases. Staircases were simulated for four different levels of inattention, i.e. inattention afflicting 0.0, 0.1, 0.2, and 0.3 of the presentations. As can be seen, in the case of higher levels of inattention, the staircase decreased more slowly and produced higher threshold values. The shown staircases were made to step down (i.e. making the task harder) following three correct responses and to step up (i.e. making the task easier) following one error. Each staircase was terminated after 30 reversals. (Low stimulus strength values mean that the task is difficult.) (B) Threshold as function of the proportion of presentations afflicted with inattention. Filled symbols show data for staircase in which three consecutive correct responses lead to a step down, and open symbols show data for staircases in which the step down occurred after two consecutive correct responses. In both cases the threshold was computed as the mean of the last 12 reversals of the staircase. The data are based on the means of 100,000 thresholds (i.e. 100,000 staircases).

staircases generated with these different levels of inattention are shown in Fig. 1A. As can be seen, increasing the level of inattention caused the staircase (i.e. delta) to decrease more slowly.

In Fig. 1B is plotted the threshold to which the staircase converged as a function of the level of inattention. The staircase was terminated after 30 reversals and the mean of the last 12 reversals was taken as the threshold. Each data point in the figure is the average of 100,000 such means. The filled symbols in Fig. 1B reflect thresholds for a staircase in which three correct responses made the task harder (and one error makes it easier), whereas the open symbols represent the thresholds from a staircase in which the task was made harder following only two correct responses. As can be seen, the thresholds in the latter case (open symbols) are the lower. This is what one would expect given that a staircase which increases difficulty after only two correct responses will converge to a probability of correct response of 0.707, whereas a staircase in which three correct responses are needed will converge to a probability of 0.794 (see above).

With regard to the effect of inattention, we see in both data sets that increasing the average number of presentations which are afflicted by inattention increases the threshold. This implies, as was noted by Stuart et al. (2001), that sensory detection thresholds obtained with the 2-AFC staircase methods can be confounded by inattention.

In the case of the open symbols in Fig. 1B, the curve is somewhat flatter than the curve represented by filled symbols at the low values. That is, going from an inattention level of 0.0 to 0.1 caused a smaller increase in threshold for the open symbols than for the filled ones. This, presumably, reflects the fact that when only two correct identifications are required in order for the task to become harder, there is less chance for mild inattention to prevent the staircase from stepping down (i.e. to become harder). This may suggest that a staircase which requires only two correct responses in order to step down is more resistant to inattention. However, the effect is small, and at higher levels of inattention, the two curves are nearly parallel indicating that even a staircase which steps down after only two correct responses is still substantially susceptible to the effects of inattention.

3.2. Two Alternative Forced Choice (2-AFC) Fixed Stimuli

In the case of 2-AFC Fixed Stimuli, the magnitude of the stimulus difference to be detected does not depend on the response. Rather, a series of different stimulus pairs with fixed stimulus differences are presented. The ability on the part of the subject to identify the stronger stimulus--i.e. the percent correct response -- is then determined as a function of the stimulus difference. This makes it possible to plot the percent correct response as a function of stimulus difference. This function, which is known as a "psychometric function", starts at 50% correct when the stimuli are identical and increases to 100 % correct when the two stimuli are substantially different.

In order to simulate such a 2-AFC Fixed Stimuli experiment, two random numbers were drawn from a Gaussian distribution, and then to one of them (i.e., to the one designated as the signal), a value, delta, was added. The program was designed so as to identify the largest response as the signal. When the stimulus identified as the signal was the same one as the one to which delta had been added, a correct response was obtained (see Methods for further details). This was repeated 100,000 times for each stimulus difference and the percent correct response was computed. As with the above staircase method, inattention was simulated by determining the outcome of some fraction of the trials by chance (i.e. by guessing). The level of inattention was varied by altering the number of presentations in which guessing occurred.

The psychometric functions for the no inattention condition, and for five levels of inattention (i.e., for inattention occurring on 0.0, 0.1, 0.2, 0.3, 0.4, and 0.5 of the trials) are shown in Fig. 2A. As can be seen, when no inattention is present, the curve is relatively steep. Adding inattention, however, causes the curve to become shallower, with further increase in the level of inattention making the curves increasingly shallower.

In the case of a psychometric function, it is a conventional practice to take as the threshold the stimulus value at which the response is 75% (75% correct is midway between pure guessing, i.e. 50% correct, and always correct, i.e. 100% correct). In order to determine the effect of inattention on the discrimination threshold, this value was determined for each of the six curves in Fig. 2A. The plot of threshold as a function of

inattention is shown in Fig. 2B. In this plot, it can be seen that increasing the level of inattention causes the thresholds to increase. Thus, thresholds measured by using the 2-AFC Fixed Stimuli Method would be expected to be influenced by attention.

