Acknowledgments

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MORE ON THE PSYCHOPHYSICS OF CONTINGENCY ASSESSMENT

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Abstract

The study of contingency assessment involves examination of the relationship between physical events (the statistical contingency between cue and outcome) and the observer's internal experience of these events. Psychophysics is the discipline relating physical events and internal experiences, so it is surprising that few psychophysicists have been concerned with contingency assessment. At ISP 2006, I described a new methodology – the streamed-trials procedure – to study contingency assessment within a psychophysical framework. More recently we have modified the procedure so that (1) we can use cues and outcomes traditionally used by contingency researchers (e.g., ingestion of certain foods and the occurrence of an allergic reaction), (2) we can assess the observer's assessment of control over the outcome (as well as the observer's assessment of the cue-outcome contingency), and (3) we can study cue interaction effects (e.g., blocking). In addition to describing these modifications, we discuss the value of a psychophysical approach in evaluating theoretical accounts of contingency assessment.

The tasks that have been used to study how an observer assesses the relationship between two binary events can be categorized as passive and active. On each trial of the passive task, a cue may, or may not, be presented, following which an outcome may, or may not, be presented. After a series of trials, the observer is asked about the strength of the relationship between the cue and the outcome. On each trial of the active task, the observer has the option of responding or not responding, following which an outcome may, or may not, be presented. After a series of trials, the observer is asked about how much control they had over the outcome. The relationship between the cue/response and the outcome can be summarized as a 2 x 2 matrix (see Table 1), where the cue or response is represented as the input variable. On each trial the input either occurs (I) or does not occur (~I), and then the outcome either occurs (O) or does not occur (~O). The letters in the cells (a, b, c, d) represent the joint frequency of occurrence of the four input-outcome combinations in a block of trials. One commonly used measure of the contingency between the input and the outcome is ΔP (Allan 1980):

Table 1: The 2 x 2 matrix for the input-outcome pairings in a contingency assessment task.

Input	Outcome	
	O	~O
I	a	b
~I	c	d

$$\Delta P = P(O \mid I) - P(O \mid \sim I) = \frac{a}{a+b} - \frac{c}{c+d}.$$

The Streamed-Trial Procedure

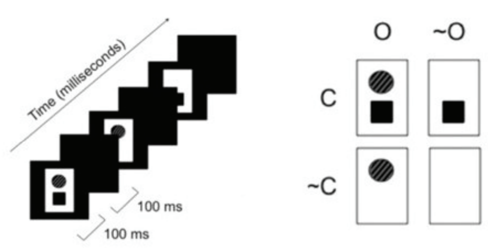

Fig 1. A streamed-trial in Crump et al. (2007). Squares are cues and were presented in blue. Circles are outcomes and were presented in red.

We previously described a new passive procedure that permits rapid, multiple within-observer assessments of the contingency between the cue and the outcome (the "streamed-trial" procedure, Crump et al., 2007). One advantage of the streamed-trial procedure over the traditional trial procedure is that it is amenable to a psychophysical analysis. The streamed trial used by Crump et al. is depicted schematically in Fig 1. The cue and the outcome were colored geometric forms. Each 100-ms presentation consisted of one of four cue-outcome combinations, and presentations were separated by a black screen of 100-ms duration. A stream of these cue-outcome combinations defined the contingency value.

Allan et al. (2008) used this stream-trial procedure in conjunction with method of constant stimuli to generate psychometric functions. Streams with different ΔP values (ranging from 0.0 to 1.0 in increments of 0.1) were presented and at the end of each stream, the observer had to categorized the relationship as "strong" (R_S) or "weak" (R_W). The data from Experiment 1 in Allan et al. are shown in Fig 2 which plots the probability of a strong response, [P(R_S)], averaged over the four observers,[1] as a function of ΔP. The cumulative normal psychometric function was fit to the data of each observer, and the line in Fig 2 is the mean of the four individual fitted functions.

The psychometric function allows the extraction of two parameters from the data. One parameter, the slope, provides a measure of the observer's sensitivity to the contingency between the cue and the outcome. The other parameter, the point of subjective equality (PSE), is the value of ΔP at which P(R_S) = .5. The PSE provides a measure of the observer's preference or bias for making a particular response. The availability of two parameters allows the conceptualization of the contingency assessment task as consisting of two distinct processes. The input process maps the external contingency value programmed by the experimenter onto an internal dimension. The output process converts the internal value into the behavioral response. The two-process model that Allan et al. (2008) used to analyze their data was Signal Detection Theory, SDT (Green & Swets, 1966).

