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Remembered instructions with symbolic and perceptual comparisons

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Semantic congruity effects (SCEs) were obtained in each of two experiments, one with symbolic comparisons and the other with comparisons of visual extents. SCEs were reliably larger when the instructions indicating the direction of the comparison were represented by consonant–vowel–consonant (CVC) nonsense syllables, which had been associated with the conventional instructions in a preliminary learning phase of the experiment. Enhanced SCEs with the CVC instructions were evident, especially when stimulus pair location and instruction direction did not match. This finding is not readily explained by any non-evidence-accrual theories of the SCE (e.g., expectancy, semantic coding, and reference point) or by their accrual-based extensions. On the other hand, the general class of evidence-accrual views of SCEs, such as those developed in Leth-Steensen and Marley (2000) and in Petrusic (1992), receive considerable empirical support when the locus of the SCE is specified in terms of the congruency of stimulus pair location and the direction of the instruction.

Early in the history of psychophysics, Henmon (1911) noted a possible dependence of the ease of discrimination on the instruction required in the experiment. He observed that the selection of the shorter of two relatively short lines was easier than the selection of the longer. Although Henmon's introspective observations were not borne out in the data he presented, his seminal idea was first established as empirical fact in the affective–hedonic domain in a pair of experiments by Shipley, Coffin, and Hadsell (1945) and Shipley, Norris, and Roberts (1946). These studies showed that selection of the more pleasant of two pleasant colors was faster than the selection of the more unpleasant one and, conversely, that selection of the more unpleasant of two unpleasant colors was faster than the selection of the more pleasant one.

In a landmark work in the sensory domain, Audley and Wallis (1964), working with stimuli varying in brightness, showed that the selection of the brighter of two relatively bright lights was faster than the selection of the darker of the two and, conversely, that selection of the darker of two relatively dark lights was faster than selection of the lighter one. They referred to this phenomenon as the *crossover effect*, labeling it in terms of the interaction between the direction of the comparison and the location of the alternatives on the continuum, which defines the effect. Acknowledging the clear dependence of the properties of comparative judgments on linguistic factors, the crossover effect is now typically referred to as the *semantic congruity effect* (SCE).

Semantic congruity effects are ubiquitous, occurring with both symbolic and perceptual comparisons. Indeed, these effects on response times (RTs) can be very large, but invariably they are not accompanied by commensurate effects with the discriminative accuracy measure. For example, with perceptual comparisons (see, e.g., Petrusic, 1992; Petrusic & Baranski, 1989a, 1989b), RT-based SCEs varied systematically with difficulty of the discrimination and varying deadlines for speed versus accuracy. However, in each of the experiments above, discriminative accuracy results were identical for both semantically congruent and incongruent trials. As such, these findings continue to pose a theoretical challenge to the theories that are able to account for RT-based SCE (e.g., Jamieson & Petrusic, 1975; Petrusic, 1992). In the present article, we present data that will provide a solution to this theoretical conundrum.

Although the main empirical properties of the SCE with perceptual and symbolic comparisons are now well established (see, e.g., Banks, 1977; Čech, 1995; Čech & Shoben, 2001; Čech, Shoben, & Love, 1990; Leth-Steensen & Marley, 2000; Petrusic, 1992; Petrusic & Baranski, 1989a, 1989b), the empirical status of the available theories of the SCE remain, for the most part, to be firmly determined. The experiments reported here permit strong tests of the available theories of the SCE. These tests are based on a novel methodology in which participants first learn to associate consonant–vowel–consonant (CVC) nonsense syllables with comparative instructions (e.g., GUF–larger; CEB–smaller). Subsequently, comparative judgments are made with the conventional instructions on half of the trials and with the CVCs on the other half, thus requiring the participant to recall the particular instruction associated with the presented CVC.

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THEORIES OF THE SEMANTIC CONGRUITY EFFECT AND REMEMBERED INSTRUCTIONS

The available classes of theories of the SCE can be viewed in terms of whether they are cast in the context of single-instance, non-evidence-accrual ideas or embedded in terms of decision processing theories of the accrual of evidence. We specify the predictions for the various theoretical positions arising within each of these two broad frameworks in terms of the magnitudes of the SCE when instructions are presented directly, as compared with when they are represented symbolically.

Additive Stages, Non-Evidence-Accrual Theories

Expectancy theory. Marschark and Paivio (1979, 1981) and Kosslyn, Murphy, Bemesderfer, and Feinstein (1977) have developed variants of the expectancy theory view of the SCE, primarily in the context of symbolic comparisons. The essence of the expectancy idea is that the instruction directs, much as in semantic priming (see, e.g., Meyer & Schvaneveldt, 1971), memory search for the relevant features of the to-be-discriminated stimulus pair. When the stimulus pair location is congruent with the instruction, the search process is semantically facilitated, and when the location is not congruent, the search process must be redirected, slowing the comparison.

Presumably, with strictly perceptual comparisons the SCE should not occur—although, as Petrusic and Baranski (1989a, 1989b) and Petrusic (1992) have shown, it does. Nevertheless, the empirical status of expectancy theory with perceptual comparisons remains to be firmly established. Thus far, tests of expectancy theory have exclusively used symbolic stimuli, and in every case the evidence has run counter to expectancy theory (e.g., Banks & Flora, 1977; Banks, White, Sturgill, & Mermelstein, 1983; Čech, 1995; Holyoak & Mah, 1981; Howard, 1983; Shoben, Sailor, & Wang, 1989).

In the present context, precisely the same expectancies are created with the CVC-based symbolic instructions as with the conventional instructions, because precisely the same instructions are activated in each case. Consequently, the same search processes occur in the two cases, and exactly the same SCE must occur, with the two forms of presentation of the instructions specifying the direction of the comparison.

Semantic coding theory. Banks, Clark, and Lucy (1975) developed the earliest version of the intuitively compelling and currently popular semantic coding theory, and Banks, Fujii, and Kayra-Stuart (1976) extended the original ideas forcefully to the domain of comparisons of numerical magnitude. These ideas are fully articulated in Banks's (1977) review of the extant literature and exposition of his theory.

Semantic coding theory asserts that the process of comparison involves discrete, strictly additive stages (i.e., coding of instructions, code activation of stimuli, code comparison, code translation if needed, and response selection). It predicts that although RTs will be lengthened with the CVC instruction due to slowed instructional access, the SCE should remain uninfluenced, because it occurs at a stage that follows the encoding of instructions. Specifically, the SCE occurs at the stimulus code translation stage, which necessarily follows the encoding of instructions. In addition, the same instructional codes would be activated with the CVC instructions as with the conventional instructions, and consequently, the same code search and stimulus code translation processes would occur with the CVC instructions as with the conventional instructions. Thus, according to semantic coding theory, the SCE will be the same with CVC instructions as with the conventional instructions.

