The Theory of Cognitive Acuity: Extending Psychophysics to the Measurement of Situational Judgment

- This presentation will introduce a theory of cognitive acuity (TCA) which provides a psychophysical method for estimating respondents sensitivity to the correctness of situational judgment test (SJT) response options.

- The Theory of Cognitive Acuity (TCA) is derived from psychophysical principles as a means for understanding and measuring practical intelligence in the context of critical incident decision-making on situational judgment tests (SJTs).

- Analogous to auditory and visual acuity, Cognitive Acuity is defined as:

  The capacity to detect correctness and to distinguish between differences in correctness among simultaneously presented situation-specific response options.

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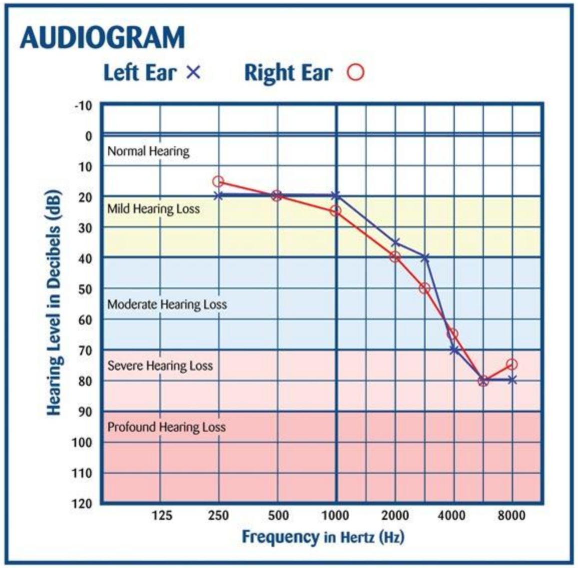
Graphed results display the patient's hearing threshold (the lowest sounds they can hear) for a range of frequencies for both ears.



* An example presbyacusis (sloping high-frequency hearing loss) synonymous with the ageing process.

❑ Like audio and stimuli, TCA proposes calibrating SJT response options and treating them as signals to be detected.

1. Auditory signal ≈ response option correctness (+/- valence)
2. Auditory acuity ≈ cognitive acuity (discrimination capacity)
3. Hearing threshold ≈ just noticeable difference (valence level at which correctness is minimally detectable)

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- ❑ SJT response option signals take two forms.

  1. Absolute signal based on their level of correctness or incorrectness. Given a situation, how effective or ineffective is this response option? (+,-)

  2. Relative signal based on the correctness contrast between two or more response options. Given a situation, and two or more response options, how well is the difference in correctness discernable? (high valence v. lower valence option)

- ❑ TCA proposes that SJT response options will be detectable based on two parameters.

  1. The respondent's level of signal sensitivity (i.e., cognitive acuity)
  2. The magnitude or level of that signal (i.e., valence and valence contrast).

An Example….

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❑ A Situational Judgment test Example:

Security Officer SJT Example

You are a security officer for a hospital on the evening shift and you are armed with a handgun and have a walky-talky radio. You notice a man who you do not recognize loading boxes of hospital supplies from the hospital loading dock into the back of an unofficial vehicle. What would you do? Select the 4 best responses below.

(-) Ineffective ______________________________ Effective (+)

-2 -1 0 +1 +2

a (+2) Call for backup and report the observation

b (-1) Confront the man and ask what he is doing

c (+1) Call your supervisor for instructions

d (-2) Draw your handgun and confront the man

e. (+2) Maintain observation and contact the loading dock supervisor

f. (-2) Wait for the man to leave and follow him in your car

g. (+1) Record a description of the man and his car plate number

h. (-1) Call another security officer for guidance.

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An additional proposition of TCA is that there is a logarithmic relationship between….

1. a SJT response option’s correctness signal (stimulus)
2. the detection of that response option’s correctness signal (sensation)

Borrowing from the Weber-Fechner law of stimulus and response, TCA proposes measuring sensitivity to correctness signals (i.e., cognitive acuity) based on probabilities of detection at various signal strengths.

Some Background…..

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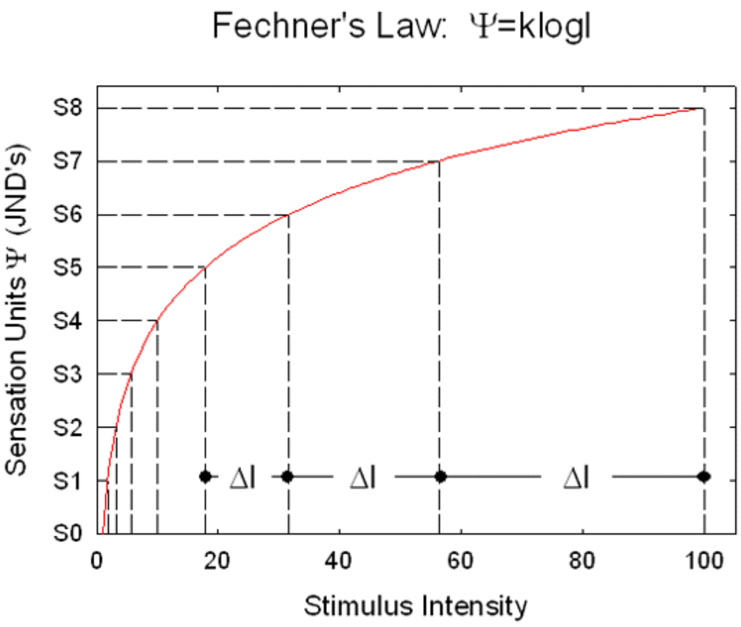
Ernst Weber (1795-1878) was born at Wittenberg in Germany and became a professor at the University of Leipzig in 1818, a position he held until his death. Weber is best known for his work on sensory response to weight, temperature, and pressure. He discovered that the experience of differences in the intensity of sensations depends on percentage differences in the stimuli rather than absolute differences. This is known as the just-noticeable difference (j.n.d.), difference threshold

Gustav Theodor Fechner - (1801-1887) German physicist and philosopher who founded the science of psychophysics. He taught at the University of Leipzig (1834 – 40) he devised an equation to express Weber's law. Measured thresholds as the point of sensitivity at which the smallest amount of change in a stimulus can be detected in a sensation (just noticeable difference that can be detected between two stimuli). Fechner proposed a mathematical equation to measure the two: S = K log R. S = the sensation, K = a constant, and R = stimulus.



