Long-term memory for elementary visual percepts: Memory psychophysics of context and acquisition effects

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In the first phase of each of two experiments, participants learned to associate a set of labels (i.e., consonant–vowel–consonant [CVC]) with a set of line lengths by using a paired-associate learning procedure. In the second phase of each experiment, these learned labels were used as memorial standards in the method of constant stimuli. Psychometric functions and the associated indices of discriminative performance (i.e., Weber fractions [WFs], just noticeable difference, and point of subjective equality) were then obtained for the remembered standards. In Experiment 1, WFs (i.e., the indices of memory precision) obtained with remembered standards were found to be higher (i.e., had poorer discriminability) than were WFs obtained with perceptual standards. In addition, WFs obtained with the remembered standards exhibited serial position effects (i.e., poorer discriminability for central items in the memory ensemble) and systematically varied with set size (i.e., the number of standards in the memory set), but WFs obtained with perceptual standards did not depend on serial position or set size. In Experiment 2, increasing the number of acquisition trials reduced WFs and diminished serial position effects. In addition, WFs did not vary systematically with the “physical” spacing between the standards in memory, but they did with the ordinal spacing. The results are consistent with a *noisy analogue* representation of remembered magnitudes, whereby central items in a memory ensemble are subject to lateral inhibition and thus reduced discriminability. Finally, presentation order effects, as defined by the classic time-order error, were observed with purely perceptual comparisons but not with comparisons involving a remembered standard. This latter finding is inconsistent with a strong form of the *functional equivalence* view of perception and memory.

Since the raw material of sensory ideas consists in every case of centrally aroused sensations, it is natural for memory to obey Weber’s Law in every instance in which the law holds for the corresponding peripheral sensations.
(Titchener, 1906, p. 286)

There has been interest in the relation between perception and memory since the beginning of experimental psychology (e.g., Bentley, 1899; Hayden, 1906; Hegel-

maier, 1852; see also the translation of Hegelmaier’s classic work by Laming & Laming, 1992). Contemporary avenues of inquiry on this topic have taken many directions, including well-known work on the nature of the memorial representation (e.g., Finke, 1985; Kosslyn, 1980; Pylyshyn, 2002; Shepard, 1987), the properties of decay in short-term perceptual memory (e.g., Blake, Cepeda, & Hiris, 1997; Blick, 1969; Kinchla & Smyzer, 1967; Laming & Scheiwiller, 1985; Magnussen & Greenlee, 1992; Palmer, 1990), and time-order errors (e.g., Hellström, 1985; Schab & Crowder, 1988). In parallel with classical lines of research in perceptual psychophysics, another, more recent line of research has sought to provide a quantitative characterization of long-term memories of perceptual magnitudes through the application of classical psychophysical methods and procedures to remembered stimuli. Accordingly, this line of research has come to be known as *memory psychophysics* (for reviews, see Algom, 1992; Baird, 1997; Hubbard, 1994).

Largely influenced by the pioneering work of Björkman, Lundberg, and Tärnblom (1960), a major thrust of memory psychophysics research to date has been the

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study of memory-based magnitude estimation and psychophysical scaling (e.g., Algom, 1992; Algom & Cain, 1991; Algom, Marks, & Cain, 1993; Bradley & Vido, 1984; Hubbard, 1994; Kerst & Howard, 1978; Moyer, Bradley, Sorensen, Whiting, & Mansfield, 1978; Moyer, Sklarew, & Whiting, 1982; Ward, 1987; Ward, Armstrong, & Golestani, 1999). Other notable areas of memory psychophysics research include multidimensional scaling analyses based on perceived and remembered judgments of similarity (Shepard & Chipman, 1970), functional measurement analyses of remembered areas (e.g., Algom, Wolf, & Bergman, 1985; Wolf & Algom, 1987), fundamental measurement analyses based on quaternary relational judgments (similarity comparisons) with remembered magnitudes (Petrusic & Aubin, 1998; Petrusic, Baranski, & Kennedy, 1998), chronometric research examining the properties of response times with perceived and remembered magnitudes (e.g., Banks, Mermelstein, & Yu, 1982; Moyer, 1973; Moyer & Bayer, 1976; Petrusic, Baranski, & Aubin, 1998), and comparative judgment research examining the discriminability and precision of remembered magnitudes (Baranski & Petrusic, 1992; Magnussen & Dyrnes, 1994; Petrusic & Baranski, 2002).

Although some notable memory psychophysics experiments have required judgments on the basis of naturalistic stimulus materials, such as map distances (Chew & Richardson, 1980; Kemp, 1988; Kerst & Howard, 1978; Kerst, Howard, & Gugerty, 1987; Shepard & Chipman, 1970), geographical distances (Bradley & Vido, 1984; Ekman & Bratfish, 1965), the sizes of common objects (Moyer et al., 1982), and labor pain (Algom & Lubel, 1994), the overwhelming majority of studies have employed a two-step procedure involving a preliminary learning phase followed by a psychophysical judgment phase. The latter methodology was first employed in Björkman et al.'s (1960) landmark study involving ratio estimation and production and has since been used in memory psychophysics paradigms involving magnitude estimation (e.g., Algom & Cain, 1991; Algom et al., 1993; Moyer et al., 1978), fundamental measurement (Petrusic, Baranski, & Kennedy, 1998), chronometric studies (e.g., Banks, 1977; Banks et al., 1982; Birnbaum & Jou, 1990; Kosslyn, Murphy, Bemesderfer, & Feinstein, 1977; Moyer & Bayer, 1976), and comparative judgment research (Baranski & Petrusic, 1992; Petrusic, Baranski, & Aubin, 1998). The objective of the procedure is to present the participant with a (typically small) set of perceptual magnitudes and to have the participant learn to identify these items errorlessly through a paired-associate learning procedure. Once learned, the stimuli are then used in a subsequent psychophysical task via their associated labels (e.g., letters, colors, or consonant–vowel–consonant [CVC] letter strings; e.g., *GUF*).

In their experiments examining the status of Weber's law with remembered magnitudes, Baranski and Petrusic (1992) applied the classic method of constant stimuli paradigm (Hegelmaier, 1852; Laming & Laming, 1992) with remembered standards to determine, directly, the

precision and the accuracy of long-term memory representations of perceptual stimuli. In the first phase of their experiments, three highly discriminable lines (10, 100, and 200 mm) were first associated with CVC syllables using the paired-associate learning procedure. In the second phase, which required comparative judgments, each of the CVCs was presented as a standard along with a range of variable perceptual comparison stimuli (i.e., $\pm 3\%$ and $\pm 6\%$ for each standard). On half of the trials, participants indicated which was longer, the line or the line represented by the CVC, and on the other half of the trials they indicated which was shorter. This condition was contrasted with a purely perceptual condition, in which the standards were the actual physical referents (i.e., the 10-, 100-, and 200-mm lines). Psychometric functions were then obtained for each participant with each perceptual and remembered standard (*St*) to obtain estimates of the just noticeable difference (JND), Weber fraction ($WF = JND/St$), and point of subjective equality (PSE).