Reference point theories. Reference point theories (Dehaene, 1989; Holyoak, 1978; Jamieson & Petrusic, 1975; Marks, 1972) posit that stimuli are represented on an analogue continuum and that presentation of an instruction activates an extreme point on the continuum, referred to as a *reference point*. Comparison requires the computation of the difference from the activated reference point to the representation of each stimulus. Comparisons are based on the ratio of the distances of the representation of each stimulus from the activated reference point, and RTs are assumed to vary inversely with the difference between the ratio of distances and a criterion value (typically 1.0 in the unbiased case). This difference between the ratio of distances and the criterion increases with nearness of the stimulus pair to the reference point. In essence, reference point theories assert that stimulus pair discriminability is better the closer the pair is to the activated reference point.

According to this class of theories, reference points are activated only upon encoding of instructions, and it is expected that CVC-based instructions will slow speed of access to the relevant reference points. However, precisely the same reference points would be activated with the CVC as with the conventional instructions. Consequently, the SCE should be of precisely the same magnitude and form with the two different forms of instructions.

Evidence-Accrual Theories

Generally, each of the various evidence-accrual theories are clear in predicting that when primary decisional RTs are slowed because of the increased memory demands with remembered instructions, the SCE will also necessarily increase, albeit for somewhat different reasons according to the various evidence-accrual theories.

SCE as strategic bias. In the context of random-walk diffusion process models (e.g., Link & Heath, 1975; Ratcliff, 1978; Usher & McClelland, 2001), the SCE arises as a consequence of a dynamic, strategic adjustment of decisional criteria upon presentation of the instruction in the context of a particular stimulus pair (see, e.g., Birnbaum & Jou, 1990; Link, 1990; Link, 1992, pp. 172–178; Schwarz & Stein, 1998). Since precisely the same instructions would be activated with both the CVC and the conventional instructions, exactly the same biases should occur with the two different ways of presenting the instructions for each trial (note, however, that it could also be argued that diminishing the salience of the instructional context by using CVC instructions might also serve to hinder the strategic biasing process, thus attenuating the SCE). Nevertheless, it is then likely that the drift of the accrual process in these models would be slowed given the increased memory requirements associated with activating the underlying instruction and distinguishing between the CVC instructions. Slower drift rates would enhance the time taken for the walk to reach the decision bounds, resulting in a decisional latency effect that would be even more enhanced for cases, such as semantically incongruent pairs, in which the boundaries have strategically been set quite far from the starting point of the walk. Consequently, the SCE would be enhanced with the remembered, CVC, instructions. Also, if CVC instructions result in slowed drift rate, overall discriminative accuracy should then be lower than with the conventional instructions. However, it should be noted that the strategic bias view is clear in predicting that discriminative accuracy is poorer with the semantically incongruent than with the congruent instruction, contrary to the consistent failures to find SCEs with the percent correct measure.

Instructional pathway interference. Leth-Steensen and Marley (2000) have developed a connectionist-based evidence-accrual model that posits the continuous accumulation of information about both the difference in stimulus magnitude and the end-point status of each stimulus item. This information is assumed to be accumulated simultaneously within two competing instructional pathways, associated with the relevant and the irrelevant instructions, respectively. SCEs arise primarily on the assumption that the strengths of each instructional pathway, and hence the overall level of competition between them, are dynamically modulated by the relative location of the stimulus items. For example, a pair of relatively small stimuli would serve to enhance the strength of the pathway associated with the instruction to choose the smaller stimulus and weaken the strength of the pathway associated with the instruction to choose the larger stimulus. As the authors of this model indicate, their notion of competition between instructional pathways is consistent with the notion of semantic interference originally proposed by Banks and Root (1979).

Given that appropriate instructional pathway activation (or inhibition) also depends on the continuously available context provided by the instructions, and that such contextual information is less salient for the CVC instructions, the strength of the relevant instructional pathway will be weaker and, hence, instructional pathway interference will be greater with the CVC instructions than with the conventional instructions. Consequently, according to the Leth-Steensen and Marley (2000) model, the SCE should be larger with the CVC instructions than with the conventional instructions.

Slowed evidence accrual. The notion that SCE occurs at the level of each accrual event in the accumulation of evidence was developed in the context of Petrusic's (1992) slow- and fast-guessing theory (SFGT). SFGT, a variant on LaBerge's (1962) discrete accumulator, posits cut points, C_1 and C_2, on a decision axis, $d = X - Y$, such that evidence favoring the response R_1 occurs if $d < C_1$ with probability p_1, evidence favoring the response R_2 occurs if $d > C_2$ with probability p_2, and evidence favoring a state of doubt occurs if $C_1 \leq d \leq C_2$ with probability $p_3 = 1 - (p_1 + p_2)$. We refer to the C_1–C_2 interval as the *interval of uncertainty* (IOU), and accruing a criterion amount of information falling in the IOU (or *inconclusive information*) triggers a state of doubt, or indifference, so that guessing becomes the basis for responding, denoted R_3. The overt response occurring on a particular trial depends on which of three preset counters first achieves a criterion number of predecisional accrual events. Let α_1, α_2, and α_3 denote the criterion numbers of events required for the overt responses R_1, R_2, and R_3, respectively.

Petrusic (1992) obtained the closed-form quantitative expressions for the probability of a particular response, $P(R_1)$, and the expected number of accrual events conditional on a particular response, $E(N/R_1)$, which are provided in the Appendix. Assuming that on average each accrual event takes a constant amount of time, Δ, the overall RT conditional on the occurrence of the R_1 response is given by $\mathrm{RT}(R_1) = \Delta E(N/R_1) + C$, where C is a constant denoting nondecisional input and output components.

Given the obtained explicit quantitative expressions of the probability of a particular response and its associated conditional RT, Petrusic (1992) obtained the relationship between these, upon variations in the underlying discriminability parameter, $\delta = p_1/(p_1 + p_2)$—that is, the *latency probability function* (LPF). Petrusic then showed that under conditions emphasizing accuracy (i.e., when α_3 is large relative to α_1 and α_2, producing *slow guessing*), the LPF is strictly monotonically decreasing. Furthermore, the theoretically predicted mean RTs on error trials would be longer than on correct trials when accuracy was stressed at the expense of speed. On the other hand, under conditions emphasizing extreme speed at the expense of accuracy—that is, when α_3 is very low (e.g., 2, for *fast guessing*), the LPF is nonmonotonic, and error responses will be associated with faster times than correct responses.