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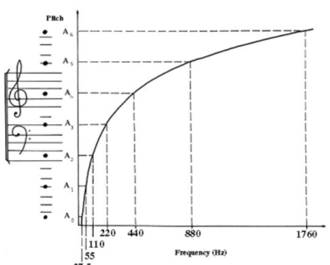
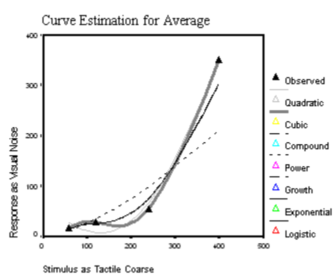
The Weber-Fechner principle has been observed over many forms of stimuli over many years of investigation and has been extended in other cognitive domains of psychology.

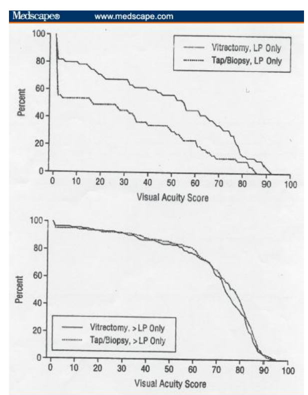
Audio



Tactile

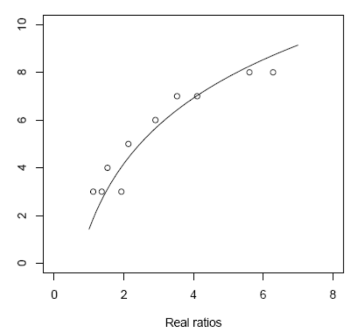


Visual



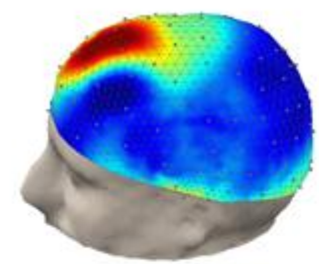
Cognitive-Visual

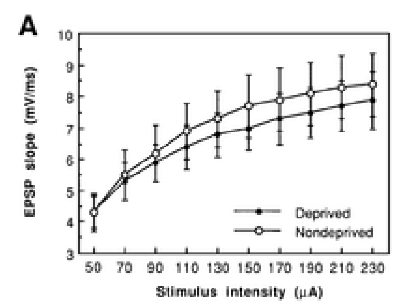
Logarithmic relation between the measured city distance ratios and (x axis) and the estimated ratios (y axis). Coefficient of determination fit (R Square) =.94



Cognitive

Human brain theta rhythm in detecting incorrect arithmetic equations





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If one can administer auditory, visual, and even cognitive signals of various magnitudes and measure sensitivity to them, then it may be possible to treat perceptions of response option correctness as stimuli and observed preference as evidence of detected signal.

Security Officer SJT Example

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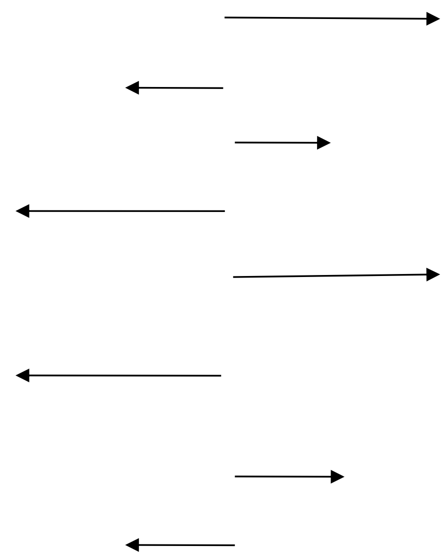
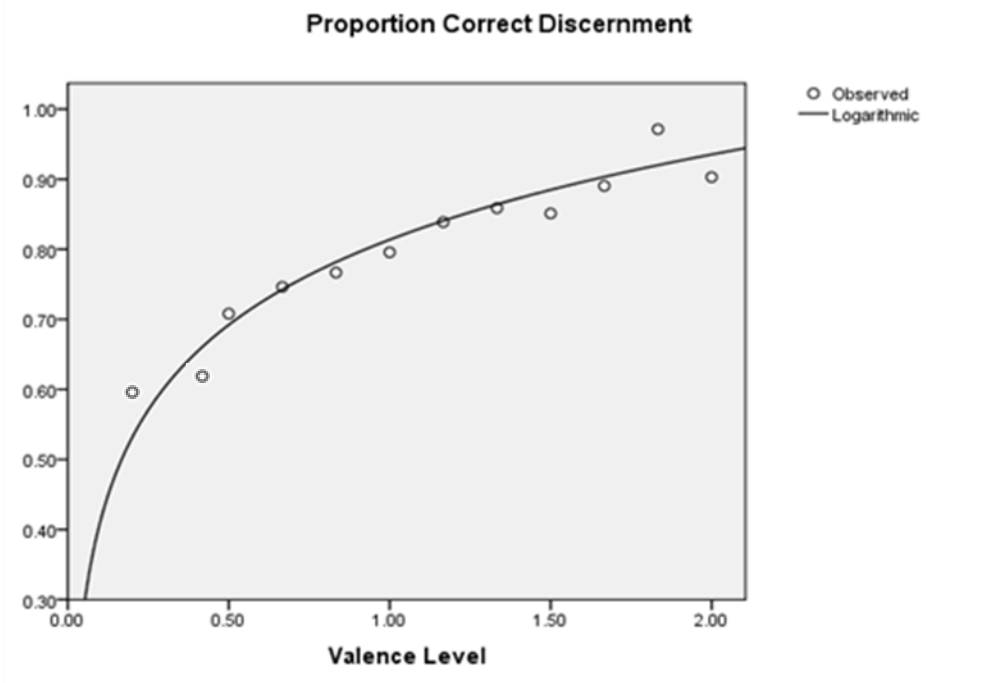


