INCOMPLETE KNOWLEDGE OF RESULTS AND THE MANIPULATION OF RESPONSE BIAS

Matthew J. Davis
CDO Technologies, Inc.
Dayton, Ohio

In signal detection theory, an optimal observer exploits all available information to achieve the desired goal of a particular decision strategy (Green & Swets, 1966). Detection experiments often provide the observer with complete knowledge of results (CKR) in order to ensure best possible performance for the task. If optimal behavior is indeed dependent upon CKR, then a degradation of that information should also reduce the likelihood of achieving optimal response bias. A single-interval auditory detection experiment was conducted to measure changes in response bias in the presence of *incomplete knowledge of results* (IKR) (i.e. feedback for some combination of true/false detections and true/false rejections) (Davis, 2015). The results were compared with the theoretical "optimal" bias level for the task. Statistical tests revealed significant differences between complete and incomplete feedback conditions. These results are consistent with the hypothesis that IKR can significantly degrade an observer's ability to achieve optimal response bias.

In the aviation industry, pilots and air traffic controllers are often presented with scenarios where it is important to detect nuanced changes between stimuli, such as detecting auditory alarms in loud environments, or correctly determining the distance between aircraft. In these instances, correct discrimination of the stimuli is improved with experience, and experience is coupled with knowledge of one's performance. The more information that is received about the outcome of a particular decision, the more that knowledge can be used to influence future decisions. Decisions about ambiguous stimuli can be described using signal detection theory (SDT), where decision outcomes are defined in terms of *sensitivity* and *response bias*. An observer who frequently detects an ambigious stimulus is considered to have a high degree of *sensitivity*. An observer who frequently responds with one decision over another (e.g. *"yes, there's a problem"* vs. *"there's no problem"*) is described as having a high degree of *response bias*. The definition of what is biased depends almost exclusively on the decision strategy being implimented, such as "maximize the proportion of correct responses", "maximize a weighted combination of hits and correct rejections", "maximize expected value", and the "Neyman-Pearson objective" (Green & Swets, 1966, pp. 20–26; Macmillan & Creelman, 2005). The ultimate goal of any decision maker is to not only obtain the highest degree of sensitivity possible, but also to obtain the optimal ratio of responses as dictated by an appropriate decision strategy.

Knowledge of results (KR) is known to be an important aid in the optimization of response bias (Green & Swets, 1966, p. 395; Macmillan & Creelman, 2005, p. 130). Many experimental tasks that require the detection or discrimination of ambigious stimuli utilize complete knowledge of results (CKR), where feedback is provided for every possible response. The real world, however, is more complex and often provides very little useful feedback information from which to optimize responses. Feedback that is not presented for every response-type is known as incomplete knowledge of results (IKR), and is comprised of continuous trial-by-trial feedback, but only for some combination of true/false detections or true/false rejections of the stimulus (Figure 1), (Davis, 2015). As more information is expected to increase one's ability reach an optimal response bias, incomplete feedback information may degrade the ability to respond optimally. Understanding the influence of incomplete feedback on response bias is imporant in understanding how humans utilize decisions strategies with incomplete information.

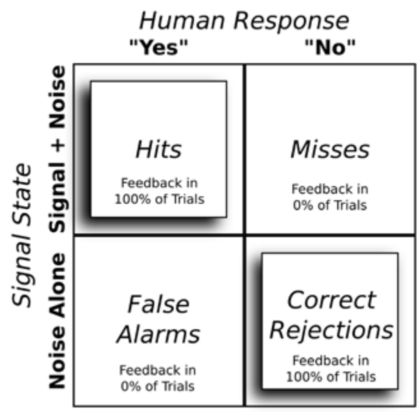

Figure 1. An example of incomplete knowledge of results. In this case, feedback is provided for hits and correct rejections, but not for misses and false alarms.

Background

Traditionally, feedback has been used in signal detection experiments as a means of stabilizing performance in sensitivity or, to a lesser extent, response bias (Green & Swets, 1966, p. 395; Macmillan & Creelman, 2005, p. 130). While feedback for every response may appear to be the most logical method of providing KR, early detection literature utilized different types of feedback and with varying nomenclature (Kaess & Zeaman, 1960; Wiener, 1963). Other studies have examined the effect of limiting feedback to a predetermined proportion of trials known as *partial knowledge of results* (Lurie & Swaminathan, 2009; McCormack, Binding, & McElheran, 1963; Szalma, Parsons, Warm, & Dember, 2000). Szalma et al. (2006) studied the effects of optimism and pessimism on stress states, and provided feedback for certain response-types and witheld them for other responses. In that study, the term "knowledge of results format" was used, though the term "incomplete knowledge of results" was proposed by Davis (2015) as a more accurate description. In each of these cases, feedback was designed to improve or at least modify behavior, though the effects on response bias were examined in only a few cases.