Petrusic (1992) argued that the SCE occurs at the level of each accrual event. That is, on semantically incongruent trials, the RT(x, y) with any stimulus pair (x, y) is given by

$$\mathrm{RT}(x, y) = C(x, y) * E(N|R_1),$$

where $C(x, y)$ denotes the average duration of each accrual on semantically incongruent trials. On semantically congruent trials,

$$\mathrm{RT}'(x, y) = C'(x, y) * E(N|R_1),$$

where $C'(x, y)$ denotes the duration of each accrual on semantically congruent trials. The SCE arises because $C(x, y) > C'(x, y)$, and the SCE is then defined by

$$\mathrm{SCE}(x, y) = \mathrm{RT}(x, y) - \mathrm{RT}'(x, y).$$

Consequently, the properties of the LPFs under varying demands for speed versus accuracy stress should be evident with the observed magnitude of the SCE. Notably, SCE should increase approximately linearly with base RTs induced by the varying demands for speed, and this increase should be greater on error trials than on correct trials. This is precisely what Petrusic (1992) obtained in each of two experiments. In one experiment, quasi-speed–accuracy trade-off functions were obtained by forming quartiles of the overall RTs, and in the other such functions were obtained through explicit deadlines reinforced through payoffs emphasizing speed at the expense of accuracy. Since the expected number of accruals increases as the discriminability of a stimulus pair decreases, SCE should vary systematically with decisional difficulty. This dependence of SCE magnitude on decisional difficulty was clearly evident in the experiments reported in Petrusic and Baranski (1989a, 1989b) and in Petrusic's (1992) Experiments 1 and 2.

Thus, in the present context with CVC instructions, any manipulation that further slows each accrual should result in an enhanced SCE. Because memory access to the relevant instruction will be slower with a CVC instruction than with a conventional instruction, if it is also the case that the CVC–instruction association must be activated on each evidence-accrual event (for discussion of a similar notion regarding stimulus representations, see Petrusic, 1992, pp. 983–984), the evidence-accrual idea developed by Petrusic predicts a larger SCE with CVC instructions rather than with conventional instructions. In sum, the duration of each accrual on semantically incongruent trials, $C(x, y)$, will be larger on CVC instruction trials than on trials with conventional instructions.

Although Petrusic (1992) developed his predictions in terms of his slow- and fast-guessing discrete accumulator model, if the accrual process is governed by a continuous accumulator in discrete time (see, e.g., Vickers, 1970, 1979), enhancement of the SCE with the remembered, CVC, instructions is also, of course, clearly predicted.

EXPERIMENT 1

Method

Participants. Twenty Carleton University students participated in one 45-min session in order to satisfy course requirements. All participants reported normal or corrected-to-normal vision.

Apparatus. Graphics production, presentation of instructions and stimuli, event sequencing and timing, and the recording of responses and RTs were controlled by a Pentium III computer running under SuperLab control. Stimuli and instructions were presented on a 17-in. (43 cm) ViewSonic video monitor with 800 × 600 pixel resolution. Responses were made using the buttons on an IBM-PC mouse with the roller ball disabled.

Stimuli. Twelve animal names, printed in Times New Roman font (25-point bold), were used as the stimulus set. Six names were of relatively small animals (*bee*, *rat*, *flea*, *crab*, *snail*, and *mouse*), and the other six names were of relatively large animals (*dog*, *pig*, *wolf*, *bear*, *horse*, and *whale*). Three pairs of relatively small animals (*bee–rat*, *flea–crab*, *snail–mouse*) and three pairs of relatively large animals (*dog–pig*, *wolf–bear*, *horse–whale*) were created. The pairs of animal names appeared at the respective centers of the left and right hemifields on the white background of the video monitor.

The words "Larger" and "Smaller" and eight nonsense syllables (GUF, BIX, NIQ, YOL, ZOE, KAG, LEX, and CEB), each with a 30% association value (see Hilgard, 1951), were used as instructions in a comparative judgment-of-size task. The instructions were printed in Times New Roman font (30-point bold) and were displayed at the center of the upper third of the screen.

Design and Procedure. The session began with a learning phase, in which the participants learned to associate each of the two instructional words ("Larger," "Smaller") with four of the eight CVCs. The CVC–instruction associations were counterbalanced across participants according to a Latin-square design. On each learning trial, a single CVC was presented at the center of the upper third of the computer screen and the words "Larger" and "Smaller" appeared below, on the left and right sides of the screen, in a random order on each trial. The participant's task was to press the left and right mouse buttons, according to the association between the CVC and the appropriate instructional word. After a response, the computer illuminated the correct association by placing a red rectangle over the correct instruction word for 5,000 msec. The CVC and both instructional words were then cleared from the screen, and the next trial began 1,000 msec later.

The learning phase was continued until the participant reached a criterion of 24 successive matches, 3 with each CVC. All participants were instructed to closely attend the semantic associations of the CVC they were learning, since they would be using this information in the next part of the experiment.

Following the learning phase, the participants were instructed that on each trial they would be presented with a pair of animal names and either an instructional word or one of the CVCs they had learned to associate with the instruction words in the former phase. The participant's task was to press the mouse button on the side of the name of the larger (or smaller) animal in the pair of names, according to the presented instruction.

A given pair appeared in both spatial arrangements (i.e., each element in the pair appeared once on the left and once on the right) and was shown with each of the two conventional instructions and with each of the eight CVC instructions. Each instruction condition (instructional word or CVC) occurred equally often with each pair. Each of the 4 CVCs requiring selection of the smaller animal and the 4 requiring selection of the larger animal accompanied each pair. In addition, each of the conventional instructions accompanied each pair 4 times, thereby comprising a total of 16 possible instructions. Each of the six stimulus pairs, two spatial arrangements of each pair, and 16 instructions was presented once in each of two blocks, for a total of 384 experimental trials, with the first block preceded by 16 practice trials. A different randomization of the 192 trials in each block was used for each participant. The practice trials were sampled randomly from the full set of trials and were different for each participant. The participants were not aware of the partition into practice and experimental trials.

Participants were tested individually in a dimly lit room, seated approximately 80 cm from the center of the screen. Participants initiated each trial by pressing both buttons of the mouse. Each trial then started with the appearance of an instruction. The pair of animal names appeared 750 msec later, while the comparative instruction remained on the screen. The stimuli and the instruction were both response-terminated, and the next trial began 1,000 msec later. The participants were encouraged to respond quickly and accurately.