The Theory of Cognitive Acuity: Extending Psychophysics to the Measurement of Situational Judgment

If stimulus intensity and response behavior are consistently logarithmically related, as the research suggests, then it may be possible to use this relationship to solve for the minimum level of stimulus detectable, or the threshold of sensory sensitivity.

Logarithmic Relationship Between Absolute Response Option Valence (X axis) and Proportions of Correct Detections (Y axis)

Probability of Identifying the Response Option Valence



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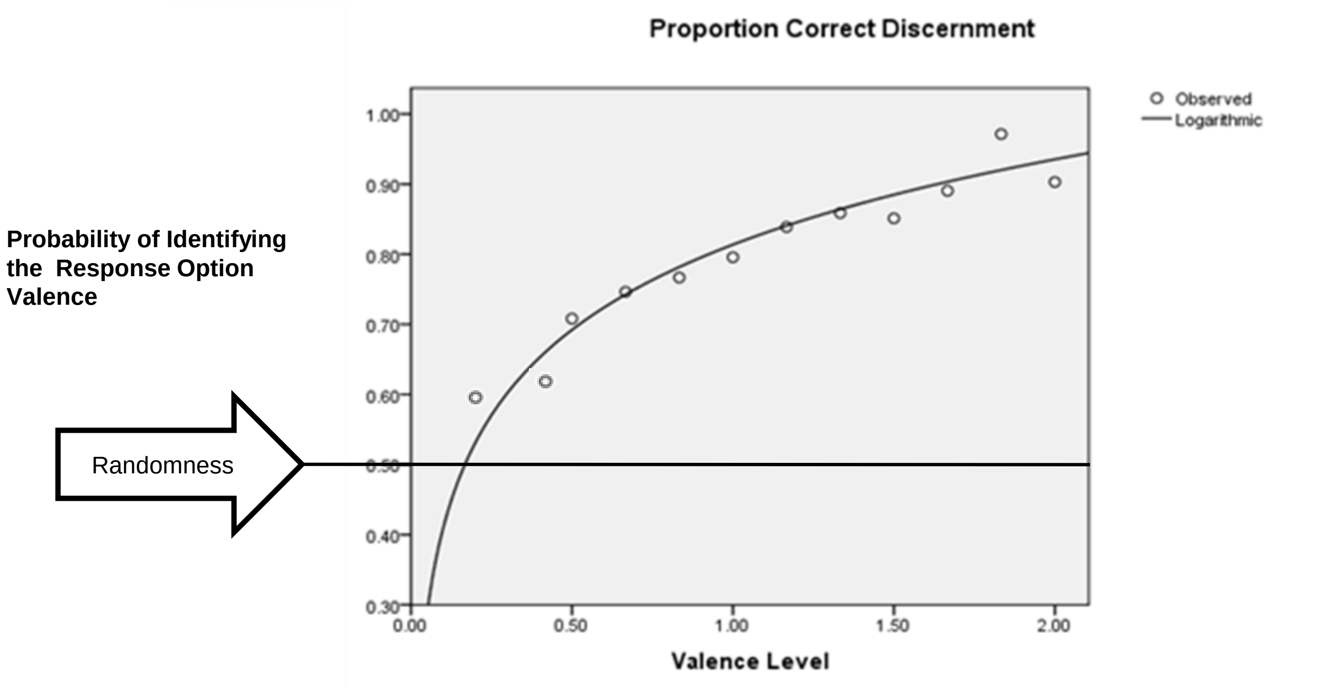

