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Clock Time: Process and Representation

By

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Dr. W. M. Petrusic**

**A Masters Thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfillment of
the requirement of the degree of
Master of Arts**

**Department of Psychology
Carleton University
Ottawa, Ontario
August, 1992**

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CLOCK TIME: REPRESENTATION AND PROCESSING

submitted by
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in partial fulfillment of the requirements
for the degree of Master of Arts

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Abstract

Rarely does one go through a day without making some kind of reference to time. The representing and processing format of clock time has been found to be digital (e.g., 12:15 p. m.) as compared to pictorial (i.e., clock face) by Geolkasian and Park (1980). In this thesis, two experiments were conducted to further examine the processing and representation of clock time. In the first, subjects indicated whether two clock times were the same or different and formats were systematically varied: word-string-pictorial (Quarter to eight), word-string-digital (Seven forty-five), Digital (7:45), and Pictorial (clock face). Although the experiment confirmed the earlier findings of faster processing with digital times than with clock face times, the particular form of word string used biased processing in favour of the code it activated.

In Experiment 2, subjects received a triplet of clock times and on one half of the trials selected the comparison time that was "Nearer" to the standard time and on the other half they selected the time that was "Farther" from the standard. Symbolic distance and semantic congruity effects were obtained and the magnitude of these effects were shown to depend on task difficulty and code translation. However, clear and orderly code translation (e.g., pictorial to digital and conversely) effects were not evident. The triadic comparison data were interpreted in terms of Petrusic's (1992) discrete state evidence accrual view of comparative judgment.

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**In Memory
of
my loving parents**

**Dr. Laurence C. K. Lin
and
Dr. Marie H. S. Feng**

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Introduction

Rarely does one go through a day without making some kind of reference to time. Modern clock times are usually displayed either in clock face or in digital form. The goal of this research is to examine the representation and processing format of clock times in memory. This information has practical significance because if one particular clock time representation is clearly found to be a preferred format then it may provide useful information and application in fields where manipulation of time is of importance.

The issue of how clock time is represented and processed was first investigated by Paivio (1978). In his experiment, subjects were presented with pairs of clock times in varied formats (Digit-Digit, Digit-Picture (clock face), Picture-Picture) and were then required to make comparative judgments of the size of angles formed by the hour and minute hands. A symbolic angular effect, similar to the symbolic distance effect (Moyer and Bayer, 1976), was obtained. There was an orderly increase in comparison reaction time as the angular size difference between the pair of clock times decreased. Paivio also found that judgment times of angle sizes were shortest in the Picture-Picture condition, intermediate for the Digital-Picture condition and longest for the Digital-Digital condition. These results were consistent with Paivio's (1975) dual-coding theory which suggested that visually presented clock times were encoded in both pictorial and linguistic representations and that, in a comparison process, the image system was more readily accessible. Hence, based on the dual-coding theory, the reaction time to Picture-Picture conditions should be the fastest. In the other two conditions (Digit-

Picture, Digit-Digit), subjects had to transform numeric cues to pictures to facilitate angle size comparisons hence contributing to a longer comparison time. Evidence of shorter Picture-Picture judgment times and the angular distance effects obtained from Paivio's study suggested that clock time was represented and processed in a pictorial format.

Goolkasian and Bunting (1985) argued that the angle size comparison task in Paivio's experiments demanded pictorial representations of clock times. The comparison was a physical size comparison rather than a time magnitude comparison. Accordingly, they required their subjects to report the difference between two successively presented clock times rather than between the angles. In their experiment, stimulus pairs were presented in Word-Picture (e.g., FOUR-FIFTEEN - clock face), Word-Digit (e.g., FOUR-FIFTEEN - 4 : 45) formats rather than Picture-Picture, Digit-Digit pairs. It was assumed that if alternate forms of clock times were used in this paradigm, it would reduce the chance of subjects making judgments based purely on physical attributes (Goolkasian & Park, 1980).

The main focus of Goolkasian and Bunting (1985) was to determine whether the presentation format of the second clock time would influence the calculation of the time difference. They found that the time difference was calculated faster and more accurately for the Word-Digit (e.g., FOUR-THIRTY - 4:15) than for the Word-Picture (FOUR-THIRTY - clock face) pairs. This finding is consistent with several other studies which have shown an advantage of digital over pictorial presentation in time processing. Whether the task was naming clock times, making same/different (Goolkasian and Park,

1980; Goolkasian, 1984) or early/late judgments (Goolkasian, 1984), or being identified as the target displays among various distractor types (Goolkasian, 1988), digital times performance was found to be superior to pictorial times.

The inconsistency between the evidence of a pictorial advantage obtained from Paivio's experiment and a numeric advantage from Goolkasian et al. experiments can be resolved easily. In both of these experiments, the demands of the tasks were such that the required comparison could be most efficiently made in that particular clock time representation. For example, in order to compare angle sizes of two clock times, the most proficient clock time representation format to accomplish such a comparison is to transform stimuli into clock faces and mentally compare the angles (i.e., Paivio, 1978). Similarly, differences in clock times can best be obtained through conventional numeric manipulations and thus the digital representation is most efficient when a difference task is performed (i.e., Goolkasian & Bunting, 1985). It is clear that neither experiment has truly addressed the issue of time processing per se. Evidence for or against either pictorial or digital representations provided by these two experiments is, therefore, inconclusive since the clock time representation format in each of the situations is task dependent.

Goolkasian and Park (1980) however, did attempt to identify the effect of various time formats on comparative judgment time involving the processing of clock time. The assumptions and logic for their experiment is examined and a discussion concerning their

experimental conditions which providing the basis for the first experiment in this research follows.

In a time comparison task with successively presented stimuli, if the encoding formats of the first and the second clock time are the same, the comparison process should be faster than if the two stimulus formats are different. In the latter case, extra time is required to transform one of the clock times into a compatible format before the comparison process can take place. If one assumes that the preferred memory representation of clock time is digital or that the task demands the manipulation of clock times in numeric form (adding or subtracting time where a numeric output is required), the first clock time of a stimulus pair takes on numeric representation in memory regardless of its presentation format (word string, digit, or clock face). The same/different judgment time of a comparison pair, therefore, depends on the presentation format of the second clock time - long if it is a mismatch and short if it is a match. Under this digital time preference assumption, judgment times are expected to increase for stimulus pairs Digit-Digit, Picture-Digit, Digit-Picture, Picture-Picture. In the cases of Digit-Digit and Picture-Digit, the second stimulus of each pair is of digital format which matches the memory representation of the first, therefore, the comparison process can proceed immediately yielding relatively shorter comparison times. As for the Digit-Picture and Picture-Picture conditions, the memory representation of the first stimulus for each stimulus pair is assumed to be in the preferred digital format and the clock time that follows is of a different format, namely, pictorial. Extra time is required to transform the representation of the second

clock time into a digital format before the comparison process can begin. This extra translation time accounts for the longer judgment time.

On the other hand, if the supposition is that of a pictorial encoding for clock time or that the task requires a pictorial comparison (size of angle formed by the two hands of clock face), then by the same reasoning, judgment times for Digit-Digit and Picture-Digit would be longer than Digit-Picture and Picture-Picture. The first clock time is encoded in the assumed preferred pictorial format for all four stimulus pairs. Only Digit-Digit and Picture-Digit stimulus pairs require the translation of the second clock time from digital to pictorial. This extra conversion stage contributes to the longer judgment time.

Theoretically, direct comparisons of stimulus pairs Digit-Digit, Picture-Picture with mixed pairs will be able to provide the necessary experimental conditions for the investigation of the memory representation of clock time. However, there is a practical problem associated with these stimulus pairs. In the context of the same/different comparison paradigm, the change in position of either the hour or minute hand(s) on a clock face or the change of digits in a digital clock will indicate a difference between the two comparison clock times and no change in the positions of the two hands or digits of the two clock times will signify the same clock time. In order to minimize the subject's use of physical cues in making same/different judgments, the first clock time is presented in a word string format. The use of word string clock time is limited to the first stimulus due to the variability in word string lengths in describing the clock times.

Sufficient time is allowed for the encoding of the first clock time, therefore, it will not be a factor in judgment time. Consequently, variations in the format of the second presented clock time permit inferences concerning the representation of the clock time format in memory.

It is reasonable to assume that the symbolic representation of time in memory is similar to the physical objects that are traditionally used to convey the time of day - clock face and digital time. Therefore, the experimental strategy to identify this preferred memory representation of clock time is to present the first clock time in "neutral" word string format. This first clock time (S_1) is then assumed to take on a preferred format in memory (either digital or clock face). To uncover the identity of this preferred memory representation of clock time, S_1 , it is paired with a digital time or a clock face time forming the comparison pairs S_1 -Digit and S_1 -Picture. The pair with the shorter judgment time provides evidence that the two representation formats of the clock times match. The first clock time, therefore, must clearly take on the same format as the second. For example, if judgment time for S_1 -Digit is faster than S_1 -Picture then S_1 and Digit must have the same internal representation, which implies that S_1 is in digital format. On the other hand, if S_1 -Picture comparison time is shorter than S_1 -Digit, then the memory representation of S_1 and Picture are the same, leading to the conclusion that the internal representation of time is clock face.

