

Juiz de Fora's sample (M=18.07) reports low levels of social readjustments compared to São Paulo's sample (M=28.32), indicating that the level of stress there is approximately 1/3 smaller. The Pearson correlation between the two sets of ratings was 0.26. The difference between the means probably indicates that cultural and social factors can have an influence, though it might also be due to different forms of management in the two schools. Beck's Depression and Anxiety Inventories (BDI and BAI) administered to Juiz de Fora's teachers indicated low levels of anxiety and no traces of depression.

Table 1. Geometric means (Juiz de Fora City), geometric means (São Paulo State) and rank order (RO) of teacher's life events

Teacher's life events	Juiz de Fora City	RO	São Paulo State	RO
Salary	290.57	1	13.21	16
Facing disrespectful students	115.4	2	112.57	1
Facing students addicted to drugs/alcohol	105.82	3	48.21	7
Student disinterest	90.44	4	101.07	3
Death of student	61.87	5	70.8	4
Serious diseases of students	57.11	6	40.24	9
Facing discipline problems	55.72	7	108.12	2
Verifying low performance of students	41.11	8	42.13	8
Receiving criticism for low quality of public education	25.34	9	63.45	6
Correcting tests	19.44	10	25.18	10
Class attribution	13.58	11	68.15	5
Filling out classroom diaries	9.92	12	13.26	15
Attending meetings of council of classes	7.41	13	17.61	12
Attending meetings of parents and teachers	6.38	14	13.34	14
Class planning	5	15	23.78	11
Tests preparation	4.66	16	10.5	19
Relationship with superiors	3.75	17	10.24	18
Class exhibition	3.48	18	9.85	20
Giving tests	3.28	19	13.46	13
Class preparation	1.7	20	10.63	17
Means	18.07		28.32	
Number of subjects	19		138	

References

- Holmes, T.H., & Rahe, R.H. (1967). The Social Readjustment Rating Scale. *Journal of Psychosomatic Research*, 11, 213-218.
- Kamizaki, R., & Faleiros Sousa, F.A.E. (2001). Social Readjustment and Teacher's Life Events Rating Scale. In E. Sommerfeld, R. Kompass, & T. Lachmann (Eds.), *Fechner Day 2001: Proceedings of the Seventeenth Annual Meeting of the International Society for Psychophysics* (pp.450 – 455) Pabst: Leipzig.
- Stevens, S.S. (1975). *Psychophysics*. Wiley, New York.

CONSTRAINED SCALING IN PSYCHOMETRIC MAGNITUDE MAPPING

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Abstract

Constrained scaling is a magnitude scaling method in which the participant is first taught a mapping between the stimulus magnitudes of a specific modality and a numerical response scale. Following the successful completion of this mapping, stimulus magnitudes from a different source are presented without feedback, interspersed with the learned stimuli (which still receive feedback). In addition to providing very low individual variability, constrained scaling can also be used to examine magnitude scaling in a very controlled way. In the present study, we examined the role of training on a perceptual modality and testing on a subjective modality (the subjective utility of money in this case). We argue that constrained scaling can be used to capture individual differences where such differences truly exist, making it a useful tool in psychometric as well as psychophysical research.

Constrained Scaling

Ward (1992) suggested that the aim of psychophysics scaling methodologies is often to eliminate biases in order to reveal a true underlying psychological scale. Rather than reducing bias, Ward proposed controlling the scaling situation as much as possible. With these insights, a new approach to scaling was initiated, one that subsequently came to be known as *constrained scaling* (West and Ward, 1994). Constrained scaling works both by calibrating the individual to a mental scale (West and Ward, 1994) and by providing a natural set of scaling units (West *et al.*, 2000). An individual is calibrated to a scale by receiving a set of training stimuli. Each training stimulus is presented, after which an experimental participant estimates the magnitude of the presented stimulus. Finally, the actual scale value is presented to the participant. Over a series of training trials, the participant learns to match his or her magnitude perception to the scale. In order that a scale may be readily learned, it must represent a natural scale such that it can be fit to Stevens' Power Law. Once the participant has learned to match his or her perceptual magnitudes to a scale, the participant receives a novel set of stimuli to scale according to the learned scale. The participant receives no feedback for the novel stimuli, but scale learning is supported and enhanced with reminder trials in which stimuli from the original scale are presented again with feedback. This process results in significantly reduced intra- and inter-participant variability compared with other scaling methods such as direct magnitude estimation (West *et al.*, 2000).