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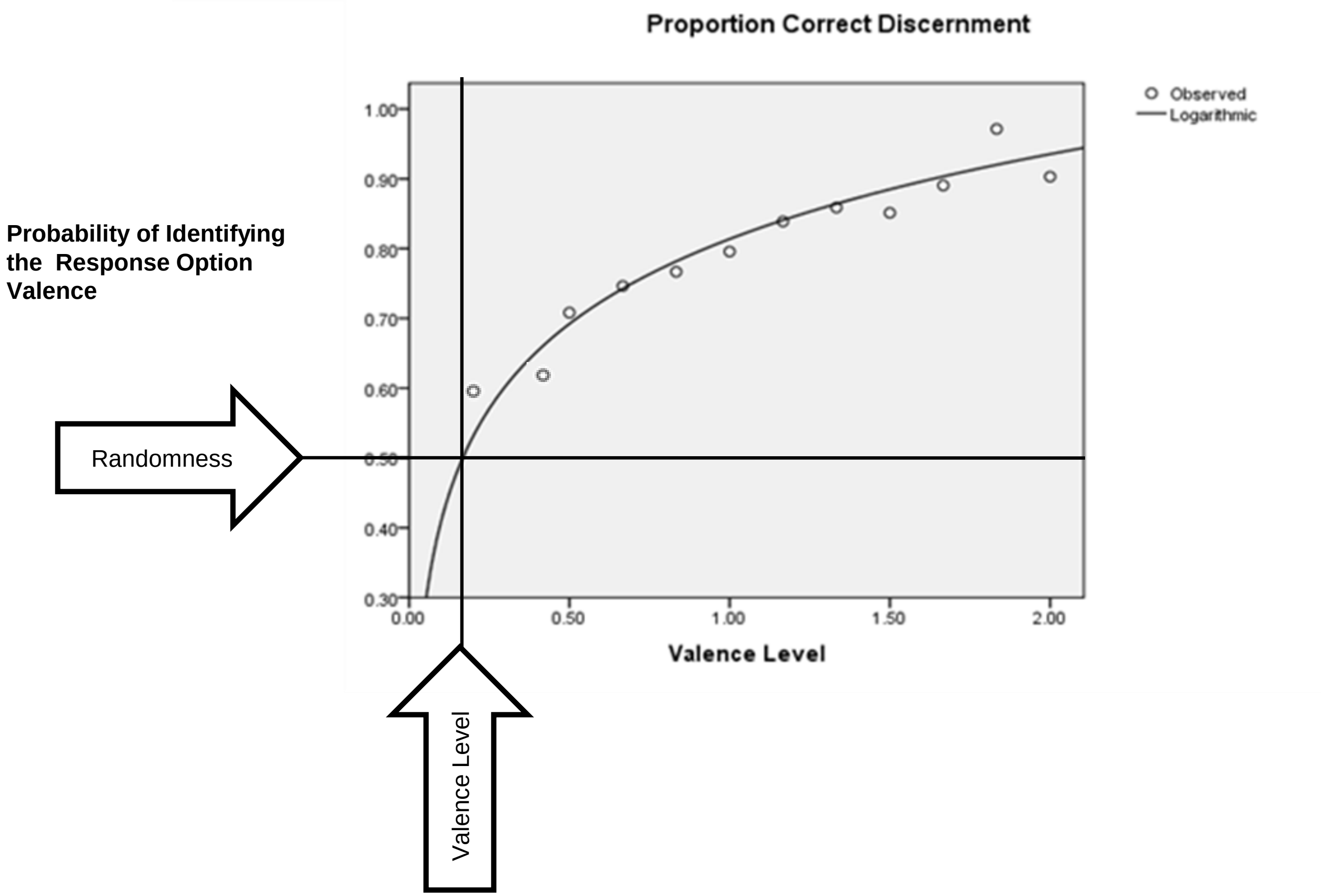

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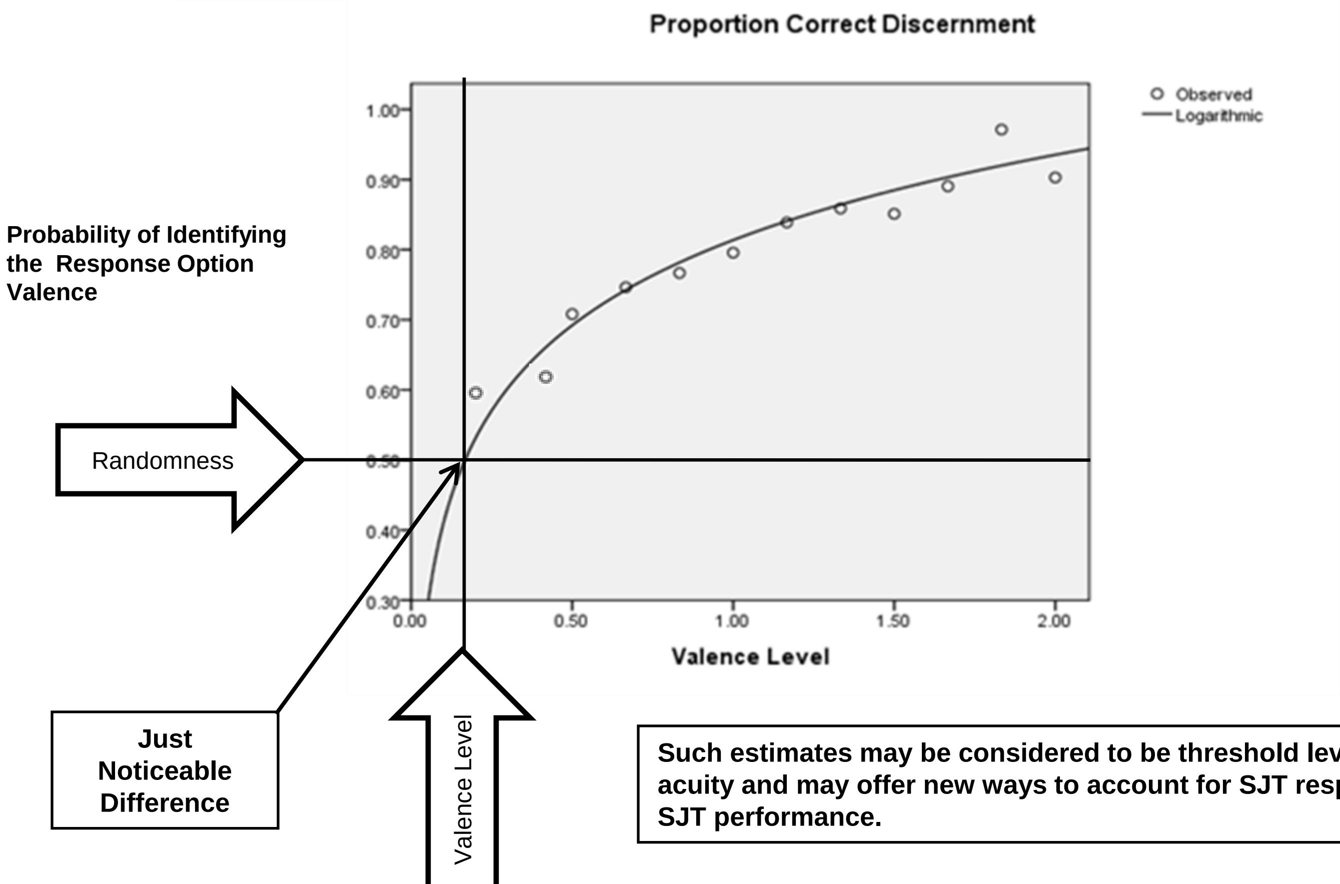

Such estimates may be considered to be threshold levels of cognitive acuity and may offer new ways to account for SJT response behavior and SJT performance.