Baranski and Petrusic (1992) found that WFs were larger with the symbolic remembered standards (7.0%) than with their perceptual referents (4.1%). This suggested that, although the remembered standards were sufficiently precise (i.e., analogue) to permit the determination of a WF, they were in fact less discriminable (i.e., were noisier) than were their perceptual referents. Moreover, Weber's law held for the purely perceptual comparisons but not for comparisons involving the remembered standards, which stands in contrast to Titchener's (1906) assertion. Specifically, memory WFs showed a bowed serial position effect, suggesting that the fidelity and precision of the central item ($WF = 9.2\%$) in the memory set was reduced relative to the longest ($WF = 4.2\%$) and the shortest ($WF = 7.6\%$) remembered standards.

Baranski and Petrusic (1992) argued that their findings provided support for the view that the representations of long-term memories of unidimensional percepts (e.g., visual extents) are organized in an array that preserves an analogue scaling of the associated perceptual representations (e.g., Petrusic, Baranski, & Kennedy, 1998; Shepard & Chipman, 1970) but with decreased precision and fidelity (i.e., a *noisy analogue* view). The exact nature of the memory representation is, of course, controversial and theoretically can take on various forms, but this is also true of perception. Indeed, one conceptualization of the noisy analogue view follows directly from assumptions developed in the perceptual domain. Following the classic work of Hubel and Wiesel (1962) and Konorski (1967), Martindale (1991) extended the application of the neural-network approach to the conceptual level. According to this view, memory "analyzers" are subject to the same principles of vertical excitation and lateral inhibition as are perceptual analyzers. Indeed, Deutsch (1972) and Deutsch and Feroe (1975) have presented impressive evidence in support of the view that short-term memory for "tone height" is organized in terms of an array of elementary analyzers subject to lat-

eral inhibition and disinhibition (see also Bennett & Cortese, 1996, for evidence in the visual domain). In addition, studies of cell recordings in monkey temporal cortex have provided evidence of neuronal selectivity of activation following paired-associate learning of visual stimuli (Miyashita, 1988; Sakai & Miyashita, 1991).

We assume here that these principles of lateral inhibition and excitation operate on the stored representations of the label-percept associations. According to one conceptualization of this view, perceptual and remembered standards are represented by nonoverlapping Thurstonian, Gaussian density functions, but memory representations are assumed to have increased variance and, hence, are a noisy analogue of the perceptual representation of the standard. The property of *nonoverlapping distributions* denotes that the memory standards are not confusable among themselves. Indeed, this property should be contrasted with the *positional discriminability* model developed by Holyoak and Patterson (1981) for perceptual linear orderings. On the basis of that view, distributions are assumed to be of equal variance and overlapping. This latter model is not applicable here, precisely because the memory standards are supraliminal and thus can be perfectly identified through learning. Rather, the noisy analogue model posits that the serial position effect emerges because the central item in the memory ensemble is of poorer quality (i.e., increased variance) than are the longest and the shortest of the memory standards.

OVERVIEW OF THE EXPERIMENTS

Context and Acquisition Effects

With the present research, we sought to extend our earlier work by examining three manipulations that are predicted to have well-defined effects on the precision and fidelity of the memorial representation, as assumed by the noisy analogue position. In Experiment 1, we sought to determine the precise dependence of the quality of the representation in memory on the number of elements in memory (i.e., on memory set size). Although set-size effects are well-documented in short-term memory search (e.g., Schneider & Shiffrin, 1977; Sternberg, 1966), distractor paradigms (e.g., Melton, 1963), long-term memory (e.g., Atkinson & Shiffrin, 1971), visual search (e.g., Palmer, 1995; Treisman & Gelade, 1980), and in the classic serial list learning paradigms (see Johnson, 1991, for a review and a theory), they have yet to be addressed in the context of memory psychophysics. According to the noisy analogue view, increasing the memory set size should have an antagonistic effect on the precision and fidelity of the memorial representation due to an increase in the amount of lateral inhibition among memory analyzers. Importantly, because perceptual representations are assumed to be much more finely tuned than memorial representations, increasing the set size will have no effect in the case of purely perceptual comparisons.

In Experiment 2, we examined the effects of varying the range (i.e., spacing) of memory standards and the

amount of learning trials preceding the comparative judgment task. Decreasing the stimulus range (i.e., narrowing the spacing among memory items) should increase the amount of lateral inhibition among the memory standards and thus decrease the precision of the memory representations, particularly for the central items in the memory ensemble. In contrast, increasing the amount of learning trials should increase the fidelity and precision of the memorial representations, reducing the amount of lateral inhibition among the memory standards and thus rendering them more finely tuned (i.e., perceptual-like). The result should be the elimination or, at the least, a dramatic reduction in magnitude of the serial position effect.

Presentation Order Effects

A second objective of the present studies was to examine further the role of stimulus presentation order when comparison involves a perceptual and a remembered standard. With strictly perceptual comparisons, Fechner (1860/1966) was the first to document that merely changing the order of presentation could have profound effects on discriminative accuracy. For example, with the lightest (300- and 312-g) pair in the set, discriminative accuracy was 61.7% correct when the heavier weight was presented first and 55.6% correct when the heavier weight was presented second. On the other hand, with the heaviest weights (3,000 and 3,120 g), only 49.7% of the judgments were correct when the heavier weight was presented first, but 80.6% of the comparisons were rendered correctly when the heavier weight was presented second. Since Fechner's landmark studies, these presentation order effects, or *time-order errors* (TOEs), as they are now more commonly known, have come to be a hallmark of perceptual comparisons with successively presented stimuli (for reviews, see Hellström, 1985, and Jamieson & Petrusic, 1975).

In their study, Baranski and Petrusic (1992) found, as was expected, that purely perceptual comparisons demonstrated TOEs, but surprisingly, comparisons with the remembered standards did not. According to positions espousing a strong functional equivalence relation between perception and memory (e.g., Farah, 1985; Finke, 1980, 1985; Martindale, 1991), discriminations with remembered standards should exhibit all of the properties typically associated with perceptual stimuli, because top-down activation from semantic analyzers can trigger activity in associatively linked perceptual analyzers. Accordingly, the present studies will provide further tests of the functional equivalence notion.

EXPERIMENT 1

Method

Participants

Thirty Carleton University honors and/or graduate students were paid a flat rate of \$25 (Canadian) for participating in two experimental sessions, each with a duration of approximately 90 min. All the participants were naive with respect to the purposes of the experiment.

Apparatus

The stimuli were presented on an Amdek-310A video monitor. High-resolution graphics were permitted with a Hercules monochrome card and MetaWindows graphics under Turbo Pascal software control. Graphics production, presentation of instructions and stimuli, event sequencing and timing, and the recording of responses and response times were controlled with an IBM-PC/XT clone computer interfaced with a Data Translation clock board and with extensive software development. Responses were made by using the buttons on an IBM-PC mouse.