Results

The findings are presented in two primary sections; the first of these presents RT analyses, and the second focuses on error rates. For each participant, in all analyses, the dependent variable is either the mean RT for the correct responses or the mean percentage of errors in each cell of the design. In each ANOVA reported, the Huynh–Feldt epsilon adjustment of degrees of freedom was used. However, the degrees of freedom associated with each value of F are those defined by the design, and the MS_es provided in the text are those given by the conventional degrees of freedom. All reported reliable effects were significant at the .05 level.

RT analyses. The data of 4 participants were not used in the following analyses. Each of these participants was faster overall in responding with the CVC instructions than with the conventional instructions, and therefore lacked the necessary condition for the tests of the alternative theories.

Mean RTs with each instruction type for each stimulus pair in each instruction format condition are provided in Figure 1A. An ANOVA confirmed a main effect of instruction format [$F(1,15) = 31.01$, $MS_e = 63{,}305$]. RTs in the conventional and CVC instruction conditions were 1,425 and 1,568 msec, respectively. The main effect of pair was also statistically reliable [$F(5,75) = 12.51$, $MS_e = 65{,}531$].

As is evident in the plots in Figure 1A, the SCE occurs with both the conventional and the CVC instructions, and the interaction between stimulus pair and instruction type is reliable [$F(5,75) = 28.67$, $MS_e = 28{,}585$]. Crucially, the three-way interaction involving instruction format condition, stimulus pair, and instruction type is also significant [$F(5,75) = 6.32$, $MS_e = 25{,}828$], affirming the fact that there is enhanced SCE with the remembered CVC instructions.[1]

The plots in Figure 1B provide an alternative way of viewing both the crossover SCEs in each condition and the enhanced SCE in the CVC instruction condition. These plots are based on an SCE index, defined as the RTs for the "Smaller" instruction subtracted from RTs for the "Larger" instruction. The full crossover effect is evident when the SCE index is positive (i.e., RTs are longer with the "Larger" than with the "Smaller" instruction) for the relatively small animals and negative for the relatively large animals. In addition, these plots show that the SCE is larger with the CVC instructions than with the conventional instructions for every stimulus pair.

Pair location and instruction direction congruency: Speed of instructional access. With a view toward determining whether speed of access to the underlying instruction with the CVC might be influenced by the relative locations of the stimulus pairs on the size continuum, when the comparison involved one of the three smaller stimulus pairs and the CVC was associated with the instruction "Smaller," pair location and instruction direction were regarded as being congruent. On the other hand, when the CVC was associated with the instruction "Larger" for these same three pairs, pair location and instruction direction were regarded as being incongruent. Similarly, pair location and instruction direction were regarded as being congruent for the three larger stimulus pairs when the CVC was associated with the instruction "Larger," and incongruent when the CVC was associated with the instruction "Smaller."

Next, a measure of the speed of instructional access time was derived for each pair by subtracting the RTs for the conventional instructions from those for the corresponding CVC instructions. The plots in Figure 2 are clear in showing that this speed of instructional access measure is indeed contingent upon the congruency of the relative location of the stimulus pair and the direction of the instructions. The difference between RTs with the CVC and the conventional instructions is substantially and reliably larger [$F(1,15) = 14.63$, $MS_e = 101{,}053$] when pair location and instructional direction do not match than when they do (see also the corresponding curves in Figure 1A). As such, these findings clearly demonstrate that the ease of memory access to the underlying comparative instruction type by the CVC differs depending on the relative location of the stimulus pair.

Error analyses. The correlation between mean RTs and mean error rates in each of the 24 cells defined by the factorial combination of instruction format condition, instruction type, and stimulus pair was positive [$r = .642$; $t(23) = 3.93, p < .001$], indicating that no speed–accuracy trade-off took place. Although SCE effects were not evi-

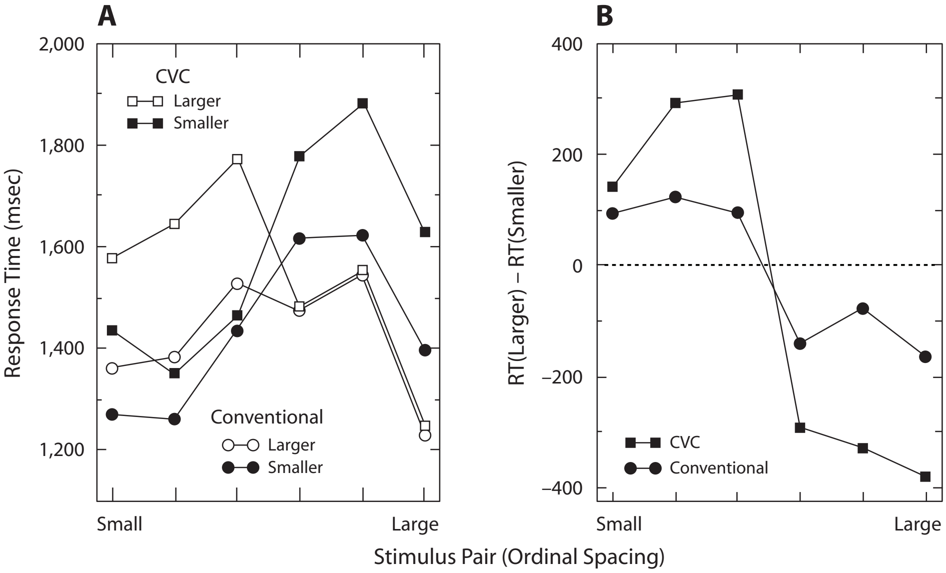

Figure 1. (A) Mean response times (RTs) with each instruction for each stimulus pair in the CVC and conventional instruction conditions in Experiment 1. (B) Semantic congruity index (RTs with the "Smaller" instruction subtracted from RTs with the "Larger" instruction) for each stimulus pair with the CVC instructions (squares) and the conventional instructions (circles) in Experiment 1.