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Hypotheses

1. There will be a significant relationship between SJT response option correctness (valence magnitude) and respondents' preference (selection frequency) for response options.

2. The correctness contrast among response options will be related to item difficulty and to response option detectability.

3. The magnitude of response option valence signal will be logarithmically related to probability of signal detection.

4. Estimates of each respondents' cognitive acuity derived from their individually determined logarithmic function will be directly related to item-level SJT performance but not related to observed on-the-job-performance.

5. SJT item performance will mediate the relationship between cognitive acuity estimates and on-the-job-performance with significant indirect effects between cognitive acuity and job performance.

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Method

Study 1

One group of 12 nursing subject matter experts (SMEs) provided independent ratings of the correctness/incorrectness valence (-3 to +3 scale) on each of four response options on a previously administered 18-item SJT (72 rated response options). A group of 30 nursing students had provided responses to the SJY items.

Study 2

A second group of 18 hospital security SMEs provided independent ratings of the correctness/incorrectness valence of 8 response options for each of 56 SJT items. A –2 to +2 ratio scale was used for these ratings. A group of 208 medical center security officers from 18 organizations provided SJT responses as part of a concurrent validation study.

Each SJT item presented 4 positively valenced and 4 negatively valenced response options of which the respondent was asked to select 4 per item.

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Response option signal strength (correctness) were estimated based on SME agreement as measured by Lindell & Brandt's (1997) coefficient of agreement r_{WGmax} using .8 as the minimal acceptable agreement for inclusion.

$$r_{WGmax} = 1 - \frac{s_x^2}{s_{MV}^2}$$

$$s_{MV}^2 = .5(H^2 + L^2) - [.5(H + L)]^2$$

Where s_x^2 = the variance of the ratings on a target

s_{MV}^2 = the maximum possible variance of target ratings given the response scale

H = highest possible rating on a target

L = lowest possible rating on a target

Lindell, M. K., & Brandt, C. J. (1997). Measuring interrater agreement for ratings of a single target. Applied Psychological Measurement, 21, 271-278.

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Results

Study 1

Hypothesis 1 was examined by correlating the 72 observed response frequencies with the mean nursing SME valence ratings. A correlation of $r = .68$ ($p < .01$) was observed.

Hypothesis 2 proposed that the valence contrast among response options would be associated with SJT item performance and a correlation of $r = .56$ ($p < .01$) was observed.

Study 2

Hypothesis 2 proposed that the contrast among response option in the item will be related to SJT item performance. A correlation of $r = .76$ ($p < .01$) was observed between individual item contrasted valence and mean SJT item performance.

Hypothesis 1 was evaluated by correlating 424 observed response option selection frequencies with response option valence levels. Graph 1 shows this relationship with an observed $r = .92$ ($p < .01$).

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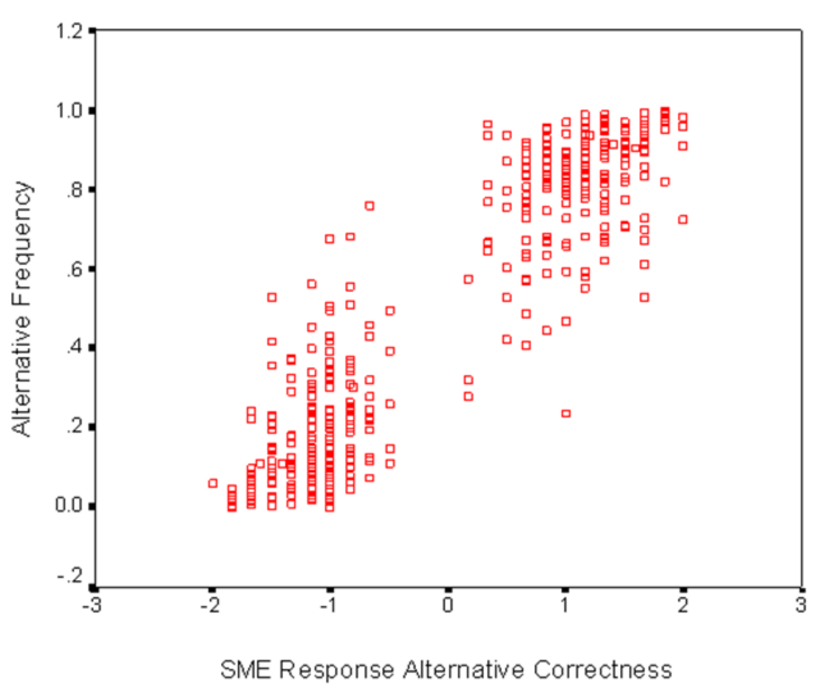
Study 2

Graph 1

The relationship between 424 observed response option selection frequencies and response option valence levels (r = .92, p < .01)