Following the argument presented above, Goolkasian and Park (1980) presented their subjects with pairs of clock times in four comparison-formats: Word-Picture, Word-Digit, Picture-Digit and

Digit-Picture. Subjects were then required to make same/different judgments. If the memory representation of clock time is numeric, then the judgment time for the Word-Digit pair would be shorter than Word-Picture because the memory representation of the first word stimulus is already in a compatible form with the second digital time. However, if clock time memory representation is pictorial (imaginal) then Word-Digit judgment times would be longer than Word-Picture. That is, extra time is required to transform the second digital time into a pictorial image before the comparison process can take place. Goolkasian and Park (1980) found that comparisons of the similarity between the two clock times were faster when the second stimulus was a digitally presented clock time. This effect provided evidence that the format in memory and the format of the second clock time were compatible and thus time was coded and processed in digital format.

A closer examination of the first stimulus presented in word form in the Goolkasian and Park's (1980) experiment, however, shows a form of numerical bias (e.g., FOUR FORTY-FIVE). There is evidence that the memory representation of numbers in digital form and numbers in word form are the same (Shepard, Kilpatrick & Cunningham, 1975). Consequently, upon presentation of the first clock time in word string form, the memory representation is biased towards a digital format encoding. A digital time that is presented next will obviously have the advantage of being of the same format and the judgment time will undoubtedly be shorter than if the second stimulus is a clock face. The word strings used in their experiment were biased towards the Word-Digit pair and therefore,

Goolkasian and Park's (1980) conclusion that clock time is coded and processed numerically may be premature.

Experiment 1

In this experiment, we examine the possibility that the memory representation of clock time can be biased by the type of word string used. For example, the numeric word string (W_N), FOUR FORTY-FIVE, is likely to elicit a digital representation in memory while a pictorial word string (W_P), QUARTER TO FIVE, may encourage an image representation in terms of positions of the hands on the clock face. A new class of pictorial word string (W_P) stimuli is, therefore, defined and added to the pool of stimuli defined in Goolkasian and Park (1980). The first clock time can, therefore, be presented in one of four different forms: numeric word string (W_N), pictorial word string (W_P), digital and clock face. Each of these stimulus types is paired with either a digital or a clock face time. The first and second clock times, however, are always of different formats. Six stimulus pairs of interest, therefore, are formed: W_N -Digit, W_N -Picture, W_P -Digit, W_P -Picture, Digit-Picture, Picture-Digit. One hundred and ninety two unique stimulus pairs with equal representation of all six comparison-formats are formulated for this experiment, of which half has identical first and second clock times (designated as the SAME pairs) while the other half has different first and second clock times (designated as the DIFFERENT pairs). Equal numbers of both SAME/DIFFERENT pairs and the six comparison-formats are represented equally by times in the four quadrants¹ of a clock face. Thus, Goolkasian and Park's (1980) experimental conditions will be replicated in this experiment and

additional comparison formats involving pictorially descriptive word strings (W_P) are also provided.

If clock time representation and processing is word string independent then the memory representation of clock time should be the same regardless of whether the word string is numerically or pictorially biased. When these word strings (W_N , W_P) are paired with clock times of the same format the decision time should be shorter than when they are paired with clock times of a different format. Decision times for the two sets W_N -Digit and W_P -Digit, and W_N -Picture and W_P -Picture, therefore, should be the same respectively. The first stimulus of each stimulus pair is assumed to be word string independent, that is, it will be encoded in the preferred format regardless of whether the word string is numerically or pictorially biased. The second stimulus for each set is the same, therefore, judgments would be immediate if the second stimulus of the set matches the memory representation of the first. If not, a transformation stage would be necessary before comparison and thus judgment time would be longer.

Therefore, under the assumption that the memory representation of clock time is independent of the type of word string used and that the preferred representation of clock time is pictorial, we would then expect judgment time for stimulus pairs W_N -Picture and W_P -Picture to be the same and short because the format of the second stimulus matches the first. As well, for stimulus pairs W_N -Digit and W_P -Digit, the judgment time would be long because the formats of the stimulus pair are different. Similarly, under the assumption of word string independence and digital

memory representation, we would expect the judgment time for stimulus pairs W_N -Picture and W_P -Picture to be the same but longer than stimulus pairs W_N -Digit and W_P -Digit.

Clock time is word string dependent if EIGHT THIRTY gives rise to or is represented in memory as digital time 8:30 or if HALF PAST EIGHT generates a clock face with the hour and minute hands at the appropriate positions in memory. The judgment time for W_N -Digit will be faster than W_P -Digit since W_N gives rise to a numerical encoding of time which matches the digital time that follows and judgment time is, therefore, shorter. Similarly, if W_P promotes a pictorial representation of clock time, the decision time for W_P -Picture will be faster than W_N -Picture. This result follows because the clock face time following W_P , presented for comparison, is of same format as the clock time already in memory (pictorial) and thus, transformation time is not required. Under this word string dependency hypothesis, the conclusion of a numeric advantage of time processing provided by Goolkasian et al. is problematic. However, one representation format may still demonstrate superiority in judgment time over the other. If it is found that judgment time for W_P -Picture is faster than W_N -Digit then time is not only word string dependent, but it also shows that the preferred mode of representation and processing of clock time is pictorial. In this case, Goolkasian et al.'s findings of numeric advantage would be questioned. On the other hand, if decision time for W_N -Digit is found to be faster than W_P -Picture, then Goolkasian et al.'s findings of a numeric memory representation and processing are supported but with modifications that clock time is word string dependent and the

numeric representation of time is shown to be of a more advantageous mode of clock time representation and processing.

Method

Subjects. Eighteen students enrolled in summer courses at Carleton University were recruited to participate in this experiment as part of their course requirements or were paid \$ 7.50 for their participation. They all had normal or corrected-to-normal vision. Subjects were randomly assigned to one of six blocks of experimental trials.

Stimulus and Design. Clock times were presented in numeric (Digit), clock face (Picture), numeric word string (W_N) and pictorial word string (W_P) formats. Figure 1 displays the four presentation formats.

Insert Figure 1 about here

On each trial, two clock times were presented in succession. The subject's task was to decide whether the two clock times were the same or different. The first clock time was presented in one of the four presentation formats (W_N , W_P , Picture or Digit) and each was paired with a second clock time in either clock face (Pictorial) or numeric (Digital) format. A total of six comparison-formats of interest were formed : W_N -Picture, W_N -Digit, W_P -Picture, W_P -Digit, Picture-Digit, Digit-Picture. The following are some examples of the pairs used in the experiment.

W_N -Picture : e.g. FOUR FORTY-FIVE paired with

W_N -Digit : e.g. FOUR FORTY-FIVE paired with 4:45.

W_P -Picture : e.g. QUARTER-TO-FIVE paired with

W_P -Digit : e.g. QUARTER-TO-FIVE paired with 4:45.

Picture-Digit : e.g.

paired with 4:45.

Digit-Picture : e.g. 4:45 paired with

Digit-Digit and Picture-Picture pairs were not investigated since there would be a possibility that the same/different judgment was based on physical attribute match of numbers on digital time or of position of hands on clock face time rather than difference in the memory representations of clock times. Therefore, judgment times obtained from Digit-Digit, Picture-Picture pairs could not be used to compare with judgment times obtained in mixed format pairs Picture-Digit, Digit-Picture in the investigation of format effect of clock times. Comparisons involving pairs of word strings (W_N - W_N , W_P - W_P , W_N - W_P , W_P - W_N) and pairs where the second clock time was word string (Digit- W_N , Picture- W_N , Digit- W_P , Picture- W_P) were also not included in the experiment since clock times are rarely displayed in word string format and that variation in word string lengths

would be a factor in judgment time. This, however, does not exclude the possibility that the internal representation of clock time is in word string format. In this experiment, word string clock time was always presented as the first stimulus. Sufficient time (3 seconds) was allowed for the encoding of the first clock time so that differences in word string length would not be a factor in judgment time. Judgment time was measured from the onset of the second clock time until subject responded by pressing a mouse button.

The pool of stimuli for the first clock time was formed by combining 12 hourly times (1 to 12 hours) and 12 clock face "marker" times (:00, :05, :10, :15, :20, :25, :30, :35, :40, :45, :50, :55) giving rise to 144 different clock times. In addition, 48 clock times were formed by assigning the remaining 48 minutes of an hour (60 minutes minus the 12 clock face "marker" times) at random but equally to each of the 12 hours. Therefore, 16 clock times (12 clock face "marker" and 4 non-clock face "marker" times) from each of the 12 hours made up this pool of 192 unique first clock times. Half of these first clock times were paired with identical times. For example, the first word string clock time FIVE-THIRTY was followed by an identical digital clock time 5:30. This type was designated as a SAME pair. The remaining half of the first clock times (96) were paired with times that differed. For example, the digital clock time 8:15 was followed by the clock face time 8:45 and was called a DIFFERENT pair. Therefore, 96 SAME and 96 DIFFERENT pairs with equal representation from each of the four quadrants constituted a block. Appendix 1 displays a typical block of stimulus pairs.