In previous experiments, constrained scaling worked to reduce scaling variability because people perceive physical stimuli in a highly similar way. For example, the way person X neurophysiologically perceives loudness is identical to the way person Y perceives it. There may be slight perceptual variations due to differences in hearing sensitivity, shape of the ear canal, or other factors. But, the process of loudness perception is largely invariant across humans. Similarly, there is a high degree of neurophysiological invariance in the way a person perceives the brightness of objects. Factors such as light or dark adaptation, age-

related diminished visual acuity, color blindness, and others may contribute to differences between individuals, but the mechanism by which humans encode and perceive brightness is largely biologically determined. Constrained scaling operates in such a way that person X 's perception is scaled to the same scale used by person Y . In other words, they are calibrated to the same numerical scale. The variability found in traditional magnitude estimation is therefore seen as an artifact of conventional scaling methods and not as a reflection of true individual differences.

Psychophysical and Psychometric Scaling

The scaling of subjective experiences is a much different enterprise than the scaling of perceptual experiences. Affective and cognitive responses are typically triggered by the complex interplay of many different dimensions of physical stimuli (e.g., light, sound, color shape, smell, etc.) as well as internal processes caused by natural affinities and learned responses. Therefore, it is problematic to come up with any sort of ordered stimulus sets for testing beyond, possibly, an ordinal scale. A second consideration in the scaling of subjective experience concerns the very nature of that experience. Subjective experience is a highly individualistic phenomenon. If a researcher developed a set of stimuli that could elicit different levels of happiness in an individual, there is no reason to assume that one person's level of happiness would equal another person's level of happiness for that set of stimuli. Whereas human biology dictates a largely homogenous set of perceptual experiences through our perceptual sense organs, affect and cognition are not bound by these types of constraints. There are certainly common neurophysiological underpinnings for affect and cognition, but the links that bind experience with particular affective or cognitive responses are not hardwired. The same phenomenon may elicit very different subjective responses across individuals.

Study Background

To address psychometric aspects of constrained scaling, two studies were conducted on the subjective happiness afforded by different amounts of money. The groundwork for the studies was a preliminary study by West and Ward (1998). There, constrained scaling was utilized as a method to determine individual differences in the subjective value of money. Whereas previous research on constrained scaling had focused exclusively on the scaling of perceptual phenomena, West and Ward's study addressed the scaling of affective and cognitive factors. The study was set up identically to the cross-modal perceptual studies in West et al. (2000), with the exception that participants were trained on a loudness scale and subsequently applied that scale to the perceived utility of various amounts of money.

Perceptual studies demonstrate a consistent and significant decrease in interparticipant variability when using constrained scaling compared to traditional psychophysical methods such as magnitude estimation (West, 1996; West and Ward, 1994; West et al., 2000). However, in West and Ward (1998), interparticipant variability actually increased when using constrained scaling to assess the subjective value of money. The authors claimed that this is because constrained scaling accurately captured the real individual differences one would expect in this domain. However, another possibility is that constrained scaling does not work for subjective stimuli and the individual differences were due to random variability in responding. The purpose of the present study was to examine this issue more closely. To this end, we conducted two studies to test the application of constrained scaling for the domain of subjective happiness. In the first study, participants were shown a sum of money and asked to respond on a 100-point scale how happy that sum of money would make them if they were to

win it. This study provided a simple baseline of human performance on the task using magnitude estimation. In the second study, the magnitude estimation task is contrasted with a constrained scaling task for the same stimulus set.

Magnitude Estimation Study of the Subjective Utility of Money

Method

Six participants were enlisted for the experiment. Since the stimuli did not involve perceptual stimuli, no screening was necessary to ensure normal hearing or color vision. To prevent carryover effects, the participants were recruited from people who had not previously participated in scaling experiments.

The experimental control software used in previous constrained scaling studies (Boring, 2004) was modified to display a monetary sum instead of a colored square of different brightness levels. The sum was kept on the screen until the participant selected a happiness level on the 100-point scale. The stimuli consisted of monetary sums ranging from \$50.12 to \$1,000,000.00, calculated according to the following equation:

$$M = 10^{x/10}, \quad (1)$$

where M is the monetary sum and where x ranges from 17 to 60 in whole-number increments. There were three rounds of the experiment. In each round, the complete set of monetary sums was presented in random order, to which participants responded using the 100-point scale with a rating of their level of happiness if they had won the displayed amount of money.

Results

Exponent values were obtained by regressing the subjective happiness values to money for each participant. The average coefficient of variation (SD/M) and the highest-to-lowest ($H:L$) exponent ratio were calculated to determine the variability of scaling for the participants. The average exponent value for the happiness elicited by money was 0.331 with $SD/M = 0.349$ and $H:L = 3.560:1$. The average goodness of fit (R^2) for the regression line of money-to-happiness scaling was 0.764. Although there was a strong goodness of fit to the data, a visual inspection of the participant data indicated that the goodness of fit might be even better for nonlinear curve fitting. Several of the participants exhibited sharp initial rises followed by a ceiling effect. There was a sharp ascent in the response values at the lower end of the monetary scale for several participants, and there was a flattening or tapering off of response values at the upper end of the monetary scale. Thus, although it may be the case that averaging across subjects would provide a relatively stable linear function and a corresponding exponent value, this methodology is problematic for examining individual differences.