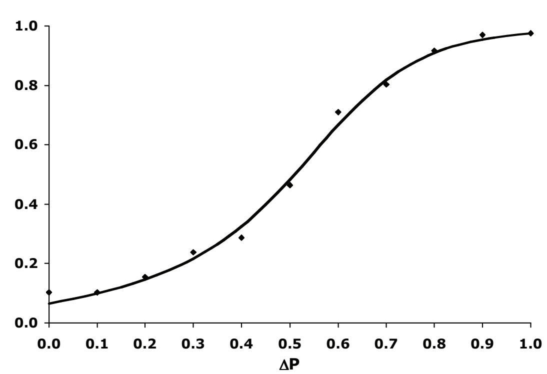

Fig 2. Psychometric function from Allan et al. (2008).

We have demonstrated that the cues and outcomes used with the streamed-trial procedure need not be restricted to geometric forms. Allan et al. (2008) used emoticons as cues and outcomes. The presence of the cue and of the outcome was represented by an emoticon with a smiling expression, and the absence of the cue and of the outcome was represented by an emoticon with a neutral expression. Hannah et al. (submitted) adapted the streamed-trial procedure for the conventional allergy stimuli (e.g., Wasserman, 1990), where food ingestion is the cue and an allergic reaction is the outcome. We have also demonstrated that the streamed-trial procedure need not be restricted to the simultaneous presentation of the cue-outcome pairs. For example, Allan et al. presented the emoticon pairs sequentially.

[1] We are presenting average data because of the page limitation.

Experiment 1: The Streamed-Trial Procedure and the Active Task

The streamed-trial procedure developed by Crump et al. (2007) was an analogue for the traditional passive task. We have since developed an analogue for the traditional active task. Rather than the experimenter rapidly presenting a series of cue-outcome pairs (as in the passive streamed-trial procedure), the observer is required to rapidly generate a series of responses (using the computer keyboard) that are then paired with an outcome or a no-outcome event. At the end of the stream, the observer is required to assess how much control they had over the outcome. Our motivation for developing the active analogue is to undertake a psychophysical analysis of *depressive realism*. There are reports in the literature that nondepressed individuals assess that they have control when in fact they do not whereas depressed individuals are realistic about the absence of control (see Allan et al., 2007 for a review). This apparent knack for depressives to be realistic has been termed depressive realism, and led to the characterization of depressives as "sadder but wiser" (Alloy & Abramson, 1979). Allan et al. (2007) suggested that depressives and nondepressives may not differ in their perception of contingency (depressives are not "wiser"), but rather that they differ in how they respond. The purpose of Experiment 1 is to document that the active analogue of the streamed-trial procedure yields orderly psychometric functions.

Method

Four paid observers (graduate students) participated. The cues and outcomes were the smiling and frowning emoticons illustrated in Fig 3. Observers were instructed that their task was to learn what degree of control they had over whether or not the computer character (Emo) smiled. During each stream, the observer sent Emo 30 smiling emoticons by triggering a Happy response (the Z on the computer keyboard, labeled 'H') and 30 frowning emoticons by triggering an Angry response (the backslash key, labeled 'A'). Immediately upon making a response choice, the observer's smiling or frowning emoticon (colored orange) was displayed at the left and Emo's smiling or frowning emoticon (colored yellow) was simultaneously displayed on the right for 100 ms. The observer could send the smiling and frowning responses in any order but was constrained to sending 30 of each response category, and two counters on the screen showed how many of each type remained to be made in the stream. At the end of the stream, the observer was required to make a binary decision. Two clickable buttons, one labeled "weak" (a R_W response) and one labeled "strong" (a R_S response) appeared on the screen. The observer was to select the button

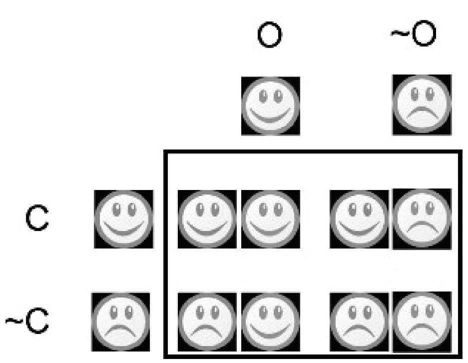

Fig 3. Cues and outcomes in Experiment 1. Cues are orange and outcomes are yellow.

which best represented how much control they had over Emo's happiness. A stream took about 15 sec to complete, depending on how quickly the observer responded.

There were 11 values of ΔP ranging from 0.0 to 1.0 in increments of 0.1, where ΔP is the programmed contingency between the response and the outcome. Each of the 11 ΔP values was presented three times in a randomized order during each block of 33 streamed-trials. A session consisted of five blocks, resulting in 15 presentations of each of the 11 ΔP values. Each observer participated for 10 sessions.