In order to investigate the format effect of clock times, digital versus clock face, each subject was exposed to all comparison-formats within each session. Therefore, each sixth (32 pairs, equally drawn from the four quadrants, called a set) of the block of 192 unique clock times was prepared in one of the six comparison-formats (W_N -Picture, W_N -Digit, W_P -Picture, W_P -Digit, Picture-Digit, Digit-Picture). Furthermore, each set was prepared in all six formats. Therefore, six blocks each containing all comparison-formats, were formed in a Latin Square fashion (see Appendix 2). Each block was presented to one-sixth of the subjects three times yielding 576 response data per subject.

Apparatus. Stimuli were presented on an Amdek-310A 23 x 17 cm video monitor controlled by an IBM-PC XT type computer. The presentation time of the stimuli was accurately controlled by computer software. Subjects registered their judgment by pressing two appropriately labeled (same/different) outer buttons of a 3-button Microsoft mouse. The letters and numbers were of font size 14 (about 6 mm) and the hour and minute hands of clock face were about 9 mm and 12 mm in length respectively and 1.5 mm in width as in Goolkasian and Park (1980).

Procedure. The subject sat in front of the computer in a dimly lit room and was informed that the first clock time would appear at the center of the screen for a short period of time (3 second to ensure that sufficient time was allowed for the encoding of word string stimulus) and would then be replaced by a second clock time. The subject's task was to decide whether the two clock times were the same or different. Subjects were instructed to registered their

responses by pressing the appropriately labeled same/different mouse button and to respond as quickly as possible without sacrificing accuracy of judgment. The next trial started two seconds after the response. Each subject was given 18 practice trials before the presentation of the 576 experimental trials (three replications of a block of 192 trials) and was given a brief rest every 96 trials. The session lasted about 75 minutes.

Upon completion of the experimental session, the subject was given a general debriefing about the purpose of the experiment to avoid possible confounding from subjects' peers who might also serve as participants in this experiment. They were, however, invited to return for a more thorough debriefing at the conclusion of the research.

Results and discussion

Subjects' error responses varied between 2% and 9% and the average reaction time for error responses tended to be longer than correct responses (1728 msec vs 1063 msec). The average error rate for the six comparison formats varied between 3 and 6%. Error trial response times were included in all analysis.

Mean judgement times for each of the six stimulus formats were computed for each subject. The overall mean and median judgment time for the six stimulus formats are presented in Table 1. No significant differences were found between the mean judgment times of stimulus pairs Digit-Picture and W_N -Picture (1195 msec and 1232 msec) and, Picture-Digit and W_P -Digit (1026 msec and 1063 msec). This pattern held true for both the mean and median judgment time (see Table 2). In the analysis of the effect of word

strings, therefore, judgment times for Digit-Picture and Picture-Digit comparison formats, were not used. An analysis based on types of word string used (W_P and W_N) and clock time presentation formats (Picture and Digit) was conducted. The results of the analysis of variance of the 2×2 factorial design with three replications are presented in Table 3. The interaction between word string types and clock time format was found to be significant ($F(1,17)=8.05$, $p<.05$). Overall means, plotted in Figure 2, show that word string types used in the experiment did not have constant effects on the clock time formats. Rather their effects varied depending on the formats of the clock time that followed.

Insert Figure 2 about here

Analysis of simple main effects was performed. For stimulus pairs where the presentation format of the second stimulus was the same, that is, both digital times or both clock face times, judgment times were found to be significantly different depending on the type of word string used as the first stimulus. Judgment time for W_N -Digit was found to be significantly faster than W_P -Digit (950 vs 1063 msec) ($F(1,34)=6.30$, $p<.05$) (See Table 4). The presentation format of the second stimulus of these pairs was a digital clock time, the difference in judgment time was due to the difference in the type of word string presented as the first stimulus. This result indicated that the internal code generated by a numeric word string, W_N , was more similar to the digital clock time code than the code generated by a pictorial word string, W_P , thus the faster judgment time. We also

found shorter judgment times for comparison pairs W_P -Picture than W_N -Picture pairs (1156 msec vs 1232 msec) but this difference was only marginally reliable ($F(1,34)=2.78$, $.05 < p < .10$). This result implies that a pictorial word string (W_P) generates memory representation more similar to a clock face time than a numeric word string (W_N). The internal representation of clock time, therefore, has been found to be word string dependent. A numeric word string, FOUR-FORTY-FIVE, gives rise to a code compatible with digital clock time and a pictorial word string, QUARTER-TO-FIVE elicits a clock face code. Goolkasian and Park's (1980) finding of shorter judgment time for W_N -Digit than W_N -Picture was, therefore, expected and was a result of word string bias, not necessarily digital memory representation and processing as claimed.

In Experiment 1, we also found that when the second clock time of any stimulus pair was digital, the comparison time was consistently faster. Judgment times for W_N -Digit and W_P -Digit were found to be shorter than W_N -Picture and W_P -Picture. In fact, performance for comparison pairs W_N -Digit was significantly shorter than W_N -Picture (950 vs 1232 msec) ($F(1,34)=38.12$, $p < .001$; See Table 4) and W_P -Digit faster than W_P -Picture (1063 vs 1156 msec) ($F(1,34)=4.12$, $p < .05$). By integrating two findings given above: judgment time was shorter for W_N -Digit (950 msec) than W_P -Digit (1063 msec) and W_P -Digit (1063 msec) than W_P -Picture (1156 msec) and by law of transitivity, one might conclude that decision time for W_N -Digit was faster than W_P -Picture (950 msec vs 1156 msec). In these last two cases, the format of both members of each pair was the same, therefore, code translation was not necessary in either

case. The difference in RT could only be explained by faster digital time processing. Most convincing, however, was the fact that judgment time for W_P-Digit was found to be significantly faster than W_P-Picture ($F(1,34)=4.12$, $p<.05$). The fact that the formats of clock times in the first pair, W_P-Digit, were different and judgment time included code translation, the faster digital time processing outperformed the judgment time for the W_P-Picture pair which did not include code translation but involved the slower clock face time processing. Results from this experiment provide evidence that the format used in time comparison process is determined by the presentation format of the second clock time. This finding combined with the fact that digital time processing is faster helps to explain the increase in comparison times for the four comparison formats: W_N-Digit, W_P-Digit, W_P-Picture and W_N-Picture (950, 1063, 1156, 1232 msec). The expected and observed judgment times for W_N-Digit pair was the shortest because format translation time was not required and digital time processing was fast. The judgment time for W_P-Digit pairs involved both the code translation time and the faster digital processing time. Translation stage was not required for W_P-Picture pairs but the longer pictorial processing time slowed the comparison process. Judgment for W_N-Picture pairs took the longest because it involved both the code translation and the longer imaginal time processing. Clock time, therefore, has been found to be word string dependent and digital clock time processing is significantly faster than clock face time processing. Goolkasian's findings of a numeric (digital) time advantage has, therefore, been found to be reliable.

Experiment 2

The results from Experiment 1 showed the advantage for digital clock time processing. Clock times, be it digitally or pictorially represented in memory, possess quantitative attributes and can be viewed as the highly learned linear ordering of digits 1 through 12. Both time and numbers (digits) have interval levels of measurement. They differ, however, in that clock time magnitudes increase in a 12-hour² circular fashion but digits increase in a linear fashion. One o'clock p.m. denotes a greater magnitude in the time frame of a day than 12 noon on the time continuum even though 1 is numerically smaller than 12. Digits have served as stimuli in many comparative judgment experiments (Moyer & Landauer, 1967; Banks, Fujii, & Kayra-Stuart, 1976; Buckley & Gillman, 1974; Sekuler, Rubin, & Armstrong, 1971) and two important findings are observed - the symbolic distance effect and the semantic congruity effect. The goals of Experiment 2 are to extend these studies of number processing by investigating the presence of these effects in the clock time continuum and to determine the effects of different clock time formats on the magnitude of the distance and the congruity effect.

The distance effect, originally discovered by Moyer and Landauer (1967) and later dubbed the symbolic distance effect (Moyer & Bayer, 1976), refers to the phenomenon in which the degree of task difficulty decreases as the distance between two comparatives increases on some continuum. This phenomenon is evident when experimental stimuli involve the retrieval and use of information already in semantic memory including: digits (Moyer & Landauer, 1967), two digit numbers (Hinrichs, Yurko & Hu, 1981), object names (Paivio, 1975), animal names (Moyer, 1973) and

remembered animal sizes (Jamieson and Petrusic, 1975). The symbolic distance effect is also evident for ordered sequences that are arbitrarily formulated. Potts (1972) had subjects memorize a series of relational sentences in the form of "A is friendlier than B", where A and B were animal names. Subjects later made pairwise judgments on the friendliness dimension and the distance effect was observed. The decision time was found to be longest for pairs of names that were adjacent on the ordered scale and shortest for names that were on opposite poles of the continuum.

