

This finding implies that the observer can estimate the gradient of the frontal slope in a relatively precise manner for the cone-shaped mountain because of its regulated shape and, as a result, can estimate the height of the mountain. On the other hand, such an estimation of the slope was more difficult in the case of the barrel-shaped mountain because of its unregulated shape, resulting in a less precise estimation of the height of the mountain. However, this explanation is hypothetical, and should be examined by means of an experiment requiring the observers to estimate the gradient of the frontal slope of the mountain on 2D images. With respect to the estimation of the gradient of a slope, Gibson (1950) proposed that the gradient of a slope would be perceived to be less inclined than the actual gradient, while Creem-Regehr, Gooch, Sahm, and Thompson (2004) proposed that the perceived gradient would be perceived as being steeper than the actual gradient. Further research on the perceived height of mountains may provide a new interpretation for the controversy with regard to slope perception.

An individual's depth perception is based on oculomotor cues, binocular retinal disparity, motion-produced cues, and pictorial cues. In the perception of 2D static images, only pictorial cues can be used. Pictorial cues can be categorized into the gradient of texture, relative height of objects on images, relative size of objects, overlapping of objects, familiar size of objects, and shading. Wanger, Ferwerda, and Greenberg (1992) proposed that the cue of shade and light is the most prominent of the pictorial cues, for the perception of 3D objects. In this study, the simulated directions of the sunlight and the line of vision were accorded, i.e., the sunlight illuminated the mountains from the due back of the observer. In this case, the slope visible from the observation point was illuminated in a relatively uniform manner and, as a result, shade and light became extremely weak. If the cue of shade and light plays an important role in the estimation of 3D shape of objects, it is expected that when the cue of shade and light is exaggerated in simulated images of mountains, the perceived shape of the object as well as the perceived height of the mountain would become more precise. It would be interesting to conduct an experiment examining this prediction. In addition, depth perception differs depending on whether or not objects are displayed within a frame (Eby & Brounsyein, 1995). Moreover, the perception of objects' height is affected by the size of the frame (Dixon & Proffitt, 2002). Moreover, it is expected that the estimation of the 3D shape of a mountain from a 2D display relates to various kinds of factors such as the texture of the mountain in the 2D images and the landscape surrounding the mountain. The findings obtained in this study should be investigated from a broader range of aspects of spatial vision.

### References

- Bingham, G. P. (1993). Perceiving the size of trees: Biological form and the horizon ratio. *Perception & Psychophysics*, 54, 485-495.
- Creem-Regehr, S. H., Gooch, A. A., Sahm, C. S., & Thompson, W. B. (2004). Perceiving virtual geographical slant: Action influence perception. *Journal of Experimental Psychology: Human Perception and Performance*, 30, 5, 811-821.
- Dixon, M. W., & Proffitt, D. R. (2002). Overestimation of heights in virtual reality is influenced more by perceived distal size than by the 2-D versus 3-D dimensionality of the display. *Perception*, 31, 103-112.
- Eby, D. W., & Braunstein, M. L. (1995). The perceptual flattening of three-dimensional scenes enclosed by a frame. *Perception*, 24, 981-993.
- Gibson, J. J. (1950). The perception of visual surfaces. *American Journal of Psychology*, 63, 367-384.
- Wanger, L. R., Ferwerda, J. A., & Greenberg, D. P. (1992). Perceiving spatial relationships in computer-generated images. *IEEE Computer Graphics & Applications*, 12, 44-58.

## TIME- AND SPACE-ORDER EFFECTS IN TIMED BRIGHTNESS DISCRIMINATION OF PAIRED VISUAL STIMULI

Geoffrey R. Patching, Mats P. Englund and Åke Hellström.  
*Department of Psychology, Stockholm University, SE-106 91 Stockholm, Sweden.*  
*E-mail: grp@psychology.su.se*

### Abstract

*Despite the considerable import of both response probability and response time for testing models of choice there is a dearth of chronometric studies of time- and space-order effects in discrimination of paired visual stimuli. In this study, systematic asymmetries in discriminating the brightness of paired visual stimuli are examined by way of binary response probability scaled in terms of log-odds ratios, as well as by signed response speed (i.e., the inverse of response time with the sign of the judged difference). For two stimuli separated by a time interval, psychometric and chronometric results revealed equivalent time-order effects, but simultaneous presentation with a spatial separation revealed no effects of space order. Implications of these findings for random walk and diffusion models of sensory discrimination are discussed.*