Stimuli

Three horizontal lines (31.95, 106.39, and 148.88 mm) were used as standards in the set size 3 condition, and the standards in the set size 6 condition were 10.54-, 31.95-, 63.90-, 106.39-, 148.88-, and 202.27-mm long horizontal lines. In order to obtain points on the psychometric function, the method of constant stimuli was used, with comparison stimuli differing by -6%, -3%, 0%, 3%, and 6% from each standard. All lines were 1 mm wide and appeared in amber color on a black background. The midpoint of each line was horizontally and vertically centered on the screen.

The participants were seated in a dimly lit room approximately 60 cm from the video screen, with the shortest and longest lines subtending visual angles of approximately 1° and 10°, respectively.

Procedure and Design

Each of the two sessions consisted of two parts. In the first phase of each session, the participants learned to associate each of the line-length standards with specific letter triads (e.g., for set size 3, *CED*, *JIB*, and *NAD*; for set size 6, *GOZ*, *CED*, *SEF*, *JIB*, *NAD*, and *WUM*). For both set sizes, three counterbalanced orders were used so that the orderings used for set size 6 corresponded with those used for set size 3; the remaining three elements were counterbalanced according to a Greco-Latin square.

On each learning trial, the participants were presented with one of the line standards, below which was a rectangular box divided into three (six) equal squares, in which the three (six) possible CVCs appeared (in a random order on each trial). By moving the PC mouse from side to side, the participants were able to illuminate, in succession, any one of the CVC-containing squares. The participants depressed the middle key on the mouse when they assumed the appropriately illuminated CVC to correspond to the presented line length. The participants had 5 sec to perform the association. If this time was exceeded, "Too Slow" appeared on the screen, and the appropriate box was illuminated for the participant for a period of 2,000 msec. If the participants responded under the time limit but were incorrect, the appropriate box was illuminated for 2 sec.

In the set size 3 condition, if a participant did not make the correct association to any one of the line-CVC pairs in a block of nine trials (with each of the three CVC-line pairs appearing three times in a different random order from block to block), additional blocks were presented until an errorless block was obtained. In the set size 6 condition, blocks were defined by a set of 18 line-CVC pairs, again with each of the 6 line-CVC pairs occurring three times in the block, with a different random ordering in each block. To try to ensure that both the set size 3 and the set size 6 standards would be maintained in memory with sufficient accuracy to permit obtaining a psychometric function on the basis of above chance performance, substantial amounts of overlearning were used. Thus, after reaching the learning criterion, 30 additional overlearning trials with each CVC standard were presented.

All the participants were instructed to attend very closely to the magnitudes of the line lengths they were learning since they would use this information in the next part of the experiment.

After the learning phase, in the comparative judgment task, the participants were verbally instructed that on each trial they would be presented, in succession, with two horizontal lines, a line and a CVC, or a CVC and a line.¹ In each case they were to select, according to the instruction, either the longer or the shorter of the two

presentations. In the case of either a line-CVC or a CVC-line presentation, the CVC was to correspond to the line length learned in the previous phase of the experiment. For all trials, the left button on the mouse corresponded to the stimulus presented first and the right to that presented second, relative to the instruction. The participants were asked to be as accurate as they could while not taking too much time to respond.

The participants were randomly assigned to either the set size 3 or the set size 6 condition, with 15 participants in each group. Over the course of the two sessions, the participants in each group made a total of 720 comparative judgments, half of these with perceptual standards and the other half with remembered standards. In each case, in each block, the various standards and their associated variable stimuli were intermixed.² In the first session, the participants in each group performed a block of 240 trials, and they performed two blocks of 240 trials in the second session. Each block was subdivided into two subblocks of 120 trials. A brief rest was permitted after each subblock.

For the set size 3 group, each of the three standards appeared 40 times in each block; that is, 20 times as a physical standard and 20 times as the remembered standard (CVC). The 20 presentations with either the perceived or remembered standard arose from the factorial combination of the two possible presentation orders (standard first, standard second), five variable comparison stimuli, and two instructions (*longer* or *shorter*). Each of the 40 cells in the design (two types of standards, five variable stimuli, two instructions, and two presentation orders) was replicated six times, resulting in the block of 240 trials. Consequently, each point on the psychometric function for each type of standard was based on 24 observations for each participant.

For the participants in the set size 6 condition, the block of 240 trials was composed of 120 trials with perceptual standards and 120 trials with remembered standards. The 120 trials with each type of standard arose from the factorial combination of six standards, five variable stimuli, two presentation orders, and two instructions. Thus, over the two sessions, after combining the data over the two presentation orders and the two instructions, each point on the psychometric function was based on 12 observations for each participant in the set size 6 condition.

The order of the presentation of the cells in the design was randomized in subblocks of 120 trials for the set size 3 group and in subblocks of 240 trials for the set size 6 group, with each participant receiving a different randomization.

Each trial began with the presentation of an instruction (*longer* or *shorter*), which remained centered near the top of the screen throughout the trial. One second after the instruction appeared, the first stimulus was presented for 2,000 msec and was then removed. Following a 500-msec interstimulus interval (ISI), the second stimulus was presented and remained on the screen until the completion of the comparative judgment. Following the response, the screen was cleared and the participants were given a visual prompt to provide a confidence rating that was to indicate their subjective probability that the comparative judgment just rendered was correct. The participants typed a confidence value (0-100) on the PC keyboard and then depressed the Enter key to record the confidence report and initiate the next trial.³ The participants operated under a 10-sec deadline. If this was exceeded, the statement "Too Slow" appeared following the response. Two seconds separated the registration of confidence and the next trial. The participants were not provided with accuracy feedback at any point during the task.

Results and Discussion

The findings will be presented in three sections. The first section will provide a summary of the acquisition data. The second section will provide analyses of the group- and individual-based psychometric functions. Finally, the third section will explore presentation order ef-

fects with remembered standards. Throughout this article, statistical significance was set at the 0.05 level, and the Huynh–Feldt epsilon correction was used to adjust for potential violations of compound symmetry assumptions.

Acquisition Data

As was indicated earlier, to permit comparability of the ease of acquisition between set size 3 and set size 6, the number of blocks required to reach the learning criterion served as the dependent variable in analyses of the acquisition data. The blocks were defined by 9 trials in set size 3 and by 18 trials in set size 6. Not too surprisingly, significantly more learning blocks [$F(1,28) = 22.13$, $MS_e = 9.45$] were required with the set size 6 standards ($M = 5.57$, $SD = 5.85$) than with the set size 3 standards ($M = 1.83$, $SD = 1.76$). Also as was expected, significantly fewer acquisition blocks [$F(1,28) = 39.66$, $MS_e = 9.71$] were required during the second acquisition session than during the first. The interaction between set size and session was also reliable [$F(1,28) = 16.49$]. In the first session of the set size 6 condition, on average 9.73 ($SD = 5.61$) blocks were required to reach criterion, but only 1.40 ($SD = 1.87$) blocks were required in the second session. With set size 3, 2.73 ($SD = 1.87$) blocks were required to reach the acquisition criterion in the first session, and 0.93 ($SD = 1.09$) blocks were needed in the second. As is evident, the set size $\times$ session interaction arose because significantly more blocks were required to reach the acquisition criterion in the initial learning session with set size 6 than with set size 3, but importantly, in the second session there was no difference in the number of learning blocks needed to reach criterion. The latter result indicates that by the end of the first acquisition session the two set sizes were equated in terms of the strength of the symbol–percept associations.