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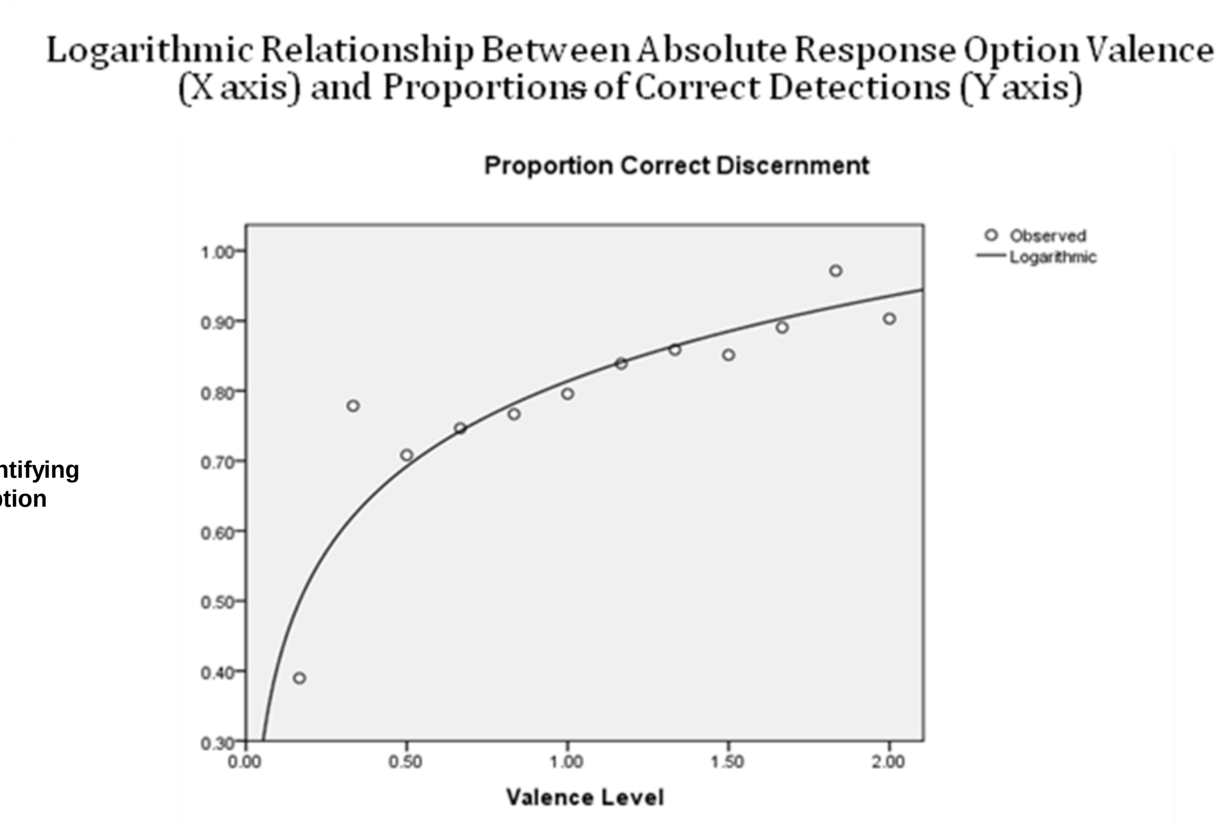
Study 2

Hypothesis 3 proposed that response option valence level (signal strength) would be logarithmically related proportion correct detection (hits). Graph 2 presents the logarithmic relation between average respondent hits and the valence levels.

Graph 2



Probability of Identifying the Response Option Valence

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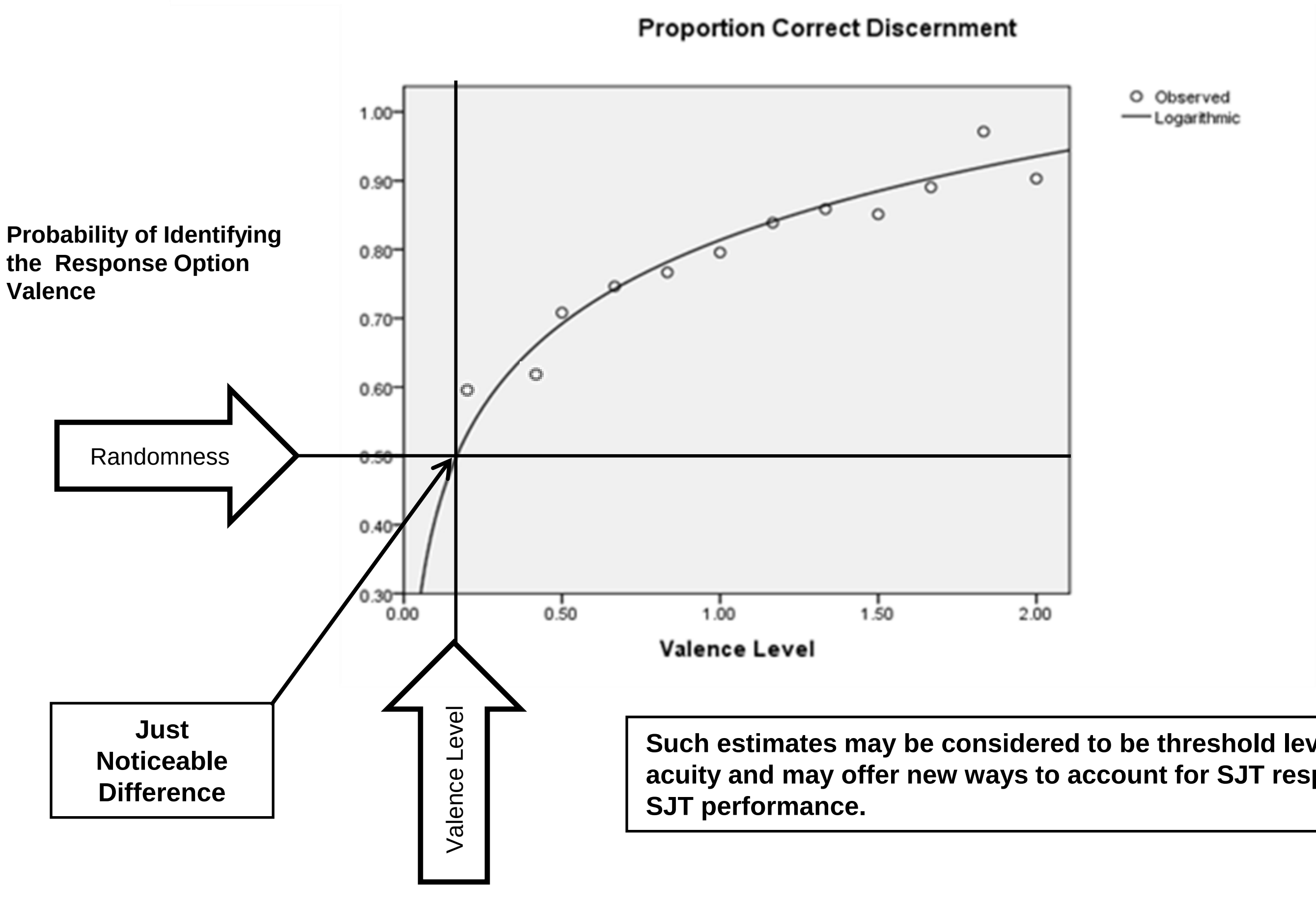
If stimulus intensity and response behavior are consistently logarithmically related, as the research suggests, then it may be possible to use this relationship to solve for the minimum level of stimulus detectable, or the threshold of sensory sensitivity.

