DISCRIMINATION, CONTEXT, AND SENSORY REPRESENTATIONS

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Abstract

Over the past two decades, a number of studies have shown that discrimination, identification, and judgments of sensory magnitude, are affected by both stimulus context and the observer's expectations. Here we argue that these contextual effects negate the possibility of deriving scales of sensory magnitude that are unique up to an affine transformation. However, in compensation, psychophysics has provided us with rich and robust techniques that enable us to explore the nature of sensory experience and how it is altered by bottom-up (stimulus driven) and top-down (knowledge driven) factors.

Over the past century a number of psychophysical methods have been developed by researchers to determine the relationship between aspects of sensation and the physical properties of the stimuli impinging upon the sensory organs of the perceiver. An implicit assumption behind this endeavor is that the sensation evoked by the stimulus can be represented as a point in an n-dimensional psychological space where the dimensions of the space correspond to the psychological attributes associated with the stimulus (Schneider & Parker, 2009). For example, the experience of a pure tone could theoretically be represented as a point in a 3-dimensional space in which the dimensions are loudness, pitch, and duration. In this article, we review what some psychyophysical methodologies (mainly discrimination techniques) have revealed about the nature of the psychological (sensory) representations of stimuli.

Determining the nature of the sensory representation from measures of discrimination

Fechner's attempt to develop a correspondence between a physical dimension of a stimulus (e.g., its weight) and its corresponding psychological attribute (e.g., heaviness) was based on the assumption that equally-often-noticed differences are subjectively equal. Note that this is a two-step process. First, it is essential to determine the discriminability of the elements in a set of stimuli. In Fechner's case, this involved determining the difference limens among a set of stimuli varying along a single physical dimension (e.g., weight). The second step involves assumptions of how discriminability is related to distance in the psychological space. Fechner assumed that if one produced a set of unidimensional physical stimuli that were equally discriminable from one another (e.g., a set of weights spaced one difference limen apart), they would also be separated by equal distances in psychological or sensory space (be equally spaced with respect to their perceived heaviness). This allowed him to develop a psychophysical correspondence between properties of the stimulus and the dimensions of psychological experience.

Given this two-step process, it should not be surprising that a great deal of effort has been expended in developing methods for specifying and interpreting measures of discrimination and difference [e.g, Thurstonian scaling techniques (Thurstone, 1927), signal-detection techniques (Green & Swets, 1966)], and in relating such measures to the psychological representations of these stimuli [measurement theories (Krantz, Luce, Suppes, & Tversky, 1971), choice theory (Luce, 1959), nonmetric multidimensional scaling (Shepard, 1966, Schneider, Parker & Stein, 1974)]. Underlying all of these developments, however, has been the implicit assumption that, once the effects of response biases have been removed or controlled for, a stable set of psychological difference measures would emerge. These measures, in turn, would reveal, given the appropriate assumptions, the nature of the psychological space that would describe sensory experience. A number of developments over the last twenty years have indicated that it is highly unlikely that this assumption is valid. Consequently, we argue that we will never be able to achieve Fechner's goal of developing a stable correspondence between the physical and mental worlds. What has emerged, however, is an approach and set of techniques that does allow us to probe and describe the nature of sensory experience, and how it is affected by the sensory and psychological (cognitive) context within which the stimuli are experienced. in other words, psychophysical methodologies have emerged that permit us to explore and map out the complexities of sensory experience. And it remains possible that the Fechnerian idea is correct – that the psychological space and discrimination always change correspondingly.

Contextual effects in identification and discrimination experiments.

Over the last 25 years, a number of studies have indicated that judgments of sensory magnitude, and of measures of stimulus discrimination and identification (see Arieh & Marks, in press, for a review) are modified by context. To achieve a stable correspondence from discrimination measures, one has to have stability among a set of such measures. Specifically, the discriminability of a pair of stimuli should be independent of whatever stimuli an observer has previously experienced or "expects" to experience. This is clearly not the case. Consider an experiment from Parker, Murphy, and Schneider (2002) in which they first determined for a set of listeners in a 2IFC paradigm, the intensity of a 1-kHz tone (dB_x) that was detected as louder than a 25 dB SPL tone approximately 82% of the time. Subsequently, listeners were asked to identify the more intense of these two intensities (25 dB and dB_x) in a 2IFC paradigm (the same instructions as previously). However, this tonal pair was presented only on 2/3rds of the trials. On the other 1/3 of the trials they presented the 25 dB tone along with a 92 dB SPL tone. The instructions were to identify the louder of the two tones presented in the 2IFC paradigm, which would usually be the dB_x tone but sometimes the 92 dB tone. Parker et al. (2002) found that performance on the (25, dB_x) trials was worse when 1/3 of the trials in the session were (25, 92 dB) trials, than when all of the trials in a session were of the (25, dB_x) type. Note that it was not simply the proximity or the presence of the 92 dB tone in the session that was responsible for the decrement in performance when there were occasional (25, 92 dB) trials because no decrement in performance occurred when a 92 dB tone served as a warning tone for a trial in sessions in which all of the trials were of the (25 dB, dB_x) type. Rather, it was the uncertainty as to when the 92 dB tone would appear that was responsible for the effect. Schneider and Parker and their colleagues have interpreted these results as suggesting that a fast-acting, non-linear gain control mechanism adjusts the perceived intensities of stimuli to protect against sensory overload and to enhance discriminability among the set of "expected" stimuli. In the experiments mentioned here, when the 92 dB tone served as a warning stimulus for a (25, dB_x) trial, auditory gain was presumably turned down when the warning tone was expected, and then immediately turned up to enhance discriminability between the tones in the (25, dB_x) pair. However, when there were mixed trials of (25, dB_x) and (25, 92 dB) with no warning tone, such that the occurrence of the 92 dB tone was unpredictable, the gain was adjusted so as to protect against sensory overload due to the presence of the 92 dB tone, thereby reducing the discriminability of the (25, dB_x) pair.