Psychometric Function Analyses

Our analyses of the psychometric function indices were based on *effect coding* (see Bock & Jones, 1968, pp. 30–33). As will be shown below, regression analyses of effect-coded, Gaussian-transformed psychometric functions permitted convenient estimation of the JND, the PSE, and the constant error ($CE = PSE - \text{standard}$).

Let $z = a + bx$ denote the z-score psychometric function, where a is the intercept, b is the slope, and x is the effect-coded variable stimulus, taking on values -2 , -1 , 0 , 1 , and 2 . Let $y = S(1 + cx)$ be a linear transformation equation relating the effect-coded equation to one representing the physical stimulus values, where S is the standard and c is a conversion constant ($c = .03$ in the present case). Since $x = (y - S)/Sc$, it can be shown that the upper limen $UL = Sc/b(.675 - a + b/c)$ and that the lower limen $LL = Sc/b(-.675 - a + b/c)$. Since $JND = (UL - LL)/2$, it follows that $JND = .675Sc/b$ and $WF = .675c/b$. Thus, WF is inversely related to the slope, and constancy of slopes is required for the strong form of Weber's law to hold. Finally, the PSE is given by $PSE = S(1 - ac/b)$.

Group psychometric function analyses. Figure 1 shows the z-score (Gaussian) psychometric functions with the overall group probabilities obtained after combining the data with the two instructions for the set size 6 (open circles) and set size 3 (filled circles) conditions separately with the perceptual and the memory standards.⁴ Several results are evident in these plots and their associated indices, which are also provided in Figure 1. First, as was found by Baranski and Petrusic (1992), serial position (or endpoint) effects are evident in the memory conditions for both set size 3 and set size 6; WFs are smallest with the endpoints and exhibit an inverted U-shaped pattern. Second, these serial position effects are much more pronounced in the set size 6 memory condition than in the set size 3 memory condition. Third, memory WFs are smaller for the set size 3 condition than for the comparable standards in the set size 6 condition. Fourth, the plots also show that there was greater precision in the representations (i.e., smaller WFs) for both the set size 3 and the set size 6 perceptual standards than for the corresponding memory standards. Fifth, there is an absence of set-size effects with the perceptual standards, and the serial position effects are minimal.⁵

Individual participant psychometric function analyses. Psychometric functions with z-transformed (Gaussian) response probabilities were obtained for each participant at each level of perceptual and remembered standard. As has been recommended by Bock and Jones (1968), we employed Berkson's (1953) procedure, setting probabilities of 0 and 1.0 to $1/(2N)$ and $1 - 1/(2N)$, respectively, where N denotes the number of observations on which the psychometric function is based. Table 1 provides a summary of the main features of the 270 psychometric functions that were obtained in Experiment 1.

Slope–Weber fraction analyses: Discriminative sensitivity. Although the mean of the slopes of individual psychometric functions given in Table 1 does not correspond in absolute value to the slopes of the group psychometric functions shown in Figure 1, precisely the same overall pattern is obtained with both group and individual psychometric functions. For example, the slopes of the group psychometric functions for the set size 6 memory condition, shown in Figure 1, are .206, .139, .103, .122, .189, and .388 for Standards 1–6, respectively. As is evident from the entries in Table 1, precisely the same pattern occurs for the mean of the slopes of the individual participant psychometric functions.

WFs, obtained from the mean of the individual participant slopes by using the expression, $WF = .03 * .675 / \text{Slope}$, for the memory and the perceptual standards for set size 3 and set size 6, are plotted in Figure 2. Given the close correspondence of slopes with the group and the individual psychometric functions, it is not surprising that the plots in Figure 2 mirror the pattern of findings evident in Figure 1.

When the slope of the psychometric function is near zero or negative, PSEs, JNDs, and WFs cannot be com-

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Figure 1. Group-based psychometric functions for set size 3 (filled points) and set size 6 (unfilled points) for the memory (top) and the perception (bottom) conditions in Experiment 1.

puted. For this reason, the statistical test for discriminative sensitivity was conducted directly on the slopes of the individual participant psychometric functions. This analysis was appropriate because, as was shown above, the JND and WF depend directly on the slope of the psy-

chometric function. The slopes of the psychometric functions in the memory condition for the set size 3 condition and the slopes of comparable standards in the set size 6 condition were subjected to an analysis of variance (ANOVA) with set size as the between-groups factor and

Table 1
Summary Features of the Individual Participant Effect-Coded Psychometric Functions in Experiment 1

	Set Size 6								Set Size 3							
	Standard	Slope	SE	Intercept	SE	PSE	CE	r^2	Standard	Slope	SE	Intercept	SE	PSE	CE	r^2
Memory	10.54	.256	.039	-.035	.168	10.58	0.04	.627								
	31.95	.170	.034	-.109	.176	32.56	0.61	.551	31.95	.290	.039	.192	.214	31.31	-0.64	.808
	63.90	.133	.028	.117	.156	62.22	-1.68	.508								
	106.39	.147	.037	.311	.198	99.61	-6.78	.471	106.39	.232	.034	.211	.184	103.48	-2.90	.784
	148.88	.226	.037	.189	.179	145.14	-3.73	.658	148.88	.361	.041	-.129	.159	150.48	1.59	.888
	202.22	.455	.058	-.046	.120	202.83	0.62	.770								
Perception	10.54	.464	.046	.044	.053	10.51	-0.04	.821								
	31.95	.407	.067	.047	.047	31.83	-0.11	.789	31.95	.491	.068	-.089	.030	32.12	0.17	.936
	63.90	.423	.048	.039	.053	63.72	-0.18	.880								
	106.39	.474	.062	-.042	.035	106.67	0.29	.894	106.39	.446	.064	-.042	.029	106.69	0.29	.933
	148.88	.555	.067	.078	.037	148.26	-0.62	.822	148.88	.493	.058	.019	.035	148.70	-0.18	.945
	202.22	.686	.054	.023	.048	202.02	-0.20	.905								

Note—Table entries with the memory and the perceptual standards for the set size 6 and set size 3 conditions are the mean slope and intercept and their respective standard errors. The point of subjective equality (PSE), constant error (CE), and the mean of the goodness of fits (mean r^2) are also provided.