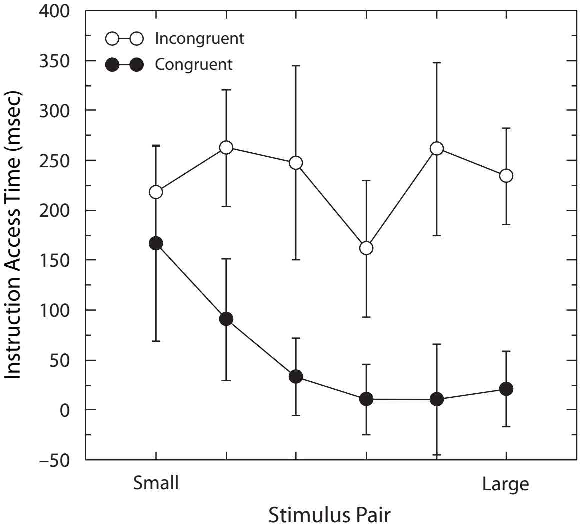

Figure 2. Speed of instruction access times for Experiment 1: RTs with conventional instructions subtracted from RTs with CVC instructions, for the cases in which pair location and instruction direction are either congruent or incongruent.

dent from the error data, the effects evident with the RTs generally also occurred with the error data. For example, more errors occurred with the CVC instructions (3.45%) than with the conventional instructions (1.66%), although this difference was not significant [$F(1,15) = 3.13$, $MS_e = 96.3$]. However, the error rates differed reliably across the pairs [$F(5,55) = 2.57$, $MS_e = 12.9$]. The error rate was lowest with the smallest animal pair (1.56%) and varied somewhat idiosyncratically over the remaining pairs. Using the arcsine-transformed error proportions as the dependent variable resulted in exactly the same statistical outcomes.

EXPERIMENT 2

With a view toward adding generality to the findings obtained in Experiment 1, strictly perceptual comparisons, with highly confusable pairs in the psychophysical tradition, were required. Participants compared the lengths of simultaneously presented visual extents using both conventional and CVC instructions, as in Experiment 1. The choice of confusable stimulus pairs was dictated by the fact that SCE magnitude with perceptual comparisons is largely dependent on the confusability of the stimulus pairs (see Petrusic & Baranski, 1989b). With errorless comparisons, for example, the SCE is minimal, on the order of 15–20 msec.

Experiment 2 was also designed to determine whether the SCE would also be enhanced by the CVC instructions in the perceptual domain. Replicating the findings in Experiment 1 with perceptual comparisons would strengthen the argument that common decisional processes underlie both symbolic and perceptual comparisons. Of course, Marschark and Paivio (1981) were clear in predicting, on the basis of their expectancy theory, that SCEs would not be obtained with strictly perceptual comparisons. In addition, finding clear and robust SCEs with both the CVC and the conventional instructions would provide further evidence of the limited applicability of the expectancy view, since it is unclear how an instruction might prime a sensory magnitude (see Petrusic, 1992; Petrusic & Baranski, 1989a, 1989b).

In Experiment 2, two separate sessions were required. The design thus provided an opportunity to examine the effects of both extended practice and additional CVC instruction learning trials on the magnitude of the SCE with CVC instructions. It might well be the case that extended practice and additional overlearning would strengthen the CVC–instruction association, so that CVC instructions would, in effect, behave more like the conventional instructions, and the enhanced SCE with CVC instruction would be considerably diminished.

Method

Participants. Twenty-one Carleton University students participated in two 50-min sessions to satisfy course requirements. All reported normal or corrected-to-normal vision.

Apparatus. The same apparatus was used as in Experiment 1.

Stimuli. Twelve horizontal lines were used as the stimulus set. Six lines were relatively short (10, 11, 20, 21, 50, and 51 pixels), and the other six were relatively long (147, 150, 200, 210, 250, and 252 pixels). Three pairs of relatively short lines (10–11, 20–21, 50–51) and three pairs of relatively long lines (147–150, 200–210, 250–252) were created. It is well known that the difficulty of comparative judgments can be effectively manipulated by varying the ratio of the longer to the shorter extent of the comparison pair (see, e.g., Münsterberg, 1894; Petrusic & Jamieson, 1979). The three short stimulus pairs are defined, in terms of difficulty, by the ratios 1.10, 1.05, and 1.02, respectively, and the ratios for the long pairs are 1.02, 1.05, and 1.008, respectively. All lines were drawn by Paintbrush software, were 1 mm wide, and appeared in black on a white background. The lines appeared at the respective centers of the left and right hemifields on the monitor.

The words "Longer" and "Shorter" and the same eight nonsense syllables as in Experiment 1 were used as instructions in a comparative judgment of line length task. The font size and the display locations for the instructions were the same as in Experiment 1.

Design and Procedure. Each session began with a learning phase in which the participants learned to associate each of the two instructional words ("Longer," "Shorter") with four of the eight CVCs, in the same manner as in Experiment 1. Following the learning phase, the participants were instructed that on each trial they would be presented with a pair of lines, one on the left and the other on the right, and either an instructional word or one of the CVCs they had learned to associate with the instruction words in the former phase. The participant's task was to press the mouse button on the side of the longer (or shorter) line, according to the presented instruction. The remaining aspects of the design were the same as in Experiment 1, with the six pairs of animal names replaced by the six pairs of line lengths. Each 50-min session included one planned break, which was ended by the participant. In addition, the two sessions were performed 3–4 days apart.

Results

As in the first experiment, the findings are presented in two sections, the first for RT analyses and the second for error rates. Given the relatively high error rate for each participant, as is expected with such perceptual comparisons, in all analyses the dependent variables are the mean RT for all responses and the mean percentage of errors in each cell of the design. In each ANOVA reported, the