Methods

Procedure

An auditory detection experiment was conducted to examine the effects of IKR using a 1 kHz tone and a white noise masker. Participants were first presented with a practice task designed to increase familiarization with the single-interval paradigm and signal/noise characteristics. The next task was designed to measure a masked signal threshold (d' ≈ 1.3) for use in the IKR experiment by utilizing the single-interval adjustment matrix (Kaernbach, 1990). The final task contained conditions that manipulated IKR and used the individualized thresholds from the SIAM procedure to present the signal and noise stimuli at a constant SNR in a single-interval yes-no paradigm (Green & Swets, 1966). Each participant completed 10 conditions, and each condition contained 10 blocks of 50 trials. Subjects were presented with the stimulus (either "signal+noise" or "noise alone") and were asked to indicate if the target signal was present in the noise. In response to the question, subjects could select either "yes" or "no" by clicking the appropriate button on a graphic user interface with a computer mouse. Feedback of some type was provided for every trial, but only for the response types that were specified by the condition [e.g. some combination of hits (H), misses (M), false alarms (FA), and/or correct rejections (CR)]. Each condition consisted of feedback for (1) no response types, (2) H, (3) M, (4), FA, (5) CR, (6) H+M, (7) H+FA, (8) H+CR, (9) H+M+FA, and (10) H+M+FA+CR. Conditions were completed in random order with the exception of the first condition (no feedback), which was always completed first as a baseline condition; and the last condition (complete feedback), which was always completed last, to prevent the complete set of feedback from influencing other conditions.

Two main features of IKR were examined in this study: *quantity* and *implicitness*. The question of IKR *quantity* refers to the amount of response-types that receive feedback. IKR *implicitness* refers to the possibility of inferring KR from missing feedback. The features of each type may be important for explaining individual results of subjects as feedback is increased in the number of response-types across conditions. Subjects were asked to utilize the decision theory that *maximizes the proprotion of correct answers* (Green & Swets, 1966, pp. 20–26). Subjects were not told the *a priori* signal probability of the signal, and were thus unaware that the optimal decision strategy would require an 50% split in "yes" and "no" responses. The optimal decision criterion for this decision strategy and signal probability was $c = 0$, where $c = -1/2[z(H) + z(F)]$ (Macmillan & Creelman, 2005, equation 2.1).

Subjects

Participants consisted of 5 male and 5 female adults (ages 18-32). Hearing thresholds were tested at 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, and 8000 Hz. Acceptable thresholds were defined as < 15 dB HL loss at these frequencies. All subjects were part of an in-house, part-time subject pool. All subjects volunteered for the study and were given the option to leave at any time, and for any reason without penalty to their standing in the subject pool. All subjects participated through the completion of the study.

Stimuli

The target stimulus consisted of a 20 ms, 1 kHz sinusoidal signal that was present in exactly 50% of the randomized trials. The masking stimulus consisted of 500 ms of white noise and was present in every trial. Both the signal and the noise employed a cosine onset/offset ramp to the first and last 10ms of the stimuli to unintended artifacts. The distribution of trials with "signal+ noise" vs. "noise alone" was randomized. The center of the target signal (when present) always coincided with the center of the noise, so that the noise was always the first and last stimulus to be heard. The rms level of the noise was 60 dB SPL, and the average presentation level of the signal and the noise combined was no more than 60.3 dB SPL.

Results

IKR Quantity

Since the *magnitude* of response bias is of primary interest for the question of IKR *quantity*, the data were organized by the absolute value of the decision criterion, *c*. Negative values of *c* indicate bias toward "yes", and positive values of *c* indicate a bias toward "no". These data were modelled using individual exponential functions per subject; $f = ae^{bx}$ (Figure 2). Of the ten subjects who participated in this study, 60% demonstrated statistically significant *negative* slopes ($p < .05$); the remaining 40% yielded flat data with no significant slopes (Table 1). None of the subjects produced statistically significant *positive* slopes as the amount of feedback was increased across conditions.