Fechner (1801-1887) was among the first to discover that when two stimuli are presented for comparison people systematically overestimate the magnitude of one stimulus and underestimate the magnitude of the other. The term, time-order effect (TOE) is used to refer to such asymmetries in paired comparisons of stimuli separated by a time interval, and the term space-order effect (SOE) to asymmetries in comparisons of paired stimuli separated spatially. By convention, a positive effect is taken to refer to an overestimation of the first (or left) stimulus as compared to the second (or right) stimulus and a negative effect as an underestimation of the first (or left) as compared to the second (or right) stimulus.

In brightness discrimination, the TOE has been found to change from positive to negative with increasing inter-stimulus interval (ISI) from 1-9 seconds (Meada, 1959). Concerning the SOE, Kellogg (1931) reports a negative asymmetry in split-disk brightness discrimination, in that participants tended to choose the right-half more frequently than the left despite equally balanced brightness differences. Yet, in darkness discrimination of paired luminance gradients, participants tend to choose gradients with the darkest end on the left as compared to the right (Mattingley et al., 1994). So, there is some preliminary evidence to suggest that asymmetries in brightness discrimination are perceptual, but precisely what processes underlie them have yet to be fully determined.

Asymmetries in sensory discrimination are all too often dismissed as bias, which may appear as a result of prejudiced decision criteria (Allen, 1977), or verbal categorization of stimuli toward the mean of the stimulus series (John, 1975). Others envisage some kind of retention loss (Link, 1978) such that the activation induced by one stimulus is compared to a lower fidelity mental representation of the other. In regard to the SOE, similar appeals have been made by reference to known functional asymmetries in neural anatomy (Mattingley et al., 1994), noncentral fixation and scanning effects (Masin, & Agostini, 1991).

In the paired comparison of stimuli, bias is associated with the notion of an additive effect. For instance, Davidson & Beaver, (1977) extended the classic BTL model (Bradley & Terry, 1952; Luce, 1959) to predict the probability,  $p(A > B|A, B)$  of choosing A over B, given that A was presented first (or left), by inclusion of a constant order effect  $w$ , which is additive

in terms of,  $\ln\psi$ :  $\text{logit}[p(A>B|A,B)]=\ln\psi(A)-\ln\psi(B)-\ln w$ , where  $\psi(\bullet)$  is a ratio scale.

Alternatively, on the basis that the TOE and SOE are perceptual phenomena, Hellström (1979) proposed a sensation weighting (SW) model that posits a weighting of activation induced by each stimulus event and a reference level (ReL) based on generic information. Formally, this model is defined as

$$d=k\{[s_1\psi_1 + (1 - s_1)\psi_{r1}] - [s_2\psi_2 + (1 - s_2)\psi_{r2}]\}, \quad (1)$$

where  $d$  is the subjective difference between the compared stimuli,  $k$  is a scale constant,  $s_1$  and  $s_2$  are weighting coefficients (1 and 2 indicate the temporal order or spatial position of the stimuli; i.e., left=1, right=2),  $\psi_1$  and  $\psi_2$  are the sensation magnitudes of the stimuli and  $\psi_{r1}$  and  $\psi_{r2}$  are the sensation magnitudes of the ReLs.

Further clues concerning the underlying causes of the TOE and SOE and those underlying perceptual discriminations, in general, may be obtained by examination of the time taken to make the discrimination (cf. Jamieson & Petrusic, 1975). Random walk and diffusion models propose some form of sequential sampling mechanism to explain patterns of response times and response probabilities in timed discrimination tasks (Link, 1975, 1992; Ratcliff, 1978). According to these models the process of comparison consists of the accumulation of noisy information about the difference between stimulus values over time, until either of two boundaries (A or  $-A$ ) is reached. Discrimination time is defined as the time from the start of the process until one boundary is reached and response probability determined by the likelihood of crossing either boundary.