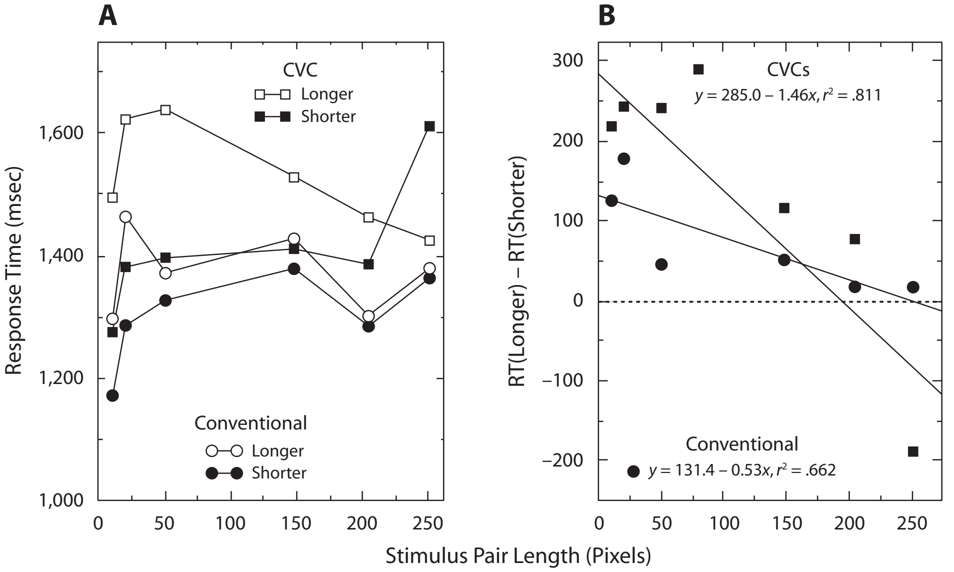

Figure 3. (A) Mean response times (RTs) with each instruction for each stimulus pair in the CVC and conventional instruction conditions in Experiment 2. (B) Semantic congruity index (RTs with the "Shorter" instruction subtracted from RTs with the "Longer" instruction) for each stimulus pair with the CVC instructions (squares) and the conventional instructions (circles) in Experiment 2. Linear regressions of the SCE index with mean stimulus pair length (in pixels) are also provided in panel B.

Huynh–Feldt epsilon adjustment of degrees of freedom was used. However, the degrees of freedom associated with each value of *F* are those defined by the design, and the MS_es provided in the text are those given by the conventional degrees of freedom. Again, all reported reliable effects were significant at the .05 level.

RT analyses. An ANOVA with the six pairs, the two instruction types, the two instruction format conditions, and the two sessions as factors showed the instructional manipulation to be effective. The main effect of instruction format was statistically reliable [$F(1,20) = 12.03$, $MS_e = 369{,}430$]. On average, the RTs were 1,337 and 1,469 msec with the conventional and CVC instructions, respectively. In addition, participants were 95 msec faster with the instruction to choose the shorter line, and this reverse lexical markedness effect was statistically reliable [$F(1,20) = 18.41$, $MS_e = 122{,}834$]. Comparisons varied systematically as a function of both the stimulus ratio and the difference, and the main effect of pair [$F(5,100) = 3.35$, $MS_e = 159{,}530$] was statistically reliable. For the shorter pairs, RTs were 1,309, 1,438, and 1,433 msec for pairs with the ratios 1.10, 1.05, and 1.02, respectively. For the longer pairs, the RTs were 1,357, 1,436, and 1,445 msec for pairs with the ratios 1.05, 1.02, and 1.008, respectively. Finally, RTs were reliably faster [$F(1,20) = 4.67$, $MS_e = 3{,}073{,}635$] in the second session (1,284 msec) than in the first session (1,522 msec).

The overall SCE was statistically reliable [$F(5,100) = 7.46$, $MS_e = 476{,}377$]. Importantly, the three-way interaction involving instruction format condition, stimulus pair, and instruction type was reliable [$F(5,100) = 3.22$, $MS_e = 57{,}706$], confirming the enhancement of the SCE with the CVC instructions relative to the conventional instructions, as is evident from the plots provided in Figure 3.[2] SCEs also remained uniform across the two sessions. The three-way interaction involving session, stimulus pair, and instruction type was not reliable ($F < 1$). In addition, the enhanced SCEs with CVC instructions were evident in both sessions and did not differ across the two sessions [the four-way interaction involving session, instruction format condition, stimulus pair, and instruction type was not reliable; $F(5,100) = 1.01$, $MS_e = 51{,}399$]. However, the three-way interaction involving session, instruction format condition, and stimulus pair proved to be reliable [$F(5,100) = 3.39$, $MS_e = 61{,}338$]. The differences between the two instruction format conditions were, in fact, increased for the relatively longer line pairs in the second session, but they diminished in the second session for the relatively shorter line pairs.

Pair location and instruction direction congruency: Speed of instructional access. As in the first experiment, pair location and direction of instruction congruency or incongruency were defined according to the match or mismatch, respectively, between the relative lengths of the line pairs and instruction type. However, because only the longest pair of lines showed an SCE with faster times to select the longer than the shorter line (see Figure 3), only this pair was examined in this analysis. As is evident from the plots in Figure 4, the difference between RTs with the CVC and the conventional instructions is substantially and reliably larger [$F(1,20) = 5.91$, $MS_e = 138{,}846$] for incongruent than for congruent cases, precisely as in Experiment 1.

Error analyses. As in Experiment 1, there was no evidence of a speed–accuracy trade-off [$r = .340$; $t(23) =$

1.69, $p < .10$ (two-tailed)]. Participants made fewer errors with the conventional instructions (31.53%) than with the CVC instructions (33.05%), mirroring the pattern obtained for RTs [$F(1,20) = 6.71$, $MS_e = 86.8$]. In addition, as with RTs, the error percentage varied systematically with stimulus pair ratio and with difference when the ratio was held constant [$F(5,100) = 73.07$, $MS_e = 237.9$], precisely as reported in Münsterberg (1894) and Petrusic and Jamieson (1979). For the short pairs, the error rates were 18.3%, 27.2%, and 40.9% for the pairs with the ratios 1.10, 1.05, and 1.02, respectively. For the long pairs, error rates were 25.6%, 36.7%, and 44.9% for the pairs with the ratios 1.05, 1.02, and 1.008, respectively. No other main effects or interactions attained statistical significance. As in the first experiment, arcsine-transformed error proportions resulted in exactly the same statistical outcomes.

DISCUSSION AND CONCLUSIONS

The present findings converge nicely with work reported in Shaki, Leth-Steensen, and Petrusic (2006). Those researchers showed, in each of two experiments requiring symbolic comparisons of animal size, that SCEs were enhanced when the instructions varied randomly from trial to trial, as compared with when they were kept constant over a block of trials. The authors argued that their findings were not permitted according to any of the single-sample (e.g., semantic coding, expectancy, or reference point) views of the SCE. Rather, precisely as in the present experiments, the enhanced SCE with the randomized instructions arose, in the context of the various evidence-accrual theories, because the greater memory demands with the randomly varying instructions slowed the rate of accrual.