Fig. 2. The estimated effect of inattention on results from 2 AFC Fixed Stimuli tests. (A) Percent correct responses as a function of stimulus difference for six levels of inattention: 0.0, 0.1, 0.2, 0.3, 0.4, and 0.5. (B) The effect of inattention on the threshold. Thresholds were computed for the data in panel A by noting where the curves cross the 75% correct response level. ($N = 100,000$). The unit for the stimulus difference was the standard deviation of the underlying normal distributions (see Methods).

In connection with the 2-AFC methods it should also be noted that a number of investigators have not plotted psychometric functions or used 2-AFC Staircase Method but have simply presented the percent correct response as the response measures (e.g., Green et al., 2003 Slaghuis, 2004). Such data also are clearly susceptible to the influence by inattention. (Also studies which have included more than two response alternatives, e.g. four-alternative forced choice, have the potential to be influenced by inattention.)

3.3. *Yes/No methods*

The Two Alternative Forced Choice methods described above have the advantage that they are "objective" techniques, which means that they do not depend on subjective criteria. To avoid the reliance on a subjective criterion is particularly important when comparing different types of subjects, such as when comparing schizophrenic subjects with non-schizophrenic subjects, since there exists the possibility that the subjects in the different groups may use different subjective criteria. This explains the widespread use of objective methods in schizophrenia research. The Yes/No Method, in contrast, depends on the subjective criterion adopted by the subject. However, in spite of this drawback, as will become clear below, the Yes/No Method does have methodological advantages in being able to distinguish sensory from attentional deficits.

In the case of the Yes/No method, the subject is typically presented with a single stimulus and is given two response choices: 1) "Yes I saw the stimulus", or 2) "No I did not see it". On any given stimulus presentation the subject then has to make a decision as to whether he/she saw the stimulus or not. This involves, consciously or not, the adaptation of some criterion above which the stimulus is reported as being seen and below which it is reported as not being seen. It should be noted that in the Yes/No methods, all stimulus presentations contain a stimulus (although of various strengths). (Because the task involves two response choices, it is sometimes confused with the two alternative forced choice method. However, in spite of this superficial similarity, the Yes/No Method is fundamentally different from the 2-AFC Method in that in the case of a 2-AFC method one response is correct and the other incorrect. In the case of the Yes/No Method, the categories

correct and incorrect do not apply. See Skottun & Skoyles, 2006a, Footnote a, p. 846 for a brief discussion of this issue.)

Results obtained with the Yes/No Method typically show a sigmoidal relationship between stimulus strength and the percentage of yes responses: when the stimulus is weak there are close to zero percent yes responses. As the stimulus strength is increased, the percentage of yes responses increases first gradually, then more rapidly, and, when the stimulus is quite strong, there is flattening of the curve as the stimulus is seen on the majority of presentations, i.e. as the percentage of yes responses approaches 100.

In the present simulations, values were drawn from a Gaussian probability distribution with mean of 0.0 and standard deviation of 1.0. In order to generate a range of stimulus strengths, a value, delta, was added to the random values. Delta was made to range from 0.0 to 3.9 in steps of 0.1. In our initial simulation, the threshold criterion was set to 1.0. That is to say, the program was made to produce a yes-response whenever the value exceeded 1.0. As in the case of 2-AFC methods, inattention was modeled by random responses (i.e. guessing). The levels of inattention modeled (i.e., the average fraction of presentations to which a random response was made) were 0.1, 0.2, and 0.3 in addition to the zero inattention level.

The simulation results are shown in Fig. 3A. As can be seen from the response curves, the percent Yes responses are quite low for small signals and increases with increasing signal strength. When we compare the four curves, we can see that increasing the level of inattention has the effect of making the curves become flatter.

In the case of the Yes/No Method, it is common to take as threshold the stimulus level at which the curve crosses the 50% level. As we can see from Fig. 1A, the stimulus level at which the curve crosses this response level is relatively unaffected by inattention. The reason for this is that when the threshold is defined by 50% yes-responses, introducing guessing into the performance adds only more 50 % yes-responses, which does not alter the proportion of yes responses at the threshold stimulus level. At lower stimulus levels where the response is below 50% yes responses, the addition of guessing, however, will elevate the curve (increase the percentage of yes responses), and at higher stimulus strengths where the yes responses are above 50%, the addition of guessing will act to decrease the

percentage of yes responses. Thus, in the case of the Yes/No Method the effect of inattention is to flatten the curves without changing the threshold.