The second important effect observed in comparison tasks involving numbers is the semantic congruity effect. When magnitude of digits were compared, subjects were faster at selecting the larger of two large digits (e.g., 7 and 8) than the larger of two small digits (e.g., 2 and 3). Conversely, subjects were also faster at deciding which was the smaller of two small digits than two large digits (Bank, Fujii, & Kaura-Stuart, 1975; Deheane, 1989). The interaction between the form of comparative and the location of the comparative alternative on the stimulus continuum was referred to as the "crossover" effect by Audley and Wallis (1964) and this effect later became known as the "semantic congruity effect" (Clark, 1969).

In 1911, Henmon first documented through introspection that judgment could be given more easily, more quickly and with greater confidence when a reaction was made to the shorter of two relatively short lines. Since then, the semantic congruity effect has been observed in a great variety of perceptual and remembered symbolic comparisons experiments such as: affective comparison judgments using color as the stimulus (Dashiell, 1937), pleasantness judgments

using color as the stimulus (Shipley, Coffin & Hadsell, 1945; Shipley, Norris & Roberts, 1946), brightness judgment using light as the stimulus (Audley & Wallis, 1964), remembered animal sizes judgments using animal names as stimuli (Jamieson & Petrusic, 1975), height judgments using appropriately labeled perceptual displays as stimuli (Banks, Clark & Lucy, 1975), pitch and loudness judgments using sound as the stimulus (Wallis & Audley, 1964; Banks & Root, 1979), "nearer" or "farther" comparison judgments using proximity of distances to a fixation point as the stimulus (Petrusic & Baranski, 1989 (Experiment 3); Petrusic, 1992); and heaviness judgments using weight as the stimulus (Petrusic & Baranski, 1989 (Experiment 2)). In each case, the comparative judgment was made more quickly when the question was congruent with the information to be evaluated. Since the pair of stimuli to be judged was identical under both types of instruction, the difference in reaction time must have been attributed to a semantic or linguistic factor rather than to the difference in magnitude of the stimuli, hence the name "semantic congruity effect".

Models of comparative judgments

Many models have been proposed to explain the distance and the semantic congruity effects in the comparative judgment tasks. These models can be classified into three groups according to where in the comparison process semantic congruity effects are assumed to take place: decisional, post-decisional and decisional. Pre-decisional locus models, such as the expectancy model proposed by Marschark and Paivio (1979) assume that the effects take place before the comparison process. Those models that assume the effects occur after

the comparative process are post-decisional locus models. One such model is the semantic code model proposed by Banks (1977). Decision locus models assume that the effects take place at the decisional level. The discrepancy ratio model put forth by Jamieson and Petrusic (1975) and recently modified and expanded by Petrusic (1992) as the evidence accrual model is a decisional locus model.

The Expectancy Model

The expectancy hypothesis (Marschark & Paivio, 1979) suggests that the semantic congruity effect is due to the bias introduced by the instruction in creating an expectancy of the magnitude range within which the stimulus pair to be compared will lie. For example, when subjects are instructed to select the smaller of two stimuli, it is assumed that the instruction to "choose smaller" has created an expectancy that the pair is of small magnitude. Subjects are, therefore, attending to a small magnitude range on the continuum and the dimension of comparison. If the magnitude of the pair of stimuli to be compared is as "expected", that is, both are actually small magnitude stimuli, then judgment time is short. However, if the pair to be compared is not as expected, that is, both stimuli are relatively large, then subjects must re-adjust to the proper range and hence, the response time is longer. Holyoak and Mah (1981), however, provided convincing evidence against the expectancy hypothesis. In their experiment, they removed the bias introduced by the instruction by placing it after the presentation of the comparison pair and at the same time varied the dimension upon which the comparison was to be performed. The subject, therefore, could not focus on the specific range on the continuum nor the

dimension of comparison to be used (large vs small; heavy vs light; tame vs fierce; long vs short). The semantic congruity effect, however, was still obtained. Howard (1983) provided his subjects with the specific size range of each stimulus to be compared. According to the expectancy hypothesis, the semantic congruity effect should disappear when the expectancy induced by the comparative is overridden. This, however, was not the case, since semantic congruity effect was still present.

The Semantic Code Model

According to the semantic code model (Banks, 1977), there are four serial stages or mental operations in comparative judgment tasks that intervene between the presentation of the stimuli and the making of the overt response. These four stages are (a) encoding, (b) discrimination, (c) matching of stimulus and instruction codes, and (d) execution of a response.

In the encoding stage, discrete codes are generated (large: L^+ or small: S^+) for each of the comparison stimuli. For example, the discrete code for single digit 9 would be L^+ and 2 would be S^+ . In the discrimination stage, the codes received from the first stage are processed until they are distinguishable from each other and then these codes are sent to the matching stage. Matching involves a comparison of the stimulus code and the instruction code. If the codes match, an overt response will be made. Otherwise, further code translation is required before subject can respond.

The probability that each of the stimuli in the comparison pair receives different stimulus codes (i. e. $L^+ - S^+$) is high when the two stimuli are far apart on the comparison continuum. The

discrimination stage, therefore, should be short because the codes are already distinguishable. If, however, the distance between the comparison pair is small, the probability is high that the two stimuli will receive the same code ($L^+ - L^+$ or $S^+ - S^+$). More time is required to process these codes until distinct codes are received by each of the two stimuli ($L^+ - L$; $L - L^+$; $S^+ - S$; $S - S^+$). This extra processing time required to arrive at the two distinct stimulus codes in the discrimination stage is directly related to the distance between the stimuli and is, therefore, the source of the symbolic distance effect.

In the matching stage, the instruction "to select larger" or to select the stimulus with "more" of a particular attribute is interpreted as the instruction code "to select L^+ ". Similarly, "to select smaller" is assigned the instruction code "to select S^+ ". When there is a match between the stimulus code received from the discrimination stage and the instruction code, a response will be executed. For example, the instruction, "choose the larger" or "which is heavier?", is interpreted as the instruction code "choose L^+ ". If one of the codes in the stimulus pair received at this matching stage (e. g. $L^+ - L$; $L - L^+$; $S^+ - L^+$; $L^+ - S^+$) matches the instruction code, L^+ , then the matching process will terminate and the final response stage will be initiated. If, however, the stimulus code and the instruction code do not match, such as in the situation where the stimulus codes are " $S^+ - S$ " and instruction code is " L^+ ", then, the stimulus codes must be processed further until the stimulus codes " $S^+ - S$ " are converted to " $L - L^+$ " to provide a match with the instruction code " L^+ ". This code transformation procedure delays the final response phase. The subject's decision time, therefore, is faster when the instruction is "to

select the smaller" (instruction code: S⁺) is for a stimulus pair that is relatively small (S⁺-S) than relatively large (L⁺-L) because the instruction code and the stimulus codes are more likely to match. Similarly, "to select the larger" between two relatively large stimuli will be faster than between a pair of small magnitude stimuli. The semantic congruity effect, therefore, is due to the extent of processing in the matching stage which occurs after comparison has been completed.

Petrusic and Baranski (1989) provided experimental evidence demonstrating the inadequacy of the semantic code model to account for the semantic congruity effect. In their first experiment, subjects performed perceptual line-length comparisons under speed-and-accuracy-tradeoff conditions. The magnitude of the semantic congruity effect for judgment time was found to be larger when accuracy was emphasized than when speed was emphasized. According to the semantic code model, when speed was stressed, the code transformation in the matching stage may not have been properly performed and, therefore, the magnitude of the semantic congruity effect is expected to diminish. Similarly, when accuracy is emphasized code matching in the matching stage will be more carefully performed thus yielding a higher proportion of correct responses. A large semantic congruity effect should be evident with the proportion of correct responses in the accuracy-instructed condition. However, Petrusic and Baranski (1989) did not obtain the semantic congruity effect in their experiment for the accuracy measure under either the speed or the accuracy tradeoff conditions.

The semantic code model also predicts that stimulus pairs near the extremities of the continuum are more likely to be coded the same and therefore require more processing in the matching stage. As a consequence, a large semantic congruity effect is expected for stimulus pairs that are close to the extreme poles. Petrusic and Baranski's (1989) experiments 1 and 3 found a smaller semantic congruity effect for more extreme stimulus pairs and a larger effect for less extreme pairs. The semantic code model was unable to account for the results obtained in their experiments.

Evidence accrual process in the discrepancy Ratio model

The discrepancy ratio model developed by Jamieson & Petrusic (1975) and later elaborated as the reference point model (an evidence accrual model) by Holyoak (1978), postulates that an ideal point³ on the comparison continuum is activated by the form of comparison initiated by the instructions given to a subject (Petrusic & Baranski, 1989). The precise location of this ideal point is determined by the span of stimuli encountered and expected (Petrusic & Baranski, 1989). A stimulus ratio, R , of distances from the two comparatives to the ideal point is formed and is compared to a decision criterion (C). When the stimulus pair is close to the ideal point, the stimulus ratio (R) assumes a large value indicating easy discrimination but is positioned far from the decision criterion (C). Since judgment time is inversely related to the distance between R and C , decision time is, therefore, fast. When the stimulus pair is incongruent with the instruction (i.e. far from the ideal point), the stimulus ratio (R) is small indicating difficult discrimination and located close to the decision criterion C , yielding a longer judgment

time. Therefore, the semantic congruity effect for the discrepancy ratio model is the result of conjoined efforts of two "distance" relationships, the distance between the stimulus pair and the ideal point and the distance between the stimulus ratio (R) and the criterion value (C). The semantic congruity effect is, therefore, a consequence of the magnitudes of distances and ratios.