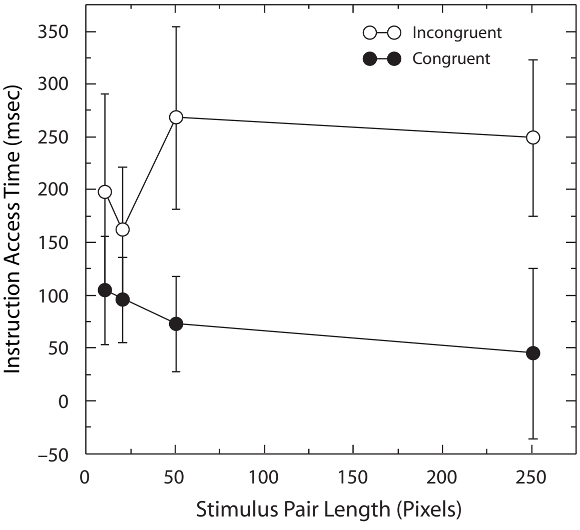

Figure 4. Speed of instruction access times for Experiment 2: RTs with conventional instructions subtracted from RTs with CVC instructions, for the cases in which pair location and instruction direction are either congruent or incongruent.

As such, the present findings are also both clear and not consistent with the single-sample (additive-stage) expectancy, semantic coding, and reference point theories of the SCE. As indicated, each of these views of the SCE, although it predicts increases in RTs with the CVC instructions, clearly also predicts that the SCE should be the same with the CVC and the conventional instructions, contrary to the enhanced SCE that was observed with the CVC instructions.

Modifications of the Single-Sample Theories

Of course, once generalized short-term or working memory limitations are assumed and these theories are viewed somewhat differently, perhaps in broader and more flexible terms, they could be modified to provide an account of most of the present findings, albeit post hoc.

Semantic coding theory. For example, with Banks's (1977) semantic coding theory, if it is assumed that the increased memory load in the CVC instruction condition slows not only the semantic code activation and code-matching processes, but also the code translation process, enhanced SCE effects would then follow from such a view.

Reference point and expectancy theories. It is not clear how short-term memory limitations might be invoked with either reference point or expectancy theory, nor how they might be altered, other than to map them into an evidence-accrual view. Moreover, the expectancy notion might well be more effectively recast in an evidence-accrual activation account.

Evidence-Accrual Extensions of the Single-Sample Theories

Semantic coding theory. This single-sample theory might well be recast in the context of an evidence-accrual view, albeit not so easily nor very successfully. Two possible views are feasible. For the first, the accrual process occurs at the level of the code generation process, and upon reaching criterion in favor of one code or the other, access to the instructional format ensues, and the code match or mismatch that is the basis of the semantic coding theory arises. Enhanced SCEs follow, as in the single-sample case, from the assumption that the increased demands on memory for the instruction slow the code-matching and code translation processes. This postdecisional response translation notion, however, is clear in predicting smaller SCE effects in RTs for error responses than for correct responses, as derived by Petrusic and Cloutier (1992), contrary to the clearly larger observed SCEs on error trials than on correct trials (Petrusic, 1992; Petrusic & Baranski, 1989a, 1989b).

In a second, somewhat implausible but logically possible, view, the code-matching process might occur at the level of each accrual. However, as Petrusic (1992, p. 967) showed, the viability of this SCE-based view depends entirely on the effectiveness of code translation on each accrual. If code translation occurs probabilistically, say with probability t on each accrual, it can be shown, using the equations for RT and accuracy developed in the context of Petrusic's SFGT, that whenever t is different from 1, a reduction in discriminative accuracy with the incongruent instruction will be obtained (i.e., an SCE for the percent correct measure). Thus, under conditions emphasizing speed at the expense of accuracy, where failures of code translation are quite likely, SCE will be especially evident with the percent correct measure but reduced with RTs. Petrusic did indeed show reduced RT-based SCEs, but he found no effect of speed stress on discriminative accuracy, contrary to this accrual view of semantic coding theory.

Reference point theories. Petrusic (1992, pp. 964, 966) was explicit in assuming that each accrual involved activation of the appropriate reference points, as well as in assuming a number of other steps in the process: computation of distances from the reference point to the points on the continuum representing the stimulus magnitudes, calculation of the ratio of these distances, comparison of that ratio to a criterion, and the registration and incrementing of the appropriate accumulator. The enhanced SCE with CVC instructions follows from the assumption that activation of reference points is substantially slowed with the CVC instructions, thus slowing each accrual. However, both the single-sample and the evidence-accrual versions of the reference point idea are clear in predicting that SCEs should be clearly evident with measures of the accuracy of discrimination. In contrast, as noted earlier, SCEs in our experiments were evident only with RTs (and confidence ratings; see Petrusic, 1992; Petrusic & Baranski, 1989a, 1989b).

Expectancy theories. The instructionally based semantic priming idea at the heart of expectancy theory might well be cast in terms of activation from evidence accrual. Instructionally based priming then might be likened to the accumulation of evidence (activation) according to either an accumulator or a diffusion-based decision process. On this view, the SCE arises because the priming-based activation of one alternative over the other rises more slowly with incongruent instructions. The enhanced SCE with CVC instructions follows from the assumption that activation grows more slowly with the CVC instructions.

Instructional Access As the Locus of the SCE

However, all of the aforementioned evidence-accrual accounts could be regarded as being incomplete, because the present experiments are quite clear in showing that overall RT increases associated with the CVC instructions relative to the conventional ones are due mainly to differences between these two instruction conditions in cases in which the relative location of the stimulus pair and the direction of the instruction are semantically incongruent. When they are semantically congruent (i.e., as in choosing the smaller of two small animals or choosing the larger of two large animals), the effect of CVC instructions is either dramatically reduced or eliminated altogether (see Figures 2 and 4). This result strongly suggests that the speed with which an instruction is accessed upon presentation of a CVC depends on whether its direction is congruent or incongruent with the relative location of the stimulus pair. More specifically, it suggests that congruency of instruction direction and pair location serves to facilitate CVC instructional access and, conversely, that incongruency serves to impede such access (i.e., semantic interference).

SCE and accrual duration: Petrusic (1992) revisited. A natural extension of this idea, that congruency of instruction direction and pair location facilitates CVC instructional access, would be to posit, more generally, that speeds of access to the underlying instructional representations associated with the conventional instructions are also controlled by the relative location of the stimulus pair. If, on each pass through the evidence-accrual process, activation of the instructional representation is facilitated when instruction direction and pair location match and slowed when they do not, SCEs would arise as a natural consequence. In addition, and most importantly, this view is clear in merely extending the duration of each accrual when instruction direction and stimulus pair location are incongruent, without altering the quality of the information on which the decision is based. As a consequence, this view is entirely in accord with failures to find SCEs with the discriminative accuracy measure, contrary to all of the other extant theories of the SCE.

