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Time-Order Errors and Memory For Percepts

Derek A. Harrison

Carleton University

Ottawa, Ontario, Canada

September 20, 1995

**A thesis submitted to the Department of Psychology in conformity with
the requirements for the Master of Arts Program**

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TOES AND MEMORY FOR PERCEPTS

**The undersigned recommend to the Faculty of Graduate Studies
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TIME-ORDER ERRORS AND MEMORY FOR PERCEPTS

**submitted by Derek A. Harrison
in partial fulfillment of the requirements for the degree of
Master of Arts**

A handwritten signature in black ink, appearing to read "William M. Petraitis", written over a horizontal line.

Thesis Supervisor

A handwritten signature in black ink, appearing to read "Bill M. Petraitis", written over a horizontal line.

Chairperson, Department of Psychology

Carleton University

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that response time (RT) varied inversely with the numerical difference between the two numbers being judged. This suggested that the process of judging symbolic differences paralleled the process involved for comparisons of differences between physical magnitudes, such as line lengths (e.g., Henmon, 1906; Johnson, 1939; Munsterberg, 1894).

Extending the mental comparison approach, and contrary to Munsterberg's original strictures, Moyer (1973) had subjects make comparisons from LTM that had objectively correct answers (e.g., "select the animal with the larger body"). In his experiment, subjects made size comparisons between pairs of animal names (e.g., ant. bee). The task was to select the larger of the two animals. Again, it was found that RT monotonically decreased as the ordinal size difference increased -- paralleling the classical psychophysical comparison experiment conducted by Johnson (1939). Moyer concluded that for comparisons involving items retrieved from LTM, subjects performed an "internal psychophysical judgement" (p. 183) which suggested a common process and/or representation for items stored in long-term memory.

Following on the Moyer (1973) findings, Moyer and Bayer (1976) extended 'internal psychophysics' by conducting an investigation that used an induced linear ordering of remembered magnitudes. Subjects were taught a series of consonant-vowel-consonant (CVC)-circle pairings and were then required to judge the relative size of either pairs of circles or their sizes denoted by pairs of CVCs. The results showed that response times (RTs) varied inversely with the physical difference between the two circles and also varied inversely with the distance between the remembered magnitudes (i.e., a *symbolic distance effect (SDE)*). In addition, RTs were faster for a large-range

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Time-order Errors and Memory for Percepts

Since the landmark experiments conducted by Bjorkman, Lundberg and Earnblom in 1960, there has been a strong and growing interest in psychophysical studies of the relation between perception and memory. Multi-dimensional scaling (Shepard & Chipman, 1970) and magnitude estimation analyses of perceptual and remembered magnitudes (Kerst & Howard, 1978; Moyer, Bradley, Sorensen, Whiting, & Mansfield, 1978) are but two examples of the various psychophysical investigations examining this relationship. Comparative judgements using both perceived and remembered perceptions provide an alternative way of exploring this relationship (see Banks, 1977; Desrochers & Petrusic, 1983; Moyer & Dumais, 1978; Petrusic & Baranski, 1994 for a review). Indeed, in regard to how items from long-term memory (LTM) are accessed for these comparisons, Moyer (1973) and Shepard and Chipman (1970) suggested that "...a similar mechanism is involved in perceptual and memorial size comparisons" (Moyer, 1973, p.183).

It is clear from both intuition and research that the richness and vividness of perceptual experience cannot be maintained in LTM (see Reed, 1974; Reed & Johnsen, 1975). Consequently, recent research has focused on the properties and the form of the representation of more elementary sensory experiences in LTM (Banks 1977; Baranski & Petrusic, 1992; Petrusic, Baranski & Harrison, 1993; Petrusic & Baranski, 1994; Petrusic, Baranski & Kennedy, 1995). Although such research helped define the properties of the representation of elementary sensory perception in LTM, it did so without precisely defining how these representations were accessed. Importantly, if Moyer's (1973) and Shepard and Chipman's (1970) conjecture is correct, then memory for percepts should

behave in a manner similar to their corresponding percepts when successive comparisons are made. Specifically, comparisons with remembered magnitudes should be subject to presentation order effects.

The fact that the order in which stimuli were presented influenced the percentage of correct responses a subject yielded in a comparison task was first discovered by Gustav Fechner (1860/1966). He termed these presentation order effects as time errors (also known as Time-Order Errors or TOEs), denoting better discrimination when the second presented magnitude was the greater of the pair as a negative TOE. In contrast, situations in which subjects showed better discrimination when the stimulus of greater magnitude was presented first are termed positive TOEs and are typically found with small magnitudes (e.g., short visual extents) and very short inter-stimulus intervals (ISIs) (see Hellstrom, 1985; Martindale, 1991, pp. 133-134; Woodrow, 1935:).

An extensive empirical and theoretical literature has developed since the discovery of TOEs (see Hellstrom, 1985, for a comprehensive review), with special focus placed on successive perceptual stimuli, especially in the context of duration discrimination (e.g., Allan & Kristofferson, 1974; Hellstrom, 1977; Jamieson & Petrusic, 1975a, 1975c; Petrusic, 1984; Schab & Crowder, 1988). It wasn't until Baranski and Petrusic (1992) investigated TOEs for judgements involving symbolic magnitudes that the study of TOEs was extended into the field of memory psychophysics.

A lack of TOEs (either positive or negative) for remembered percepts has consistently been found (Baranski & Petrusic, 1992; Petrusic, Baranski, & Harrison, 1993), suggesting, contrary to Moyer (1973) and Shepard and Chipman (1970), a fundamental difference between the way that items are compared when they are

perceptual versus when they are retrieved from LTM. The purpose of the present research was to continue the research in memory psychophysics for visual extent and to extend memory psychophysics to the area of duration discriminations. Special emphasis was placed on the examination of TOEs for both types of continua in order to examine any common processes for paired comparisons involving memory or perception.

MEMORY PSYCHOPHYSICS

1) Direct Estimation

The earliest study of memory psychophysics in the context of the direct estimation methods was conducted by Bjorkman et al. (1960). They assigned an arbitrary label to a physical stimulus in an attempt to study the relationship of a percept, not to the stimulus that generated it but to how it was remembered. Bjorkman et al. (1960) determined that the power function was "...an adequate description of the relationship between memory magnitude and perceptual magnitude" (p. 136). The results, however, were equivocal because they intermixed both memory and perceptual trials.

a) Memory for percepts as re-perception

Meanwhile, Moyer et al. (1978) and Kerst and Howard (1978), developed the idea of re-perception to characterize the relationship between memory and perception. According to the re-perception idea, the remembered representation arises upon the application of a power transformation to the perceived magnitude, which in turn arises as a power function of the physical magnitude. Formally, the psychophysical function for perception is given by $\Psi_p(x) = \alpha_p x^{\beta_p}$, where α_p and β_p , respectively, denote the unit of measurement and the exponent on the subjective perceptual scale, and $\Psi_p(x)$ represent

the perceptual magnitude of a stimulus with physical magnitude, x . Since the input to memory is a power function of the perceptual magnitude, $\Psi_M(x) = \alpha \Psi_P(x)^\beta$, where β denotes the exponent for the transformation from perception to memory and $\Psi_P(x)$ the magnitude in memory. The re-perception idea has clear testable consequences when it is assumed that $\beta = \beta_P$. Consequently, the memory psychophysical function is given by $\Psi_M(x) = \alpha_M x^{\beta_M}$ with $\alpha_M = \alpha \alpha_P$ and $\beta_M = \beta_P^2$. Thus, if the representation for perception is compressive, then it must be even more so for memory; similarly if it is expansive in perception, it must be more expansive in memory.

Although the argument was compelling, the re-perception idea failed on two accounts. First, Moyer, Sklarew and Whiting (1982) demonstrated, using the roughness of sandpaper and the heaviness of weights, that when $\beta_P > 1$, the memory exponent was considerably less than the perceptual exponent, although it should be larger (see Algom, 1992 for a review).

Second, the use of direct estimation methods and numerical estimates (that purportedly preserve ratios of sensation magnitudes) contain inherent methodological biases and difficulties (see Krueger, 1989 concerning the representation of number and its role in determining the exponent in the power function). Therefore, it is not clear whether violations of the re-perception idea were due to basic conceptual failure or because of biases and difficulties inherent in the methodology.

2) Comparative Judgements

In 1967, Moyer and Landauer studied memory psychophysics using paired comparisons, by having subjects choose the larger of two numbers. The results showed

that response time (RT) varied inversely with the numerical difference between the two numbers being judged. This suggested that the process of judging symbolic differences paralleled the process involved for comparisons of differences between physical magnitudes, such as line lengths (e.g., Henmon, 1906; Johnson, 1939; Munsterberg, 1894).

Extending the mental comparison approach, and contrary to Munsterberg's original strictures, Moyer (1973) had subjects make comparisons from LTM that had objectively correct answers (e.g., "select the animal with the larger body"). In his experiment, subjects made size comparisons between pairs of animal names (e.g., ant, bee). The task was to select the larger of the two animals. Again, it was found that RT monotonically decreased as the ordinal size difference increased -- paralleling the classical psychophysical comparison experiment conducted by Johnson (1939). Moyer concluded that for comparisons involving items retrieved from LTM, subjects performed an "internal psychophysical judgement" (p. 183) which suggested a common process and/or representation for items stored in long-term memory.

Following on the Moyer (1973) findings, Moyer and Bayer (1976) extended 'internal psychophysics' by conducting an investigation that used an induced linear ordering of remembered magnitudes. Subjects were taught a series of consonant-vowel-consonant (CVC)-circle pairings and were then required to judge the relative size of either pairs of circles or their sizes denoted by pairs of CVCs. The results showed that response times (RTs) varied inversely with the physical difference between the two circles and also varied inversely with the distance between the remembered magnitudes (i.e., a *symbolic distance effect (SDE)*). In addition, RTs were faster for a large-range

circle set than for a small range set (i.e., a *range effect*) for both types of comparisons (perceptual and symbolic).

The Moyer and Bayer (1976) range effect with remembered stimuli, however, gave only limited metric information. Although they demonstrated that the distance between the representations in the narrow range condition was smaller than the distance between representations in the wide range condition, no information on the relation of the distances within the range conditions was available. The range effect was, in fact, not sufficient for an interval scale representation of size information in memory. Nonetheless, the range effect was important in that it was sufficient to deny that memory representations for percepts were stored exclusively at the level of an ordinal scale, and provided the strongest evidence that perceptual magnitudes may be stored in an analogue form. The metric properties of the representations used in 'internal psychophysical' judgements, however, remained illusive. Moyer and Bayer's (1976) range effect was the catalyst for several studies and methodological advances. Henderson and Well (1985) used colour names (yellow, orange, etc.) as the symbolic associates for different circle sizes in an attempt to replicate Moyer and Bayer (1976). Although they did find a SDE, they failed to find a range effect.

Banks, Mermelstein and Yu (1982) also failed to find a range effect in an effort to modify and extend Moyer and Bayer (1976). Their subjects performed not only strictly symbolic (CVC-CVC) and strictly perceptual (circle-circle) comparisons, but symbolic/perceptual (CVC-circle) comparisons as well. The results showed that circle-circle comparisons were faster than CVC-CVC comparisons, which were, in turn, faster than CVC-circle comparisons. That is, comparisons involving two memory items were

processed faster than those with only one item in memory. Failure to replicate the range effect, combined with differential processing speed for the different type of comparisons called into question analogue views of remembered magnitudes and supported Banks' (1977) discrete semantic coding model.

Analogue views of remembered magnitudes (Jamieson & Petrusic, 1975d; Holyoak, 1977) hold that perceptual information (e.g., visual extent) is stored in memory in such a way as to preserve the metric/spatial information contained in the original stimulus--albeit in a less precise, interval scaling format. It was postulated that analogue representations may be retrieved and used in comparisons involving perceptual stimuli directly (Holyoak, 1977; Kosslyn, Ball, & Reiser, 1978; Moyer & Landauer, 1967)

On the other hand, Banks' (1977) semantic coding model, a special case of a propositional system, postulated that items in a memory set were stored as discrete semantic codes, as an ordinal scaling. It was believed that for comparisons involving symbolic stimuli, there was some interim processing stage where the perceptual stimuli were transformed into symbolic representations. When two CVCs were presented, comparisons apparently occurred on the basis of activated semantic codes. However, when a perceptual stimulus and a CVC were presented, the perceptual stimulus was not in a format permitting comparison with the symbolic representation activated by the CVC. The semantic coding model denied the possibility that perceptual information was stored in LTM in such a way as to preserve the metric spatial information inherent in the perceptual stimulus (an analogue); consequently, the perceptual stimulus must be re-coded into a semantic format to allow the comparison with a percept stored in LTM. This additional re-coding would take time and thus comparisons involving a single CVC

should be longer than those involving two CVCs. The CVC-CVC comparisons should be faster than the CVC-circle comparison because they do not require this code translation stage; they can be made 'directly' on the basis of the activated semantic (ordinal) codes.

Banks et al. (1982) provided a critical set of findings. Their failure to replicate the Moyer and Bayer (1976) range effect undermined the major source of support for analogue based representations. More importantly, their set of findings followed clearly from a discrete semantic code-propositional framework. Their findings also allowed for certain predictions to be tested with respect to how perceptual information is stored and manipulated in LTM. Specifically, they predicted that if subjects made the comparisons of remembered size on the basis of images (analogue representations), more time would be required to generate two images than a single image. Since this analogue prediction was contrary to the empirical findings (where subjects took longer for CVC-circle than CVC-CVC), Banks et al. were able to provide strong support for the propositional view.

Petrusic, Baranski, and Aubin (1995) recently conducted a series of experiments to explore the form of the representation of remembered magnitudes in LTM. In one experiment subjects were required to make comparisons between a pair of *simultaneously* presented stimuli. They found that, contrary to Banks et al. (1982), CVC-circle comparisons were slower than CVC-CVC comparisons only in the small range condition (Experiment 3). This suggested that, for the most part, comparison time was dependent upon the number of stimuli being retrieved from memory. Some support for Moyer and Bayer's (1976) range effect was also found, with CVC-CVC and CVC-circle pairs having faster reaction times in the medium and large range conditions than in the small range condition. The findings more nearly resembled the original results obtained by Moyer

and Bayer (1976) than the Banks et al. (1982) and Henderson and Wells (1985) failure to replicate.

OTHER APPROACHES TO MEMORY PSYCHOPHYSICS

Recent advances in methodology have allowed for testing of the predictions listed above and provided a more stringent test of the form of the representation in memory (Baranski & Petrusic, 1992; Petrusic, Baranski, & Kennedy, 1995; Petrusic et al. 1995a; and Petrusic, Baranski, & Harrison, 1993). These studies showed that there was a high level of precision with the perceptual comparisons and also a remarkable level of precision for comparisons with items retrieved from LTM. The results of these experiments have weakened support for the idea of propositionally based, discrete coding theories, and suggested that the representation of remembered magnitudes were, at least, at the level of an ordered metric scale.

1) Similarity/dissimilarity (quaternary) comparisons.

Petrusic et al. (1995a) also developed a paradigm in which similarity/dissimilarity comparisons were rendered using representations from memory. Whereas Dember (1957) had subjects make similarity comparisons from memory between pairs of five adjectives (always, often, rarely, seldom, & never), Petrusic et al. (1995a) used representations which were derived from quaternary stimuli along a well defined continuum -- visual extent.

Of interest was whether perceptual items were stored in memory as discrete semantic codes or whether they were stored at the level of an interval scale. Petrusic et al. (1995a) argued that:

...in order to determine if the properties required for an interval scale are present, it is necessary to test the axioms that yield representations invariant up to a linear transformation (as Nelson & Chaiklin, 1980 noted in the context of memory for spatial position). (p. 30).

By requiring subjects to make similarity comparisons between pairs of pairs (quaternary relations) of remembered extent, tests of the axioms¹ for the metric properties of remembered magnitudes were determined without the methodological difficulties arising from the use of variations in pairwise discriminability through changes in range (i.e. the detection of necessarily very small effects).

With the examination of the properties of RTs for these similarity/dissimilarity comparisons, common decisional processes in memory and perception were exhibited. Quaternary relational comparisons for similarity/dissimilarity revealed that with both the perceptual and the remembered quads, RTs decreased monotonically as the ordinal distance between the pairs increased (i.e., a distance effect). This illustrated that comparisons involving both the remembered and perceived quads were sensitive to the underlying physical properties involved--providing support for the analogue view of remembered representations and implicating a common decisional system in perception and memory.