According to Petrusic (1992), a more basic process, the evidence accrual process, operates within the context of the discrepancy ratio model. Evidence accrual theory assumes that evidence is accrued over the duration of a trial and that the semantic congruity effect occurs on each evidence accrual event. Therefore, when the comparison task is more difficult, in particular when stimulus pair location and instruction are incongruent, or when accurate judgment is emphasized, the magnitude of the semantic congruity effect is predicted to be large because more evidence accrual is needed to obtain the required degree of accuracy. Furthermore, when error reaction time is longer than correct response time, a larger congruity effect for error responses than for correct responses is expected and this important finding has been confirmed by Petrusic and Baranski (1989) and Petrusic (1992).

Experiment 2 examines the presence of the distance and the congruity effects in the time continuum and the effect of alternative clock time formats on the magnitude of these effects. Three clock times, each presented in two possible formats, digital and pictorial, are used as in the method of triads. The paradigm is formally identical to that used by Holyoak (1978) in his elaboration of reference point theory. In Holyoak's experiment, subjects were

presented with three digits: one of the digits was designated as the reference digit or the standard; and the other two were the comparison digits. For example, the triplet [5 ; 7, 8] indicates that the standard is 5 and the comparison digits are 7 and 8. The subject's task was to select the digit that was closer to or further from the standard according to the instruction, "CLOSER" or "FURTHER". In the case where both of the comparison digits were greater than (e.g., [5 ; 7, 8]) or less than (e.g., [5 ; 2, 4]) the reference digit, the comparison digits (the pair) form a unilateral pair. When one of the comparison digits was greater than the reference digit and the other was smaller (e.g., [5 ; 6, 2]), then the pair was called a bilateral pair.

Three main findings were obtained from Holyoak's (1978) experiments. First, Holyoak found that the decision time was a linear function of the ratio of distances between comparison digits and the standard. For example, for stimulus triplet [5 ; 6, 7], the distances between the two test digits and the standard 5 are 1 and 2 respectively and the ratio of the distances is $1/2$ (0.5) while the ratio of the distances for triplet [5 ; 7, 8] is $2/3$ (.66). Holyoak found that decision time for comparison of triplet digits was directly proportional to this ratio: judgment time increased as the ratio approached 1.0. In other words, judgment time increased with increasing distance between the reference digit and the closer comparison digit (holding the difference between the comparison digits constant). Second, Holyoak found that decision time decreased with increasing difference between the comparison digits. For example, the judgment time for [5 ; 6, 7] was longer than [5 ; 6, 8] because the distance between 6 and 7 was smaller than the distance

between 6 and 8. Finally, Holyoak found the remoteness effect, that was, judgment time increased as the reference digit was moved farther away from the stimulus pair. For example, the discrimination time for comparison pair (2, 3) increased when the reference digit 5 was changed to 7.

Traditional clock times are presented in either digital or clock face formats. Therefore, in this experiment, three clock times, each presented in two forms, provide eight possible triplet formats ($2^3 = 8$: [P; P, P]; [P; D, D]; [P; P, D]; [P; D, P]; [D; P, P]; [D; D, D]; [D; P, D]; [D; P, D]). Symbols P and D indicate pictorial (clock face) and digital clock time formats, with the first element within the square brackets representing the standard clock time and the last two representing the comparison times. Two standard times, 12 noon and 3 p.m. are used to evaluate possible difference between standards.

In order to investigate the distance effect, two types of distances were varied - distances between the two comparison clock times, and distances from the standard clock time to the comparison clock times. Two sets of data, near and far, are formed to correspond to the two types of instructions "NEARER" and "FARTHER" to facilitate the investigation of the semantic congruity effect. The subject's task in this experiment is to select the comparison time that is nearer to or farther from the standard time according to the instruction, "NEARER" or "FARTHER".

Given the fact that both time and numerical digits share the same interval levels of measurement with the exception of the 12-hour circularity property of clock time, it is possible that the distance effects observed in Holyoak (1978) using digits will also be present

when comparative judgments are made on clock times. However, the two experiments differ in the following respect: subjects in Holyoak's experiment make comparative judgment in one dimension only (number magnitude) while subjects in this experiment have to not only make comparative judgments on the time continuum but also must attend to the differences in the presentation format of clock times. The process of code translation will be necessary in some clock time triplets when different clock time formats are presented in the comparison task. Several hypotheses that have been formulated for both the code translation and the evidence accrual process are used to predict the results under each of the hypotheses.

It is hypothesized that the standard clock time format dictates the format of comparison for a given triplet, meaning that if the presentation format of the standard clock time is pictorial then the comparison clock times will be transformed into clock faces before judgments are made. For triplets with the pictorial standard, decision time should increase with the number of transformations required. For example, triplet [P; P, D], under a pictorial standard clock time, requires the translation of one digital time to clock face whereas no translation will be necessary for [P; P, P]. Thus, response times from fastest to slowest will be: [P; P, P], [P; P, D], [P; D, P], [P; D, D].

Since code translation is assumed to occur at every evidence accrual event and because of the code translation, the duration of each pass through the accrual process is longer, therefore time is expected to increase with increases in the number of format code translations. More evidence accrual passes are required in the code translation for [P; P, D] and since the congruity effect occurs with

every evidence accrual event, a larger congruity effect is expected for this triplet than for the triplet [P; P, P]. Similarly, under the same hypothesis of standard time format dominance, the decision time is expected to be from fastest to slowest for triplets with digital standard: [D; D, D], [D; P, D] and [D; D, P], [D; P, P]. The magnitude of the semantic congruity effect is also predicted to be the largest for the triplet [D; P, P] where two code translations are required, and the congruity effect is smallest for [D; D, D] since no code translation is required.

It is also very probable that the subject may opt for the most economical and efficient way to conduct the comparison by using the strategy of majority rules. That is, the subject adopts the format that holds the majority of the triplet time presentation formats (at least 2 out of three) and makes judgments using the majority format that appears in the triplet regardless of the standard time format. In this case, triplets that have the "most" common clock time presentation format will have the shortest comparison time. The expected order of reaction time will be fastest for triplets: [P; P, P], [D; D, D] and slower for triplets [P; D, D], [D; P, P], [P; P, D], [P; D, P], [D; P, D], [D; D, P]. Further, based on the evidence accrual model, the magnitude of the semantic congruity effect decreases as a function of the degree of majority of clock time format present in the triplet. For example, under the hypothesis that digital format holds the majority, then, when all three clock times are digital (maximum degree of majority) the magnitude of the congruity effect will be less than when one of the clock times in the triplet requires translation. In the latter case,

more evidence accrual events are required and therefore, a larger congruity effect is expected.

It is also possible that the preferred mode of representation and processing of clock time dictates the format in which the comparison is to be made. For example, if digital code for clock time is the preferred format in time processing then perhaps all clock times in the triplet are transformed into digital format before the comparison process begins. If this is the case, then given the situation where all three clock times are pictorial, three transformations from pictorial to digital code are necessary before any judgment can be made. This scenario only seems logical if the processing of digital time is far superior to clock face times and if code translation from pictorial to digital requires little effort and time. The decision time and magnitude of congruity effect under the hypothesis of numeric preference for triplets is expected to be increasing in the following order: [D; D, D]; [D; D, P], [D; P, D], [P; D, D]; [P; D, P] [P; P, D] [D; P, P]; [P; P, P]. This order is reversed if the hypothesis is the pictorial preference.

Irrespective of the particular basis for format translation considered above, examination of the symbolic distance and the congruity effects as a function of the number of format translations required is especially informative concerning the decision processing in the triplet comparison task. For example, on the assumption that format translation occurs on every evidence accrual event, distance effects are, therefore, magnified with each format translation. This result follows, because format translation prolongs the duration of each evidence accrual event and more evidence accruals are required

for format translation. The magnitude of the semantic congruity effect is also predicted to depend on the number of format translations. Since the congruity effect is assumed to occur on each evidence accrual, triplets that require more code translations are predicted to show a greater congruity effect.

Method

Subjects. Eight Carleton University students were recruited to participate in four one-hour sessions and were paid \$22.50. Subjects all had normal or corrected-to-normal vision.

Stimulus and Design. Three circles containing three clock times (called the triplet) were presented on the screen in a pyramid fashion (See Figure 3.). The centrally located circle contained the standard time. The comparison times were located slightly lower and to the left and right of the standard time. An instruction "NEARER" or "FARTHER" was positioned above the standard time. The subject's task was to select the comparison time that was nearer to the standard time, on some trials and farther from the standard time, on others.