Figure 2. Weber fractions obtained from the average slope of individual effect-coded psychometric functions for set size 3 (filled points) and set size 6 (unfilled points) for the memory (circles) and the perception (triangles) conditions in Experiment 1.

the three standard lengths as the within-subjects factor. The main effect of set size was reliable [$F(1,28) = 8.47$, $MS_e = 0.034$], confirming reduced discriminative sensitivity with the set size 6 standards. The main effect of standard was also reliable [$F(2,56) = 5.91$, $MS_e = 0.014$], indicating the presence of serial position effects with reduced sensitivity for interior standards. A comparable ANOVA with strictly perceptual standards revealed main effects of neither set size nor standard. For set size 6, an additional ANOVA confirmed uniformly reduced sensitivity with memory standards [$F(1,14) = 39.54$, $MS_e = 0.083$] and a main effect of the standard [$F(5,70) = 15.42$, $MS_e = 0.023$], reflecting endpoint effects. However, the interaction between type of comparison and the corresponding standard failed to attain statistical reliability.

Points of subjective equality: Memory accuracy. Table 1 also provides mean intercepts of the individual participant psychometric functions (and their standard errors). As was shown above, when effect coding is used, the intercepts together with the slopes permit estimates of the PSEs. Table 1 also provides the PSEs and the CEs. Like the WFs, the PSEs and consequently the CEs obtained with the group-based psychometric functions corresponded closely to those obtained with the means of the slopes and the intercepts of the individual psychometric functions. For example, the CEs for set size 6 memory standards were 0.03, 0.44, -2.05 , -7.54 , -3.67 , and 0.74 for Standards 1–6, respectively, for the group psychometric functions, and this pattern is mirrored perfectly by the CEs in Table 1.

The pattern of CEs with the memory standards reflects the pattern of serial position effects evident with

the WFs. Notably, the CEs were largest with the middle items and smallest with endpoint items. Moreover, the CEs were smaller with the perceptual standards than with the memory standard for both set size 3 and set size 6. Finally, as the standard errors of the intercepts show, the PSEs were considerably more variable with the memory standards than with the perceptual standards in every instance for both set size 3 and set size 6.

The relatively small CEs obtained with both the group- and individual participant-based psychometric functions appears to convey the impression that participants' long-term memories were rather accurate when, in fact, they were not. Mean PSEs near the standard arose as a consequence of averaging across participants, some of whom had large negative CEs and others who had equally large positive CEs. The plots in Figure 3, which indicate the proportion of PSEs that were within the range of variable stimuli, provide a clearer view of the participants' lack of memory for the exact location of the standard (or the presence of substantial biases). As is evident, these plots closely parallel those in Figure 2 for the WFs. First, set-size effects were evident in memory; PSEs were more likely to be close to the standard in the set size 3 condition than in the set size 6 condition. Second, the bowed serial position effect was also evident in both memory conditions, with less accurate memories for the interior standards. PSEs in the perceptual condition were near their respective standards in every case and, in contrast to the memory PSEs, exhibited neither serial position effects nor set-size effects.

Linearity of the z-score psychometric functions. The mean proportion of variance in the psychometric func-

Figure 3. Probability that the point of subjective equality (PSE) is within the range of variable stimuli (i.e., $\pm 6\%$ of the true standard value) in the memory and perception conditions for set size 3 and set size 6 in Experiment 1.

tion accounted for by linear regression (r^2) is summarized in Table 1. The values of r^2 exhibited set-size and serial position effects in memory, paralleling both the WFs and the CEs. In addition to greater memory precision (WF) and accuracy (CE) and the absence of clear bowed serial position effects with the perceptual standards, the values of r^2 were reliably higher than those obtained with the memory standards for both set size 6 [$F(1,14) = 60.31$, $MS_e = 0.048$] and set size 3 [$F(1,14) = 10.83$, $MS_e = 0.026$]. For the set size 6 perceptual standards, r^2 was lowest with the shortest standard and largest with the longest standard, in parallel with the slight violation of Weber's law evident with the WFs.

Presentation Order Effects and the Time-Order Error (TOE)

Local dependencies in perception. As was indicated earlier, since Fechner's (1966) study, it has been evident that discriminative accuracy can change substantially merely upon changing the presentation order of the stimuli to be compared. Figure 4 reveals clear presentation order effects (i.e., TOEs) for the perceptual comparisons with each standard. As the plots show, discriminative accuracy is higher when the stimulus pair is presented in the short-long stimulus order than when it is presented in the long-short order—that is, a negative TOE.

Time-order errors in memory. As was indicated earlier, perceptual TOEs occur when the first presented stimulus is in memory—that is, when the stimulus pairs are presented successively with some specified ISI. As in Baranski and Petrusic (1992), the participants in the present experiment were able to use the variable stimuli to infer which memory standard to activate and were able

to begin the comparison process without waiting for the actual presentation of the CVC representing the standard. For example, mean response times with the set size 6 memory standards were 3,154.6 msec in the CVC-line order and 2,897.6 msec in the line-CVC order. On the other hand, with the perceptual standards, the difference in response times was minimal; it was 1,674.4 msec when the standard was presented first and 1,652.3 msec when it was presented second. Thus, the necessary condition of successiveness with the memory comparisons occurred only when the CVC was presented first, thereby complicating the analysis of presentation order effects in memory.

To examine the TOEs for the memory comparisons, we used the stimulus pairs with the variable stimulus equal to the standard. In the memory condition, the CVC-line order was used. As Baranski and Petrusic (1992, Experiment 2) have shown, when identical pairs are presented, perceptual TOEs parallel those evident in Figure 4; namely, the second presented stimulus is judged to be longer than the first. Accordingly, the dependent variable in the present analyses with the identical stimulus pair is the percentage of time the second presented stimulus is judged to be longer than the first. An ANOVA with set size as the between-subjects factor and perceptual versus memory comparisons as the within-subjects factor revealed a clear main effect of type of comparison [$F(1,28) = 5.59$, $MS_e = 24,974.05$, $p < .025$]. Specifically, the second presented stimulus was judged longer on 62.6% of the trials with the purely perceptual comparisons but on only 52.9% of the trials with comparisons involving memory standards. Neither the effect of set size nor the interaction between type of comparison

Figure 4. Probabilities of correct responses for each standard with each variable stimulus as a function of presentation order for the perceptual comparisons in Experiment 1.

and set size approached significance ($F_s < 1.0$). For perception, the negative TOE was reliably different from chance [$t(28) = 4.367, p < .001$, two-tailed], but for memory it was not [$t(28) = 1.005, p > .346$, two-tailed]. Thus, these analyses revealed minimal presence of TOEs with remembered comparisons in contrast to the clear negative TOEs with the perceptual comparisons. Accordingly, the strong form of the functional equivalence hypothesis is not supported.