Petrusic et al. (1995b) explored the properties of the representation of remembered and perceived visual extent through the testing of axioms. They continued with similarity/dissimilarity comparisons and utilized irregular spacing of the stimuli along the underlying continuum, thereby eliminating the limitations noted in Petrusic et al.'s (1995b) subsequent research. Petrusic et al. (1995b) demonstrated that there was

clear satisfaction of the axioms for a metric representation for items in memory and noted that the representation of extent in memory was maintained at the level of an interval scale. The effects for both perception and memory were consistent, thereby establishing further parallels in the process of comparing across the two domains. This suggested that a common structural representation in perception and memory exists and provided further evidence that internal representations in memory have analogue properties.

Overall, the findings of Petrusic et al. (1995b), and Petrusic et al. (1995a), provide support for the view that perceptual magnitudes are stored in memory as analogue representations. Their findings showed that quaternary relational judgements with both remembered and perceived magnitudes satisfied the necessary axioms (e.g., transitivity, monotonicity, and intradimensional subtractivity) for an interval representation, and thus were not stored in LTM at a strictly ordinal level as suggested by Banks (1977); rather, the representation of a percept in LTM satisfied the conditions for an interval scale. The finding of common representations for perception and memory complements similar findings for perceived and remembered odors by Algom and Cain (1991) and, more recently, those of Izmailov and Sokolov (1992) who have shown that memory for colours exhibits the structures evident in perception only after sufficient paired-associate training. The results were also consistent with Petrusic and his colleagues' work using paired comparisons (Petrusic et al., 1995a and Petrusic et al. (1995b).

2) Method of constant stimuli with remembered standards.

Recently, Baranski and Petrusic (1992) extended the memory psychophysics research even further. They introduced the use of confusable relational judgements with symbolic magnitudes to examine the precision of remembered perceptions. In their

experiment, three line lengths were used as standards in the Method of Constant Stimuli. After learning the paired associations between line lengths and CVC labels, subjects compared either a perceptual standard or its symbol with a set of perceptual comparison lines. Comparison stimuli were ± 3 and ± 6 percent different from each standard. Ratios for comparison lines were held constant for all standards to allow tests of Weber's law. If Weber's law held, discriminative sensitivity should have remained constant for all the standards.

With this new paradigm, the classical measures of just noticeable differences (JND), point of subjective equality (PSE) and Weber fractions could be compared for the perceptual and remembered standards. Their findings gave further support for an analogue view for perceptual memory and demonstrated that Banks' (1977) discrete-semantic coding model could not provide a full account of their data.

Of primary importance was the fact that it was possible for subjects to perform the task well above a chance level with remembered standards. Indeed, it is hard to imagine how such comparisons could be performed in the absence of quite precise analogue representations. Of course, relative to strictly perceptual comparisons, discriminative sensitivity was reduced with remembered standards. In addition, performance for the middle CVC standard displayed a marked reduction in discriminative sensitivity (higher Weber fractions) and a reduction in location-precision (more variable PSEs)--characterizing a *serial position effect (SPE)* for mental comparisons. There was also superior discriminative sensitivity with the long standards for both perceptual and remembered comparisons, thus violating Weber's law for both conditions.

The discrete-semantic coding model (Banks, 1977) was unable to deal with these results adequately and it was only through the adoption of an analogue based model, such as Holyoak & Patterson's (1981) position discriminability model, together with Johnson's (1991) distinctiveness model of serial learning, that the results could be accounted for. According to Johnson, the variance of the representations of the 'CVC' standards depends directly upon the strength and number of forward and backward associations the item possesses with other standards in the memory set. Hence, the middle standard has a poor quality representation because it is less distinctive than end items in the list.

Petrusic, Baranski, and Harrison (1993) continued the work with confusable relational judgements by investigating three predictions elaborated in Baranski and Petrusic (1992). The first concerned the range of the stimuli learned. According to Moyer and Bayer (1976) and Baranski and Petrusic (1992), a set of items in memory that vary greatly on a given dimension (i.e., a wide range for visual extent), should be more discriminable than a narrow range of items in memory. The discrete semantic coding theory stated that perceptual magnitudes were stored as discrete ordinal codes in memory. The actual physical spacing of these magnitudes should have no influence on the translation of the perceptual information to discrete semantic codes that were stored in LTM and would, therefore, have no effect on mental comparison performance involving remembered magnitudes. The main support for this viewpoint was demonstrated by the lack of a range effect in the results of Banks et al. (1982) and Henderson and Well (1985).

However, as Baranski and Petrusic (1992) state, the Henderson and Well (1985) and the Banks et al. (1982) findings were not as conclusive as previously believed. For example, Banks et al. also failed to find a range effect for strictly perceptual comparisons;

thus, the lack of a range effect for their symbolic comparisons was not entirely surprising. In addition, the lack of a perceptual control condition by Henderson and Well (1985) prevented a comparison with the remembered comparison data. It is quite possible that a range effect would not have been found for their perceptual condition as well, thereby removing much of the force of their argument.

The second prediction concerned the number of learning trials subjects are provided with during the paired associate task. Subjects given additional learning trials should have sharper, more distinct, mental representations of these stimuli than subjects who received no additional learning trials. When tested, over-learning subjects should exhibit more accurate recall of the learned stimuli and thus, yield better discriminability in the comparative judgement task.

Finally, the number of items to be stored and retrieved in long-term memory would also influence performance. With increasing set size, items in the set should become less distinct from one another in LTM according to Johnson (1991), which in turn would lead to poorer discriminability for large set sizes.

All three predictions were substantiated. The Weber fraction, or normalized sensitivity index, for each standard in both experiments showed clear SPEs for items in memory. SPEs for the Weber fractions denoted a reduction in discriminability for comparisons made with the middle CVC standards in each condition. The effect of range for Experiment 1 was reliable for the no-over-learning condition, with the wide-range group more accurate than the narrow-range group. However, range effects were greatly diminished in the over-learning conditions with subjects in the "over-learning" group more accurate than subjects in the "no over-learning" group for Experiment 1.

Experiment 2 dealt with set-size effects specifically and varied the number of perceptual items (either 3 or 6) a subject was required to learn. All subjects in Experiment 2 were given extensive paired associate learning. Weber fractions for the set size three and set size six memory conditions showed clear SPFs, and the memory Weber fractions were smaller in the set size three condition than the set size six comparable standards. Strictly perceptual comparisons showed greater precision in the representation (i.e., smaller Weber fractions) for both the set size three and the set size six perceptual standards than the corresponding memory standards. There was also a lack of a set size effect in the perceptual condition.

An alternative, although less desirable index of memory precision was the point of subjective equality (PSE) which corresponds to the subjective standard value assumed by the observer in contrast to the actual standard value. The difference between the actual standard and the PSE (i.e., the Constant Error) provides an index of stimulus location-precision. PSEs, which represent the magnitudes of the remembered standards, showed considerable variability. Overall, the narrow-range "no over-learning" condition (Experiment 1) showed the greatest variability and contained the most subjects for which PSEs could not be computed (i.e., the slopes of the psychometric functions were negative or zero), reflecting the poorest performance in this condition. However, its interpretation as an index of precision was reduced because of the occurrence of considerable response biases.

The middle standards for all conditions also showed greater variability in their PSEs as compared to the endpoint standards (i.e., standards 1 and 4 for Experiment 1).

This was congruent with the peak in the Weber fractions for these standards and further supported the idea that middle standards were less discriminable than the endpoints.

Taken together, learning, range and set size effects for items stored in memory also pointed to some form of mental representation above the ordinal level. If Banks' (1977) view was correct, that perceptual magnitudes were stored as discrete ordinal codes, then neither stimulus range, degree of over-learning, nor the number of items stored in memory should have had an effect on subsequent recall of the information. For ordinal codes, all adjacent stimuli within a memory set should be equally discriminable. Therefore, according to the semantic coding model, the absolute difference of the perceptual magnitudes from which these codes were derived should not affect this spacing in memory. This prediction was clearly contrary to the obtained variations in the Weber fractions observed by Petrusic et al. (1993).

As well, the amount of over-learning should not have had an effect on subsequent recall of the stimuli according to the semantic coding model: the code is generated initially and should be unaffected by additional presentations of the stimuli. A similar argument would be made for the number of items stored in memory. Once an ordinal relationship was established between items in memory, retrieval of a particular item from memory should not be influenced by the other items.

In contrast, Holyoak and Patterson's (1981) positional discriminability model stated that mental representations of magnitudes were distributed as analogue position codes along a continuum with a finite mean and variance. For a narrow-range condition, such as the one used by Petrusic et al. (1993), the distributions of the standards should overlap more than in the wide-range condition. This would cause memory standards to

become more confusable or "noisier". Conversely, in the wide-range condition, the standards are more widely separated and thus, should overlap less.

The assumptions of the positional discriminability model were in agreement with Johnson's (1991) distinctiveness model of serial learning. Items which were more distinct in memory should be less affected by intra-list associations. The greater the relative spacing in a set and the greater the number of trials presented for learning, the more distinct an item within the list should be.

Time-order Errors

Recent findings provide strong support for the view that elementary perceptual experiences are stored as analogue representations, and thus allow for direct comparisons with perceptual stimuli. The question remains, however, as to whether these internal representations are influenced in the same manner as their perceptual counterparts when presented successively?

Time-order errors (TOEs), or the fact that discrimination depends upon presentation order of the stimuli to be compared, have been studied extensively since Fechner (1860/1966) first discovered them. The theoretical and empirical literature on TOEs included the study of durations (Stott, 1935; Woodrow, 1935; Jamieson & Petrusic, 1975a, 1975b; Hellstrom, 1977; Allan & Kristofferson, 1974; Petrusic, 1984; Schab and Crowder, 1988), duration reproduction (Eisler, 1975; Jamieson & Petrusic, 1975c; Petrusic, 1984; Schab & Crowder, 1988), tonal intensities (Needham, 1934), and weights (Fechner, 1860/1966; Petrusic & Baranski, 1989, Experiment 2; Woodrow, 1933). Stimuli varying in visual extent, on the other hand, received very little attention in the TOE literature (but see Baranski & Petrusic, 1992).

It has been shown that the direction and magnitude of the TOE depends upon a number of factors such as stimulus modality, length of the inter-stimulus interval (ISI) (Jamieson & Petrusic, 1975c; Hellstrom, 1979), intensity level (Woodrow, 1933; Jamieson & Petrusic, 1975b; Hellstrom, 1977), the subject's experience or training (Needham, 1935; Jamieson & Petrusic, 1978), practice (Woodrow, 1935) and trial-by-trial feedback (Jamieson & Petrusic, 1976, 1978).

While the factors that effect TOEs are not in debate, the origins of the effect itself are. TOEs have been attributed to either a bias in the subject's responding (Engen, 1971; Galanter, 1962; John, 1975; Luce & Galanter, 1963, pp. 224-232; Restle, 1961, pp. 157-159; Wickelgren, 1968) or a perceptual phenomena (Hellstrom, 1977, 1985; Jamieson & Petrusic, 1975a, 1975c; Petrusic, 1984).

BIASES

1) Response Bias

a) Peripheral Response Bias

If a result of biases due to the subject's responding, TOEs would be due to some sort of tendency of the subject to favour one particular response over the other. This bias would be exhibited either as a physical response bias or as a criterion bias. A peripheral response bias would be evidenced as a preference to respond in a certain manner (i.e., responding to the second stimulus as always being longer). Biases of this type are easily examined and controlled for by counter-balancing both presentation order and using both forms of the comparative.

b) Criterion Bias

Criterion bias views, on the other hand, place the locus of the TOE closer to the decisional comparison process. Luce and Galanter (1963) modified Thurstone's model for discrimination to explain TOEs. In this view, the internal representation of a perceptual item was viewed as a normally distributed, random variable with a mean proportional to the magnitude of the stimulus. According to Thurstonian models, the first stimulus from a pair was selected as being larger if a value that was randomly sampled from its distribution exceeded the value that was sampled from the second stimulus' distribution. Luce and Galanter extended this viewpoint and proposed that the first stimulus would be chosen as being larger only if its value exceeded that of the second stimulus by some constant (C) amount. If $C > 0$, negative TOEs should result because the first stimulus would be underestimated relative to the second; conversely, positive TOEs would result if $C < 0$, because the first stimulus would be overestimated in relation to the second.

A second criterion bias view proposed by Wickelgren (1968) took a similar approach to the problem as Luce and Galanter (1963). However, according to Wickelgren both values sampled for the stimuli (the first and second) were transformed relative to the adaptation level, by biases. The judgement would then be made using the newly transformed values instead of those that were originally sampled from the distribution, thus accounting for both positive and negative TOEs.

As compelling as response bias views of TOEs may seem, they are lacking in that they can not account for all the experimental evidence available. It was unclear how TOEs are affected by variables such as range and ISI (Jamieson & Petrusic, 1975a, 1975c) which are likely to affect perceptions or memory but should not alter preferences

or biases. It also seems unrealistic that different subjects must adopt similar biases and that these biases must change regularly with ISI (Jamieson & Petrusic, 1975a).

2) Perceptual Bias

Other, more recent, theories have postulated that the TOE effect is a perceptual-memory phenomena (Hellstrom, 1977, 1985; Jamieson & Petrusic, 1975a, 1975c; Petrusic, 1984). Notably, Hellstrom's (1985) differential sensation weighting model provided a detailed description of the processes that are presumably involved in the comparison of successively presented stimuli without the reliance on any kind of bias. Comparisons were believed to occur not with the subjective values of the stimuli directly, but with weights which were understood to reflect dynamic contrast and assimilation effects operating on the perceptual-memory representations of the stimuli to be compared. According to this view, the direction and magnitude of the TOEs depended on both the relation between the differential weights applied to the stimuli as well as the stimuli used (i.e., adaptation level). This view seems to provided a fuller accounting of the available TOE findings then the response bias views.

PRESENT STUDY

The occurrence of TOEs with symbolic magnitudes have important implications about the nature of symbolic representations and how these representations are activated. TOEs imply that a symbolic CVC code can activate the same sensory mechanisms involved in direct perceptual experiences and suggest that a functional equivalence exists between perception and memory. Strong imagery views of memory representations (e.g., Farah, 1985; Finke, 1980, 1985) have proposed just such a functional equivalence between perception and memory. A failure to obtain TOEs with symbolic magnitudes,

on the other hand, would provide a criterion for distinguishing between the processing of perceptual and memory-based information.

Baranski and Petrusic (1992) conducted a pair of experiments exploring the possible occurrence of TOEs with symbolic magnitudes. Using visual extents in each of two experiments, classic negative TOEs were observed for the perceptual comparisons but they were not evident for comparisons involving remembered standards. The failure to obtain TOEs with symbolic magnitudes was taken to suggest that the representations of remembered stimuli either existed, predecisionally, in a format not subject to sensation weighting as suggested by Hellstrom, or by entering the information-processing stream in a similar format at some point after the sensation weighting has taken place.

Though it seemed that a remembered magnitude did not exhibit the full range of functionally equivalent perceptual-like properties, there was an underlying assumption that the task utilized successive stimulus presentation. It is possible, however, that TOEs were not evident with CVC standards because those comparisons were simply *not* successive. Faster RTs in the line-CVC order were observed which suggested that retrieval of the standard took place while the line was still available. Baranski and Petrusic (1992) argued that although RTs were relatively fast in the line-CVC order, they were not faster than the line-line comparisons. The line-CVC comparisons would have to be considerably faster than the line-line comparisons if the task was not successive such that the standard was activated before the removal of the line. However, this line of argument failed to consider the generally faster decision process with the more precise perceptual, line-line comparisons.

Global versus local variable stimuli

Although the lack of TOEs for comparisons involving remembered visual extents has been well documented (Baranski & Petrusic, 1992; Petrusic et al., 1993), the use of *local* variable stimuli for these comparisons makes a definitive conclusion about the nature of the comparison process premature.

Insert figure 1 about here

Local variable stimuli are sets of variable stimuli used in comparisons with specific standards. When a variable stimulus is presented first, the memory standard which is required for the comparison can be predicted perfectly and simultaneously activated. This precludes the maintenance in perceptual memory of the first presented stimulus which is necessary for the occurrence of TOEs. A set of *global* variable stimuli, on the other hand, are used in the comparison process for *all* standards. Since the *global* variable stimuli are not specific to any particular standard, they do not predict which standard will be presented and may be sufficient to ensure the requisite of successive comparison for the study of TOEs (see *Figure 1*).