Insert Figure 3 about here

Due to the circular nature of clock times, it becomes necessary to set up a range within which the comparison times can vary. It seems reasonable to adopt a 12-hour cycle range, ± 6 hours from the standard. For example, if the standard time is 12 noon, the comparison times will be between 6 a.m. and 6 p.m. The nearer time for the triplet [12 : 9, 10], therefore, is 10 because 10 a.m. is nearer

to 12 noon than 9 a.m. Without the specification of this range, 9 and 10 o'clock could also be interpreted as 9 p.m. and 10 p.m. in this case, 9 would be the correct response. To avoid such ambiguity, the 12-hour range ± 6 hours from the standard was imposed and subjects were informed of this. Two standard times, 12 noon and 3 p.m. were used in this experiment. For the standard time, 3 p.m., the comparison times ranged from 9 a.m. to 9 p.m.. Twelve o'clock was selected because it was the conventional start of a 12-hour cycle. Three o'clock was also used in the experiment to evaluate possible effects of different standards. Only hourly times were used as comparison times (called a pair) for the triplets.

Comparison times were classified according to two dimensions, unilateral vs bilateral and near vs far. Within the unilateral times, the hourly times in the clockwise direction of the standard time were called the clockwise times and in the counter-clockwise direction were called the counter-clockwise times. Therefore, for the standard time, 12 noon, the clockwise times were 1 to 5 p.m. and counter-clockwise times were 7 to 11 a.m.; the near times were in the first and fourth quadrants and far times were in the second and third quadrants. The corresponding features for the standard time 3 p.m. were: 4 to 8 p.m. for clockwise times and 10 a.m. to 2 p.m. for counter-clockwise times, near times were in the first and second quadrants and far times were in the third and fourth quadrants.

For each of the standard times, all possible combinations of hourly times were formed for the near sets and far sets respectively (i.e. clockwise-near; clockwise-far; counter-clockwise near; counter-clockwise-far; bilateral-near; bilateral-far) (see Table 5). However,

six o'clock and nine o'clock were not used as comparison times for the respective standards 12 and 3 o'clock because they obviously formed the farthest stimulus of any pair. Hours that were of equal distance from the standard times were also not used. Therefore, three near and three far pairs, each in the clockwise and counter-clockwise direction of the standard clock time and six near and six far bilateral pairs were formed. The presentation of these triplets was counter-balanced for the left-right position of comparison times, yielding a total of 48 triplets for each of the standard times.

Clock time was presented in either digital (numeric) or clock face (pictorial) format. Eight comparison-triplet formats of interest were used in this experiment : [P; P, P]; [P; D, D]; [P; P, D]; [P; D, P]; [D; P, P]; [D; D, D]; [D; P, D]; [D; D, P], where P represents time in clock face form and D indicates digital clock time.

In order to investigate the presence of the semantic congruity effect, two instructions were used - "NEARER" to instruct the subject to select time that is closer to the standard time and "FARTHER" to select time that is farther from the standard time. Forty-eight triplets, each presented in all six comparison-triplet formats and two types of instructions, yield a total of 576 triplets for each of the standard times. To ensure that the subject attended to the format of the standard time, both 12 noon and 3 p.m. were used in the same experimental session. Therefore, triplets generated from both standards were combined to form a pool of 1152 (2 x 576) triplets. Due to the size of the pool and the length of the experiment, two equi-sized blocks were formed, each containing both standard times and similar triplets. Each of the two blocks was replicated twice to

give greater reliability to the variance measure and the experiments were conducted in four one-hour sessions over four days. Thus, each subject provided a total of 2304 judgments. Subjects were given brief rests after every 96 trials within a session.

Procedure. Each subject sat in front of the computer in a dimly lit room and was shown a sample of a typical screen containing the three clock times in three circles with instructions positioned near the top. The subject was informed that the instruction "NEARER" or "FARTHER" would precede (by 1 second) the presentation of the triplet clock times. This was to ensure that instruction reading and comprehension time would not contribute to the judgment time. Instructions varied randomly from trial to trial but remained on the screen for the duration of the trial. The subject was also informed that the standard time would always be placed in the top circle and the two comparison times would occupy the two remaining circles. The subject's task was to select the comparison time that was nearer to or farther from the standard time according to the instruction given. Decision of judgment was registered by pressing the mouse button corresponding to the position of the comparison clock time on the computer screen. Judgment time was measured from the onset of the triplet until subject responded by pressing the mouse button. The 12-hour range of the comparison times with respect to both standard times was also explained. The subject was instructed to make a decision as quickly as possible without sacrificing accuracy. To ensure that the subject clearly understood the procedure, the task and the 12-hour span of comparison times, 18 practice trials were given. The experimenter tracked the accuracy of judgment on these

trials and if the subject made mistakes on any of the practice trials, a copy of that particular trial was shown to the subject and explained immediately after the practice session and before the experimental trials. This tracking was conducted for each of the four sessions.

At the end of the experiment, the subject was given a short debriefing about the purpose of the experiment and was invited to return for a more thorough debriefing at the completion of the research.

Results and discussion

Findings for Experiment 2 are presented in four sections - global analyses, the format effect, the semantic congruity effect, and the distance and remoteness effects.

Global analyses. Subjects' error response rates varied between 2 and 9 % and the error rate for the triplet formats varied between 2 and 4%. Slightly more errors were made when the standard time was 3 o'clock than 12 o'clock (4% vs 3%). Subjects who rated their familiarity with clock face time as high were more accurate in their judgment than those who were less familiar with clock face time (97% vs 91%). Error trial judgment times were included in all analysis.

An analysis of variance was performed on the 2x8x3x2x2x2 within subjects experimental design with two standard clock times (3 and 12 o'clock), eight triplet formats, three possible locations of the comparison times in relation to the standard time (clockwise, counter-clockwise and bilateral) and near and far set to correspond to "NEARER" and "FARTHER" instructions. A further factor arose from the two blocks of experimental data. Mean judgment time for each

subject for each standard, triplet format, location, set and instruction per block was calculated and served as the dependent variable. Throughout the analysis, the level of significance is defined by the Greenhouse and Geisser epsilon adjusted degrees of freedom, although the degrees of freedom indicated in the text are defined by the design.

Format effects. Analysis of variance revealed a significant main effect of triplet formats ($F(7,49) = 7.23, p < .0001$; See Table 6). However, interpretation of this main effect is greatly complicated by the presence of three-two way interactions involving the format factor. Generally, judgment times were faster for triplets with pictorial comparison times ([D; P, P], [P; P, P]) and triplets with digital standards ([D; P, P], [D; D, P], [D; D, D], [D; P, D]).

First, the interaction between triplet format and standard clock time was found to be significant ($F(7,49)=7.23, p < .01$). For standard time 12 o'clock, using Newman-Keuls range as the critical value ($p < .05$), judgment times for triplet formats [P; P, P] and [D; P, P] were found to be significantly faster than the other six triplet formats ([P; P, D], [P; D, P], [P; D, D], and [D; P, D], [D; D, P], [D; D, D]; See Table 7). This result indicates that for standard time 12 o'clock, comparison times presented in clock face forms are more advantageous than digital or mixed formats. This may be due to the fact that subjects are more familiar with making judgment with 12 o'clock using angular comparison rather than using the time continuum or in the digital form.

Indeed, subjects may rely on angular judgment because of previous training in mathematics, trigonometry and geometry. The

90° vertical line in trigonometry and geometry has served as a reference line in many applications involving angles. Twelve o'clock holds the same position as this reference line. Therefore, when comparison times are both presented in clock face format, it is natural for subjects to make the comparison judgment based on angular sizes. Comparison times presented in the clock face format clearly provide the visible angle sizes and they also provide the visual vertical line representation at 12 o'clock. Therefore, subjects need not, in fact, attend to the presentation format of the standard. As a consequence, judgments can easily be made by using purely, perceptual angular comparison which are likely to be considerably faster than those required with the symbolic representations of time.

However, for the 3 o'clock standard, the above pattern of findings was not observed. Again, using Newman-Keuls range ($p < .05$) as the critical value, judgment times for triplets with standard time presented in digital format were faster than in pictorial format with the exception of [P; P, P] (See Table 7). That is, judgment times for triplets [D; P, P], [D; D, D], [D; D, P], [D; P, D] and [P; P, P] were found to be significantly faster than [P; D, P], [P; P, D] and [P; D, D]. In these cases, it appears that digital standard determines the format of comparison and since time processing in digital format generally has been found to be superior, as found in Experiment 1, judgment times for triplets with a digital standard are faster. Although 3 o'clock does not hold a special significance as a reference time in the time frame of a day, it does hold the position of the zero degree line in geometry and trigonometry. Again, this lends familiarity to subjects when the comparison times are all presented in pictorial format. This may

have helped to facilitate comparison using size of angles for triplet [P; P, P] for 3 o'clock standard, rather than using the faster digital time processing.