EXPERIMENT 2

The set-size effects obtained in Experiment 1 would appear to demonstrate a dependence of the *quality* of the memory representation on the *number* of stimuli in the memory set, thus establishing a principle of *nonindependence from other alternatives* based on the noisy analogue view. However, this conclusion may be premature, because the examination of set size in Experiment 1 was confounded with stimulus range—that is, the range was narrower for set size 3 (i.e., from 31.95 to 148.88 mm) than for set size 6 (i.e., from 10.54 to 202.29 mm). This confound arose by design, in order to permit assessments of set size with comparable standards that were non-endpoints. As the results of Experiment 1 showed, memory precision with endpoint standards is substantially

better than with non-endpoint standards. Thus, it is likely that the endpoint standards are subject to floor effects that would not be very sensitive to any form of experimental treatment.

Accordingly, in Experiment 2, stimulus range was systematically varied while holding set size constant; one group of participants learned to associate CVCs with a narrow range of four stimuli (10.54, 30.03, 50.16, and 70.00 mm), and a second group worked with a wide range of four stimuli (10.54, 70.00, 140.89, and 200.00 mm). If it is determined that WFs are larger in a wide range than in a narrow range, then indeed the larger WFs obtained in the set size 6 condition in Experiment 1 might well have arisen as a consequence of the confound of set size with range. On the other hand, if range has no effect or if memory precision is in fact poorer in the narrower range, then the set-size effect in Experiment 1 would not have arisen as an artifact of a confound with range.

The range manipulation employed in Experiment 2 of the present study was related in some respects to the well-known Moyer and Bayer (1976) range experiment, a classic attempt to determine whether analogue information is maintained in memory. In that study, one group of participants learned to associate labels with a set of circles varying in area across a wide range, and another group learned to do so with a set that varied across a nar-

row range. When participants compared the sizes of two circles from memory (CVC–CVC comparisons), response times monotonically decreased as the difference in the actual sizes of the circles increased, in parallel with the typical distance effect with perceptual comparisons. More important, comparisons with remembered stimuli paralleled the faster times with perceptual comparisons when the wide range was used, and Moyer and Bayer claimed this *range effect* was sufficient evidence for an interval scale representation of size information in memory. Subsequently, however, the range effect has not been replicated (e.g., Banks, 1977; Banks et al., 1982; Henderson & Well, 1985). However, the effect can be obtained if the necessary conditions for its occurrence are satisfied; namely, that the range effect occurs in perception (see Petrusic, Baranski, & Aubin, 1998).

The noisy analogue view predicts that the effects of range in the present study should be evident in *larger* WFs in the small range than in the large range, primarily because lateral inhibition in the memory array increases with increases in similarity among the underlying perceptual referents and, consequently, in terms of proximity of the analyzers in the memory array. It is reasonable to assume that the amount of lateral inhibition any analyzer in a memory array exerts on its neighbor depends jointly on the proximity of the analyzer and the strength of the connection between the memory analyzer and its referent perceptual analyzer. According to this conjecture, therefore, the dependence of long-term perceptual memory precision must depend on both the underlying range of the perceptual referents and on the conditions governing acquisition. In accord with this view, therefore, in Experiment 2 the stimulus range was factorially varied with the conditions governing the strength of the association between the label and the underlying perceptual magnitude. The narrow and the wide range groups were therefore each divided into a no-overlearning group and an overlearning group.

Method

Participants

Sixty-four Carleton University undergraduate students participated for one 90-min experimental session in return for course credit. All the participants reported normal or corrected-to-normal vision and were naive with respect to the nature and the aims of the experiment.

Apparatus

The apparatus described in Experiment 1 was used in this experiment.

Stimuli

In all conditions, four horizontal line lengths served as standards in the method of constant stimuli. In the *wide range* conditions, the standards were 10.54, 70.00, 140.89, and 200.00 mm, and in the *narrow range* conditions they were 10.54, 30.03, 50.16, and 70.00 mm. Like the stimuli in the first experiment, variable stimuli were equal to $St \pm .03k \times St$, with $k = 0, 1, 2$.

Procedure and Design

The design of Experiment 2 involved four conditions defined by factorially crossing the two stimulus range conditions and two

learning conditions, with 16 participants randomly assigned to each group. As in Experiment 1, all sessions began with the learning phase, which required the participants to learn to associate each of the four line-length standards with specific CVC letter triads (*GUF*, *BIX*, *ZOC*, and *LEJ*) by using the procedure described earlier. However, in this experiment, if a participant did not make the correct association to any one of the line–CVC pairs in a block of four trials (each of the four CVC–line pairs appearing exactly once in random order from block to block), additional blocks were presented until three errorless blocks in a row occurred. In the *overlearning* conditions, 40 additional presentations of each standard followed the criterion three blocks of trials. In the *no-overlearning* conditions, no additional learning trials were provided following acquisition of the criterion three blocks of trials.

Following the learning phase, the participants were instructed that on each trial they would be presented, in succession, with either a line and a CVC or a CVC and a line (perceptual comparisons were not obtained in this experiment). Each participant performed three blocks of 80 randomized trials. The 80 trials in each block arose from the factorial combination of 4 standards $\times$ 2 presentation orders (CVC first, CVC second) $\times$ 5 comparison stimuli (–6%, –3%, 0%, 3%, or 6% different from the standard) $\times$ 2 instructions (*longer*, *shorter*). The first block was viewed as practice and was not analyzed. Consequently, each point on the psychometric function for each participant was based on eight observations.

The procedure that was used in Experiment 1 for the comparative judgments was also used in this experiment.

Results and Discussion

Like the results of Experiment 1, the results of Experiment 2 will be presented in three major sections. The first will examine the acquisition data, the second will provide analyses of the group and individual participant psychometric functions and associated indices, and the third will explore presentation order effects with the remembered standards.

Acquisition Data

As in Experiment 1, the number of blocks (block size was four trials) prior to reaching the criterion run served as the measure of speed of acquisition. In the overlearning condition, the mean number of blocks required to reach criterion was 15.44 ($SD = 2.31$) and 16.38 ($SD = 3.39$) in the wide and narrow ranges, respectively. In the no-overlearning condition, 12.81 ($SD = 1.59$) and 15.69 ($SD = 2.47$) blocks were required in the wide and narrow ranges, respectively. An ANOVA conducted on the number of blocks required to reach the acquisition criterion revealed no main effect of range ($F < 1$), no main effect of learning ($F < 1$), and no interaction between the two ($F < 1$). Thus, we can conclude that the four groups were equated in terms of the strengths of the associative bonds between symbols and percepts and, consequently, that any subsequent differences among the conditions can be attributed to the precision of the respective memory representations.