The series of experiments conducted were designed with a view towards precluding the perfect prediction of which memory standard was to be activated upon the presentation of the variable perceptual stimulus, thereby ensuring that the comparison process was based on the perceptual memory of the first stimulus and the long term memory of the percept. It was hoped that this objective would be achieved by using a set of global variable stimuli

Experiment 1

Experiment 1 was designed to explore the effects of a set of global comparisons on the comparison process for successively presented perceptual items and items retrieved from LTM. More specifically, it sought to determine if TOEs would occur for comparisons involving remembered visual extent and visual extent as stimuli in order to permit comparability with these earlier studies which also used visual extents.

Method

Subjects

35 Carleton University undergraduate students participated in one ninety-minute session for course credit. All subjects reported normal or corrected to normal vision and were naive with respect to the nature and the aims of the experiment. Prior to participation all subjects were required to read and sign an informed consent form in line with departmental regulations.

Apparatus

Stimuli were presented on a Goldstar Model 1460 Plus VGA monitor. High resolution graphics were permitted with a VGAWonder+ video card and MetaWindows graphics under Turbo Pascal Version 7 software control. Timing, accurate to within ± 1 ms, was possible with a Data Translation clock board and extensive software development. Graphics production, stimulus presentation, event sequencing and the recording of responses and response times were controlled by an IBM-PC/486DX, 50 MHz clone computer. Responses were made using the buttons on an IBM-PC mouse.

Stimuli

Horizontal visual extent was used as standards and variable stimuli. For the two experimental conditions used, two line lengths were used as *standards* in the method of *constant stimuli*: 146.88 mm and 190.94 mm in the memory condition and 146.88 mm and 168.91 mm in the perceptual condition. Through preliminary test subjects, it was determined that subjects in the perceptual condition were much more accurate and tended to give step-like psychometric functions. To compensate for the relative ease of the comparisons in this condition, standards and variable stimuli were located closer together on the underlying dimension. Computer generation of the lengths of the standards was calculated using the actual number of pixels that comprised the extent. This allowed fourteen *comparison* line lengths to be generated at 0 and 24 pixel increments from the standards in the memory condition and 0 and 12 pixel increments from the standards in the perceptual condition. In the memory condition, this generated a comparison set of global variables with values of 111.63, 120.44, 129.25, 138.07, 146.88, 155.69, 164.51, 173.32, 182.13, 190.94, 199.76, 208.57, 217.38, and 226.56 mm for both standards. In the perceptual condition, a global comparison set, composed of lines with the values of 129.25, 133.66, 138.07, 142.47, 146.88, 151.29, 155.69, 160.10, 164.51, 168.91, 173.32, 177.72, 182.13, and 186.54 mm, was generated for both standards.

Hence, as the length of the standard increased, the absolute stimulus differences between adjacent variable stimuli were held constant but the ratios with the standard (and thus a priori ease of comparison) decreased (i.e., approached 1.0).

All lines were 1 mm wide and appeared white on a black background. The midpoint of each line was horizontally and vertically centred on the screen for the learning phases but for the comparison tasks, they were randomly shifted from centre by $\pm 0, 1.47$.

and 2.94 mm to preclude using the side of the monitor as a cue. The shortest and longest lines subtended visual angles of approximately 1 and 10 degrees respectively.

Procedure

Prior to each phase, subjects were read a prepared statement that explained what they were about to do (see appendix A). Subjects were run individually in a moderately illuminated room. The subject was seated at a table that supported the computer, video monitor and mouse, located approximately 45 cm from the display. For the memory condition, the experiment consisted of two parts: a learning phase and a comparative judgement task.

Memory Condition

Part 1: Learning. Sessions for subjects randomly assigned to the memory condition began with a learning phase in which they learned to associate the two line length standards with specific CVC letter triads (GUF and BIX) which were counterbalanced across subjects. On each learning trial, a single line was presented on the computer screen below which was a rectangular box, divided into two equal squares, in which the two possible CVCs appeared (in a random order on each trial). By moving the mouse from side to side, subjects were able to illuminate, in succession, either of the two CVC-containing squares. Subjects depressed the left key on the 'mouse' when they assumed the illuminated CVC corresponded to the line length presented. Subjects had 3500 ms to perform the association. If this time was exceeded, "Too Slow" appeared and the appropriate box was illuminated for 2000 ms. If the subject responded under the time limit but was incorrect, then again the appropriate box was illuminated for 2000 ms. If the subject was correct, the correct box remained illuminated for 2000 ms.

Subjects performed these associations until they met a criterion of 6 successive matches: three with each CVC standard. After reaching this criterion an additional 80 learning trials were given: 40 additional presentations of each standard. All subjects were instructed to closely attend to the magnitudes of the line lengths they were learning since they would be using this information in the next part of the experiment.

Part 2: Comparative judgement task. Following the learning phase, subjects were instructed that on each trial they would be presented, in succession, either a line and then a CVC, or a CVC and then a line. CVCs could be either one of the two the subject had paired with the standard in the learning phase. In each case they would have to select, according to the instruction, either the longer or the shorter of the two items presented, with the CVC corresponding 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. Subjects were asked to be as accurate as they could while not taking too much time to respond.

Each session for the memory condition was comprised of 4 blocks of 112 randomized trials. The trials in each block arose from the factorial combination of the 2 standards x 2 presentation orders (CVC first, CVC second) x 14 comparison stimuli x 2 instructions (LONGER, SHORTER).

Each trial began with the presentation of an instruction (LONGER or SHORTER) which remained centred near the top of the screen throughout the trial. One second after the instruction appeared, the first stimulus was presented for 1000 ms and was then removed. Following a 500 ms ISI, the second stimulus was presented and remained on the screen until the completion of the comparative judgement. Response times were

recorded from the onset of the second stimulus until response selection. Following the response, the screen was cleared and a 2000 ms ITI followed. Subjects were not provided with accuracy feedback at any point during the comparison phase. Subjects had 30 seconds from the onset of the second stimulus to respond.

Following the first comparison block, subjects in the memory condition were given an additional learning phase. This second learning phase was identical to the first learning phase except for the presentation order of the standards to be learned, which was randomly generated. It was believed that having two standards in the learning phase might be considered trivial by subjects and that they may not have attended to the actual extents fully. By providing the first block of comparisons, subjects were able to see exactly how demanding the task was. It was believed that during the second learning phase, subjects would attend to a greater degree and, thus, have more precise representations stored in memory. The second learning phase was followed by three more comparison blocks with subjects having a rest period between each block.

Perceptual Condition

The Comparative judgement task. Subjects in the perceptual condition were not given learning and the experiment immediately commenced with the comparative judgements. Subjects were instructed that on each trial they would be presented, in succession, with two horizontal line lengths. In each case they would have to select, according to the instruction, either the longer or the shorter of the two presentations. For all trials, the left button on the 'mouse' once again corresponded to the stimulus presented first and the right to that presented second. Subjects were asked to be as accurate as they could be without taking too much time to respond.

Each session for the perceptual condition was comprised of 5 blocks of 112 randomized trials. The trials in each block arose from the factorial combination of the 2 standards x 2 presentation orders (standard first, standard second) x 14 comparison stimuli x 2 instructions (LONGER, SHORTER).

Presentation of the strictly perceptual comparisons and recording of responses was accomplished in exactly the same manner as were comparisons in the memory condition.

Results

Thirteen subjects provided pilot sessions in order to establish the comparative difficulty levels and session duration for both the memory and perceptual conditions in the experiment. The data for these subjects are not be reported. The data for two subjects are also not reported here. Both subjects accidentally started the practice block of comparisons without the instructions and proceeded through the practice phase, the second learning phase and part of the comparison phase before alerting the experimenter to the situation.

Prior to running the experiment, cutoff levels for the learning trials and the comparison task were established. During the learning phase, if a subject received 200 presentations overall, the subject was removed from the experiment and no comparison trials were presented to that subject. No subjects in the learning phase exceeded this criterion and, therefore, no subjects were excluded from the experiment for this reason.

The first block of comparisons was considered the practice block and was not analyzed. A comparison phase cutoff was also established, based on the subject's percent correct ($P(\text{corr})$) for the remaining comparison phase blocks and was set at 50 % correct. Subjects performing below this chance level were excluded from further analysis. None

of the subjects from either condition fell below this criterion so no subjects were excluded from the experiment due to this criterion.

For the remaining 32 subjects, 16 in the memory condition and 16 in the perceptual condition, trials on which response times preceded 200 ms or exceeded 10 sec were discarded. This accounted for 21 of the 5328 trials obtained (0.4%) in the memory condition, with 17 trials (0.3%) being discarded for preceding 200 ms and 4 trials (0.1%) being excluded for exceeding the 10 sec cutoff. In the perceptual condition, 28 of the 7165 trials obtained (0.4%) were excluded due to this criterion, with all 28 trials being excluded for preceding 200 ms.

Psychometric Functions. Gaussian transformed psychometric functions were obtained for each standard for each subject in both the perceptual and memory conditions (see figures 2 and 3 for the memory and perceptual conditions, respectively).

Insert figures 2 and 3 about here

Examination of these psychometric functions reveals a property of considerable interest: the use of global variable stimuli results in distinctive segmental, psychometric functions, with well defined join points. The form of these psychometric functions poses a problem for calculation of indices of discriminative sensitivity such as JNDs, PSEs and Weber fractions. These calculations have traditionally been completed by using a least-squares criterion, first order regression through the Gaussian transformed probabilities that the variable stimulus was judged greater than the standard. The flat, horizontal sections observed in the psychometric functions for both perception and memory (see figures 2

and 3) indicate that subjects responded in a consistent manner with respect to the standard for those variable stimuli. As can be seen from figures 4 and 5 (for remembered and perceptual conditions, respectively), a simple least squares criteria using all the variable stimuli and not taking into account the join points or flat, horizontal regions would cause the slope of the psychometric function to decrease and the y-axis intercept to shift in the positive direction, causing calculated JNDs, PSEs and Weber fractions to be in error (higher JNDs and Weber fractions and shifted PSEs).

Insert figures 4 and 5 about here

In order not to overestimate the differential threshold and, therefore, underestimate sensitivity, a criterion for the exclusion of points on the psychometric function was used. This criterion was developed by Grondin (1993) to deal with a similar problem. In his experiment, if a subject had a probability of one or zero for a point on the psychometric function, Grondin logically assumed that the next point would be easier to discriminate and this point and subsequent points were not used in his analysis. The present experiment poses a slightly different problem Grondin had to deal with. Whereas Grondin had 60 replications for each point on the psychometric function, the present experiment has only 12 replications for each point for each subject in the memory condition and 16 replications for each subject in the perceptual condition. It is possible (though improbable) that for the present experiment, a subject could consistently respond in a certain way for a given variable stimulus, either saying that the specific variable stimulus was longer or shorter than the standard due to chance. In order to employ a stricter exclusion criterion, Grondin's criterion was modified slightly.

If a subject responded consistently for a point on the psychometric function (either saying that the variable was longer or shorter than the standard for all comparisons) and this point was followed or preceded (depending on whether the variable stimulus was actually larger or smaller than the standard) by a point where at least all but one response was in the same direction, the following point and all subsequent points were excluded from further analysis.

Standard least squares linear regression techniques were then used with the remaining points to obtain the slope and intercept of the best fitting equation (figures 6 and 7 for memory and perception, respectively).

Insert figures 6 and 7 about here

The usual indices of discriminative sensitivity were then obtained; i.e., 75% just noticeable differences (JNDs), Weber fractions and points of subjective equality (PSEs).

Weber Fractions and PSEs for Perception and Memory

As has been demonstrated in previous experiments (Baranski & Petrusic, 1992; Petrusic et al. 1993), performance is clearly superior with perceptual standards; in particular, the psychometric functions for perceptual standards (figures 6 and 7) are uniformly monotone increasing and have a steeper slope than those for remembered standards, indicating increased precision for these standards. The psychometric functions with remembered standards, on the other hand, exhibit considerably more variability and much shallower slopes.

Insert figure 8 about here

Figure 8 plots the mean of the subject PSEs, against the length of the standard, separately for perception and memory. The PSEs are also evident in figures 6 and 7 as the point at which the psychometric functions intercept the *x-axis*. In contrast to the actual standard value, the PSE corresponds to the subjective standard value assumed by

the observer and the difference between the actual standard and the PSE, is commonly referred to as the constant error and provides an index of stimulus location precision.

The superior performance with the perceptual standards is evident by the very small constant errors found for these standards. In fact, PSEs for comparisons involving strictly perceptual stimuli were nearly identical to the values of the standard (the mean PSE for standard 1 was 147.50 mm with an actual value of 146.88 mm and for standard 2 the PSE was 169.19 mm with an actual value of 168.91). In contrast, the memory standards show substantial constant errors. In particular, biases and/or drift in memory results in a PSE for the small standard which was located towards the lower extreme of the range of the variable stimuli (i.e., a PSE of 125.36 mm versus an actual value of 146.88 mm). The larger standard was also shifted slightly towards the smaller end of the continuum (188.57 mm PSE versus an actual standard of 190.94 mm). This location of the small standard is in a direction opposite to that predicted by Hollingworth's (1910) and Leuba's (1892) classic notions of memory "pooling" or "central tendency" or the idea that remembered items tend to drift towards the mean of the set to be remembered.

Weber fractions (WF), or normalized sensitivity indices, were also calculated for each standard for each subject for both memory and perception and the mean value for each standard both in memory and perception is provided in figure 9.

Insert figure 9 about here

It is quite evident from the plot that performance in perception was considerably better with a perceptual standard than a memory standard. The 2-way ANOVA conducted

using individual subject WFs as the dependent variable, standard (1 and 2) as the within-subjects factor and condition (memory or perception) as the between-subjects factor confirms the reliability of the enhanced perceptual sensitivity. The main effect of condition was reliable [$F(1, 30) = 7.51, p < .0103$] with the memory WF (11.69%) being significantly larger than the WF for perceptual condition (5.48%). The main effect of standard was also significant [$F(1, 30) = 7.15, p < 0.0120$] as was the interaction between condition and standard length [$F(1, 30) = 4.48, p < .0427$], indicating that the WFs decreased as standard length increased for the memory condition (15.07% and 8.31% for standards one and two respectively) but not for the perceptual condition (5.88% and 5.09% for standards one and two).

Presentation-Order Effects: Time-Order Errors

As noted earlier, previous research has found a lack of TOEs for comparisons involving a remembered percept (Baranski & Petrusic, 1992; Petrusic et al. 1993). The magnitude of TOEs for these successive comparisons involving both perceptual and remembered percepts has been reported using the index developed by Jamieson and Petrusic (1975a, 1975c):

$$T = \frac{1}{2} [P(\text{corr}|(L,S)) - P(\text{corr}|(S,L))],$$

where $P(\text{corr}|(L,S))$ denotes the probability of a correct response when the larger stimulus is first. Correspondingly, $P(\text{corr}|(S,L))$ denotes the probability of a correct response when the smaller stimulus is presented first.

Figure 10 plots this index at each level of the variable stimuli (excluding comparisons involving a standard and a variable stimulus equal to it) for both perception and memory.

Insert figure 10 about here

This index, suggested by Fechner's view of TOEs, is uniformly negative with the strictly perceptual comparisons, reflecting the general tendency to judge the second presented extent as longer. In contrast, and precisely as has been found in previous studies (Baranski & Petrusic, 1992; Petrusic et al. 1993), TOEs are simply not evident with remembered percepts. In fact, the magnitude of the TOE shifts from being positive to negative and back again. This lack of stable consistency of the sign of the TOE index suggests that what is occurring with comparisons involving remembered percepts is quite different from that with perceptual standards.

It may be possible in the present case, that subjects in the memory condition were able to make a choice before the second stimulus was even presented when the first stimulus was perceptual and located near either end of the continuum of the set of variable stimuli. Being able to identify that the perceptual stimulus was smaller or larger than all of the standards would allow subjects to render a judgement before a CVC was even presented, removing the successiveness required for TOEs to occur. Variable stimuli located in the middle of the continuum between the two extreme standards, however, do not provide the subject with any information about what choice to make. Examination of the four variable stimuli located between the standards in figure 10

indicates the magnitude of the TOE index is inconsistent in the memory condition with these variable stimuli. Thus, it seems clear from figure 10 that TOEs are present for comparisons involving strictly perceptual stimuli but not for comparisons involving remembered standards.