Bias is assumed to arise as a result of changes in the initial state of evidence, bound rate change, or drift rate change (Diederich & Busemeyer, 2006). For instance, Link (1978) assumes that in paired comparison tasks the activation induced by one stimulus is compared to a lower (or higher) fidelity mental referent of the other (Link, 1978, 1992). In support of this view Link (1978) re-examined Kellogg's (1931) data in terms of the predicted relationship between response probability and response time,

$$\text{ERT}_i = \frac{A}{m} [(2P_{Ai}-1)/(S_i-S_r)] + K, \quad (2)$$

where  $\text{ERT}_i$  is expected response time,  $A/m$  is an unknown slope,  $K$  is mean non-decision time,  $S_i$  is stimulus magnitude and  $S_r$  the value of the mental referent defined in units of the stimulus. The probability  $P_{Ai}$  of the random walk's exceeding one boundary (A) given stimulus  $S_i$  is given by the equation of the logistic distribution function where estimates of the logistic variable can be obtained by a least squares fit to  $S_i$  of the informational value  $\theta_i A$ , which is the logit of  $P_{Ai}$ :  $\ln(P_{Ai}/(1-P_{Ai}))$ .

Link (1978) found a close correspondence between ERT (Equation 2) and mean RT as reported by Kellogg (1931). However, Kellogg (1931) did not manipulate the spatial separation between stimuli nor the absolute physical magnitude of stimuli. His data show a constant asymmetry while the TOE and SOE are characterised by changes in magnitude and direction with changes in the configuration and absolute physical magnitude of the stimuli. Consequently, without due care, differences between current sequential sampling models and human ability will continue to exist because the processes identified are grounded on an oversimplification of the actual perceptual processes involved.

Current random walk and drift diffusion models are based on the outcome of a simple comparator which merely accumulates a signed difference by subtraction. On these grounds, Experiments 1 and 2 were conducted to examine further the TOE and SOE in timed brightness discrimination of paired visual stimuli. If the comparison process is based on the simple subtraction of stimulus information, and if systematic asymmetries in brightness

discrimination change in magnitude and direction with changes in the configuration and absolute physical magnitude of the stimuli, then it is obligatory for theories based on notions of bias to explain such effects. If, however, a more complex process of comparison is admitted time- and space-order effects may be explained by perceptual weighting and by inclusion of the influence of generic information.

## Experimental method

*Participants.* 40 participants took part in Experiment 1, and 40 different participants from the same student population took part in Experiment 2. All claimed to be right-handed.

*Stimuli.* The visual stimuli were circular spots with constant 5 mm diameter, presented on a gamma-corrected 21" video monitor with a background illumination held constant at 0.01 cd/m<sup>2</sup>. In Experiment 1, the paired stimuli were presented successively. Each stimulus was presented at 9 different brightness levels from 3.5 to 5.9 cd/m<sup>2</sup> in 8 steps of 0.3 cd/m<sup>2</sup>, for 200 msec. The ISI was 400, 800, 1600 or 3200 msec. In Experiment 2, paired stimuli were presented simultaneously, for 200 msec, separated by a spatial interval. The spatial separation between stimuli was 10, 20, 40 or 80 mm, and the brightness of each stimulus ranged from 1.5 to 7.9 cd/m<sup>2</sup> in 8 steps of 0.8 cd/m<sup>2</sup>.

*Design.* The 9 separate brightness levels of each visual stimulus were combined semi-factorially to form a 'diamond' shape about mean physical brightness, to create 25 different stimulus pairs. In Experiment 1, the physical differences (i.e., first minus second) between the stimuli in each pair ranged from -1.2 to +1.2 cd/m<sup>2</sup> in 4 steps of 0.6 cd/m<sup>2</sup> across one diagonal, and mean stimulus brightness ranged from 4.1 to 5.3 cd/m<sup>2</sup> in 4 steps of 0.3 cd/m<sup>2</sup> across the opposing diagonal. In Experiment 2, the physical difference between the stimuli ranged from -3.2 to 3.2 in 4 steps of 1.6 cd/m<sup>2</sup> across one diagonal and mean stimulus brightness ranged from 3.1 to 6.3 in 4 steps of 0.8 cd/m<sup>2</sup> across the opposing diagonal.