Semantic facilitation and the Leth-Steensen–Marley pathway interference model. The notion of semantic facilitation is consistent with the instructional redintegration idea that Čech (1995) posited in his reexamination of Duncan and McFarland's (1980) findings. The notion of semantic facilitation of instructional access is consistent with the view currently taken by some task-switching researchers, that the activation of task sets (i.e., to choose the smaller or the larger item, in the present case) can involuntarily be elicited by the task stimuli themselves (Koch & Allport, 2006). Given such a notion, it then becomes important to determine why this priming occurs. In their discussion of stimulus-based priming of task sets, Koch and Allport proposed that such priming arises because "individual task stimuli become implicitly associated with the tasks and task contexts in which they have previously occurred" (p. 434). Although this account is an intuitively compelling one, given that real-world comparisons of small things (for instance) are invariably made according to which is smaller, such an account does not then provide an explanation for the robustness of semantic congruity effects in paradigms employing artificially learned linear ordering with equal presentations throughout of both forms of the instruction for all pairs (e.g., Leth-Steensen & Marley, 2000), as well as for the fact that the pattern of semantic congruity effects obtained for a particular fixed set of stimulus items can depend contextually on the range of stimuli presented within an experiment (in that the SCE for, say, moderately small pairs can reverse, depending on whether a pair is among the largest ones presented; Čech & Shoben, 2001).

It is possible, though, that such stimulus-based priming of the comparative instructions is mediated by the use of categorical labeling of the stimulus items, whereby the determination that, say, the flea–crab pair comprises two small things would then facilitate the configuration of the task set to choose the smaller. Under such an account, the present findings could then be regarded as providing some converging evidence in support of an explicit role for categorization in comparative judgments, as argued by symbolic comparison researchers such as Čech and Shoben (2001). Importantly, the present findings reveal clearly that these categorization processes occur with *both* perceptual and symbolic comparisons, suggesting common decisional processes in the two domains.

It is also possible, however, that a categorical-like coding of the stimulus items could arise as a consequence of processing mechanisms, such as those in the model of symbolic comparison proposed by Leth-Steensen and Marley (2000). In that model, it is assumed that information about the potential end-point status of the items in a comparison pair is determined according to a similarity transformation of the distance of the item magnitudes from upper and lower anchor reference points. Because it is important to keep track of which end of the continuum each end point refers to within any particular experimental context, in order to map the evidence associated with those similarity values onto the appropriate responses, Leth-Steensen and Marley argued that the similarity values themselves end up conveying information about, say, either the smallness or largeness (i.e., with respect to the present Experiment 1) of the stimulus items. This information is then assumed to moderate the degree of instructional pathway competition within the model by enhancing the activation of the pathway associated with the congruent instruction relative to the activation of the pathway associated with the incongruent one. This enhancement leads to a fairly robust competition, or interference, between instructional pathways whenever the incongruent instruction is, in fact, the relevant one. As explicitly stated by Leth-Steensen and Marley,

> [semantic] interference effects could arise either because such information leads to a form of implicit response competition . . . or, perhaps, because such information interferes with [or facilitates] the construction and maintenance of the internal representation of the context [i.e., task set] provided by the comparative instruction. (p. 85)

Clearly, the second of these two notions is the theory most supported by the present findings.

AUTHOR NOTE

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NOTES

1. As a check of whether the enhanced SCE with CVC instructions might have arisen as an artifact of more outliers in the CVC instruction condition than in the conventional instruction condition, two additional analyses were conducted. First, RTs longer than three standard deviations above the mean were censored. This resulted in cutting off 1.84% of the 5,987 observations, and an ANOVA with mean correct RTs as dependent variable was conducted. Precisely the same reliable effects were obtained as appeared with the outliers present. In particular, the critical three-way interaction involving instruction format condition, stimulus pair, and instruction type was still reliable [$F(5,75) = 4.87$, $MS_e = 16{,}982$]. Second, the ANOVA was repeated with median RTs (without censoring) as the dependent variable. This ANOVA also resulted in precisely the same reliable effects as with means. Notably, the three-way interaction defining the enhanced SCE with CVC instructions was still reliable [$F(5,75) = 4.89$, $MS_e = 24{,}033$].

2. As in the first experiment, RTs longer than three standard deviations above the mean were censored, resulting in a loss of 2.08% of the overall 16,128 observations. In the ANOVA with overall RTs, the critical three-way interaction involving instruction format condition, stimulus pair, and instruction type was still reliable [$F(5,100) = 2.77$, $MS_e = 9{,}984$]. Second, the ANOVA was conducted with median RTs (not censored), and here the critical three-way interaction failed to attain significance [$F(5,100) = 1.88$, $MS_e = 29{,}936$]. However, contrary to expectation, as the plots in Figure 4 show, the two shortest of the a priori long lines fail to show the expected SCE. Hence, an ANOVA with just the three short lines and the longest line pair was conducted with median RTs as the dependent variable. This ANOVA did result in a significant three-way interaction of instruction format condition, stimulus pair, and instruction type [$F(3,60) = 2.81$, $MS_e = 32{,}781$].

APPENDIX

The probability of the response R_1 is given by

$$P(R_1) = \sum_{s=0}^{\alpha_2-1} \sum_{t=0}^{\alpha_3-1} \frac{(\alpha_1+s+t-1)!\,p_1^{\alpha_1} p_2^s p_3^t}{(\alpha-1)!\,s!\,t!} + g \sum_{s=0}^{\alpha_1-1} \sum_{t=0}^{\alpha_2-1} \frac{(\alpha_3+s+t-1)!\,p_1^s + p_2^t + p_3^{\alpha_3}}{(\alpha_3-1)!\,s!\,t!}, \tag{1}$$

where s and t in the top portion of Equation 1 denote the number of evidence-accrual events in the counters that favor responses R_2 and R_3, respectively. In the lower part of Equation 1, s and t denote the numbers of evidence-accrual events favoring responses R_1 and R_2, respectively.

The expected number of evidence accruals conditional on the occurrence of the overt response R_1 is given by

$$E(N \mid R_1) = \left[\sum_{s=0}^{\alpha_2-1} \sum_{t=0}^{\alpha_3-1} \frac{(\alpha_1+s+t)!\,p_1^{\alpha_1} p_2^s p_3^t}{(\alpha_3-1)!\,s!\,t!} + g \sum_{s=0}^{\alpha_1-1} \sum_{t=0}^{\alpha_2-1} \frac{(\alpha_3+s+t)!\,p_1^s p_2^t p_3^{\alpha_3}}{(\alpha_3-1)!\,s!\,t!} \right] \Big/ P(R_1). \tag{2}$$

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