Psychometric Function Analyses

Group psychometric function analyses. Figure 5 provides z-score (Gaussian) psychometric functions with the overall group probabilities for each standard with

Figure 5. Group-based psychometric functions in the no-overlearning conditions (top) and the overlearning conditions (bottom) for the narrow range (triangles) and the wide range (circles) conditions in Experiment 2. Weber fractions (WFs), points of subjective equality (PSEs), and goodness of fit (r^2) are provided above the midline in each plot for the narrow range and below the midline for the wide range.

each of the four conditions arising from the factorial combination of learning and range. The WF, the PSE, and r^2 , the index of goodness of linear fit, are also provided on the plots. Several results were evident with these plots and the associated indices. First, the serial position effects present in the memory conditions of Experiment 1 were evident, especially in the no-overlearning condition. Second, for every standard, in both the wide and the narrow ranges (except the longest standard in the wide range), the WFs were smaller in the overlearning condition than in the no-overlearning condition, thereby providing strong evidence that memory precision can be substantially improved with extended acquisition.

Examination of the WFs in the no-overlearning condition with comparable standards in the two ranges revealed a small range effect for the shortest standard but no effect with the 70-mm standard. However, after endpoint comparisons were precluded and the range effect examined at an ordinal level, the range effect was clearly evident. Most important, it was not the case that extending the range impaired memory precision.

Individual participant analyses. Like the analyses in Experiment 1, z -score (Gaussian) psychometric functions were obtained for each participant for each standard. Given effect coding (i.e., ordinal spacing), the slopes of these functions allowed direct comparisons across the

four conditions resulting from the factorial combination of the range and learning factors. Table 2 provides a summary of the main features of the indices obtained from the 256 individual participant psychometric functions, and also provides slopes, intercepts, and their related standard errors. In addition, the mean goodness of linear fit (r^2), the PSEs, and the CEs are provided.

Weber fraction analyses. WFs, obtained from the mean of the individual participant slopes, are plotted in Figure 6. The plots in Figure 6 show that entirely the same configuration of findings is evident with the group psychometric functions (in Figure 5) as with those based on the mean of the slopes of the individual participant psychometric functions. The increased memory sensitivity with overlearning is clear, and serial position effects are especially evident with the no-overlearning condition. Most important, there is no clear evidence of a range effect.

On the other hand, when the range effects were examined at the ordinal level, thereby eliminating floor effects arising from comparisons with endpoint standards, there was clear evidence for a range effect. An ANOVA of the slopes with ordinal coding of the standards resulted in a main effect of the learning factor [$F(1,60) = 4.96$, $MS_e = 0.069$]. In the no-overlearning condition, the main effect of range was reliable [$F(1,30) = 4.81$, $MS_e = 0.036$], as was the effect of standard [$F(3,90) = 10.65$, $MS_e = 0.016$].

Table 2
Summary Features of the Individual Participant Effect-Coded Psychometric Functions in Experiment 2

	Narrow Range								Wide Range							
	Standard	Slope	SE	Intercept	SE	PSE	CE	r ²	Standard	Slope	SE	Intercept	SE	PSE	CE	r ²
No Overlearning	10.54	.162	.036	.387	.203	9.78	−0.76	.501	10.54	.206	.046	−.212	.216	10.87	0.33	.537
	30.03	.101	.027	−.098	.259	30.91	0.88	.382	70.00	.203	.043	.045	.219	69.56	−0.44	.554
	50.16	.104	.025	−.108	.260	51.73	1.57	.420	140.09	.129	.042	.561	.215	121.77	−18.32	.347
	70.00	.199	.039	−.343	.247	76.31	3.61	.606	200.00	.375	.048	.141	.178	197.69	−2.31	.687
Overlearning	10.54	.257	.061	−.039	.135	10.59	0.05	.556	10.54	.250	.081	−.029	.213	10.58	0.04	.508
	30.03	.239	.053	.144	.192	29.49	−0.54	.626	70.00	.256	.089	.325	.201	66.98	−3.02	.572
	50.16	.193	.038	.243	.161	48.27	−1.89	.477	140.09	.212	.095	.566	.148	128.86	−11.23	.566
	70.00	.316	.059	−.186	.190	71.24	1.24	.735	200.00	.373	.054	−.471	.165	207.56	7.56	.663

Note—Table entries with the factorial combination of the no-overlearning and overlearning conditions crossed with the narrow and wide range condition are the mean slope and intercept and their respective standard errors. The point of subjective equality (PSE), constant error (CE), and the mean of the goodness of fits (mean r^2) are also provided.

In the overlearning condition, only the effect of standard was reliable [$F(3,90) = 3.67$, $MS_e = 0.032$].

Points of subjective equality analyses: Memory accuracy. PSEs were also obtained from the individual participant psychometric functions, and these were used as an index of memory accuracy. Like the CEs in Experiment 1, the relatively small CEs in Experiment 2 convey the impression of relatively good memory for the exact location of the standard on the length continuum. However, here too the apparent good memory accuracy is a consequence of averaging oppositely signed CEs.

As in Experiment 1, a more accurate view of memory accuracy is conveyed by examining the proportion of times the PSE fell within the range of the variable stimuli, as is illustrated in Figure 7. For example, the CEs are among the smallest in the narrow range's no-overlearning condition; but as the plots show, very few PSEs fall within the range of the variable stimuli in this condition. Generally, the plots in Figure 7 closely parallel those in Figure 6 for WFs, revealing good correspondence between

memory precision and memory accuracy. Serial position effects were evident in the no-overlearning condition, but they were absent in the overlearning condition. In addition, memory accuracy provided no evidence of a range effect when standards of matching length were compared (in fact, memory accuracy was somewhat better in the narrow range in the overlearning condition). However, a range effect was evident with non-endpoint (ordinal) comparisons in the no-overlearning condition.

Goodness of linear fits. Overall, fits were significantly better in the overlearning condition ($r^2 = .591$) than in the no-overlearning condition ($r^2 = .504$) [$F(1,60) = 4.10$, $MS_e = 0.117$]. Goodness of fits also varied significantly with ordinal serial position, generally paralleling slopes [$F(3,180) = 5.16$, $MS_e = 0.099$].

Presentation Order Effects and the Time-Order Error (TOE)

There were no perceptual comparisons in this experiment to use as a baseline to gauge the occurrence of

Figure 6. Weber fractions obtained from the average slope of individual effect-coded psychometric functions in the no-overlearning conditions (left panels) and the overlearning conditions (right panels) for the narrow range (triangles) and the wide range (circles) conditions in Experiment 2.

Figure 7. Probability that the point of subjective equality (PSE) is within the range of variable stimuli (i.e., $\pm 6\%$ of the true standard value) for each standard in the narrow range (triangles) and in the wide range (circles) for the no-overlearning and the overlearning conditions in Experiment 2.

TOEs in memory. However, as in Experiment 1, the proportion of times the second presented stimulus was chosen as longer in the CVC-line order provided evidence that TOEs were not clearly evident with remembered standards: Overall, the second stimulus was chosen as longer on 51.1% of the trials. Thus, the lack of a clear TOE in this experiment and in Experiment 1 provides compelling evidence against the strong form of the functional equivalence hypothesis.