A similar fast-acting, gain control mechanism appears to be operative for visual contrast. Recently de la Rosa, Gordon, & Schneider (2009) have shown that discriminability among a set of four low-contrast stimuli in an absolute identification experiment is reduced when an additional high-contrast stimulus is added to the base set of four low-contrast stimuli. Presumably, the gain control mechanism for visual contrast is kept turned down when the high-contrast stimulus occurs unpredictably on 20% of the trials to protect against sensory overload of the mechanisms responding to visual contrast. Interestingly, when the occurrence of the high-contrast stimulus is signalled 500 ms before its presentation, discriminability among the four low-contrast stimuli returns to its baseline value, indicating that the gain control mechanism is fast acting, with its gain determined by the range of stimuli "expected" by the observer.

The presence of contextual effects alters the relationship between discriminability and sensory magnitude

In any form of Fechnerian, Thurstonian, or nonmetric scaling, contextual effects will alter the nature of the derived sensory representation of the stimuli. If, for example, the presence of context changes the discriminability of stimuli in a non-linear fashion, the resulting psychological representations derived from different contexts will be nonlinearly related. Consider a simple example where a set of four intensities (10, 20, 30, 40) are either linearly mapped into subjective magnitude, $\psi(I) = (I - 10)$ (Figure 1, top panel), or transformed by a power function, $\psi(I) = 2.04767 * (I - 10)^{0.6}$ (Figure 1, middle panel). In both cases it is assumed that a stimulus' representation in psychological space is a normally distributed random variable whose standard deviation is independent of psychological magnitude ($\sigma = 1.0$ in these two examples). Assume, for the moment, that subjective scales for these two examples are derived by cumulating d' values. Figure 1 lists the d' values separating adjacent stimuli. If we assign stimulus 1, the subjective value of 0, then the computed subjective magnitudes for the top panel are {0, 2, 4, 6}, whereas the cumulative subjective magnitudes for the middle panel are {0, 3.104, 4.704, 6}. If the top panel represents the distribution of stimuli under one context, and the middle panel represents the distribution of stimuli under a second context, then the derived sensory scales from these two contexts are nonlinearly related. Hence, if the sensory systems adjust their gain nonlinearly, dependent on context, as argued above, there cannot be a single interval scale psychological representation of sensory magnitude.

In the bottom panel of Figure 1, the mean locations of the stimuli in psychological space are the same as in the top panel, but variability is assumed to increase with the mean. Also shown in the bottom panel of Figure 1 are the computed d' values between adjacent stimuli, assuming that the decision criteria are located at the intersections between adjacent probability density functions. Note here that the same d' values are obtained as in the middle panel. Hence if context induces nonlinear changes in either the locations of stimuli along the psychological dimension or their variance, sensory scales derived from these two different contexts cannot be linearly related. Finally, note that the rank order of differences between