Two five-way analyses of variance (ANOVAs) were used to evaluate the results. The first used mean correct as the dependent variable and standard type (line, CVC), the two standards, 12 comparison stimuli (comparisons involving a standard with a variable equal to the other standard were removed), presentation order (standard-line, line-standard), and instruction (shorter, longer) as within-subject factors. The second ANOVA was identical to the first except that presentation order was changed to reflect TOEs (long-short, short-long). All significance levels are reported using Greenhouse-Geisser criterion but the degrees of freedom are those defined by the design. The main effect of standard type was not significant [$F(1, 30) = 3.41, p > .0746$] nor were the main effect of standard length [$F(1, 30) = 0.45, p > .5094$] and the interaction between standard type and standard length [$F(1, 30) = 0.19, p > .6668$], indicating that $P(\text{corr})$ was not different for the two conditions (87.74% for perception vs. 83.34% for memory) and that both standards were responded to correctly equally often for both the perceptual standards (short = 87.58% and long = 87.90%) and the CVC standards (short = 82.57% and long = 84.12%). The main effect of comparison stimulus was reliable [$F(11, 330) = 9.80, p < .0001$], which confirmed that the percentage of correct responses to the variable stimuli increased as distance between the variable stimulus and the standard increased. This main effect is qualified by the significant two-way interaction between standard type and variable stimulus [$F(11, 330) = 3.03, p < .0319$] and three-way interaction between

standard length, variable stimulus and standard type [$F(11, 20) = 3.52, p < .0192$] indicating that these rates of change were not consistent across standard type or standards.

The main effect of TOE (long-short order vs. short-long order) was reliable [$F(1, 30) = 23.44, p < .0001$], as was the interaction between standard type and TOE [$F(1, 30) = 21.05, p < .0001$] supporting the previous findings evident on figure 10 that TOEs were present for perception but not for memory. The interaction between variable stimulus and TOE was also significant [$F(11, 330) = 4.15, p < .0002$] but this interaction was qualified by both a three-way interaction between variable stimulus, TOE and standard length [$F(11, 330) = 5.60, p < .0001$] and a four-way interaction between standard type, variable stimulus, TOE and standard length [$F(11, 330) = 3.77, p < .0013$] indicating that TOEs were present only in the perceptual condition and that the magnitude of these TOEs decreased with increasing distance between the standard and the variable stimulus and that the amount of this decrease was dependent on the standard length (the decrease was less for the large perceptual standard than with the small perceptual standard).

The main effect of order (line-standard, standard-line) was not reliable [$F(1, 30) = .16, p > .6962$] as was the interaction between order and standard type [$F(1, 30) = .13, p > .7225$] indicating that $P(\text{corr})$ did not depend upon whether the standard was presented first or second, both when the standard was perceptually present (line-standard .8775 vs. standard-line .8773) or was a CVC (line-CVC .8357 vs. CVC-line .8312). The interaction between variable stimulus and order [$F(11, 330) = 6.76, p < .0001$] and the three-way interaction between standard type, order and comparison stimulus [$F(11, 330) = 7.24, p < .0001$] were significant, however. The interpretation of these effects must take into account that in the present context, the order variable specifying if the standard

was presented first was confounded with the short-long, long-short presentation orders. When a standard is presented first, it could be either the longer or the shorter of the pair, depending upon the variable stimulus presented. Upon further examination of this three-way interaction, it was confirmed that the order effect for $P(\text{corr})$ was actually reflecting TOEs. In perception, $P(\text{corr})$ was dependent upon presentation order (standard first or second) and the variable stimulus used in the comparison in the respect that the pairings reflected long-short, short-long presentation orders. The presentation of the longer stimulus second (either a variable stimulus or the standard), significantly improved $P(\text{corr})$ for that pair of stimuli, in perception only. Comparisons involving a remembered percept were not subject to systematic $P(\text{corr})$ order effects. Analysis of these order effects support the earlier findings of TOEs for perceptual comparisons but not for remembered standards.

Response Time Analysis

Recall that global variable comparison stimuli were used in an attempt to ensure that the short-term perceptual memory representation was compared with the long-term representation of the percept, that is, the comparisons were successive in the line-CVC order.

Insert figure 11 about here

Figure 11 plots the mean response times for comparisons with the two levels of the perceptual and remembered standards as a function of presentation order (standard first vs. standard second) for the combined data of all subjects. As expected, response times

were slower when comparison involved a remembered standard. In addition, the negative TOEs evident in the previous section with the percent correct measure for the perceptual standards are also evident with the response time for comparisons involving the perceptual standards. Specifically, for variable stimuli less than the respective standard (146.88 and 168.91 mm), response times are faster in the variable-standard presentation because the standards are longer. For comparisons involving variables that are greater than the standard, response times are faster in the standard-variable order because the variable lines are longer.

Comparisons involving a remembered standard are in striking contrast to those involving a perceptual standard and do not reflect a comparable TOE effect on response time. Response times for these remembered comparisons were faster when the line segment was presented first with almost every variable stimulus for both standards, precisely as obtained when local variable stimuli are used (cf., Baranski & Petrusic, 1992). Indeed, using local variable stimuli, Baranski and Petrusic believed that this result was quite logical. When the CVC appears first, subjects must wait until the line is presented before they can initiate the comparison. However, if the line appears first, the subject immediately knows which CVC will be presented and the appropriate retrieval operation can be initiated during the ISI. The present experiment was design to specifically deal with this possibility. Since all variable stimuli were paired with each standard, subjects would not be able to predict above a chance level which standard would be presented when the variable was presented first. Both the monotonicity of the plots and the uniformly faster times when the perceptual stimulus was presented first

(especially for standard 2), however, could arise only if the both memory standards were activated and comparisons with each of these standards is conducted in parallel.

Finally, for both memory and perception, there is clear evidence of a distance effect: in both presentation orders, comparison times are dependent on the difference in the length between the standard and the variable stimulus, since response times peak at or near the standard, or rather, more accurately at the PSE and decrease as the difference between the PSE and variable stimuli increases.

Two, five-way ANOVAs were used to evaluate these results. The first used mean response time as the dependent variable and standard type (line, CVC), the two standards, 12 comparison stimuli (comparisons involving a standard with a variable equal to the other standard were removed), presentation order (standard-line, line-standard), and instruction (shorter, longer) as within-subject factors. The second ANOVA was identical to the first except that presentation order was changed to reflect TOEs (long-short, short-long). As expected, response times were faster for comparisons with a perceptual standard than with a CVC standard [975 ms vs. 1706 ms; $F(1, 30) = 52.85$, $p < .0001$]. The main effect of standard was not reliable [$F(1, 30) = 3.20$, $p > .0837$] nor was the interaction between standard type and standard length [$F(1, 30) = 2.02$, $p > .16$] indicating that both standards were equally fast for both the perceptual standards (short = 969 ms and long = 981 ms) and the CVC standards (short = 1,652 ms and long = 1,760 ms). The main effect of comparison stimulus was reliable [$F(11, 330) = 6.23$, $p < .0001$], which confirmed that response times depended on the values of the variable stimuli and decreased as distance between the variable stimulus and the standard increased (i.e., a distance effect). The main effect of TOE (long-short order vs. short-long order) was

reliable [$F(1, 30) = 12.80, p < .0012$] as was the interaction between standard type and TOE [$F(1, 30) = 12.01, p < .0016$], supporting previous findings that TOEs were present for perception but not memory. The interaction between comparison pair and TOE was also significant [$F(11, 330) = 8.44, p < .0001$]. This interaction was qualified by a three-way interaction between standard type, TOE and variable stimulus [$F(11, 330) = 4.13, p < .0004$], indicating that TOEs occurred only in the perceptual condition and decreased with increasing distance between the standard and the variable stimulus. The main effect of order (line-standard, standard-line) was also reliable [$F(1, 30) = 47.89, p < .0001$] as was the interaction between order and standard type [$F(1, 30) = 23.50, p < .0001$], confirming that presentation with the standard second was faster only in the memory condition. The interaction between comparison pair and order [$F(11, 330) = 2.77, p < .0095$] and the three-way interaction between standard type, order and comparison stimulus [$F(11, 330) = 3.22, p < .0031$] were significant and confirmed the faster responses for the line-CVC than the CVC-line comparisons for trials involving remembered standards and that this effect was maximal with variable stimuli close in length to the remembered standard.

Biases in Memory and Local Dependencies in Perception

Examination of comparisons of variable stimuli equal to the standard proves especially revealing in distinguishing comparisons with strictly perceptual stimuli from those involving a remembered percept.

Insert figure 12 about here

Figure 12 plots the proportion of times the second presented stimulus was reported as the longer for each of the standards, separately for the remembered and for the perceived standards. First, in perception, in accord with the earlier demonstrations of negative TOEs, when two identical extents are presented, the second is reported as the longer. In contrast, such TOEs are clearly absent with CVC comparisons. Rather, when faced with a difficult comparison, these subjects bias their responses to reflect the proportion of stimuli larger than it. When the CVC corresponding to the small standard is presented first, the proportion of responses indicating that the line was judged longer (54.26%) reflects the actual proportion of variable stimuli that are longer than the standard (69%). When the small standard is presented second, the proportion of times it is judged greater than the variable stimulus (36.17%), reflects the actual proportion of variable stimuli it is greater than (31%). However, comparisons involving the large memory standard and its corresponding perceptual referent do not exhibit these biases. The proportion of times that the second stimulus was judged larger was 53.19% and 52.63% in the line-CVC and CVC-line order, respectively. The corresponding proportions that the second was actually larger than the first are 69% and 31% respectively.

Thus, in summary, these analyses reveal strikingly different processes in operation in perception and in memory. TOEs are evident in both P(corr) and RTs in perception but not in memory and in memory, response biases are used. Given that RTs are significantly faster in the line-CVC order for comparisons involving a LTM

representation, and that simultaneous activation and comparison with standards occurs, the successiveness requisite for the occurrence of TOEs is not obtained. The lack of TOEs for items retrieved from long-term memory, is, therefore, not surprising. What is unclear, however, if this simultaneous activation of the standards in memory occurs as a consequence of the use of global variable stimuli or the fact that only two items were stored in LTM. A set size of two might not be large enough to place demands on the retrieval system and prevent this parallel activation. Experiment 2 was conducted to explore this possibility further and to, once again, examine TOEs for remembered percepts.

Experiment 2

Petrusic et al. (1993) have shown that the number of items to be retrieved from memory has an influence on how well representations are stored and subsequently retrieved; they obtained a clear serial position effect (SPE), with end items showing greater precision. Experiment 2 examined the set size effect for both perception and memory by having a set size two and set size three condition. If the pattern of results found in Experiment 1 was due to the fact that only two standards were used, then the set size three condition should produce a different pattern of results. The use of set-size three also allows for a fuller examination of constant errors and the form of the serial position effect (SPE) for remembered standards when global variable stimuli are used.

Method

Subjects

Seventy-six Carleton University undergraduate students participated for a single ninety minute session for course credit. All subjects were required to have normal or

corrected to normal vision and were naive with respect to the nature and the aims of the experiment. Prior to participation, all subjects were required to read and sign an informed consent form in line with departmental regulations.

Apparatus

The apparatus was identical to that used in experiment 1.

Stimuli

Four stimulus conditions were used in the present study arising from the two by two factorial combination of number of standards (two or three) and whether the standards were perceptually available or in memory. In two of the conditions, two horizontal line lengths were used as standards in the method of constant stimuli while in the other two conditions, three horizontal extents were used. Standards for the respective groups were, 138.07 and 190.94 mm in the memory-2 standards (M2Std) condition, 142.47 and 168.91 mm in the perceptual-2 standard (P2Std) condition, 138.07, 164.51 and 190.94 mm in the memory-3 standard (M3Std) condition and 142.47, 155.69 and 168.91 mm in the perceptual-3 standard (P3Std) condition. Eleven comparison line lengths for each condition were generated as in Experiment 1 at 0 and 24 pixel increments from the standards in the memory condition and 0 and 12 pixel increments from the standards in the perceptual condition. As in experiment 1, stimuli in the perceptual condition were more closely spaced on the underlying perceptual continuum due to the greater ease with which subjects can make these comparisons. For both the M2Std and M3Std conditions, the following global variable stimuli were used: 120.44, 129.25, 138.07, 146.88, 155.69, 164.51, 173.32, 182.13, 190.94, 199.76, and 208.57 mm for the standards. In the P2Std and P3Std conditions, global variable stimuli with values of 133.66, 138.07, 142.47,

146.88, 151.29, 155.69, 160.10, 164.51, 168.91, 173.32, and 177.72 mm were generated for the standards.

Once again, as the length of the standard increased, the absolute stimulus differences between the variable stimuli were held constant but the ratios with the standard (and thus a priori ease of comparison) decreased (i.e., approached 1.0); i.e., the comparisons became more difficult.

All lines were presented and responses recorded exactly as they were in experiment 1 except for one alteration. Segalowitz and Graves (1990) noted that when a mouse is used to indicate a subject's response, it is possible that as much as 20 ms may be added to the RTs due interference of information from the movement of the trackball of the mouse with the button response. By disabling the trackball (physically removing it), this competition of information was prevented and more accurate response time measures could be obtained.

Procedure

Generally the procedure for Experiment 1 was followed exactly except for some modifications. For subjects in the memory conditions, the first learning phase was followed by a practice block of 20 comparisons, randomly selected from a full block of comparisons. This practice block was then followed by an additional learning phase identical to the first one. Following the second learning phase the subject was presented with three full blocks of comparative judgements, each separated by a brief rest.

The number of trials presented in a block to a subject depended upon the set-size condition they were present in and arose from the factorial combination of the number of standards for the given condition x 2 presentation orders (standard first, standard second)

x 11 comparison stimuli x 2 instructions (LONGER, SHORTER). Therefore, for the set-size two condition, there were 88 trials and for the set-size three condition, there were 132 trials. Using these combinations and equal number of blocks for the perceptual and remembered conditions, the number of presentations of each standard during the comparison phase for both perceptual and memory conditions were equated.

Results

As in Experiment 1, the practice block was not analyzed. Four subjects in total were excluded from the experiment because they responded at or below chance level, primarily because of an inability to understand the instructions. Two of these subjects were in the M3Std conditions and two were in the P2Std condition.

For the remaining 72 subjects, 18 in each cell of the factorial combination of set-size (2 or 3) and condition (memory or perception), trials on which response times preceded 200 ms or exceeded 10 sec were discarded. This accounted for 2 of the 3166 trials obtained (0.06%) in the memory, set-size 2 condition, with both trials being excluded for exceeding the 10 sec cutoff. In the perceptual set-size 2 condition, 2 of the 3166 trials obtained (0.06%) were excluded due to this criterion, 1 trial (.03%) falling below the 200 ms criteria and 1 trial (.03%) exceeding 10 sec. In the set-size 3 memory condition, 10 trials were excluded from the 4737 trials obtained: 3 trials (.06%) were less than 200 ms and 7 trials (.15%) were greater than 10 sec. For the set-size 3 perceptual condition, 5 trials were excluded from the 4748 trials obtained: 2 trials (.04%) were less than 200 ms and 3 trials (.06%) were greater than 10 sec.

Psychometric Functions. Gaussian transformed psychometric functions were obtained for each standard for each subject for both set size conditions in the remembered

and the perceptual conditions (figures 13, 14, 15 and 16 for the M2Std, P2Std, M3Std, and P3Std conditions, respectively).

Insert figures 13, 14, 15, and 16 about here

Examination of these psychometric functions once again revealed distinctive *segmental*, psychometric functions, with well defined join points as found in Experiment 1 when *global* variable stimuli were used. The overestimation of difference thresholds and the underestimation of sensitivity remains a point of concern for these psychometric functions also and thus the modified Grondin (1993) criterion was used to control for this problem (figures 17, 18, 19 and 20 for the M2Std, P2Std, M3Std, and P3Std conditions, respectively).

Insert figures 17, 18, 19, and 20 about here

Standard least squares linear regression techniques were then used to obtain the slope and intercept of the best fitting equation and then the usual indices of discriminative sensitivity were obtained; that is, 75% JNDs, WFs and PSEs.

Weber Fractions and PSEs for Perception and Memory.

As in Experiment 1 and previous studies (Baranski & Petrusic, 1992; Petrusic, Baranski & Harrison, 1993), performance was clearly superior with perceptual standards. Functions for these standards were uniformly monotone with steeper slopes than the functions for remembered percepts.

Insert figure 21 about here

Figure 21 plots the obtained PSEs against the length of the standard separately for perception and memory for each set size. Again, in perception, the constant errors were very small with the PSEs nearly identical to the values of the standard. In contrast, as the top panels of the plot show, systematic and substantial constant errors are present with the memory standards and these effects are especially evident in set-size three. In particular, biases and/or drift in memory results in PSEs which move towards the extremes of the range of the variable stimuli. PSEs for the standards located near the end of the continuum for both set-size conditions in memory are actually outside the range of the variable stimuli for several subjects. These results are in direct contrast to Hollingworth's (1910) and Leuba's (1892) classic notions of memory "pooling" or "central tendency".