Results and Discussion

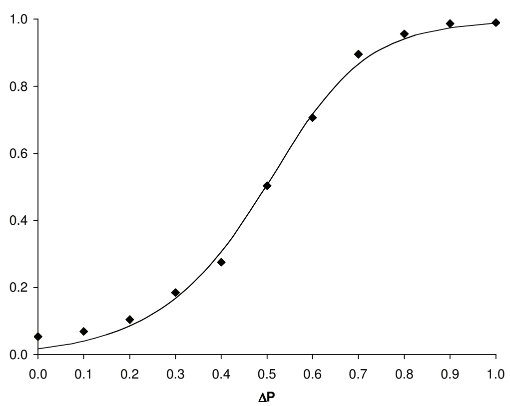

Fig 4. Active psychometric function in Experiment 1.

Fig 4 plots $P(R_S)$, averaged over the four observers, as a function of ΔP. The cumulative normal was fit to the data of each observer, and the line in Fig 4 is the mean of the four individual fitted functions. The streamed-trial active task, like the passive task, produces orderly functions.

Experiment 2: Cue-Interaction

Cue-interaction effects have been of central interest in the contingency assessment literature for much of the last 20 years (for recent reviews see Allan & Tangen, 2005; De Houwer & Beckers, 2002). These effects arise from pairing multiple cues with a common outcome. It is well established that each of the multiple cues is not rated independently. For example, when two cues (a target cue C_T and a companion cue C_C) are paired with a common outcome, the typical finding is that the rating of the relationship between C_T and the outcome depends on the strength of the relationship between C_C and the outcome. Cue-interaction effects have been central to the evaluation of competing theoretical accounts of contingency assessment.

Cue interaction has been studied using a number of different paradigms: one-phase blocking, two-phase blocking, relative cue validity, and overshadowing. In Experiment 2, we use the one-phase blocking paradigm, where there are four possible cue combinations: both cues are present (C_T C_C), both cues are absent ($\sim C_T$ $\sim C_C$), the target cue is present and the companion cue is absent (C_T $\sim C_C$), or the target cue is absent and the companion cue is present ($\sim C_T$ C_C). For each cue combination, the outcome either occurs (O) or does not occur (~O), resulting in eight possible cue-outcome combinations. The usual finding is that the assessment of the contingency between C_T and the outcome depends on the contingency between C_C and the outcome. Tangen and Allan (2004), for example, showed that for a fixed contingency of 0.5 between C_T and the outcome, ratings of C_T were lower when the contingency between C_C and the outcome was perfect (ΔP = 1.0) than when there was no contingency between C_C and the outcome (ΔP = 0.0).

While it is well established that the C_C contingency affects the assessment of the relationship between C_T and the outcome, there is little agreement about whether the C_C contingency affects the input process (sensitivity to the relationship between C_T and the outcome), or whether it affects the output process (the observer's behavioral response). In Experiment 2, we generate psychometric functions to determine whether C_C contingency affects the slope (the input process) or the PSE (the output process).

Method

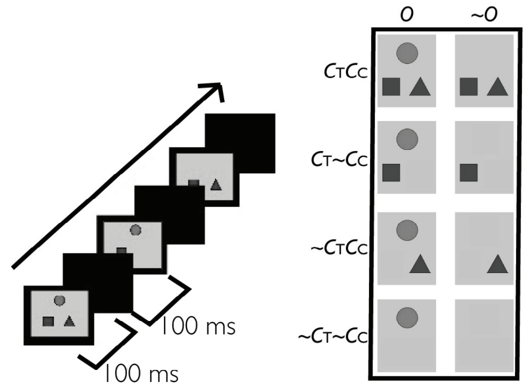

Fig 5. A streamed-trial in Hannah et al. Squares and triangles are cues and were presented in blue. Circles are outcomes and were presented in red.

Fig 5 shows the stream-trial procedure as adapted by Hannah et al. (submitted) for the one-phase blocking paradigm. Cues were blue squares and blue triangles and the outcome was a red circle. Either square or triangle could function as C_T or as C_C in any given stream. Two values of C_C contingency (0.0, and 1.0) were crossed with four values of C_T contingency (.2, .4, .6, .8), resulting in eight contingency combinations. An experimental session consisted of five blocks of 48 streamed-trials. Each of the eight contingency combinations occurred six times in a block, in a randomly determined order. At the end of a stream, the observer was signaled to make a binary response about the relationship between one of the cues and the outcome by clicking one of two buttons ("weak" or "strong") on the computer monitor. For each of the eight contingency combinations, C_T was signaled at the end of half the streams, and C_C was signaled on the remaining presentations. Each observer participated in 15 sessions.