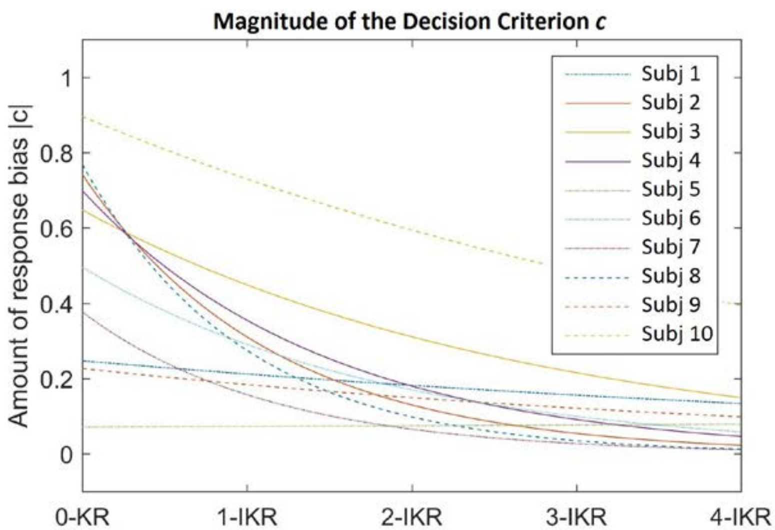

Figure 2. Analysis of inividual response biases for each subject across conditions with different quantities of feedback.

Table 1.
Exponential model coefficients of individual and group response bias.

Subject	*a*	pVal	*b*	pVal
1	.247	.013	-.153	.371
2	.741	.000	-.870	.013
3	.647	.000	-.367	.005
4	.699	.000	-.678	.002
5	.071	.105	.025	.910
6	.496	.000	-.535	.010
7	.377	.002	-.874	.064
8	.768	.000	-1.029	.019
9	.227	.001	-.208	.106
10	.896	.000	-.205	.009
Group	.72	.000	-.39	.009

Note. Results are significant at the $p < .05$ value.

IKR Implicitness

If subjects are able to use *implicit* feedback information to optimize their responses, then it is expected that the three implicit conditions being examined in this study (H+M, H+CR, and H+M+FA) would have an optimal decision criterion (c = 0). Across all subjects, a total of 23% of all *implicit* IKR conditions contained means in the range the optimal decision criterion. However, 70% of the conditions (across all subjects) contained means in the range of the complete feedback (CKR) condition. A total of 50% of individual subjects demonstrated similarity with $c = 0$, and 90% of all subjects contained bias similar to the CKR condition in at least one of the three implicit conditions.

Discussion

The primary purpose of this study was to better understand the degredation of optimal response bias as feedback information is provided at various levels of incompleteness. The results of IKR *quantity* demonstrate that conditions of different amounts of feedback can be modelled individually using a negative exponential curve. The data can be split into two types of behavior: subjects who become more optimal with more feedback information, and subjects who maintain near-optimal behavior from the beginning. It is important to note that even though some subjects did not yield a signficant negative exponential slope approaching $c = 0$, subjects did not significantly *increase* their bias as the number of feedback response types were increased. These data are consistent with the hypothesis that the type of feedback, not just the proprtion of feedback trials, is important for optimizing response bias for a given decision strategy.

The results of the *implicit* feedback conditions suggest a surprising inability of subjects to utilize missing feedback information to achieve optimal bias. Many subjects who did demonstrate optimal bias in these conditions were also relatively unbiased in every condition. One possible explanation for this behavior stems from the definition of optimal bias. In reality, the subjects had two tasks: (1) discover the optimal ratio of responses with limited information, and (2) optimize their responses with the aforementioned ratio. These two tasks, while similar, are not the same. It is entirely possible that the participants failed to properly estimate the optimal bias while also using the missing feedback to optimize responses to their own imperfect internal representation of the optimal strategy.

Conclusion

The results of this study reveal the importance of feedback in the attainment of optimal response biases for the decision strategy that maximizes the proportion of correct responses. As the number of response types associated with feedback increases, the probability that humans will respond optimally also increases. Additionally, it was expected that participants would be able to utilize the implicit feedback conditions to further optimize their responses. Instead, bias for the implicit conditions in most subjects contained greater similarity to the individual bias levels for the complete feedback condition than for the optimal bias level, (which were often not equal). These results suggest that humans are imperfect estimators of optimal response bias, though in general this imperfection is consistent with their internal representation of the optimal decision strategy. These results provide important insights into the decision making processes of humans, and reveal that the type of feedback information that is witheld is nearly as important as feedback that is accessible.

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