Insert figure 22 about here

Figure 22 plots the mean of individual subject Weber fractions in the set size 2 and 3 conditions, separately for perception and memory. An ANOVA conducted on individual subject WFs, with set-size (2 or 3) and condition (memory or perceptual) as the between subject factors and standard as the within subject factor, was used to evaluate the results. Standard 2 was removed from the set-size 3 conditions so that all four groups could be included in the analysis. As is clearly evident in figure 22, Weber fractions for perception are considerably smaller (4.91%) than with memory standards (11.94%) and

this difference is highly reliable [$F(1, 68) = 18.83, p < .0001$]. A second ANOVA was conducted that used the individual subject WFs from the set-size 3 conditions only, and included standard 2. The significant difference between perception and memory found with the first ANOVA was supported by a significant difference between the set-size 3 conditions [$F(1, 34) = 15.58, p < .0001$], with perception having greater precision than memory.

As noted earlier, clear set-size and serial position effects have been found when extensive over-learning is *not* employed (Petrusic et al. 1993). In contrast, in the present case, where very extensive over-learning was employed, neither set size effects [$F(1, 68) = .01, p > .93$] nor serial position effects [$F(1, 68) = .11, p > .74$] are evident in the memory conditions. Furthermore, entirely as found in previous studies (Petrusic et al. 1993), perceptual discriminative sensitivity does not depend on set size or the contextual surround (e.g., the average Weber fractions with global and local variable stimuli are comparable).

Presentation-Order Effects: Time-Order Errors

The magnitude of the TOE index developed by Jamieson and Petrusic (1975a and 1975c) are plotted in figure 23 for both set-sizes and both conditions.

Insert figure 23 about here

As in Experiment 1, the index is uniformly negative with the strictly perceptual comparisons, reflecting the general tendency to judge the second presented extent as longer. In contrast, and precisely as found in Experiment 1, TOEs are simply not evident

with remembered percepts. These findings were evaluated by conducting an ANOVA on individual subject mean percent correct as the dependent variable, set-size (2 or 3) and condition (memory or perceptual) as the between subject factors with standard, variable stimulus, TOE (long-short order, short-long order) and instruction as the within subject factors. Comparisons between a standard and a variable stimulus equal to another standard were removed as were values associated with standard 2 so that all 4 groups could be analyzed at once. All significance levels are reported using Greenhouse-Geisser criterion but the degrees of freedom are those defined by the design.

The TOEs plotted in figure 23 were found to be significant for $P(\text{corr})$ [$F(1, 68) = 73.78, p < .0001$] as was the interaction between condition and TOE [$F(1, 68) = 86.93, p < .0001$], confirming that TOEs occurred in the perceptual condition but not in the memory condition. These TOEs were further qualified by significant three-way and four-way interactions which are apparent from figure 23. The three-way interactions between standard length, TOE and condition [$F(1, 68) = 4.45, p < .0386$] and variable stimulus by TOE by condition [$F(7, 476) = 2.39, p < .0223$] were both significant as was the four-way interaction of standard length by variable stimulus by TOE by condition [$F(7, 476) = 16.04, p < .0001$]. This four-way interaction confirms what is evident in figure 23, not only are TOEs present only in the perceptual condition but these TOEs decrease with increased distance of the variable stimulus from the standard and the amount of this decrease is dependent upon the standard that the variable stimulus is compared to.

A second ANOVA examining only the set-size three condition was also conducted. Individual subject mean percent correct was used as the dependent variable, with condition (memory or perceptual) as the between subject factors and standard,

variable stimulus, TOE (long-short order vs. short-long order) and instruction as the within subject factors. Comparisons between a standard and a variable stimulus equal to another standard were removed. The effects of the first ANOVA were confirmed. The main effect of TOE was once again significant [$F(1, 34) = 26.6, p < .0001$] as was the interaction between TOE and condition [$F(1, 34) = 35.17, p < .0001$]. Again, the standard length by TOE interaction [$F(2, 68) = 4.45, p < .0166$] was significant. However, the three-way interaction between standard length, TOE and condition [$F(2, 68) = .90, p < .4087$] was not significant. Finally, the variable stimulus by TOE [$F(7, 238) = 4.26, p < .0006$] and the variable stimulus by TOE by condition [$F(7, 238) = 2.59, p < .0211$] interactions were also significant.

Response Time Analysis

Global variable comparison stimuli were originally used to ensure that the short-term perceptual memory representation was compared with the long-term representation of the percept; that is, that the comparisons were successive in the line-CVC order. Experiment 1 indicated that with set-size 2, this was not the case and comparisons involving a remembered percept are *not* successive in the line-CVC order. The set-size 3 condition for the present experiment was an attempt to increase the memory load and prevent the simultaneous activation and comparisons with the standards as was found in Experiment 1. Figure 24 provides the plots for mean overall response times and permits a determination if, in fact, successiveness occurred in the line-CVC order with set-size three.

Insert figure 24 about here

The plots of mean overall response times with each variable stimulus for each standard in the memory condition in set-size two (figure 24) will suffice to convey the main points which are also evident with the set-size three. First, and most importantly, comparisons are faster when the line segment is presented first with almost every variable stimuli for both standards, precisely as obtained in Experiment 1 and when local variable stimuli are used as in Baranski and Petrusic (1992) and Petrusic et al. (1993) experiments. Furthermore, there is clear evidence in both presentation orders that comparison times depend on the difference in the length between the standard and the variable stimulus; response times peak at or near the standard, or rather, more accurately, at the PSE. Once again however, both the monotonicity of the plots and the uniformly faster times when the perceptual stimulus is presented first can arise only if the representation of each of the memory standards are simultaneously activated and comparisons with each of these standards is conducted in parallel. Examination of the plots in figure 24, for the set size 3 memory condition, shows the same configuration, suggesting that parallel activation and comparison is possible with three percepts in memory!

On the other hand, the pattern of response times with the perceptual standards is strikingly different and reflects the pervasive and very substantial presentation order effects presented earlier with the proportion correct measure. Namely, response times are uniformly faster when the shorter line segment is presented first. For example with standard 1 in the set-size 2 condition, when the standard is presented first and the longest variable comparator second, response times are approximately 200 ms faster than when this comparator is presented first.

Two, five-way ANOVAs were used to evaluate the results. The first used mean response time as the dependent variable and standard type (line, CVC), the two standards (the middle standard for the set-size 3 conditions were removed), 8 comparison stimuli (comparisons involving a standard with a variable equal to a standard were removed), presentation order (standard-line, line-standard), and instruction (shorter, longer) as within-subject factors. The second ANOVA was identical to the first except that presentation order was changed to reflect TOEs (long-short, short long). As expected, response times were faster for comparisons with a perceptual standard than with a CVC standard [1225 ms vs. 1804 ms; $F(1, 68) = 24.91, p < .0001$]. The main effect of standard length was reliable [1495 ms vs. 1533 ms; $F(1, 68) = 5.61, p < .0207$] while the interaction between standard type and standard length was not [$F(1, 68) = 1.70, p < .1973$], indicating that shortest standard was significantly faster than the longest standard in both perceptual and remembered conditions (1216 ms vs. 1233 ms in the perceptual condition and 1774 ms vs. 1834 ms in the remembered condition). The main effect of comparison stimulus was reliable [$F(7, 476) = 2.41, p < .0330$], which confirmed that response times decreases with increasing distance from the standard. The main effect of TOE (long-short order, short-long order) was reliable [$F(1, 68) = 47.45, p < .0001$] as was the interaction between standard type and TOE [$F(1, 68) = 29.97, p < .0001$] indicating the TOEs were present in perception but not in memory. The interaction between comparison pair and TOE [$F(7, 476) = 15.71, p < .0001$] was significant and was qualified by a three-way interaction between standard type, TOE and comparison stimulus [$F(7, 476) = 10.64, p < .0001$], which confirms the response time TOE for the

successive perceptual comparisons but no such effect for the remembered standards and that these TOE effects decreased with increased distance from the standard. The main effect of order (line-standard, standard-line) was also reliable [$F(1, 68) = 37.04, p < .0001$] as was the interaction between order and standard type [$F(1, 68) = 34.85, p < .0001$], which confirms results shown in figure 24 that response times were faster in the line-standard order only for the memory condition. There were also significant interactions between comparison pair and order [$F(7, 476) = 8.97, p < .0001$] and the three-way interaction between standard type, order and comparison stimulus [$F(7, 476) = 6.49, p < .0001$] which confirmed the difference between the line-CVC and CVC-line comparisons for trials involving remembered standards, and that this effect diminished with increasing distance between the variable stimulus and the standard.

Strategic Biases in Memory and Local Dependencies in Perception

Examination of comparisons of variable stimuli equal to the standard, once again, proved especially revealing in distinguishing comparisons with strictly perceptual stimuli from those involving remembered percepts. Figure 25 provides plots of the proportion of times the second presented stimulus was reported as the longer for each of the standards, separately for the remembered and for the perceived standards, and for both set-sizes.

Insert figure 25 about here

First, in perception, in accord with the earlier demonstrations of negative TOEs, when two identical extents are presented, the second tends to be reported as the longer and this is evident for both set sizes. In contrast, such TOEs are clearly absent with CVC

comparisons. Rather, when faced with a difficult comparison, these subjects make use of strategic information and bias their responses accordingly. For example, when the CVC corresponding to standard 3 is presented first, the probability that the second presented line segment is judged longer is .20, which corresponds approximately to the actual proportion of variable stimuli that are longer than that standard. Similarly, for the shortest standard, where approximately .80 of the variable stimuli are longer, subjects report the second presented stimulus, the line segment, as longer nearly 90% of the time.

Thus, in summary, these analyses reveal, as in Experiment 1, strikingly different processes in operation in perception and in memory. TOEs occur in perception but not in memory and in memory, strategic response biases are used. Using global variable stimuli and in spite of extensive over-learning, the present findings provide a clear replication of Experiment 1 and earlier work (Baranski and Petrusic, 1992; Petrusic et al. 1993): discriminative sensitivity for remembered percepts is considerably poorer than for the percept. The present experiment used massive over-learning and, in contrast to earlier work, neither set-size nor serial position effects were obtained. Evidently, with increased learning, the properties of long-term memory for percepts begin to resemble those of the percept but not with respect to the occurrence of TOEs.

In spite of the increase in set-size, the use of global variable stimuli, once again, did not result in strictly successive presentations. Rather, subjects were able to activate the memory representations of the entire set and initiate the comparison process during the inter-stimulus interval. Finally, perception and memory can be further distinguished by the fact TOEs are clearly absent for remembered stimuli but they are large and consistent for perceived stimuli. On the other hand, comparisons with remembered

standards involve, global, strategic biases but in perception these are not so evident; rather the biases are more likely to be local.

Experiment 3

Though relatively brief durations have been extensively studied with respect to TOEs, they have been largely ignored in the field of memory psychophysics. Experiment 3 was designed to lend greater generality to the overall findings from Experiments 1 and 2. For this experiment, it was necessary to use very brief durations to avoid the use of uniquely human timing mechanisms such as chronometric counting during the comparison phase. Given the extensive work that has developed concerning TOEs for perceptual durations (see Allan, 1979 for a review), Experiment 3 was thus designed to determine if the well-established properties of TOEs with brief durations would be evident with the memories of such very brief durations.

Method

Subjects

Three Carleton University graduate students (denoted as MFB, SAM, and PAC) participated for 17, 19, and 13 ninety-minute sessions respectively. All subjects had normal or corrected to normal vision and were naive with respect to the nature and the aims of the experiment. Prior to participation, all subjects read and signed an informed consent form in accord with departmental regulations.

Apparatus

Instructions were presented on a Zenith ZCM-1492 video monitor. High resolution graphics were permitted with a VGAWonder+ video card and MetaWindows graphics under Turbo Pascal Version 7 software control. Timing was accurate to within

± 1 ms through the use of a Data Translation clock board and extensive software development. Graphics production, stimulus presentation, event sequencing and the recoding of responses and response times was controlled by a IBM PC 486DX, 33 MHz clone computer. Responses during the learning phase were made using the buttons on an IBM-PC mouse. Responses during the comparison phase were made using the buttons on a response panel interfaced with the computer.

Stimulus durations were defined by the period of illumination of a clear, diffused, red, Quality Technologies light-emitting diode (MV5021A) that was .47 cm in diameter with a rise and fall time of 50 ns. The diode was mounted on a clear red plastic panel placed directly in front of the video monitor and was located approximately 35 cm above the table.

Stimuli

Two stimulus conditions were used in the present study. One presented the standards using the corresponding CVC while the other used the actual physical standards for the comparisons. In both conditions, three durations were used as standards in the method of constant stimuli. For the memory condition, standards of 72, 124, and 215 ms were used and for the perceptual condition, standards of 67, 102, and 155 ms were used. Eleven comparison durations for each condition were generated using a fixed *percentage* difference between the comparisons beginning with a 50 ms comparison. For the memory condition, variable stimuli were separated by 20% while the variable stimuli for the perceptual condition were separated by differences of 15%. For the memory condition, the eleven comparison durations had values of 50, 60, 72, 86, 103, 124, 149,

179, 215, 258, 310 ms and for perceptual condition the set was comprised of durations with the values of 50, 58, 67, 77, 89, 102, 117, 135, 155, 178, 205 ms.

Ratios of the differences between variable stimuli were held constant. According to Weber's Law, equal ratios should be equally discriminable and, therefore, a priori ease of comparison was equated.

All durations were presented and responses recorded in the same manner as in experiments 1 and 2 except that responses for the comparison phase were recorded using a response panel and were measured from the onset of the first stimulus.

Procedure

Prior to participating in the experiment, subjects were read a prepared statement that explained what they were going to be doing. The subjects were run individually in a moderately illuminated room and were seated at a table that supported the computer, video monitor, diode, mouse and response panel and were located approximately 45 cm from the display.

The sessions that composed the memory condition preceded the sessions that composed the perceptual condition. It was discovered part-way into the memory sessions that comparisons involving a CVC standard and a variable stimulus equal to the actual standard were missing for the duration-CVC order. Subject PAC had completed five sessions and was given an additional four sessions with the complete set of comparisons. Subject MFB had just completed all of the memory sessions (nine in total) when the error was discovered; an additional four sessions were then added. For both of these subjects, after completing all of the memory sessions, four sessions were conducted in which only perceptual durations were presented. Subject SAM had completed the entire experiment

(both memory and perception) when the error was discovered. An additional 5 memory sessions were added to obtain the data for the missing comparisons.

As in Experiments 1 and 2, the memory condition consisted of two parts: a learning phase and a comparative judgement task.

Memory Condition

Part 1: Learning. Sessions for the memory condition proceeded in much the same way as the learning phases for the first two experiments. Subjects learned to associate three duration standards with specific CVC letter triads (GUF, BIX and ZOC) which were counterbalanced across subjects according to a Latin-square design. Aside from the different stimuli to be learned, the learning phase was identical to that used in Experiment 1.

On each learning trial, a single duration determined by the duration onset of the diode was presented. On the computer screen, below the diode, a rectangular box appeared which was divided into three equal sections, in which the three possible CVC's appeared (in a random order on each trial). By moving the PC-Mouse from side to side, subjects were able to illuminate, in succession, any of the CVC-containing sections. Subjects pressed the left key on the 'mouse' when they believed the illuminated CVC corresponded to the duration presented. Subjects were instructed to respond after the *offset* of the duration and had 3500 ms from the offset of the duration to perform this association. If this time was exceeded, "Too Slow" appeared on the screen and the appropriate CVC was illuminated for 2000 ms. If the subject responded under the time limit but was incorrect, then again the appropriate CVC was illuminated for 2000 ms.

All subjects in the memory condition performed these associations until they had the learning criterion of nine successive matches, three with each standard, in a row. After reaching their respective criterion, all subjects received an additional 40 presentations of each standard. All subjects were instructed to attend very closely to the durations of the diode illumination they were learning to label since they would be using this information in the next part of the experiment.

Part 2: Comparative judgement task. Following the learning phase, subjects were instructed that on each trial they would be presented, in succession, with either a duration and then a CVC, or a CVC and then a duration. In each case they would have to select, according to the instruction, either the longer or the shorter of the two presentations with the CVCs corresponding to the respective durations learned in the previous phase of the experiment. For all trials, the left button on the response panel corresponded to the stimulus presented first and the right button to those that were presented second, relative to the instruction. Subjects were asked to be as accurate as they could while not taking too much time to respond.