GENERAL DISCUSSION

Taken together, the present findings from Experiments 1 and 2 replicate and extend Baranski and Petrusic's (1992) view that long-term memory representations of elementary sensory events, although less precise than their perceptual counterparts, are analogue in nature. Baranski and Petrusic argued that if the memory representation is not in a format analogous to its perceptual counterpart, then it is unlikely participants could even render (above chance) comparisons of variable stimuli that differ from the standard by as little as 3%. Indeed, in each of the two experiments reported here, the slopes of Gaussian-transformed individual participant psychometric functions were significantly different from zero.

The present findings converge nicely with work reported in Petrusic, Baranski, and Kennedy's (1998) study. Like the participants in the present experiments, their participants first learned to associate labels (CVCs) with line lengths. Subsequently, they were presented with two pairs of CVCs (quads), and they were to indicate on some trials which pair corresponded to the more similar pair of lines and the more dissimilar on other trials. By employing quads in which the similarity comparison could not

be rendered on the basis of ordinal-based relations alone, they showed that these judgments satisfied the axioms for a positive difference structure (see Krantz, Luce, Suppes, & Tversky, 1971), thereby demonstrating that the similarity comparisons were based on the computation of differences of analogue-based interval scale representations.

The empirical status of the range effect manipulation in Experiment 2 of the present study remains moot. On the one hand, as was argued earlier, since endpoint standards are subject to floor effects and are likely to be insensitive to any form of experimental manipulation, the examination of the range effect at the ordinal level is appropriate. In this case, there was strong evidence for the range effect at the ordinal level. On the other hand, there was no evidence of a range effect when the examination was with comparable standards in the two ranges. In either case, the lack of a *decrease* in the WF in the *wide* range is sufficient to rule out the range artifact as an explanation of the set-size effects obtained in Experiment 1. Thus, the set-size findings of Experiment 1 and the ordinal-based range effect in Experiment 2 implicate a context-dependent memory psychophysics and provide some support for the idea that long-term memories of elementary percepts are subject to a principle of nonindependence from other alternatives.

An important problem, one that will guide our future work, is to determine whether this principle of nonindependence from other alternatives and the attendant violation of Weber's law arises from the fact that the points on the psychometric function were obtained by intermixing the standards within a block of trials. Thus, further experiments in which the psychometric functions are obtained with each standard held constant within a block are planned.

Similarities and Differences Between Perceptual and Remembered Comparisons

Although the present findings implicate a memory representation that is analogous to its perceptual counterpart, memory comparisons exhibited several properties that clearly distinguish them from perception. First, perceptual comparisons in the present experiment were not subject to the global contextual effect of set size.⁶ Second, only memory comparisons exhibited a serial position effect. Finally, perceptual comparisons were subject to local dependencies that revealed themselves as presentation order effects, but memory comparisons did not exhibit presentation order effects (i.e., TOEs). This latter point is especially important because the occurrence of TOEs with memory comparisons would have provided impressive support for the strong form of the functional equivalence hypothesis.

The Noisy Analogue View of Memory Psychophysics

The characterizations of the memory psychophysics of recently acquired, albeit relatively long-term, memories for elementary percepts are largely in accord with the noisy analogue, linear array ideas described in the introduction. It is surmised that the nonindependence principle arises as a consequence of lateral inhibition and that increases in the strength of the associative bond between percept and the label diminishes lateral inhibition. Indeed, Experiment 2 provided strong evidence that a large number of overlearning trials can significantly improve memory precision and greatly diminish serial position effects. Although there is some support for the noisy analogue, linear array ideas, this account is not sufficiently well developed to provide a rigorous quantitative account of the properties of the memory representation of elementary percepts and the acquisition and processing of this information. We are currently developing a connectionist-based auto-associative network that is capable of activation of a percept-like memory representation by a symbol and, conversely, activation of the symbol by the percept. The coding scheme developed by Lacouture and Marley (1995) for absolute identification provides the basis for the mapping of percepts onto an array of ordered symbols. The auto-associative neural network, conjoined with any of a variety of evidence accrual decision models (e.g., Link, 1992; Petrusic, 1992; Vickers, 1979), will permit extension of this work in memory psychophysics to account for not only the properties of the psychometric function but also response times, confidence, and their interrelationships.

As was noted by Baranski and Petrusic (1992), Woodworth (1938), in his classic text *Experimental Psychology*, concluded, "The experimental results are in good agreement on the negative conclusion. No absolute difference exists between an image and a percept, and there is no sure fire criterion by which one can be distinguished from the other" (p. 45). Although serial position effects and an absence of TOEs with the memory standards serve to distinguish memory from perception, it is inter-

esting to conjecture that these bases may not be "sure fire" criteria in the long run. Indeed, it may well be the case that with extended, massive overlearning with a variety of different acquisition paradigms (e.g., reproduction), serial position effects will be eliminated, WFs for memory will converge to those for perception, and TOEs will emerge for memory. If this is the case, Woodworth's conclusion would prove fundamentally correct.

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NOTES

1. Baranski and Petrusic (1992) showed that estimates of the WFs for memory were the same when comparisons with perceptual standards followed those with the remembered ones as when they were intermixed.
2. This decision to intermix the standards, and not to test them in separate blocks, was based on the view that practice effects and possible forgetting of the perceptual referents with the memory standards would be distributed approximately uniformly over the standards over the course of the block.
3. The confidence rating data were obtained for a different purpose and are not reported in the present paper.
4. Effect-coded, group-based psychometric functions were first obtained separately with each instruction. The slopes of the psychometric functions with each instruction revealed comparable properties. For ex-

ample, with set size 6 memory standards, the slopes with the instruction *shorter* were .171, .143, .129, .121, .165, and .424 for Standards 1-6, respectively. With the instruction *longer*, the slopes were .243, .137, .076, .124, .222, and .356 for the comparable standards. Likewise, for the set size 6 perceptual standards, the slopes were .407, .371, .449, .427, .465, and .665 with the instruction *shorter* and .456, .353, .341, .465, .549, .639 with the instruction *longer* for Standards 1-6, respectively. As well, set-size effects were evident with both instructions for the memory standards, and they were absent with both instructions for perception. Given the close correspondence of the psychometric functions obtained separately with each instruction, the data were combined over the two instructions, thereby providing more reliable points on the psychometric functions for both the group and, especially, the individual participant psychometric functions.

5. As in Baranski and Petrusic's (1992) study, the WFs with the perceptual standards generally decreased as the standard increased in length, indicating a small violation of Weber's law. The violation arose because as the length of the standard increased, with variable stimulus ratios held constant, the differences between the standard and the variable stimulus also increased (as did *a priori* ease of comparison); discriminative sensitivity varied with both ratios and differences.

6. Powerful contextual effects of set size, spacing, and range are typically obtained with intensive continua. Contextual effects with extensive continua have been reported only rarely. Marks (1992) reported that Potts (1990) obtained a small but reliable slippery context effect with magnitude estimates of line lengths when the vehicle dimension was spatial orientation. However, Marks (1992, Experiment 4), employing the double-shifting paradigm, failed to obtain a context effect for line lengths presented at two colors.

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