Second, although the main effect of near vs far sets was significant with overall longer judgment times for all far sets, this factor also interacted with format ($F(7,49)=3.50$, $p<.05$). For the near set, judgment times were faster for digital standard triplets and triplets with pictorial comparison times. On the other hand, for the far set, judgment times for triplets with pictorial comparison times were judged faster.

Finally, the interaction between triplet format and location of comparison digits was also found to be reliable ($F(14,98)=5.02$, $p<.01$). Triplets where both comparison times are positioned on the clockwise location, judgment times were found to be shorter for [D; D, D] and [D; P, P] but for counter-clockwise and bilateral triplets, [P; P, P] and [D; P, P] were faster (See Table 9).

The format of presentation of clock times has been found to interact with several factors. No distinct and consistent clock time presentation format or triplet format was found to be more advantageous than any other. The hypothesis of majority rule, that is, triplets with the most common format ([P; P, P] and [D; D, D]) and the hypothesis that the presentation format of standard may determine the format of processing are not supported. There is, however, some evidence that subjects are able to strategically use perceptual angular comparison in triplet comparisons where the angular size is clearly visually evident as in the case of [P; P, P] and [D; P, P] for standard 12 o'clock.

Semantic congruity effect. Analysis of variance yielded a two-way interaction involving Instruction and Set (near and far: $F(1,7)=25.8$, $p<.01$) affirming the reliable overall occurrence of semantic congruity effects with comparisons of clock times. Importantly, this two-way interaction is qualified by a three-way interaction involving Standard ($F(1,7)=9.23$, $p<.05$). Figure 4 provides a view of the congruity effect, separately with each standard.

Insert Figure 4 about here

Judgment time for the near set when the instruction is "NEARER" is shorter than when the instruction is "FARTHER". Conversely, decision time for the far set when the instruction is "FARTHER" is faster than when the instruction is "NEARER". A clear semantic congruity effect for standard clock time has thus been found for both standard 3 and 12 o'clock. The magnitude of this semantic congruity effect (See Table 10), however, is greater for 3 o'clock (515 msec) than 12 o'clock (265 msec) because of task difficulty. Comparison judgments are more difficult for the 3 o'clock standard than 12 o'clock as indicated by the significantly longer mean response times ($F(1,7)=151.6$, $p<.0001$; 2510 vs 2189 msec). The slower response time for the 3 o'clock standard was consistent across all triplet formats, across both unilateral and bilateral locations and across all subjects.

Further examination of this interaction together with results reported in the format section, that is, the interaction between triplet

format and standard, provided the following three important findings (Refer to Table 11 and Figure 5):

Insert Figure 5 about here

(1) The magnitude⁴ of the congruity effect for 12 o'clock using average RT of triplets where the comparison times are pictorial (i.e. [P; P, P] and [D; P, P]) is 233 msec, and is smaller than the average RT for triplets of the other six comparison formats (327 msec). If judgments for triplets [P; P, P] and [D; P, P] are based on angular sizes then the comparison judgment is based on a perceptual analysis (i.e. angle). Since perceptual stimuli are less variable (in terms of the slope of the psychometric function (Baranski & Petrusic, 1992; Petrusic, 1992)) and consequently, more precise, the number of evidence accrual events should be small which, in turn, produces smaller congruity effects and faster judgment times. For the 3 o'clock standard, we also found smaller semantic congruity effect magnitude for triplets with digital standards [D; P, P], [D; D, P], [D; P, D], [D; D, D] and [P; P, P] than triplets with pictorial standard ([P; D, P], [P; P, D], [P; D, D]) (507 msec vs 511 msec). (2) The magnitude of congruity effect for 3 o'clock is found and predicted by the evidence accrual model to be considerably larger than with the 12 o'clock standard (in the 500 msec range vs in the 200-300 msec range) due to more difficult discrimination; (3) the difference in magnitude of the congruity effect between the two groups for the 12 o'clock standard is found to be greater (100 msec, difference between 233 and 327) than for 3 o'clock (5 msec, difference between 511 and 507).

Distance and remoteness effect

Distance effects were evident with these triplet time comparisons. As the distance between two comparison times increased from 1 hour to 2 hours, the mean discrimination time was found to decrease from 2378 msec to 2292 msec (e.g., Judgment time for triplet [12; 1, 3] was faster than [12; 1, 2]). Judgment time was also found to increase with increasing distance between the standard time and the nearer time. For example, judgment time for [12; 2, 3] was found to be longer than [12; 1, 2]. As distance between stimulus pair and the standard increased from 1 hour to 4 hours, decision time was found to increase from 2117 msec to 2595 msec (2117, 2371, 2449 and 2595 msec). These results are similar to the results obtained by Holyoak (1978) using triplets of digits.

Holyoak (1978) also found the remoteness effect, that was, for a fixed pair of test digits, decision time increases as the distance between the standard and the test pair increases. In the present experiment, the pairs (10, 11) and (4, 5) each provide test of the remoteness effect. Judgment time for comparison pairs (10,11) increased from 1970 msec to 2537 msec (an increase of 567 msec) as the standard was moved from 12 to 3 and this finding is consistent with the remoteness effect found by Holyoak. For comparison times (4,5), as distance from the test pairs to the standard increased from 3 to 12 o'clock, the judgment time was found to have decreased from 2253 msec to 2067 msec (a decrease of 186 msec). However, this does not necessarily exclude the possibility that this remoteness effect is still present. It is possible that it is due to longer discrimination time for 3 o'clock (321 msec longer than 12 o'clock)

which may have, in turn, masked the remoteness effect when the comparison was made with 3 and 12.

General discussion and conclusion

Both distance and semantic congruity effects were found to be present using the triplet comparisons with the time continuum. Judgment time has been found to decrease as distance between comparison times increases and that judgment time increases with increasing distance between reference (standard) time and stimulus pair. For pairs of clock times that are near the standard, judgment time to select the nearer time is faster than selecting the farther time. Similarly, for pairs of clock times that are far from the standard time, decision time to select time that is farther from the standard is shorter than selecting the nearer time.

The magnitude of the semantic congruity effect has been found to increase with task difficulty, format translation and quality of information. This result follows from the view that the more difficult discrimination (as indicated by longer judgment time), will require more evidence accrual passes to achieve the criterion value for the overt response to occur. Since the congruity effect is assumed to occur at every pass, the magnitude of the effect will increase with task difficulty. In cases where clock time format is transformed into another format on the assumption that code translation occurs at every pass it follows that congruity magnitude will be larger for formats with slower overall times.

Investigation of the effects of format in the time continuum was the main goal of this research. However, we did not find a clear format effect. Indeed, it is possible that clock time may be dual-

coded in memory in both the digital and clock face formats. In Experiment 1, we found evidence that the memory representation of time could be biased by the type of word string used. If Pictorial word string elicits only the pictorial representation in memory, then when it is compared with clock time in the same format (Picture) decision time should be faster than when it is compared with clock time in a different format (Digit) (i.e., $RT(W_P-P) < RT(W_P-D)$). However, we found the contrary, decision time for Pictorial word string and Picture pair (W_P-P) was significantly longer than Pictorial word string and Digit (W_P-D) pair. However, if one assumes that Pictorial word string (W_P) generates dual representations of time in memory (i.e., both the clock face and digital forms), and given the finding that digital processing time was far superior than pictorial then it follows that upon presentation of the second clock time in digital form the subject employs the most efficient format in processing, digital. Thus, shorter judgment time was found for stimulus pair where the second clock time was a digital time ($W_P-Digit$).

The superior performance of digital time format was not observed consistently in the second experiment. Decision time for triplet format involving three clock faces, $[P; P, P]$ was 118 msec faster than $[D; D, D]$. This was, perhaps, due to a perceptual angular comparison strategy used by subject for this triplet format ($[P; P, P]$). The overall mean decision time for triplet format in digital form ($[D; D, D]$) ranked fourth, behind $[D; P, P]$, $[P; P, P]$ and $[D; D, P]$ and sixth for standard 12 o'clock and second for standard 3 o'clock. This fluctuation of the more advantageous clock time format between

digital and clock face formats or lack of a consistent superior clock time format also suggest that time may be in both formats in memory. Indeed, it is striking that in the triplet task, where it was expected that format effects would be most evident (given that comparison cannot proceed until the representations are in the same format), the format effect is of a smaller magnitude than the congruity effect. Thus, either format effects are indeed very small and of little consequence or both formats are simultaneously available.

The format, digital or clock face, employed in a comparison tasks, therefore, relies on familiarity, ease of encoding and format translation and perhaps rate and ease of processing. In this current form of delivery of time stimuli, it is not clear if subjects are always making judgments on the time continuum. A different type of mode of delivery, other than digital and clock face time (e.g., voice delivery of time, mood setting of time - bright and warm surroundings to give a sense of day, dark and cooler settings to give a sense of night), may provide the necessary conditions for the investigation of time.