Each trial began with the presentation of an instruction (LONGER or SHORTER) which also served as a ready signal and remained centred near the top of the screen throughout the trial. One second after the instruction appeared, the first stimulus was presented. Following a 500 ms ISI, the second stimulus was presented. Due to the temporal nature of the stimulus, it may have been possible that subjects were able to identify the perceptual stimulus presented first as being either larger or smaller than any of the other alternatives. If so, subjects may have been able to respond during the ISI or even before the first duration was complete. To control for such a possibility, responses

and response times were recorded from the *onset* of the trial until response selection. Subjects had 30 seconds after the *offset* of the second stimulus to respond. Following the response, the screen was cleared and a 2000 ms inter-trial-interval followed. Subjects were not provided with accuracy feedback at any point during the comparison phase.

Following the practice block, subjects in the memory condition were placed in the learning phase once again. This second learning phase was followed by three more complete blocks of comparison with subjects being allowed to rest between each block.

Subjects were asked to complete 3 full blocks of comparisons during an experimental session. The blocks of comparisons were composed of 132 randomized trials which arose from the factorial combination of the 3 standards x 2 presentation orders (CVC first, CVC second) x 11 comparison stimuli x 2 instructions (LONGER, SHORTER). Practice blocks for each subject contained 20 trials which were randomly selected from a full block of comparisons for the respective condition.

Perceptual Condition

Comparative judgement task. Subjects in the perceptual condition did not receive the learning phase and began the experiment with the comparative judgements. Subjects were instructed that on each trial they would be presented, in succession, with two brief durations. In each case they would have to select, according to the instruction, either the first or the second of the two presentations. For all trials, the left button on the response panel corresponded to the stimulus presented first and the right to that presented second, relative to the instruction. Subjects were asked to be as accurate as they could while not taking too much time to respond.

The presentation of the comparisons for the perceptual conditions was identical to that in the memory condition except that no CVCs were present.

Results

Two subjects provided pilot data in order to establish the comparative difficulty levels and session duration for both the memory and the perceptual conditions in the experiment. The data for these subjects were not reported. As in the previous two experiments, a learning criterion of 200 trials was used as a cutoff. One subject was tired and unable to concentrate and was excluded from the experiment for exceeding this cutoff on the first day. For the remaining three subjects, the practice block for each day was not analyzed.

Because of the temporal nature of the perceptual stimuli used, the use of RTs in the analysis of the results is a problem. Response times were recorded from the onset of the trial in order to allow for calculations of new response times, taking the length of the first stimulus into account. The new RTs were calculated using the original RT and removing the length of the time the first stimulus was presented. When a perceptual stimulus was presented first, the actual length of the duration was removed from the overall RT to provide a new RT for the trial. When a CVC was presented first, it remained on the computer screen for 1000 ms, so 1000 ms was removed from the overall response time to calculate the new RT (to be referred to as RT for the remainder of the paper).

Trials on which the RT was less than 0 ms (i.e., responses made before the off-set of the first stimulus) or exceeded 10 s were excluded from further analysis. Since presentation of the results will focus only on individual subject data, the number of trials

excluded for each subject for each condition is reported. In the memory condition, subject MFB had 4,980 trials with 3 (.06%) being excluded for falling below 0 ms and 3 (.06%) for exceeding 10 sec. Subject SAM was presented with a total of 5,757 trials and had only 2 (.04%) excluded for being less than 0 ms. A total of 3,473 trials were presented to subject PAC and 1 trial (.3%) was excluded for exceeding 10 s. In the perceptual condition, subject MFB had 1,820 trials and 1 (.06%) was excluded for exceeding 10 s. Both subjects, SAM and PAC had none of their trials excluded for exceeding the criterion and were presented with 1,824 and 1,822 trials respectively.

Figure 26 plots each subject's $P(\text{corr})$ for each day and for each stimulus set the subject was presented with, either the memory condition with the three missing comparisons, the memory condition with a complete set of comparisons or the perceptual condition.

Insert figure 26 about here

Examination of the individual plots indicate that the missing comparisons had no influence upon overall performance. $P(\text{corr})$ does in fact increase across the sessions for each of the subjects even though trial-by-trial feedback was not provided. Interestingly, this result follows from Johnson's (1991) distinctiveness model for serial list learning. According to the model, items are represented in memory in a format that allows other items in the array to influence its precision. Through repeated exposures, however, an item that has been learned may be made more precise and distinctive from other items in the array and thus, are protected from the influence of other items in the array. This

would allow the item to be retrieved more quickly and more *accurately* after subsequent exposures. This is precisely the case for the present experiment where the $P(\text{corr})$ increases after numerous sessions. The $P(\text{corr})$ for the two sets in the memory condition do not deviate from each other in a systematic manner, however, and the influence of the missing comparisons can be disregarded. For the remainder of the analysis, the two sets of memory data were combined.

Psychometric Functions. Gaussian transformed psychometric functions were obtained for each standard for each subject for both remembered and perceptual conditions (figure 27). These functions differed with those obtained in Experiments 1 and 2.

Insert figure 27 about here

Whereas distinctive *segmental*, psychometric functions, with well defined join points were found in the previous two experiments when *global* variable stimuli were used, the psychometric functions obtained in the present experiment are not so clearly segmental. What is clear is that over repeated sessions, subjects are not able to respond consistently to every comparison involving every variable stimulus. A simple mistake in choosing the wrong response key or a momentary loss of attention would cause the probability of the responses for that comparison pair to deviate from 1 and, thus, the segmental nature of the functions found in Experiments 1 and 2 would not occur. The overestimation of difference thresholds and the underestimation of sensitivity remains a point of concern however, with the sections on the functions further away from the values of the respective

standard being still somewhat flat. Use of a least-squares criterion, first order regression or the modified Grondin (1993) criteria are, therefore, both inappropriate in the present context. Instead, it was decided to approach the problem from a more traditional position. Typically, in memory psychophysics (e.g., Baranski & Petrusic, 1992), the local variable stimuli used are symmetrically located around the respective standard and consist of two stimuli that are larger than the standard and two that are smaller (also one that is equal to the standard but it is not used in the calculation of the psychometric function). This approach was adopted for the present experiment. Four variable stimuli (two on either side of a standard) were used in the calculation of the psychometric functions. Standard least squares linear regression techniques were then used (figure 28) to obtain the slope and intercept of the best fitting equation and then the usual indices of discriminative sensitivity were obtained: that is, 75% JNDs, WFs and PSEs.

Insert figure 28 about here

Weber Fractions and PSEs for Perception and Memory.

The psychometric functions obtained in the present experiment are in sharp contrast to those obtained in the two previous experiments. Whereas in Experiments 1 and 2 and previous research (Baranski & Petrusic, 1992; Petrusic et al. 1993) performance was clearly superior with perceptual standards, this was not so with the perceptual condition in Experiment 3. Both sets of functions exhibit similar slopes with the perceptual condition demonstrating only slightly better performance.

Insert figure 29 about here

Figure 29 plots the obtained PSEs against the length of the standard for each subject in perception and memory. Again, in perception, the constant errors tend to be very small with the PSEs nearly identical to the values of the standard except for the largest standard for each subject. In contrast, the memory standards show quite substantial constant errors for each subject. These errors appear to be specific to the subject but some consistency across subjects is evident. In particular, biases and or drift in memory seems to occur in the same direction (underestimation of the standard in memory) for all standards and all subjects. These errors also increase with increasing size of the standard, with the largest constant errors occurring with the largest standard. Once again, as with the previous two experiments, the PSEs are not subject to Hollingworth's (1910) and Leuba's (1892) classic notions of memory "pooling" or "central tendency". Instead, the representations of durations in memory seem to reflect a process of "subjective shrinkage" as found previously with remembered durations, both with pigeons (Spetch & Wilkie, 1983; Spetch, 1987; Spetch & Rusak, 1989) and humans (Wearden and Ferrara, 1993).

Insert figure 30 about here

Figure 30 plots the individual subject Weber fractions for perception and memory. As noted earlier, clear set-size and SPEs have not been found when extensive over-learning is employed (Petrusic et al. 1993). This was the case in Experiment 2 and is also true for the present case. Of interest, the WFs for both conditions appear to be approximately equal in magnitude (except for SAM's smallest standard in the perceptual condition). This equating of the WFs appears to be due largely to poorer performance on the part of the perceptual comparisons. The WFs for the memory condition are in line with those found earlier with remembered visual extent but the WFs for the perceptual comparisons are 5-10% higher than those typically found with visual extents. It seems in the present context, perceptual comparisons are not necessarily better than remembered.

Presentation-Order Effects: Time-Order Errors

The TOE index, developed by Jamieson and Petrusic (1975a; 1975c), is plotted in figure 31 for both set-sizes and both conditions.

Insert figure 31 about here

It has been typically found with very brief perceptual durations that the magnitude of the TOE is positive reflecting the general tendency to judge the first presented extent as longer (Jamieson & Petrusic, 1975b; Stott, 1935; Woodrow, 1935, 1951). This was also the case with the present experiment. In contrast, as found in Experiment 1 and 2, TOEs

are simply not evident with remembered percepts. There does seem to be some effect nearer the standard for the memory condition, but the effect is inconsistent across standards and shifts from positive to negative. Also of interest, the magnitude of the TOE for the perceptual condition appears to greatest with the largest standard. This is of interest because this standard also exhibited the largest constant errors for each subject.

Results were evaluated by conducting six between groups ANOVAs (two on each subject's data), using individual trials as subjects and correct response as the dependent variable for both. For the first ANOVA for each subject, condition (memory or perceptual), standard, variable stimulus, order (standard-line vs. line standard) and instruction were then viewed as between subject factors. Comparisons between a standard and a variable stimulus equal to a standard were also removed. The second ANOVA was identical to the first in every respect except that order was replaced by TOEs (long-short order vs. short-long order). Results of the ANOVAs are reported in Table 1².

The main effect of TOE evident in figure 31 was found to be significant for each subject [$F(1, 5075) = 31.35, p < .0001$; $F(1, 5660) = 81.62, p < .0001$; $F(1, 3933) = 44.96, p < .0001$] as was the interaction between condition and TOE [$F(1, 5075) = 142.59, p < .0001$; $F(1, 5660) = 99.15, p < .0001$; $F(1, 3933) = 131.61, p < .0001$], confirming that TOEs occurred in the perceptual condition but not in the memory. The three-way interaction between condition, variable stimulus, and TOE was found to be significant but, more importantly, it is qualified by a significant four-way interaction that is readily visible in figure 31. The four-way interaction between condition, standard length, variable stimulus and TOE [$F(14, 5075) = 15.61, p < .0001$; $F(14, 5660) = 5.42, p < .0001$]

.0001; $F(14, 3933) = 11.94$, $p < .0001$] reflects that the magnitude of the FOE in perception was not only dependent upon the variable stimulus used in the comparison but also on the standard itself, although this does not occur with the remembered comparisons.

Further, the ANOVA revealed a main effect of condition for all three subjects [$F(1, 5075) = 27.57$, $p < .0001$; $F(1, 5660) = 23.41$, $p < .0001$; $F(1, 3933) = 14.75$, $p < .0001$]. Typically, WFs are a better indicator of performance in the conditions because they are standardized and with the different range of variable stimuli used for both memory and perception, direct comparison of performance is problematic. Of interest, however, is that the memory condition had a *higher* $P(\text{corr})$ than the perceptual condition for all three subjects (MFB 92.26% vs. 88.32%; SAM 84.57% vs. 80.27%; PAC 90.20% vs. 86.83% for remembered and perceptual conditions respectively). This result is in direct contrast to the results obtained in Experiments 1 and 2 and confirms what was indicated by the WFs: the perceptual condition performance was not as good as typically found. This is not to say that performance in the perceptual condition was poor, on the contrary, performance was quite good. It does appear though, that in the given context, comparisons involving a remembered duration are different from those involving visual extent which are influenced by TOEs.

A main effect of standard [$F(2, 5075) = 15.11$, $p < .0001$; $F(2, 5660) = 14.29$, $p < .0001$; $F(2, 3933) = 14.95$, $p < .0001$] was also found but is not readily interpretable. Though the middle standard does have a higher $P(\text{corr})$ than the end stimuli for all three subjects, examination of standard as a function of condition reveals that this was the case for two of the subjects (MFB and PAC) in the perceptual condition but not for SAM. A

significant main effect of variable stimulus was also found which is further qualified by interactions with condition, standard, and the interaction of condition and standard [$F(14, 5075) = 7.77, p < .0001$; $F(14, 5660) = 16.78, p < .0001$; $F(14, 3933) = 3.66, p < .0001$]. $P(\text{corr})$ increases with increasing distance of the variable stimulus from the standard and this increase is greater in the memory condition. This increase is not consistent between standards, however.

Examination of the results for the order variable also provided intriguing information. The interaction between variable stimulus and order (duration-standard, standard-duration) was significant but is further qualified by the significant three-way interaction between condition, variable stimulus and order [$F(7, 5075) = 17.28, p < .0001$; $F(7, 5660) = 8.44, p < .0001$; $F(7, 3933) = 9.77, p < .0001$]. The use of order in the present context, was also confounded with short-long, long-short presentation orders. Upon further examination of this three-way interaction, it was confirmed that the order effect for $P(\text{corr})$ was actually reflecting TOEs. In perception, $P(\text{corr})$ was dependent upon presentation order (standard first or second) and the variable stimulus used in the comparison in the respect that the pairing reflected long-short, short-long presentation orders. The presentation of the longer stimulus first, significantly improved $P(\text{corr})$ for that pair of stimuli, in perception only. This effect is most evident with variable stimuli larger or smaller than all the standards. For variable stimuli located between the standards, they were both longer than some standards and shorter than others. The TOE effects observed with the extreme variable stimuli, therefore, are not so clear. On the other hand, comparisons involving a remembered percept were not subject to $P(\text{corr})$ order effects. The four-way interaction between condition, variable stimulus, order, and

standard [$F(14, 5075) = 22.43, p < .0001$; $F(14, 5660) = 11.75, p < .0001$; $F(14, 3933) = 24.08, p < .0001$] was also significant and clarifies the three-way interaction by specifying the effect at the level of the standard in perception. Given a specific standard, the length of one of the middle variable stimuli to the specific standard was fixed and the TOEs observed with the extreme variable stimuli were also observed with the middle ones.

Response Time Analysis

RT analysis also reveals striking differences from the first two experiments. Figure 32 plots RT as a function of presentation order (standard first or second) for each subject at each level of the respective standard.

Insert figure 32 about here

The peak of the response times do fall at or near the value of the standard and decrease as the distance between the standard and the variable stimulus increases as in Experiments 1 and 2, but what is readily evident from the memory condition plots is that RTs are faster in the CVC-duration order than the duration-CVC order. This result is opposite to those found in Experiment 1 and 2 where comparisons were faster when the perceptual stimulus was presented first. This result suggests that subjects are unable to process a perceptual stimulus and start the comparison process immediately by activating all the possible standards with which it will be compared, as was done in Experiments 1 and 2. Instead, when the CVC is presented first, subjects are able to use the time that the CVC is presented and the ISI to retrieve the corresponding representation and prepare for the

comparison. Global variable comparison stimuli were originally used to ensure that the short-term perceptual memory representation was compared with the long-term representation of the percept; that is, that the comparisons were successive in the stimulus-CVC order. It appears that when remembered durations are used, successive presentation in the stimulus-CVC order is achieved.

On the other hand, the pattern of response times with the perceptual standards is consistent with the finding of the previous experiments, reflecting the pervasive and very substantial positive TOEs presented earlier with the proportion correct measure. Namely, response times are uniformly faster when the longer duration is presented first. For example, in the perceptual condition, most of the plots from figure 32 exhibit a clear cross-over effect of RTs which occurs at the value of the standard. When the standard is first and a variable stimulus that is less than it is presented second, RTs are faster than if the variable was first. When the variable is longer than the standard however, RTs are faster when the variable is presented first. Both of these effects reflect the advantage of the long-short presentation order over the short-long (a positive TOE) for the perceptual condition.

These results were evaluated by conducting six totally between groups ANOVAs (two on each subject's data), using individual trials as individual subjects and RT as the dependent variable for both. For the first ANOVA, condition (memory or perceptual), standard, variable stimulus, order (standard-line vs. line standard) and instruction were all then viewed as between subject factors. Comparisons between a standard and a variable stimulus equal to a standard were also removed. The second ANOVA was identical to

the first in every respect except that order was replaced by TOEs (long-short order vs. short-long order). Results of the ANOVAs are reported in Table 2.