In each experiment participants took part in four 30-min sessions, one on each of 4 days. Within each session, each stimulus was shown in pseudo-randomly constructed cycles of 100 items. The first 25 trials (Exp.1) and 100 trials (Exp. 2) were designated as practice trials, immediately after which each participant was required to complete a further 400 trials per session. New random orders were used for each participant and each session.

In Experiment 1, 20 participants were instructed to press a left response key if they perceived the first stimulus to be brighter than the second, or a right key if they perceived the second stimulus to be brighter than the first. The other 20 participants were instructed to use the reverse stimulus-response assignment. In Experiment 2, all participants were instructed to respond by pressing the left response key if they perceived the left stimulus to be brighter than the right, and the right key if they perceived the right stimulus to be brighter than the left.

*Procedure.* At the beginning of each session participants were presented with written instructions on the video monitor. The importance of responding as quickly and as accurately as possible was stressed. The inter-trial interval was 3000 msec. On the average, participants took 30 minutes to complete each session.

## Results

In Link's analysis (Equation 2) the drift rate  $\mu$  is estimated by  $m(S_i-S_r)$ , where  $m$  is a constant. The actual perceived stimulus difference is not measured directly but represented by  $\theta_i A$ , which needs only to be monotonically related to  $\mu$ . Therefore, ignoring the non-decision part of RT, an alternative way of thinking about  $\mu$  is in terms of  $\mu^*=A/RT$  for first brightest responses and  $\mu^*=-A/RT$  for second brightest responses, termed "signed response speed" (SRS).

**Table 1.** Mean log-odds ratios of the proportion first (left) brightest responses over second (right) brightest responses and mean signed response speed for the 5 brightness levels by ISI.

Experiment 1: Successively presented stimuli									
Mean brightness (cd/m <sup>2</sup> )	ISI (msec)	Mean log-odds ratio				Mean signed response speed			
		400	800	1600	3200	400	800	1600	3200
4.1		-0.06	0.20	0.15	0.11	-0.52	1.27	0.70	0.59
4.4		-0.06	0.16	0.09	0.01	-0.62	1.01	0.53	-0.06
4.7		-0.14	0.06	0.06	-0.02	-0.87	0.34	0.53	-0.22
5.0		-0.21	-0.01	-0.12	-0.16	-1.06	0.13	-0.44	-0.91
5.3		-0.23	-0.06	-0.08	-0.27	-1.01	-0.01	-0.25	-1.3
Experiment 2: Simultaneously presented stimuli									
Mean brightness (cd/m <sup>2</sup> )	ISI (mm)	10	20	40	80	10	20	40	80
3.1		-0.07	0.03	0.07	0.12	-0.63	0.31	0.79	1.24
3.9		-0.16	0.01	0.10	0.13	-1.55	0.01	0.10	1.06
4.7		-0.07	0.02	0.14	0.13	-0.63	0.07	1.55	1.23
5.5		-0.13	-0.08	0.09	0.21	-1.12	-0.76	1.13	1.87
6.3		-0.04	-0.03	.015	0.21	-0.29	-0.20	1.44	1.72

Here, SRS is calculated as 100/RT for first brightest response, and -100/RT for a second brightest response. The use of SRS reduces the influence of outliers and can be scaled in a similar, directly comparable, manner as response probability.

To investigate the nature of the relationship between  $\text{logit}(p)$  and SRS, stepwise polynomial 3<sup>rd</sup>-degree regressions were fit to each participant's data over each stimulus condition and ISI (Exp.1), and spatial separation (Exp. 2), using mean SRS as the independent variable. On the group average, all cubic and quadratic terms in both Experiments 1 and 2 proved to be statistically nonsignificant, indicating that SRS and  $\text{logit}(p)$  are linearly related.

Now, consider the effect of changes in average stimulus brightness and ISI on the direction and magnitude of the TOE and SOE, as shown in Table 1. For successively presented stimuli, asymmetries can be seen to change systematically in magnitude and direction with changes in stimulus brightness and ISI, both in terms of log-odds ratios and mean SRS. For simultaneously presented stimuli, there is some indication that asymmetries go from negative to positive with increased spatial separation between the stimuli but no indication of any systematic variation with changes in average stimulus brightness.