Constrained Scaling Study of Subjective Utility of Money

Method

Five participants with self-reported normal color vision were enlisted to participate in the study. There were two experimental phases, separated by a week. During one phase, participants were trained to scale grayscale stimuli according to an exponent equal to 0.20. In the other phase, participants were trained to scale grayscale stimuli according to an exponent equal to 0.46. These two exponent values were equidistant from 0.33, the natural brightness scaling exponent often found using magnitude estimation (Stevens, 1975). The order of the experimental phases was alternated between participants. In both experimental conditions, the participants were instructed to use the learned scale to estimate how happy the displayed amounts of money would make them. During the testing phase, the monetary stimuli without feedback were alternated with the grayscale stimuli with feedback.

Results

In the experimental condition in which the training exponent equaled 0.20, the average scaling exponent value for the grayscale stimuli was 0.175 with $SD/M = 0.158$ and $H:L = 1.524:1$. For the monetary stimuli, the average scaling exponent was 0.195 with $SD/M = 0.505$ and $H:L = 3.284:1$. In the experimental condition in which the training exponent equaled 0.46, the average scaling exponent value for the grayscale stimuli was 0.397 with $SD/M = 0.076$ and $H:L = 1.183:1$. The average exponent for the monetary stimuli was 0.269 with $SD/M = 0.570$ and $H:L = 4.589:1$. For the experimental condition in which the training exponent equaled 0.20, the average scaling R^2 value for grayscale stimuli was 0.749. For the monetary stimuli, the average scaling R^2 value was 0.781. In the experimental condition in which the training exponent equaled 0.46, the average R^2 value for the grayscale stimuli was 0.824. For the monetary stimuli, the average R^2 value was 0.783. Also, compared to the magnitude estimation procedure described above, the happiness functions of the individual subjects were much more linear in appearance, suggesting that the power law does hold for happiness judgments, and that the less than linear results of the first experiment were due to participants having difficulty applying an unbiased mapping.

If the logic of constrained scaling holds, then the ratio of the exponents of the novel stimuli (B) should equal the ratio of the exponents of the training stimuli (A) when training on two exponent conditions (1 and 2), such that:

$$\frac{A_1}{A_2} = \frac{B_1}{B_2} \quad (2)$$

Substituting the appropriate exponent values from the present study into Equation 2, the following result is produced:

$$\frac{0.397}{0.175} = \frac{0.269}{0.195} \quad (3)$$

which simplifies to $2.269 \neq 1.379$. The scaling relationship is not constant, suggesting that constrained scaling using a perceptual training scale did not consistently map to the subjective domain.

However, resolution may be found by looking at the exponent values of the individual participants. The relationship between training and testing exponents does, in fact, hold

constant for two of the five participants. If constrained scaling worked, then the ratio of the exponents for the two learned scales (i.e., brightness) divided by the ratio of the exponents for the two unlearned scales (i.e., happiness) should equal 1. For participants 2 and 4, these ratios were equal to 0.987 and 0.982, respectively. These ratios suggest that the application of the two learned scales held constant across the two testing phase. Participants 1, 3, and 5 also showed remarkable consistency, but in a different way. For them, the ratio of the exponents for the unlearned happiness scales was approximately equal to 1 (1.035, 0.955, and 1.258, respectively). This indicates that they may simply have ignored the training in the second round of testing and used the same scale they had learned in the first round of testing. Consistent with this, participants 2 and 4 shared a common order for testing phases, having first been trained to scale with an exponent equal to 0.46 and then an exponent of 0.20 in the second phase. Participants 1, 3, and 5 received the opposite order. The results suggest that it is easier to move from a higher training exponent to a lower training exponent and harder to move from a lower training exponent to a higher training exponent. This may be viewed as consistent with the finding that higher exponents are harder to learn and maintain (West *et al.*, 2000).

Discussion

To put these results in a larger framework we need to consider the results of Boring (2004), which used the same apparatus and training stimuli. Boring (2004) applied similar procedures to judgments of the brightness of different colors (intramodal) and judgments of the loudness of tones (cross modal). He found consistent evidence that constrained scaling works significantly better intramodally. This suggests that the neural coding of magnitude differs from modality to modality but not within modalities, so that cross modality scaling requires an extra step to map one code onto another. However, the results from the two participants for whom the procedure worked in this study suggest that constrained scaling may work cross modally when the novel stimuli are subjective rather than perceptual. This may indicate a difference between how subjective and perceptual magnitudes are processed. However, more work needs to be done to resolve the testing order effect.