The main effect of condition was found to be significant for MFB [$F(1, 5075) = 882.53, p < .0001$] and PAC [$F(1, 3933) = 337.55, p < .0001$] but not for SAM indicating that response times were faster in the perceptual condition (1850.94 ms vs. 1130.23 ms and 1347.32 ms vs. 1173.63 ms) for MFB and PAC respectively. The main effect of variable stimulus was also significant and was qualified by interactions with condition, standard and the three-way interaction of condition, standard and variable stimulus [$F(14, 5075) = 11.65, p < .0001$; $F(14, 5660) = 5.58, p < .0000$; $F(14, 3933) = 4.52, p < .0001$]. The three-way interaction can be seen in figure 32 where response times peak at or near the standard (or, more precisely, the PSE). This peak in response times is larger in the memory condition than the perceptual condition and varies in magnitude across standards.

In the previous two experiments, analysis of the RTs as a function of presentation order has been especially revealing. The present experiment is no exception. The main effect of order was reliable as well as the interaction with condition and the three-way interaction with condition and standard. The significance of the three-way interaction of condition, standard and order for all three subjects [$F(14, 5075) = 2.70, p < .0006$; $F(2, 5660) = 3.01, p < .0496$; $F(2, 3933) = 14.25, p < .0001$] is fundamentally different from the finding of the first two experiments. Whereas, in Experiments 1 and 2, subjects were faster in the stimulus-standard order for the memory conditions, the opposite is true for this experiment. As can be seen in figure 32, RTs are significantly faster in the standard-stimulus order for the memory condition only and the degree of this difference is

dependent upon the standard used in the comparison (with the larger differences for the end standards). A significant four-way interaction of condition, standard, variable stimulus and order for subjects MFB [$F(14, 5075) = 2.70, p < .0006$] and PAC [$F(14, 3933) = 3.95, p < .0001$] qualify the effect further as also varying with the difference between variable stimulus and the standard and becoming maximal near the standard. Of greatest importance is the fact that the stimulus-standard order was significantly slower than the standard-stimulus order, thereby confirming that these comparisons were truly successive.

Response time TOE effects, taking into account the successive nature of the comparisons for the memory condition, were also found to be quite prevalent for all three subjects. Even with successive comparisons in memory, the interaction of condition and TOE is significant for all three subjects [$F(1, 5075) = 9.56, p < .0020$; $F(1, 5660) = 3.94, p < .0471$; and $F(1, 3933) = 45.85, p < .0001$] confirming that TOEs were present for the perceptual condition but *not* for the memory condition. The significant three-way interaction of condition, variable stimulus and TOE [$F(7, 5075) = 5.21, p < .0001$; $F(7, 5660) = 4.69, p < .0001$; and $F(7, 3933) = 24.13, p < .0001$] also confirm that TOEs are specific to successive comparisons involving perceptual stimuli and that the magnitude of the effect decreases with increasing distance of the variable stimulus from the standard. A significant four-way interaction between condition, standard, variable stimulus and TOE for subject SAM [$F(14, 5660) = 2.62, p < .0009$] and PAC [$F(14, 3933) = 3.97, p < .0001$] also qualifies the effect as varying in magnitude across standards in the perceptual condition only.

Biases in Memory and Local Dependencies in Perception

Given that comparisons involving a remembered duration are successive in the stimulus-standard order, examination of comparisons of variable stimuli equal to the standard, once again, proved especially revealing in distinguishing comparisons with strictly perceptual stimuli from those involving a remembered percept.

Insert figure 33 about here

Figure 33 plots the proportion of times the second presented stimulus was reported as the longer for each subject for each of the standards, separately for the remembered and for the perceived standards. First, in perception, in accord with the earlier demonstrations of positive TOEs, when two identical extents are presented, the first is reported as the longer a larger proportion of the times and this is especially evident with the largest standard where the largest TOEs occurred.

The figure proves to be especially revealing with respect to comparisons involving a remembered percept and whether the representation is subject to shrinkage in LTM as indicated by the PSEs. If Wearden and Ferrara (1993) are correct in assuming that the representations of durations do shrink in memory, then the shrinkage they observed over varying ISIs of very short durations should be accentuated in the present case. Given that shrinkage was observed over ISIs of only a few seconds, then in the present case, where minutes separated the learning trials and the comparison phase, this shrinkage in memory should be even more readily visible. This shrinkage should be even more apparent if the influence of previous sessions is taken into account in determining

the representation of the durations in memory. The sessions in the present experiment were separated by *at least* 24 hours and shrinkage of the representation in memory should be quite extreme relative to the ISI effects observed by Wearden and Ferrara. The comparisons involving a CVC with a stimulus equal to the length of standard the CVC represents should provide support for the shrinkage hypothesis, if it occurred. Assuming, under this hypothesis, that the representation of the duration has shrunk, then, in comparisons with a value equal to the standard, the CVC of the respective standards should all be judged shorter than the variable stimulus.

For the memory condition, all three subjects exhibit unique results. Subject MFB conformed to the shrinkage hypothesis for the largest standard only. This was exhibited by responses that indicated 92.31% of the time that the duration was longer in the CVC-duration order and 44.17% of the time when the duration was presented first, when in fact the standard that the CVC represented was longer than 80% of the variable stimuli. For the remaining standards, however, this shrinkage effect is not evident. Instead, responses seem to indicate some sort of expansion of the representation in memory. Responses for the shortest standard indicated that the CVC was judged larger than the duration on approximately 41% of the responses for both presentation orders when in fact, it was larger than only 20% of the variable stimuli. This effect was also evident with the middle standard.

The responses of subject SAM most closely resemble the findings of the previous two experiments through the use of strategic information in making the responses. When the CVC representing the largest standard is presented first, the probability that the second presented line segment was judged longer was .122, which corresponds

approximately to the actual proportion of variable stimuli that are longer than that standard (20%). Similarly, for the shortest standard, where 80% of the variable stimuli are longer, subject SAM reported the duration as longer on 96.67% of the trials in the duration-CVC order and 76.67% of the trials when the CVC was presented first. The responses to the middle variable stimulus are also contrary to a shrinkage in memory hypothesis. Namely, when the CVC was presented second, it was judged longer 60% of the time when, in actuality, it was only larger than 50% of the stimuli. When the CVC was first, only 24.4% of the variable stimuli were judged longer than it. If the standard had shrunk in memory, then the results for this subject would be expected to be opposite to those that were actually obtained.

Subject PAC exhibited responses that most closely resembled the predictions from a shrinkage hypothesis. Both the middle and largest standards for this subject were judged as being shorter than the durations a greater proportion of the times for both presentation orders. For the largest standard, when the CVC was presented first, 83.33% of the responses indicated that the duration was judged as being longer. When the CVC was presented second, the CVC was judged as being longer on only 75% of the responses. Similar findings were obtained for the middle standard. Responses for the smallest standard, however, indicated that the CVC was judged as longer than the duration in 45.83% of the trials when the CVC was presented second and 46.41% of trials when the CVC was first. In actuality, 80% of the variable stimuli were larger than the standard. Though responses to the two larger standards did indicate some shrinkage, the apparent expansion of the smallest standard seriously questions the shrinkage hypothesis. Taken with the findings of the other subjects, the shrinkage of the representations of

durations in LTM is not adequate to describe the findings. If shrinkage does occur, it should be evident by consistent responding to the CVC. This was not evident and suggests that subjects adopted idiosyncratic response strategies and attempted to deal with the task as best they could.

In summary, these analyses reveal strikingly different processes in operation in perception and in memory. In contrast to Experiments 1 and 2, successive presentation in the stimulus-CVC order was obtained. TOEs were obtained in perception, although, they were still absent in memory. In memory, idiosyncratic response biases were evident and the possibility of the shrinkage of the standards in memory was discounted. Through extensive over-learning of remembered percepts and the TOEs present in perceptual comparisons, discriminative sensitivity for remembered percepts was comparable, with respect to $P(\text{corr})$ measures and WFs, to perceptual comparisons. Perceptual comparisons were superior, however, with respect to PSEs (smaller constant errors than for memory) and faster RTs. Given that the comparisons in the present experiment were successive for remembered percepts, the lack of TOEs for these comparisons seems conclusive in distinguishing a percept and the memory for it.

Discussion

The present experiments examined the properties of remembered percepts and provided clear support for the findings of earlier studies (Baranski and Petrusic, 1992; Petrusic, Baranski, and Harrison, 1993) that performance in perception was better than memory. For example, in Experiments 1 and 2, discriminative sensitivity for remembered percepts was considerably poorer than for the percept, despite the use of extensive over-learning. This was exhibited through slower RTs, larger constant errors,

and larger WFs for remembered percepts. This result, however, must be qualified for durations. In Experiment 3, the use of filled visual durations demonstrated the influence of positional order effects on the comparison process for strictly perceptual comparisons; namely, accuracy decreases when massive TOEs occur and precision for standards in these comparisons drifts (i.e., subjects showed the largest constant errors in perception for the largest standard, which also had the largest TOEs). Though $P(\text{corr})$ and WFs were comparable for memory and perception in Experiment 3 due to extensive over-learning of the standards in memory and the TOEs observed in the perceptual comparisons, RTs were still able to differentiate memory from perception. Comparisons involving a remembered percept were significantly slower than perceptual comparisons. For all three experiments, increased RTs reflect the necessary added retrieval time required to activate the long-term representations.

The use of extensive over-learning replicated earlier work (Petrusic et al., 1993), where neither set-size nor serial position effects were obtained with the WFs (Petrusic et al., 1993). The properties of the long-term memory for percepts did begin to resemble those of the percept with increased learning. However, the similarities were not perfect, as indicated by the sensitive RT measure.

The finding of poorer performance for items retrieved from LTM is in striking contrast to Magnussen and Dyrens (1994) who recently claimed that the long term memory for percepts (spatial frequencies) exhibited perfect fidelity. It is important to note, however, that their findings were based on the memory for a *single* percept (i.e., set-size 1). On the other hand, Johnson (1991) stated that interference with the storage and retrieval of other items in a memory set is inevitable. Increased learning of the items has

been shown to increase the precision of these representations (Petrusic et al., 1993) but in the present cases, with massive over-learning present in all three experiments, LTM representations were still not as precise as perception and this was true with sets of standards as small as two. It may not be possible to completely remove the influence of other items in the set, even when the set is composed of only two items.

Successiveness of Presentations

The present experiments were designed (through the use of global variable stimuli) to ensure that comparisons involving a remembered percept were truly successive in the stimulus-standard order. It was quite surprising to see that successive presentations were not obtained for visual extents, even when three standards were stored in LTM. Rather, subjects were able to activate the memory representations of the entire set and initiate the comparison process during the inter-stimulus interval. This process was, however, a logical extension of Baranski and Petrusic's (1992) conjecture that subjects were able to identify the variable stimulus that was presented first and then place it in relation to the respective standard stored in LTM. In the present context, the process was more complex in that subjects had two or three (depending on the respective set-size conditions) possible items with which to compare. Given that RTs were very fast with comparisons involving a variable stimulus located near the opposite end of the continuum, it seems that subjects were able to categorize the relationship of some of these pairs rather quickly and make a decision. Distance effects were also exhibited through increased RTs as the distance between the variable stimulus and the standard decreased, indicating that these comparisons were more difficult and subjects were not able to complete the particular comparison during the ISI.

Comparisons involving remembered durations, however, did prove to be successive. Though RT distance effects were also exhibited, comparisons in which the variable stimulus was presented first were significantly slower than when the CVC was presented first. It seems that when a CVC is presented first, retrieval of the appropriate LTM representation could commence during the ISI and possibly be completed before the presentation of the variable stimulus. If completed during the ISI, the comparison process could commence as soon as a variable stimulus was presented. With the CVC presented second, the subjects were unable to initiate the retrieval of the representation until the CVC was presented and this retrieval time required for the CVC would be added to the time required for the comparison process.

TOEs and Shrinkage in Memory

It is clear from the successiveness of comparisons involving a remembered duration that durations are either stored in a format or accessed in a manner that is different from visual extents. This difference prevents the simultaneous activation of numerous LTM representation of durations. Even with possible storage or retrieval differences between visual extents and filled visual durations, it is clear that TOEs are not present in comparisons involving these remembered percepts. Strictly perceptual comparisons, however, are distinguished from their LTM counterparts through the large and consistent TOEs exhibited for these comparisons. This was true both when the presentation of stimuli were not successive in the stimulus-CVC order (Experiments 1 and 2) and when they were (Experiment 3). The findings of Experiment 1, indicated that biases were adopted when comparing a CVC to its referent. In Experiment 2, these biases were shown to be strategic and reflect the actual proportion of variable stimuli

larger and smaller than the standard. Taken together, it seems that when global variable stimuli are used with visual extents, global, strategic biases are adopted when making a comparison involving a remembered percept and a variable stimulus equal to it.

The biases exhibited for comparison of a remembered duration and its referent are more idiosyncratic. Responses could vary from a single subject and indicate that a global, strategic bias was adopted for comparisons involving a specific standard and that another standard had shrunk or expanded in memory. It seems clear, given these different responses, that a shrinkage of durations in memory hypothesis proposed by Wearden and Ferrara (1993) is not able to account for the present findings. It is possible, that for these comparisons, both global strategic biases and shrinkage of the standard in memory was occurring and that the idiosyncratic responses reflects this competing processes. Comparisons of the standard with variable stimuli located close to it do not reflect, however, a consistent shrinkage of the standard in memory.

The use of global variable stimuli has provided intriguing new insights into the comparison process for items retrieved from LTM. Subjects were able to make comparisons with a global variable set and the successiveness of presentations in the comparison, for which the global variable stimuli were selected, was finally achieved with remembered durations. It seems, from present findings, that a percept and the memory for it can finally be further distinguished by the fact that TOEs occur in perception but not memory.

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informed by the computer to rest again) you may leave to get a drink etc. You then resume the task until all the blocks are completed (the computer will inform you of this). You may then come and tell me. I will remain at the beginning to answer any questions but will then leave to go into the room at C563. You may place the mouse and proceed when ready.

Perceptual Condition

Comparison Phase:

The experiment you are about to participate in is concerned with how we make judgements and comparisons. Specifically, I am looking at comparisons between perceptual stimuli. It is believed that much about how we store and compare sensory information in both long and short term memory can be discovered from this type of experiment.

In this experiment there will be 2 horizontal line lengths which will be presented successively. Your task is to follow the instruction at the top of the screen and choose between the two stimuli using the mouse. You must choose the stimulus that corresponds to the instruction (shortest/longest). The lines presented will vary in length and some will be very close in length, just do your best. The left button on the mouse indicates that you have chosen the first stimulus as corresponding to the instruction while the right button indicates that you have chosen the second stimulus. There will be 5 blocks of this type of comparison and a block is just a certain number of responses. At the end of each block the computer will inform you that you may rest (i.e., get a drink etc.). If you wish, you may rest or proceed on to the next block by pressing any button on the keyboard. When ready, proceed onto the next block until all the blocks are completed (the computer will inform you of this). You may then come and tell me. I will remain at the beginning to answer any

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Appendix A

Memory ConditionLearning Phase:

The experiment you are about to participate in is concerned with how we make judgements and comparisons. Specifically, I am looking at comparisons between perceptual stimuli (a stimulus that is present at the moment) and remembered stimuli (a stimulus that is stored into long term memory). It is believed that much about how we store and compare sensory information in both long and short term memory can be discovered from this type of experiment.

The first part of the experiment consists of you learning to associate a nonsense word with a specific line length. The nonsense words are three letter combinations that are pronounceable but have no meaning outside of this experiment. The words are GUF and BIX. A line will appear on the screen just above a box that contains the two, three letter words. Your task is to use the mouse to light up the word that you feel corresponds to the line and then press the left mouse button to signal your choice. At first it will be trial and error, but after a few presentations you will begin to form the associations. If you are correct the light will remain on the word that you have selected, but if you are wrong the correct word will be lit. You have a time limit and if you exceed it the correct response will be shown. It is important to remember the line lengths and their corresponding names for that information will be needed for the second part of the experiment. The task takes approximately 10 minutes to complete and will be completed after you have reached a certain number of responses. You may place the mouse so that you feel comfortable when you make your selection. I will be here at the beginning to aid you but I will leave. When

you have finished the learning phase, an instruction will appear on the screen telling you to leave the room and tell the experimenter that you have completed the learning phase. Please do so. I will be in room C563. You may proceed when ready.