Fig. 3. (A) The percentage of yes responses as a function of stimulus intensity are shown for four different levels of inattention: Inattention on 0, 10, 20 and 30 percent of the trials. As can be seen, increasing the amount of inattention, flattens the curve but does not increase the threshold. That is to say, the curve crosses the 50 % "yes" response level at the same stimulus intensity.

(B) "Yes" responses as a function of stimulus intensity for criteria of 0.5, 1.0 and 1.5. As can be seen, increasing the criterion shifts the curve towards higher stimulus values, and consequently the stimulus intensity at which the curve crosses the 50% yes response level is shifted to higher stimulus values when the criterion is increased. (All data points are based on $N = 100,000$).

The main limitation of the Yes/No Method is, as was mentioned above, that it depends on the criterion used by the subject. In Fig. 3B, we have plotted response curves for three different criteria: 0.5, 1.0, and 1.5. (No inattention was simulated in these trials.) As can be seen, changing the criterion causes the curves to be shifted along the stimulus axis (i.e. the X-axis). However, and importantly, the slopes of the curves remain (roughly) unaltered.

In summary: In the case of the Yes/No Method, loss of attention leaves the thresholds substantially unaltered, but changes the slope of the response curve, whereas changes in subjective criterion act to change the threshold, but leaves the slopes roughly unaltered.

4. Discussion

In the present study, we have simulated the effect of inattention on three different psychophysical methods: On the Two Alternative Forced Choice (2-AFC) Staircase Method, on the method of 2-AFC Fixed Stimuli, and on the Yes/No Method³. We find that inattention would be expected to influence the 2-AFC Staircase Method. With this method, only a single value, i.e. the threshold value, is generated. As a result, there is no reliable way to differentiate a genuinely higher threshold from an elevation in threshold measure caused by inattention. In the case of 2-AFC Fixed Stimuli Method, this method also is affected by inattention because lapses of attention causes the psychometric curves to become shallower which, in turn, causes the estimated thresholds to become higher. As a result, also in the case of this method, it is not generally possible to differentiate attentional effects from genuinely higher sensory thresholds. However, in the case of the Yes/No Method, inattention causes the response functions to become flatter without affecting the threshold value (when this is defined as the crossing of the 50% level). On the other hand, changes in criterion and genuine differences in sensitivity causes the threshold to change.

³ For the sake of completeness, it should also be pointed out that it is possible to have a Yes/No staircase. In this method Yes responses would make the stimulus become weaker and No responses would make them become stronger. This method was not examined because it seems to be of relatively little interest in the present context. The reason for this is that unlike the 2-AFC staircase, it lacks the advantage of providing an objective test, nor does it have the advantage of allowing for a separation between attention and threshold, as does the Yes/No fixed stimuli method we examined.

This means that the Yes/No Method has the potential to differentiate attentional effects, on the one hand, from criterion effects and sensitivity effects on the other. It seems, therefore, that it would be possible to utilize the Yes/No Method to identify effects of inattention, and to use the 2-AFC methods to differentiate criterion effects from sensitivity effects.

The present analyses were motivated by the commonly held view that schizophrenia is associated with attentional problems. Many of the studies of sensory function in schizophrenia have made use of a 2-AFC method (e.g., Slaghuis, 2004; Kurylo et al., 2007). Based on the present considerations it seems clear that it may not be possible to differentiate attentional effects from genuine sensory deficits in these experiments. We have here attempted to outline one possible way to disentangle the effect of attention from genuine sensory deficits. But in the absence of research that seeks such a disentanglement, it is difficult to evaluate the many reports of sensory deficits in schizophrenia. That is, it is difficult at present without further investigation to exclude the possibility that these deficits represent wholly, or in part, attentional problems.

5. Conclusion

It is held that schizophrenia is associated with attentional problems. This makes it possible that the sensory deficits shown by schizophrenic subjects reflect, at least in part, attentional problems. In the present report it is pointed out that in the case of both the 2-AFC Staircase Method and the 2-AFC Fixed Stimuli Method it is not possible to differentiate sensory deficits from attentional effects. However, in the case of the Yes/No Method this may be possible. The drawback with the Yes/No Method is that it is not independent of the subjective criterion. Thus, in order to differentiate genuine sensitivity effects from both attentional effects and criterion effects, it may be necessary to employ a combination of a 2-AFC methods and the Yes/No Method. Given the widely held view that schizophrenic individuals suffer from attentional problems, without an approach that seeks to control for the possible effects of inattention, it is not clear how to interpret many of the reports of sensory deficits in schizophrenia.

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