Logarithmic Relationship Between Absolute Response Option Valence (X axis) and Proportions of Correct Detections (Y axis)



Such estimates may be considered to be threshold levels of cognitive acuity and may offer new ways to account for SJT response behavior and SJT performance.

Study 2

Hypothesis 4 proposed that respondent's cognitive acuity could be estimated using the above logarithmic function and shown to be related to SJT performance.

The following formula was used to fit the log function for each respondent and then to solve for the interpolated valence level at which probability of correct detection (y) is expected to be random.

$$y = b_0 + b_1 \ln(t)$$

Where b_0 = constant
b_1 = unstandardized beta weight
t = valence

Algebraically rearranging....

$$t = e^{\frac{y - b_0}{b_1}}$$

Let y = .50 and use each respondent's log regression equation to solve for his/her projected valence threshold level t. Cognitive acuity threshold level is the estimated valence magnitude at which signal discernment is no longer possible and expected to produce a probability (or proportion) of correct detection of .50. Thus t at y = .50 provides an estimate of cognitive acuity for each respondent.

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Study 2

- Hypothesis 4 and 5 proposed that cognitive acuity is a determinant of SJT performance and is indirectly related to on-the-job- performance ratings through the mediation of SJT scores.

- Applying the 4 step procedure of Baron and Kenny (1986) the data showed that SJT scores completely mediated the cognitive acuity- job performance relationship.

- A structural equation model was conducted and is presented in Graph 3. results shows complete mediation and significant direct and indirect effects of acuity on performance, with SJT scores as mediators.

- The data suggest that greater amounts of criterion-related variance may be accounted for using both direct and indirect effects validity evidence.

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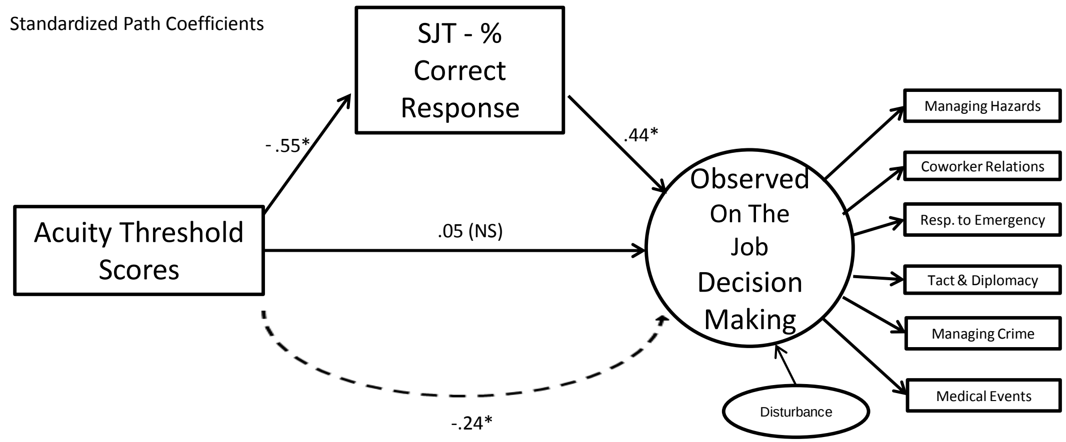
Study 2

Graph 3

Structural Equation Model of the Relationship Between Acuity Threshold Scores and Observed On-the-Job Decision Making Fully Mediated by Situational Judgment Test Scores (n= 124)



The 95% confidence interval for the indirect effect of cognitive acuity on job performance scores [-.39 , -.12] was estimated using a bootstrap sample of 3,000. *P < .01