Comparison Phase

The first part of the experiment was the learning phase and was required so that you would be able to perform this part of the experiment. In this part of the experiment there will be 2 stimuli presented successively. This combination could consist of a name and then a line or a line and then a name. Using your memory of the lengths of lines the words represent, your task is to follow the instruction at the top of the screen and choose between the two stimuli using the mouse again. You must choose the stimulus that corresponds to the instruction (shortest/longest). The lines presented will vary in length and some will be very close in length to the lines you have learned, just do your best. The left button on the mouse indicates that you have chosen the first stimulus as corresponding to the instruction while the right button indicates that you have chosen the second stimulus. There will be 1 block of this type of comparison and at the end the computer will inform you that you may rest (i.e., get a drink etc.). If you wish, you may rest or proceed on to the next part of the experiment by pressing any button on the keyboard. Following this block of comparisons, you will enter the learning phase that you had at the beginning of the experiment. Proceed through this phase exactly as you did with the first learning phase. This learning phase will also be followed by a rest period. After the second learning phase, you will be given 3 blocks of comparisons like the one you completed earlier. Complete these comparisons in the same way that you completed the earlier comparison phase. The comparison blocks take approximately 15 minutes each to complete. After a block has been completed (you will be

informed by the computer to rest again) you may leave to get a drink etc. You then resume the task until all the blocks are completed (the computer will inform you of this). You may then come and tell me. I will remain at the beginning to answer any questions but will then leave to go into the room at C563. You may place the mouse and proceed when ready.

Perceptual Condition

Comparison Phase:

The experiment you are about to participate in is concerned with how we make judgements and comparisons. Specifically, I am looking at comparisons between perceptual stimuli. It is believed that much about how we store and compare sensory information in both long and short term memory can be discovered from this type of experiment.

In this experiment there will be 2 horizontal line lengths which will be presented successively. Your task is to follow the instruction at the top of the screen and choose between the two stimuli using the mouse. You must choose the stimulus that corresponds to the instruction (shortest/longest). The lines presented will vary in length and some will be very close in length, just do your best. The left button on the mouse indicates that you have chosen the first stimulus as corresponding to the instruction while the right button indicates that you have chosen the second stimulus. There will be 5 blocks of this type of comparison and a block is just a certain number of responses. At the end of each block the computer will inform you that you may rest (i.e., get a drink etc.). If you wish, you may rest or proceed on to the next block by pressing any button on the keyboard. When ready, proceed onto the next block until all the blocks are completed (the computer will inform you of this). You may then come and tell me. I will remain at the beginning to answer any

questions but will then leave to go into the room at C563. You may place the mouse where you feel comfortable and proceed when ready.

Footnotes

1. The axioms for similarity comparisons can be divided into both testable and technical axioms. The testable axioms are defined as: 1) weak ordering and 2) weak monotonicity condition.

Weak ordering: i) comparability - subjects are able to render a judgement; ii) transitivity, which is defined as: for all triples of pairs ab , cd , ef with S denoting "more similar than"

if $abScd$ and $cdSef$ then $abSef$

Weak monotonicity: also known as the sextuple condition is defined as: for all a , b , c , a' , b' , c'

if $abSa'b'$ and $bcSb'c'$ then $acSa'c'$

The other conditions are technical and non-testable (see Krantz, Luce, Suppes, & Tversky, 1971; and Petrusic, Baranski & Kennedy, 1995 for a fuller discussion).

2. Only results that were significant for all three subjects will be reported and F-ratios will always be reported for the subject in the order, MFB, SAM, and PAC respectively.

Table 1. Experiment 3 individual subject P(corr) ANOVA

Main Effects and Interactions	MFb	SAM	PAC
Standard Type (remembered vs. perceptual) [M]	F(1, 5075)=882.53, $p < .0001$	N.S.*	F(1, 3933)=337.55, $p < .0001$
Standard Length [S]	N.S.*	N.S.*	F(2, 3933)=27.71, $p < .0001$
Variable Stimulus [C]	F(7, 5075)=24.21, $p < .0001$	F(7, 5660)=2.07, $p < .0433$	F(7, 3933)=16.56, $p < .0001$
Order (Standard First, Standard Second) [O]	F(1, 5075)=12.56, $p < .0004$	F(1, 5660)=42.68, $p < .0001$	F(1, 3933)=137.16, $p < .0001$
M x S	N.S.*	N.S.*	F(2, 3933)=11.64, $p < .0001$
M x C	F(7, 5075)=16.90, $p < .0001$	F(7, 5660)=3.84, $p < .0003$	F(7, 3933)=7.82, $p < .0001$
M x O	F(1, 5075)=19.23, $p < .0001$	F(1, 5660)=67.34, $p < .0001$	F(1, 3933)=199.95, $p < .0001$
S x C	F(14, 5075)=40.59, $p < .0001$	F(14, 5660)=24.91, $p < .0001$	F(14, 3933)=52.22, $p < .0001$
S x O	N.S.*	F(2, 5660)=3.42, $p < .0328$	N.S.*
C x O	N.S.*	N.S.*	F(7, 3933)=10.89, $p < .0001$
M x S x C	F(14, 5075)=11.65, $p < .0001$	F(14, 5660)=5.58, $p < .0000$	F(14, 3933)=4.52, $p < .0001$
M x S x O	F(14, 5075)=2.70, $p < .0006$	F(2, 5660)=3.01, $p < .0496$	F(2, 3933)=14.25, $p < .0001$
M x C x O	N.S.*	N.S.*	N.S.*
S x C x O	N.S.*	N.S.*	N.S.*
M x S x C x O	F(14, 5075)=2.70, $p < .0006$	N.S.*	F(14, 3933)=3.95, $p < .0001$
TOE (Short-Long vs Long-Short) [T]	N.S.*	F(1, 5660)=6.14, $p < .0132$	F(1, 3933)=38.38, $p < .0001$
M x T	F(1, 5075)=9.56, $p < .0020$	F(1, 5660)=3.94, $p < .0471$	F(1, 3933)=45.85, $p < .0001$
S x T	F(2, 5075)=3.34, $p < .0354$	F(2, 5660)=7.48, $p < .0006$	F(14, 3933)=52.22, $p < .0001$
C x T	F(7, 5075)=3.33, $p < .0015$	F(7, 5660)=2.70, $p < .0085$	F(7, 3933)=7.92, $p < .0001$
M x S x T	N.S.*	F(2, 5660)=6.51, $p < .0015$	F(2, 3933)=12.12, $p < .0001$
M x C x T	F(7, 5075)=5.21, $p < .0001$	F(7, 5660)=4.69, $p < .0001$	F(7, 3933)=24.15, $p < .0001$
S x C x T	N.S.*	F(14, 5660)=1.73, $p < .0434$	F(14, 3933)=5.47, $p < .0001$
M x S x C x T	N.S.*	F(14, 5660)=2.62, $p < .0009$	F(14, 3933)=3.97, $p < .0001$

* Not Statistically Significant

Table 2. Experiment 3 individual subject response time ANOVA

Main Effects and Interactions	MFB	SAM	PAC
Standard Type (remembered vs perceptual) [M]			
Standard Length [S]	F(1, 5075) = 27.57, $p < .0001$	F(1, 5660) = 23.41, $p < .0001$	F(1, 3933) = 14.75, $p < .0001$
Variable Stimulus [C]	F(2, 5075) = 15.11, $p < .0001$	F(2, 5660) = 14.29, $p < .0001$	F(2, 3933) = 14.95, $p < .0001$
Order (Standard First, Standard Second) [O]	F(7, 5075) = 10.91, $p < .0001$	F(7, 5660) = 6.85, $p < .0001$	F(7, 3933) = 12.79, $p < .0001$
M x S	N.S.*	F(1, 5660) = 11.81, $p < .0006$	N.S.*
M x C	F(2, 5075) = 14.78, $p < .0001$	N.S.*	F(2, 3933) = 5.41, $p < .0045$
M x O	F(7, 5075) = 7.49, $p < .0001$	F(7, 5660) = 24.26, $p < .0001$	F(7, 3933) = 4.59, $p < .0001$
S x C	N.S.*	F(1, 5660) = 8.97, $p < .0027$	N.S.*
S x O	F(14, 5075) = 50.43, $p < .0001$	F(14, 5660) = 97.17, $p < .0001$	F(14, 3933) = 47.62, $p < .0001$
C x O	F(2, 5075) = 13.10, $p < .0001$	N.S.*	F(2, 3933) = 6.99, $p < .0009$
M x S x C	F(7, 5075) = 11.69, $p < .0001$	F(7, 5660) = 6.66, $p < .0001$	F(7, 3933) = 5.54, $p < .0001$
M x S x O	F(14, 5075) = 7.77, $p < .0001$	F(14, 5660) = 16.78, $p < .0001$	F(14, 3933) = 3.66, $p < .0001$
M x C x O	N.S.*	N.S.*	N.S.*
S x C x O	F(7, 5075) = 17.28, $p < .0001$	F(7, 5660) = 8.44, $p < .0001$	F(7, 3933) = 9.77, $p < .0001$
M x S x C x O	F(14, 5075) = 7.73, $p < .0001$	F(14, 5660) = 12.66, $p < .0001$	F(14, 3933) = 5.92, $p < .0001$
TOE (Short-Long, Long-Short) [T]	F(14, 5075) = 22.43, $p < .0001$	F(14, 5660) = 11.75, $p < .0001$	F(14, 3933) = 24.08, $p < .0001$
M x T	F(1, 5075) = 31.35, $p < .0001$	F(1, 5660) = 81.62, $p < .0001$	F(1, 3933) = 44.96, $p < .0001$
S x T	F(1, 5075) = 142.59, $p < .0001$	F(1, 5660) = 99.15, $p < .0001$	F(1, 3933) = 131.61, $p < .0001$
C x T	F(2, 5075) = 16.86, $p < .0001$	F(2, 5660) = 7.73, $p < .0001$	N.S.*
M x S x T	F(7, 5075) = 6.35, $p < .0001$	F(7, 5660) = 5.64, $p < .0001$	N.S.*
M x C x T	N.S.*	F(2, 5660) = 13.51, $p < .0001$	F(2, 3933) = 17.46, $p < .0001$
S x C x T	F(7, 5075) = 5.56, $p < .0001$	F(7, 5660) = 4.68, $p < .0001$	F(7, 3933) = 10.99, $p < .0001$
M x S x C x T	F(14, 5075) = 7.66, $p < .0001$	F(14, 5660) = 7.36, $p < .0001$	F(14, 3933) = 6.05, $p < .0001$
	F(14, 5075) = 15.61, $p < .0001$	F(14, 5660) = 5.42, $p < .0001$	F(14, 3933) = 11.94, $p < .0001$

* Not Statistically Significant.

Figure 1. Local and global variable stimuli.

Local Variable Stimuli

V1 V2 STD1 V4 V5 V6 V7 STD2 V9 V10

Global Variable Stimuli

V1 V2 STD1 V4 V5 V6 V7 STD2 V9 V10

Figure 2. Individual subject Gaussian transformed psychometric functions for the two levels of the remembered standards. Standard 1 is represented by the filled circles and standard 2 by the open circles.

Figure 3. Individual subject Gaussian transformed psychometric functions for the two levels of the perceptual standards. Standard 1 is represented by the filled circles and standard 2 by the open circles.

Figure 4. Individual subject Gaussian transformed psychometric functions for the two levels of the remembered standards with the best fitting linear regressions. Standard 1 is represented by the filled circles and standard 2 by the open circles.

Figure 5. Individual subject Gaussian transformed psychometric functions for the two levels of the perceptual standards with the best fitting linear regressions. Standard 1 is represented by the filled circles and standard 2 by the open circles.

Memory Condition

Figure 7. Individual subject Gaussian transformed psychometric functions for the two levels of perceptual standards with the best fitting linear regressions - Grondin criterion. Standard 1 is represented by the filled circles and standard 2 by the open circles.

Figure 8. Mean of individual subject PSEs as a function of the actual, respective, standard length for both levels of perceptual (filled circles) and memory (open circles) standards.

Figure 9. Mean of individual subject WFs for both levels of perceptual (filled circles) and memory (open circles) standards.

Figure 10. TOE index for small (left figure) and large (right figure) standard for perceptual (filled circles) and memory (open circles) conditions.

Figure 11. Mean response times for presentations in which the standard (either perceptual or CVC) was presented first (filled circles) or second (open circles) for the two levels of the memory (top two panels) and perceptual (bottom two panels) standards.

Figure 12. TOEs for the standard with itself in perception (filled squares) and biases for the CVC and its referent when the CVC was first (open circles) and second (filled circles).

Figure 13. Individual subject Gaussian transformed psychometric functions for the two levels of the standard in the set-size two, memory condition. Standard 1 is represented by the filled circles and standard 2 by the open circles.

Figure 14. Individual subject Gaussian transformed psychometric functions for the two levels of the standard in the set-size two, perceptual condition. Standard 1 is represented by the filled circles and standard 2 by the open circles.

Figure 15. Individual subject Gaussian transformed psychometric functions for the three levels of the standard in the set-size three, memory condition. Standard 1 is represented by the open, inverted triangles, standard 2 by the filled circles and standard 3 by the open squares.

Figure 16. Individual subject Gaussian transformed psychometric functions for the three levels of the standard in the set-size three, perceptual condition. Standard 1 is represented by the open, inverted triangles, standard 2 by the filled circles and standard 3 by the open squares.

Figure 17. Individual subject Gaussian transformed psychometric functions for the two levels of the standard in the set-size two, memory condition with the best fitting linear regressions - Grondin criterion. Standard 1 is represented by the filled circles and standard 2 by the open circles.

Figure 18. Individual subject Gaussian transformed psychometric functions for the two levels of the standard in the set-size two, perceptual condition with the best fitting linear regressions - Grondin criterion. Standard 1 is represented by the filled circles and standard 2 by the open circles.

Figure 19. Individual subject Gaussian transformed psychometric functions for the three levels of the standard in the set-size three, memory condition with the best fitting linear regressions - Grondin criterion. Standard 1 is represented by the open, inverted triangles, standard 2 by the filled circles and standard 3 by the open squares.

Figure 20. Individual subject Gaussian transformed psychometric functions for the three levels of the standard in the set-size three, perceptual condition with the best fitting linear regressions - Grondin criterion. Standard 1 is represented by the open, inverted triangles, standard 2 by the filled circles and standard 3 by the open squares.

Figure 21. Mean of individual subject PSEs as a function of the actual, respective, standard length for both levels of set-size (set-size 2, filled symbols; set-size-three, open symbols) for memory (upper panel-circles) and perception (lower panel-squares).

Figure 22. Mean of individual subject WFs for both levels of set-size (set-size 2, filled symbols; set-size-three, open symbols) for both memory (circles) and perceptual (squares) conditions.

Figure 23. TOE index for both set-size 2 (upper two panels) and set-size 3 (lower three panels) for perception (filled circles) and memory (open circles).

Figure 24. Mean response times for presentations in which the standard (either perceptual or CVC) was presented first (filled circles) or second (open circles) for the set-size 2, memory (two upper left panels) and perceptual (two upper right panels) conditions and the set-size 3 memory (three bottom left panels) and perceptual (three bottom right panels) conditions.

Figure 25. TOEs for the standard with itself in perception (filled squares) and biases for the CVC and its referent when the CVC was presented first (open circles) and second (filled circles) for set-size 2 (left panel) and set-size 3 (right panel).

Figure 26. Individual subject, proportion of responses correct as a function of session and the stimulus set: memory, missing comparisons (filled circles); memory, complete set (filled triangles); and perceptual (open squares).

Figure 27. Individual subject Gaussian transformed psychometric functions for the three levels of the standard in the memory (upper panels) and perceptual (lower panels) conditions. Standard 1 is represented by the open circles, standard 2 by the filled, inverted triangles, and standard 3 by the open squares.

Figure 28. Individual subject Gaussian transformed psychometric functions for the three levels of the standard in the memory condition with the best fitting linear regressions using two variable stimuli on both sides of the respective standards in the memory (upper panels) and perceptual (lower panels) conditions. Standard 1 is represented by the open circles, standard 2 by the filled, inverted triangles, and standard 3 by the open squares.

Figure 29. Individual subject PSEs as a function of the actual, respective, standard length for all three levels of perceptual (open circles) and memory (filled circles) standards.

Figure 30. Individual subject WFs for all three levels of perceptual (open symbols) and memory (filled symbols) standards.

Figure 31. Individual subject TOE indices for small (left column), middle (centre column) and large (right column) standards for perceptual (open circles) and memory (filled circles) conditions.

Figure 32. Individual subject mean response times for presentations in which the standard (either perceptual or CVC) was presented first (open circles) or second (filled circles) for the three levels of the memory (left three columns) and perceptual (right three columns) standards.

Figure 33. Individual subject TOEs for the standard with itself in perception (filled squares) and biases for the CVC and its referent when the CVC was presented first (filled circles) and second (open circles).

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