To examine changes in the magnitude and direction of the TOE and SOE the data were analysed in terms of Hellström's SW model (Equation 1). On the basis of the SW model  $s_1-s_2$  indicates the direction of asymmetry, and the relation  $s_1 \neq s_2$  was tested by (two tailed) one sample t-tests. The results of this analysis are shown in Table 2.

Further, analysis of the influence of response assignment on the magnitude and direction of  $s_1-s_2$  revealed no statistically reliable effects (all  $ps>.05$ ).

**Table 2.** Weights  $s_1-s_2$  estimated by logistic regression of binary responses and std regression of SRS on log physical brightness (cd/m<sup>2</sup>) of the first (left) and second (right) stimuli.

Experiment 1: Successively presented stimuli								
ISI(msec)	Response frequency				SRS			
	400	800	1600	3200	400	800	1600	3200
$s_1-s_2$	-0.74	-1.25	-1.26	-1.61	-0.02	-0.05	-0.05	-0.08
$p \mid (s_1-s_2) = 0$	.02	.001	.001	.001	n.s.	.003	.012	.001
Experiment 2: Simultaneously presented stimuli								
ISI(mm)	10	20	40	80	10	20	40	80
$s_1-s_2$	0.16	-0.11	0.03	0.09	0.004	-0.009	0.009	0.009
$p \mid (s_1-s_2) = 0$	n.s	n.s	n.s	n.s	n.s.	n.s.	n.s.	n.s.

**Table 3:** Psychometric function of stimulus difference and linear fit of Equation 2

Experiment 1: Successively presented stimuli								
ISI (msec)	400		800		1600		3200	
	$0=\theta A=$ $X\Delta s+C$	$(2P_{Ai}-1)$ $\mu$						
Least squares fit								
$S_r$	.14	.38	-.09	-.06	-.06	.06	.05	-.29
Multiple R (SSE)	.94 (.42)	.88 (1227)	.91 (.45)	.88 (898)	.94 (.18)	.89 (704)	.94 (.20)	.89 (633)
Slope (SE)	.93 (.15)	-294 (99)	.92 (.16)	24 (61)	.77 (.12)	57 (31)	.67 (.11)	-135 (110)
Intercept (SE)	-.20 (.12)	880 (99)	.04 (.13)	834 (25)	.01 (.09)	820 (15)	-.07 (.10)	862 (39)
Experiment 2: Simultaneously presented stimuli								
Spatial sep. (mm)	10		20		40		80	
$S_r$	.21	.53	.006	.43	-.29	-.09	-.38	-.58
Multiple R (SSE)	.98 (1.14)	.86 (2565)	.98 (.53)	.86 (2083)	.98 (.21)	.86 (1338)	.96 (.23)	.89 (713)
Slope (SE)	.73 (.08)	280 (115)	.73 (.07)	278 (93)	.54 (.04)	120 (74)	.36 (.05)	263 (175)
Intercept (SE)	-.21 (.18)	554 (33)	-.05 (.14)	526 (32)	.15 (.11)	569 (21)	.20 (.11)	623 (29)

Additional tests of the extended BTL and SW models were conducted by regression of binary responses and separately SRS on  $[\ln(\Phi_1)-\ln(\Phi_2)]$  and  $[\ln(\Phi_1)+\ln(\Phi_2)]$ , where  $\Phi_1$  and  $\Phi_2$  are the physical brightness values of the first (left) and second (right) stimuli in  $\text{cd/m}^2$ . This analysis revealed significant coefficients for  $[\ln(\Phi_1)-\ln(\Phi_2)]$ , all  $ps<.05$ , and for Experiment 1 statistically significant and marginally significant coefficients obtained also for  $[\ln(\Phi_1)+\ln(\Phi_2)]$ , implying  $s_1 \neq s_2$ . Specifically, for stimuli separated by an ISI of 3200 msec,  $t(388)=1.59$ ,  $p=.056$ ,  $\beta=1.92$  (response probability) and  $t(388)=1.62$ ,  $p=.053$ ,  $\beta=0.11$  (SRS), and ISI of 1600 msec,  $t(391)=1.51$ ,  $p=.066$ ,  $\beta=1.82$  (response probability),  $t(391)=1.51$ ,  $p=.066$ ,  $\beta=0.11$  (SRS), which suggests that time-order effects in brightness discrimination do not arise merely as result of an additive bias (cf. Davidson & Beaver, 1977).