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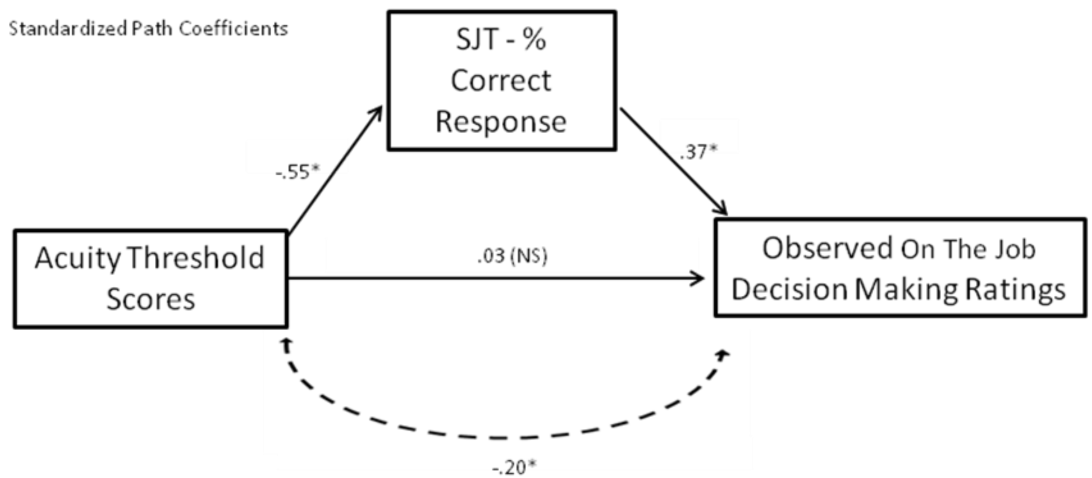
Graph 4

Structural Equation Model of the Relationship Between Acuity Threshold Scores and Observed On-the-Job Decision Making Fully Mediated by Situational Judgment Test Scores (n= 124)



The 95% confidence interval for the indirect effect of cognitive acuity on job performance scores [-.34 , -.09] was estimated using a bootstrap sample of 3,000. *P < .01

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Study 2

Additional Findings

An assumption of this research was that negatively and positively valenced response options were equally detectable as such by the respondent. A check of this assumption was conducted using binary logistic regression. Table 1 presents the results of this analysis.

Table 1

Binary Logistic Regression of Response Option Detection on Binary Valence and Absolute Valence Level

Predictor	*B*	S.E.	Wald	odds ratio	95% C.I.for odds ratio	
					Lower	Upper
Absolute Valence Level	1.1*	.03	1360.95	2.99	2.82	3.17
Binary Valence	.04	.02	3.18	1.04	1.00	1.08

*p < .01

In this analysis I treated each respondents' binary correct detection (true positive/negative = 1 and false positive/negative = 0) of each response option as the DV (N = 61,896). I treated absolute valence level and binary valence (0 = negative, 1 = positive) as independent variables. Results showed that binary valence had a non significant beta weight and accounted for no variation in correct detection over absolute valence level. Thus, whether a response option had a negative or positive valance was not important to the detection of valence signals.

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Study 2

Additional Findings

Table 2

Cognitive Acuity Score Descriptive Statistics and *d* Effect Sizes by Race

				d effect size		
				White	Hispanic	Black
	N	Mean	S.D.			
White	42	.186	.127	0	-.003	-.044
Hispanic	10	.186	.173		0	-.029
Black	45	.191	.127			0

All estimates include 0 within the 95% confidence intervals indicating non-significance

Acuity scores derived using the log function showed no racial subgroup differences

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Study 2

Additional Findings

Table 3

Conventional SJT Score Descriptive Statistics and d Effect Sizes by Race

				d effect size		
				White	Hispanic	Black
	N	Mean	S.D.			
White	42	.826	.042	0	.322	.830*
Hispanic	10	.813	.041		0	.496
Black	45	.791	.045			0

Estimate within the 95% confidence interval of .45 and 1.19

Conventional (1 pt for each correct response) SJT scoring produced substantial racial subgroup differences

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Conclusions

- This study showed that SJT response options may be treated as cognitive signals to be detected using methods barrowed from the psychophysical literature.

- Results show that SJT response options may be assigned signal strength estimates using SMEs ratings of correctness valence levels and that the resulting estimates may be used to predict subsequent SJT responding behavior.

- Researchers interested in developing SJT items may use SME valence level estimates to construct items having more intermediate levels of difficulty

- Results show that SJT response option valence level acts as a signal magnitude with probability of detecting that signal following the classic Weber-Fechner logarithmic curve.

- By observing response behavior as a function of signal strength presentation, it was possible to estimate the respondents' valence signal sensitivity as an estimate of cognitive acuity.

- The data show that cognitive acuity relates directly to SJT performance and job performance but also indirectly to job performance through the mediated path of SJT performance.

- Finally, the results of subgroup difference analysis shows that threshold cognitive acuity scores show no significant effects for race or gender but are predictive of observed job performance.

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Practical Implications

- By using SMEs to calibrate SJT items one may and manipulate response option correctness in order to manipulate the *p* value of SJT items even before they are administered.
- Acuity scores were shown to be related to job performance but had no subgroup differences and thus may be valuable in reducing adverse impact against protected classes.
- Acuity may be the initial variable in a mediated relation between Acuity-SJT-Performance and may contribute to total effects indirectly thus bolstering criterion-related validity evidence for SJTs.

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Although not directly tested in this study, the results point to new ways to develop and assemble SJT response options

- ❑By calibrating response option difficulty using such pairs the researcher need develop fewer response options than with traditional multiple choice SJTs.

- ❑TCA allows for [n(n – 1)/2] signals to be generated for every n response options developed for an item stem.

- ❑Thus, four response options may be uniquely paired in n(n – 1)/2, or six ways

- ❑By adding the singular administrations, [n(n – 1)/2]+n total signal detection opportunities (10 in this case) are afforded the researcher who generated only four calibrated response options.

- ❑The advantages increase exponentially with five yielding 15, six yielding 21, and 7 yielding 28 unique cognitive signal detection opportunities.