References

- Boring, R.L. (2004). *Cognition and Psychological Scaling: Model, Method, and Application of Constrained Scaling*. PhD dissertation, Institute of Cognitive Science, Carleton University, Ottawa, Canada.
- Stevens, S.S. (1975). *Psychophysics. Introduction to its perceptual, neural, and social prospects*. New York: Wiley.
- Ward, L.M. (1992). Who knows? In G. Borg & G. Neely (Eds.), *Fechner day 92. Proceedings of the eighth annual meeting of the international society for psychophysics* (pp. 217-222). Stockholm, Sweden: International Society for Psychophysics.
- West, R.L. (1996). Constrained scaling: Models, methods, and response bias. In S.C. Masin (Ed.), *Fechner day 96: Proceedings of the twelfth annual meeting of the international society for psychophysics* (pp. 423-427). Padua, Italy: International Society for Psychophysics.
- West, R.L., & Ward, L.M. (1994). Constrained scaling. In L.M. Ward (Ed.), *Fechner day 94. Proceedings of the tenth annual meeting of the international society for psychophysics* (pp. 225-230). Vancouver, Canada: International Society for Psychophysics.
- West, R.L., & Ward, L.M. (1998). The value of money: Constrained scaling and individual differences. In S. Grondin & Y. Lacouture (Eds.), *Fechner day 98. Proceedings of the fourteenth annual meeting of the international society for psychophysics* (pp. 377-380). Quebec City: International Society for Psychophysics.
- West, R.L., Ward, L.M., & Khosla, R. (2000). Constrained scaling: The effect of learned psychophysical scales on idiosyncratic response bias. *Perception and Psychophysics*, 62, 137-151.

VISUAL ENHANCEMENT OF AUDITORY DETECTION: A THEORETICAL MODEL

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Abstract

Audio-visual enhancement is the phenomenon whereby a visual signal can enhance the perception of an auditory signal. This effect has been commonly explored in high-level processes like speech communication yet some aspect of this enhancement can be shown to arise from early sensory processes. Our previous work has shown that the auditory detection threshold of a sinusoidally amplitude modulated tone in quiet is reduced by an average of 2.1 dB when a concurrent, co-modulated visual signal is presented. We report here that the addition of noise does not appear to affect enhancement (average 2.2 dB shift) despite a common notion that noise increases the relative enhancement. We introduce a signal detection model which seeks to quantify the benefit of a co-modulated visual signal. This model is based on the concept of 'matched filters' and can account for the improved detection and spread of the psychometric function observed in experiment, as well as shed some light on the roles of synchrony and modulation frequency in cross-modal enhancement.

In human perception, many modalities contribute to create the full entire sensory experience. How the various sensory modalities interact with each other is known as cross-modal processing. One example of cross-modal interaction/enhancement is in audiovisual speech. The perception of auditory speech can be enhanced or modified through the presentation of a concurrent visual stimulus such as a talking face. 'Speech-reading', as it is commonly referred to, has long been explored at the behavioural level and is thought to be a higher-order process. This is based on the belief that the different sensory modalities, such as audition and vision, are first processed individually and only interact in the later stages of sensory processing. More recently however, cross-modal effects have been repeatedly identified in early sensory processing areas such as the primary sensory cortices (Ghazanfar and Schroeder, 2006). Thus it is entirely possible that some of the benefits of AV interaction in speech or otherwise are, at least partially, derived from early sensory processing. We took inspiration from this point to develop a low-level model to account for the visual enhancement of auditory detection.

The paradigm we are studying involves very simple stimuli. The experimental task is to detect amplitude-modulated pure tones in noise, with or without accompanying visual stimulation. Both the visual and the auditory signals are modulated (i.e. *co-modulated*) by an identical mathematical function thereby allowing us to explore how a visual 'code' or 'imprint' can help pick-up an identically coded sub-threshold auditory signal. While simple in nature, the co-modulated signals form the atomistic basis to probe more complex audiovisual phenomenon like speech.

In our previous work (Sheena and Wong, 2007), we explored the effect of a co-modulated visual signal on the detection performance of participants in a quiet background. We found that addition of the visual stimulus reduced the average detection threshold by 2.1dB. In the present work, we measure the level of enhancement with the auditory signal embedded in additive white noise. To help understand the experimental results, we also propose a low-level model of audio-visual enhancement based on the theory of signal detectability.