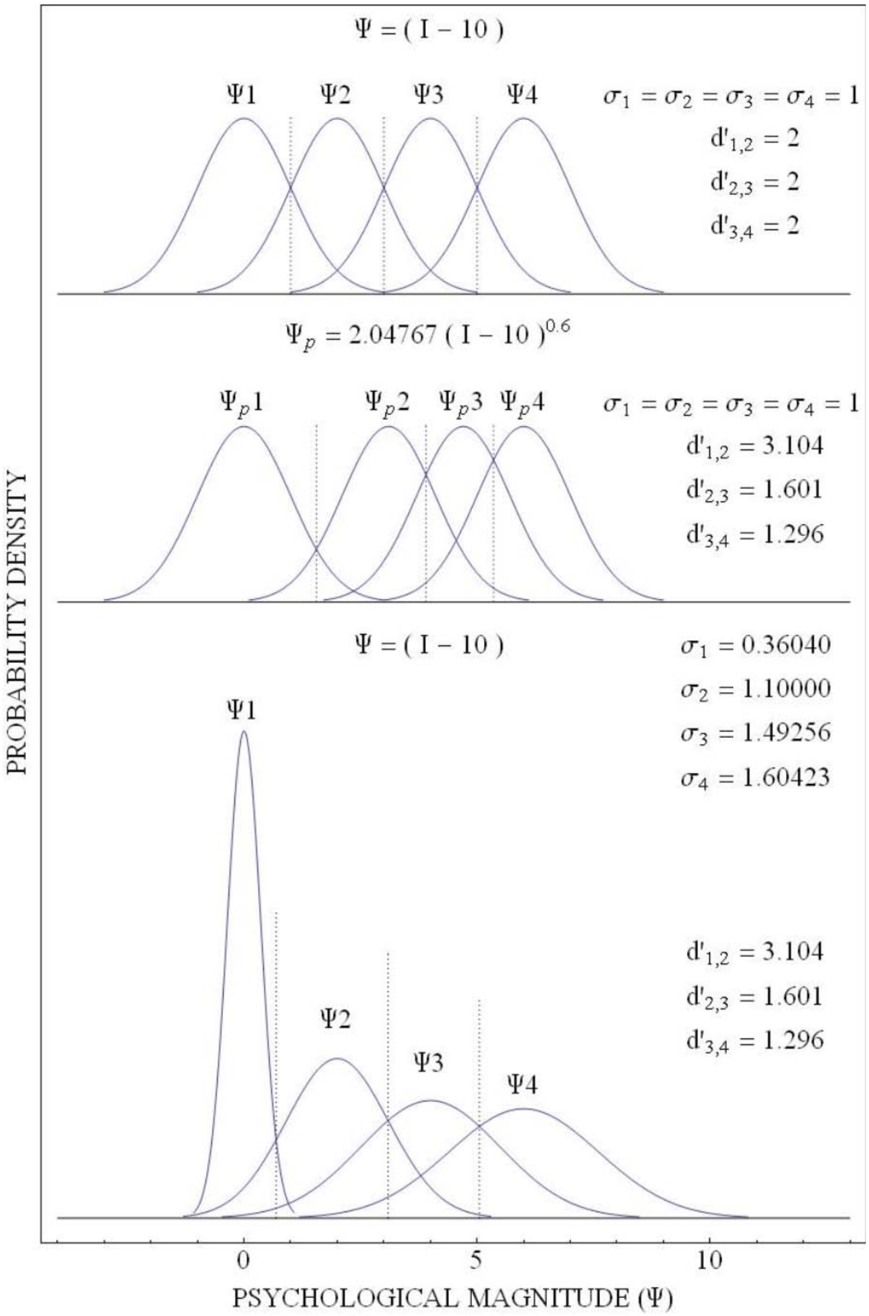

Figure 1. In all three panels, the four physical intensities {10, 12, 14, 16} are assumed to be mapped onto the decision axis (psychological magnitude) by the function given at the top of each panel. The top panel represents an instance in which intensity is mapped linearly into psychological magnitude. The standard deviations of the probability density functions associated with each stimulus are assumed to be equal. In this panel they are set to 1.0. The middle panel represents the case where the intensities are mapped into psychological space by a power function, again with standard deviations equal to 1.0. The bottom panel represents a linear mapping into psychological magnitude with the standard deviation of each stimulus distribution increasing with psychological magnitude. The associated standard deviations and d' values between adjacent stimuli are reported in each panel.

stimuli along the psychological dimension will differ between the top and middle panels. For the top panel, the rank order of pairwise differences is [{1,2} = {2,3} = {3,4} < {1,3} = {2,4} < {3.4}]; for the middle and bottom panels, the rank order of pairwise differences is [{3,4} < {2,3} < {2,4} < {1,2} < {1,3} < {1,4}]. Hence, if context differences change the underlying psychological representations nonlinearly, then scales derived from the rank order of difference judgments will also be nonlinearly related. This follows from the work of Shepard (1966).

The presence of context alters the relationship between direct judgments and sensory magnitude

A number of experiments have also shown that context affects direct judgments of sensory magnitude nonlinearly (Ariel & Marks, in press). It should be noted that if direct judgments derived in one context differ nonlinearly from those derived in another context, then there can be no stable mapping of physical intensity into sensory magnitude based on direct judgments (Schneider & Parker, 2002), unless one particular context is defined as unbiased, with all other contexts being labelled biased in one fashion or another. Because we cannot conceive of how one could derive and/or define one particular context as unbiased, again we have to conclude that there is no hope of establishing a stable correspondence between sensory magnitude and physical intensity.

The new psychophysics: Exploring the nature of sensory representations

Rather than being saddened by the fact that one aspect of Fechner's dream cannot be achieved, we note that as a result of the efforts to achieve it, we have developed a rich and potent set of techniques for exploring the nature of sensory experience. This exploration has shown us that the sensory systems are much more complex than originally conceived, and that sensory experience is modified by a number of bottom-up (stimulus-driven) and top-down (knowledge driven) factors. By broadening our objectives, we re-invigorate the discipline of psychophysics.

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