*Wave theory.* Following the procedures developed by Link (1978) an average estimate of each participant's mental referent,  $S_r$ , was obtained by solving the least-squares fit at which  $\theta_i A=0$ , as a function of the brightness difference ( $\Delta s$ ) in  $\text{cd/m}^2$  between the stimuli in each pair giving 80 data points for each condition per participant. Equation 2 was then fit to mean RT as a function of  $\Delta s$ . As shown in Table 3, this analysis revealed a good least-squares fit to  $S_i$  of the informational value  $\theta_i A = \ln(P_{Ai} / (1-P_{Ai}))$ , and reasonable correspondence between ERT (Equation 2), and mean RT for each condition as obtained empirically in Experiments 1 and 2.

*Diffusion model* analysis is currently ongoing using the DMAT toolbox (Vandkerckhove & Tuerlinckx, 2008). In the first instance, six nested models of increasing complexity were fit to the data as a function of stimulus brightness difference in  $\text{cd/m}^2$ ; namely, i) all parameters fixed, ii) linear regression of  $\Delta s$  on drift rates by ISI, start position fixed midway between the two boundaries iii) linear regression of  $\Delta s$  on drift rates by ISI, start position free to vary, iv) logistic regression of  $\Delta s$  on drift rates by ISI, start position free to vary, and inter-trial range of start position free to vary, v) drift rates free to vary, start position free to vary, inter-trial range of start position free to vary, and vi) all seven parameters free to vary. The results of this analysis show no significant improvement in fit beyond linear regression of stimulus difference on drift rates allowing for changes in the intercept and slope with changes in ISI and variation in the start position of the diffusion process.

## Conclusion

The findings of Experiments 1 and 2 show characteristic time- but not space-order effects in timed brightness discrimination of visual stimuli. The TOE was found to change in magnitude and direction with changes in the temporal separation between stimuli and with changes in the

absolute physical magnitudes of the stimuli, whereas statistical analysis of the SOE revealed no systematic changes in magnitude and direction with changes in the absolute physical magnitudes of the stimuli. Taken together, these data provide further support for the view that the TOE is a perceptual phenomenon not explainable in terms of simple response bias, verbal categorization of stimulus values toward the mean, or by the idea that the activation induced by one stimulus is compared to a lower (or higher) fidelity mental referent of the other. The use of SRS permits consideration of current random walk and diffusion models without assumptions concerning the simple subtraction of stimulus information and hence realistic modification of these models to allow for explanations of the paired comparison of stimuli based on sensation weighting and influence of generic information.

### References

- Allen, L.G. (1977). The time-order error in judgments of duration. *Canadian Journal of Psychology*, 31, 24-31.
- Bradley, R.A., & Terry, M.E. (1952). Rank analysis of incomplete block designs: I. The method of paired comparisons. *Biometrika*, 39, 324-345.
- Davidson, R.R., & Beaver, R.J. (1977). On extending the Bradley-Terry model to incorporate within-pair order effects. *Biometrics*, 33, 693-702.
- Diederich, A., & Busemeyer, J.R., (2006). Modeling the effects of payoff on response bias in a perceptual discrimination task: Bound-change, drift-rate-change or two-stage-processing hypothesis. *Perception & Psychophysics*, 68, 194-207.
- Hellström, Å (1979). Time errors and differential sensation weighting. *Journal of Experimental Psychology: Human Perception and Performance*, 5, 460-477.
- Hellström, Å (1985). The time-order error and its relatives: Mirrors of cognitive processes in comparing. *Psychological Bulletin*, 97, 35-61.
- Hellström, Å (2003). Comparison is not just subtraction: Effects of time- and space- order on subjective stimulus difference. *Perception & Psychophysics*, 65, 1161-1177.
- Jamieson D.G., & Petrusic, W.M. (1975). Presentation order effects in duration discrimination. *Perception & Psychophysics*, 17, 197-202.
- John, I.D. (1975). A common mechanism mediating the time-order error and cross-over effect in comparative judgments of loudness. *Australian Journal of Psychology*, 27, 51-60.
- Kellogg, W.M. (1931). The time of judgment in psychometric measures. *American Journal of Psychology*, 241, 1-52.
- Link, S.W. (1975). The relative judgment theory of two choice response time. *Journal of Mathematical Psychology*, 12, 114-135.
- Link, S.W. (1978). The relative judgment theory of the psychometric function. In J.Requin (Ed.), *Attention & Performance VII*. (pp. 619-630). Hillsdale, NJ: Erlbaum.
- Link, S.W. (1992). *The wave theory of difference and similarity*. Hillsdale, NJ: Erlbaum.
- Luce, R.D. (1959). *Individual choice behavior: A theoretical analysis*. New York: Wiley.
- Maeda, H. (1959). On the inhibitory effects of extrapolated stimuli in the successive comparison of brightness (I). *Japanese Journal of Psychology*, 30, 3-20.
- Masin, S.C., & Agostini, A. (1991). Attentional scanning and space errors. *Perception & Psychophysics*, 50, 285-289.
- Mattingley, J.B., Bradshaw, J.L., Nettleton, N.C., & Bradshaw, J.A. (1994). Can task specific perceptual bias be distinguished from unilateral neglect? *Neuropsychologia*, 32, 805-817.
- Ratcliff, R. (1978). A theory of memory retrieval. *Psychological Review*, 85, 59-108.
- Vandkerckhove, J., & Tuerlinckx, F. (2008). Diffusion model analysis with MATLAB: A DMAT primer. *Behavior Research Methods*, 40, 61-72.