Results and Discussion

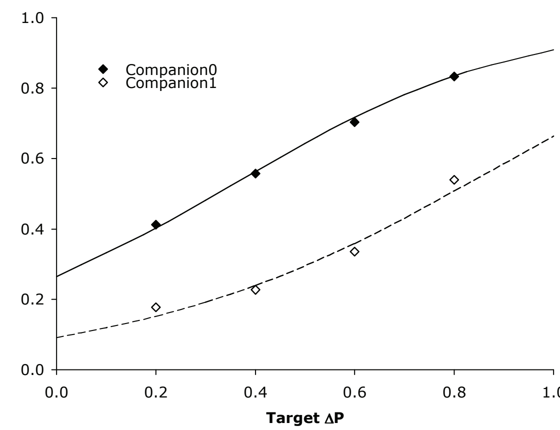

Fig 6. Psychometric functions from Hannah et al.

$P(R_S)$ on C_T-signaled streams is shown in Fig 6 averaged over the six observers. $P(R_S)$ is plotted as a function of target ΔP separately for the two C_C contingencies. It is clear that the two functions differ indicating that the response to a fixed value of ΔP depended on the C_C contingency. $P(R_S)$ is higher when the C_C contingency was 0.0 than when it was 1.0. Psychometric functions were fit to each observer's data. For every observer, the PSE was smaller when the C_C contingency was 0.0 (mean PSE = .29) than when it was 1.0 (mean PSE = .79). Overall, the slopes differed little for the two C_C streams, and the direction of the difference varied among the observers. The lines in Fig 6 are the means of the fits with the constraint that the psychometric functions have the same slopes. The data are well described by psychometric functions that have the same slope and differ only in PSE.

The same-sloped functions in Fig 6 suggest that the ability to discriminate among the contingencies is not affected by C_C contingency. Rather the effect of C_C is on the PSE – the placement of the criterion. The location of the criterion regarding the strength of the

C_T contingency depends on the value of the C_C contingency in the stream. When C_C is a good predictor of the outcome ($\Delta P = 1.0$), the observer is likely to indicate that the relationship between the C_T and the outcome is weak. In contrast, when C_C is a poor predictor of the outcome ($\Delta P = 0.0$), the observer is likely to indicate that the relationship between C_T and the outcome is strong. This effect of C_C on the criterion is consistent with variable-criterion accounts in the literature for data generated in other tasks. For example, Treisman (1984) argues that "a criterion is defined not only for a particular judgment, but also for particular conditions under which this judgment may be made. … Thus, the decision criterion may have different values for different sets of circumstances." (pp. 132-133), and he discusses the application of his criterion-setting model to diverse phenomena in the literature.

Acknowledgements

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REINTERPRETING CORRECT VERSUS ERROR RESPONSE TIMES

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Abstract

Early psychological theories of choice and decision followed from developments by Gauss, Fechner, Thurstone, Peterson Birdsall and Fox, and Tanner and Swets. That theoretical structure advanced experimental work in psychophysics and eventually found its way into interpretations of memory performance. A starkly different view of sensory processes rejects this foundation and substitutes for it more recent developments in stochastic processes often viewed as random walks. A critical prediction of the random walk approach concerns the relation between correct and error times. But, these critical predictions are often misunderstood and tests of the predictions misapplied.

In 1821 Karl Gauss published his famous *Theoria combinationis observationum erroribus minimis obnoxiae* (Theory of the Combination of Observations Least Subject to Errors). Gauss's introduction is frankly psychological:

> Certain causes of error are such that their effect on any one observation depends on varying circumstances that seem to have no essential connection with the observation itself. Errors arising in this way are called irregular or random, and they are no more subject to calculation than the circumstances on which they depend. Such errors come from the imperfections of our senses and random external causes, as when shimmering air disturbs our fine vision. (Trans G. W. Stewart)

Nearly 40 years later, in *Elemente der Psychophysik*, pages 104-111, Gustav Fechner developed more extensively Gauss's suggestion that our sensory systems may be perturbed by the same error that affects other measuring devices. This breathtaking application of mathematical ideas to the measurement of mental phenomena defines the origin of scientific investigations of psychological phenomena.

For Gauss the sum of random errors defined the extent of deviations of the observed measure from the true value of the phenomenon to be measured. And, although the individual errors may not be observed, their sum was the cause for variability in repeated measures of the same object. An illustration of Gauss's idea appears in Figure 1. Ten examples of the sum of fifty independent and randomly determined "errors" with mean zero fill the space with stochastic paths illustrating great variability. The end points of each path define the total value of the sum of errors – the possible effect on each of ten individual measurements.

Fechner set himself the task to measure the variabilities that "come from the imperfections of our senses" as postulated by Gauss. His idea launched a thousand experiments and remains today a flagship of experimental psychology. The surprise is that so few know that Fechner invented the idea that launched the thousand ships