## TWO METHODOLOGICAL APPROACHES TO COGNITIVE ALGEBRA OF PURCHASE CHOICE

Massidda D.<sup>1</sup>, Bastianelli A.<sup>1</sup>, Vidotto G.<sup>1</sup>, and Noventa S.<sup>2</sup>

<sup>1</sup> *Dipartimento di Psicologia generale, Università di Padova, Italy*

<sup>2</sup> *Dip.to di Psicologia dello Sviluppo e della Socializzazione, Università di Padova, Italy*

### Abstract

*A consumer's evaluation of a product is affected by several factors. Information integration theory assumes that the evaluation process consists in a combination of information integration rules known as cognitive algebra. Functional measurement methodology applied to information integration theory provides the way of determining the most adequate integration function. Conjoint analysis was originated in mathematical psychology and developed in market research by Paul Green to determine the factors that predict consumer preferences for multi-attribute options about a wide variety of products and which combination of a limited number of attributes is most influential on respondent choice. In the present study, consumers' perceptions have been evaluated regarding three different prices, discounts, and brands of milk. Both functional measurement and conjoint analysis were used with the aim of estimating all the possible effects of interaction. The results are discussed in light of these two methodological frameworks.*

The perception of a product convenience is a multi-attribute choice process in which several factors, like price (Olson, 1977), variety, habit, quality, brand name, even country of origin (Anderson & Cunningham, 1972; Hastak & Hong, 1991), affect the final evaluation by the consumer; the principal difficulty lies in detecting and identifying those factors that greatly influence the process; many kinds of multi-attribute utility models have therefore been developed for marketing applications with the aim of defining which product attributes move the consumer towards a precise purchase choice (J. G. Lynch, 1985; Oral & Kettani, 1989). Above all, two paradigms have been very effective: 'Conjoint analysis' (Luce & Tukey, 1964; Green & Rao, 1971; Green & Srinivasan, 1978) and 'Functional measurement', a methodology of Information integration theory (Anderson, 1981).

Despite the fact that these models are very similar in spirit, they emphasize different aspects (Lynch, 1985). The present work aims to simultaneously apply these models in order to integrate and compare them. In particular the goal of the experiment is threefold: firstly, to study how the perception of brand, price and discount affect the evaluation of dairy milk offers; secondly, to detect which integration function provides the best description of the evaluation phenomena; thirdly, to discuss the results obtained with the two methodologies.

### *Cognitive algebra and Functional Measurement*

Information integration theory (Anderson, 1981) is a general paradigm applied in many fields of psychology, psychophysics and cognitive sciences. It assumes that perception, thought and action depend on the integration of multiple determinants: each level of a factor, that describes some attribute of a phenomenon, is represented in a cognitive system by a pair of values: a subjective scale value and a weight that represent its importance. Subjects' final responses depend on the integration of these pairs and IIT describes these processes adopting