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Footnotes

¹ Clock face is divided into four equal quadrants (Q₁, Q₂, Q₃, Q₄) by the horizontal line anchored at 9 and 3 o'clock and the vertical line at 12 and 6 o'clock. The times (t) within each of the quadrant are classified as follows:

First quadrant	Q ₁ :	$12:00 \leq t < 3:00$
Second quadrant	Q ₂ :	$3:00 \leq t < 6:00$
Third quadrant	Q ₃ :	$6:00 \leq t < 9:00$
Fourth quadrant	Q ₄ :	$9:00 \leq t < 12:00$

² I assume that the overwhelming majority of the population traditionally operates in the framework of two 12-hour cycles per day. This paper will not make reference to metric time (0 to 24 hour) which is only prevalent in aviation and the military.

³ The ideal point is used in the context of Coombs (1950, 1964) unfolding theory.

⁴ For 12 o'clock, average judgment times were calculated for the triplets with shorter judgment time ([P; P, P] and [D; P, P]) and with slower judgment time ([P; D, P], [P; P, D], [D; P, P], [D; D, P], [D; P, D] [D; D, D]). And for 3 o'clock, average judgment times were also calculated for triplets with faster judgment time ([D; P, P], [D; D, P], [D; P, D], [D; D, D], [P; P, P]) and slower judgment time ([P; D, P], [P; P, D], [P; D, D]). These averages are used in the investigation of the semantic congruity effect.

Table 1

Mean and median judgement time (msec) for six comparison formats.
Ranked in order of magnitude.

Set	Stimulus Pairs	Mean (msec)	Median (msec)
1	W _N -Picture	1232	989
2	W _N -Digit	950	787
3	W _P -Picture	1156	979
4	W _P -Digit	1063	869
5	Picture-Digit	1026	810
6	Digit-Picture	1195	951

Table 2

Mean and median judgement time (msec) for Digit-Picture and W_N -Picture pairs and, Picture-Digit and W_P -Digit pairs.

Set	Stimulus Pairs	Mean (msec)	Median (msec)
5	Picture-Digit	1026	810
4	W_P -Digit	1063	869
6	Digit-Picture	1195	951
1	W_N -Picture	1232	989

Table 3

Analysis of Variance Table of 2 x 2 factorial design with 3 replications (blocks).

2 x 2 x 3 ANOVA table

Source of variation	df	Sum of Squares	Mean Squares	F Value	p-value
Word-String (A)	1	19608.76216	19608.76216	.39	.543
Error	17	863981.24981	50822.42646		
Time-Format (C)	1	1897365.38578	1897365.38578	36.02	.000
Error	17	894071.17664	52592.42216		
Block (B)	2	986089.96209	493044.98104	5.91	.006
Error	34	2835765.57047	83404.86972		
Word-String x Time-Format (A x C)	1	484157.90043	484157.90043	8.05	.011*
Error	17	1022721.20496	60160.07088		
Word-String x Block (A x B)	2	13852.22869	6926.11434	.62	.545
Error	34	380939.54866	11204.01614		
Time-Format x Block (C x B)	2	8207.68818	4103.84409	.43	.651
Error	34	320857.70961	9436.99146		
Word-String x Time-Format x Block (A x C x B)	2	7955.47138	3977.73569	.18	.838
Error	34	763538.00648	22457.00019		
Residue	17				
Total	215	305718259.8			

Table 4

ANOVA table of simple main effects for Experiment 1.

Source of Variation	d.f.	Sum of Squares	Mean Squares	F	p-value
Word-Strings and Digit time (W _N -D vs W _P -D) (A at C1)	1	349319.1	349319.1	6.30	p<.025 *
Error (SSA + SSAC)	34	1886702.4	55491.25		
Word-Strings and Digit time (W _N -P vs W _P -P) (A at C2)	1	154447.1	154447.1	2.78	.05<p<.10
Error (SSA + SSAC)	34	1886702.4	55491.25		
Time Formats and Numeric Word-String (W _N -D vs W _N -P) (C at A1)	1	2149210.1	2149210.1	38.12	p<.001 *
Error (SSC + SSAC)	34	1916792.4	56376.25		
Time Formats and Numeric Word-String (W _P -D vs W _P -P) (C at A2)	1	232312.7	232312.7	4.12	p<.05 *
Error	34	1916792.4	56376.25		

Table 5

Experimental conditions for triplet clock times used in Experiment 2.

Standard time	Type	Clockwise (C, F) (F, C)		Counter Clockwise (C, F) (F, C)		Bilateral (C, F) (F, C)	
12:00	Near	(1, 2)	(2, 1)	(11, 10)	(10, 11)	(1, 10)	(10, 1)
		(1, 3)	(3, 1)	(11, 9)	(9, 11)	(1, 9)	(9, 1)
		(2, 3)	(3, 2)	(10, 9)	(9, 10)	(2, 9)	(9, 2)
						(11, 2)	(2, 11)
						(11, 3)	(3, 11)
						(10, 3)	(3, 10)
	Far	(3, 4)	(4, 3)	(9, 8)	(8, 9)	(3, 8)	(8, 3)
		(3, 5)	(5, 3)	(9, 7)	(7, 9)	(3, 7)	(7, 3)
		(4, 5)	(5, 4)	(8, 7)	(7, 8)	(4, 7)	(7, 4)
						(9, 4)	(4, 9)
3:00	Near	(2, 1)	(1, 2)	(4, 5)	(5, 4)	(2, 5)	(5, 2)
		(2, 12)	(12, 2)	(4, 6)	(6, 4)	(2, 6)	(6, 2)
		(1, 12)	(12, 1)	(5, 6)	(6, 5)	(1, 6)	(6, 1)
						(4, 1)	(1, 4)
						(4, 12)	(12, 4)
						(5, 12)	(12, 5)
	Far	(6, 7)	(7, 6)	(12, 11)	(11, 12)	(6, 10)	(10, 6)
		(6, 8)	(8, 6)	(12, 10)	(10, 12)	(6, 11)	(11, 6)
		(7, 8)	(8, 7)	(11, 10)	(10, 11)	(7, 10)	(10, 7)
						(12, 7)	(7, 12)
						(11, 8)	(8, 11)
						(12, 8)	(8, 12)

Table 6

Mean RT (msec) for the eight triplet formats.

Triplet Format	Judgment time (msec)
[D; P, P]	2220
[P; P, P]	2243
[D; D, P]	2359
[D; D, D]	2361
[D; P, D]	2372
[P; D, P]	2429
[P; P, D]	2450
[P; D, D]	2467

Table 7

Ranked according to judgment time (msec) of triplet formats with each standard time.

12 o'clock	
[P: P, P]	2000
[D: P, P]	2030
[D: P, D]	2260
[D: D, P]	2263
[P: D, P]	2266
[D: D, D]	2269
[P: P, D]	2277
[P: D, D]	2302
3 o'clock	
[D: P, P]	2410
[D: D, D]	2454
[D: D, P]	2455
[D: P, D]	2483
[P: P, P]	2487
[P: D, P]	2592
[P: P, D]	2622
[P: D, D]	2632

Table 8

Judgment time for eight triplet formats for each NEAR and FAR set.

Triplet format	Set	
	NEAR	FAR
[D; P, P]	2109 (1)*	2331 (1)
[P; P, P]	2137 (2)	2350 (2)
[D; D, D]	2156 (3)	2567 (6)
[D; D, P]	2171 (4)	2556 (5)
[D; P, D]	2209 (5)	2535 (3)
[P; D, D]	2303 (6)	2631 (8)
[P; D, P]	2308 (7)	2549 (4)
[P; P, D]	2331 (8)	2568 (7)

* number within brackets is the ranking according to judgment time within the set.

Table 9

Ranked according to judgment time (msec) of triplet formats for clockwise, counter-clockwise and bilateral times.

Clockwise	
[D; P; P]	2140
[D; D; D]	2146
[P; P; P]	2215
[D; D; P]	2228
[P; D; D]	2237
[D; P; D]	2312
[P; D; P]	2319
[P; P; D]	2396
Counter-clockwise	
[D; P; P]	2096
[P; P; P]	2119
[P; P; D]	2264
[D; D; D]	2276
[D; P; D]	2323
[D; D; P]	2337
[P; D; P]	2379
[P; D; D]	2393
Bilateral	
[P; P; P]	2320
[D; P; P]	2322
[D; P; D]	2426
[D; D; P]	2436
[P; D; P]	2508
[D; D; D]	2512
[P; P; D]	2569
[P; D; D]	2619

Table 10

Mean judgment time for standard time 12 o'clock and 3 o'clock.

12 O'CLOCK			
Instruction			
		"NEARER"	"FARTHER"
Set	Near	2034	2125
	Far	2299	2270
3 O'CLOCK			
Instruction			
		"NEARER"	"FARTHER"
Set	Near	2211	2437
	Far	2726	2666

Table 11

Average judgment time (msec) for triplet format by instruction ("NEARER" and "FARTHER") by set (Near and FAR sets) for each standard (3 and 12 o'clock).

12 O'CLOCK

		Instruction	
		"NEARER"	"FARTHER"
Set	Near	1888	1999
	Far	2121	2054

Average RT for triplet formats:
[P: P, P], [D: P, P].
Magnitude of SCE: 233 msec

		Instruction	
		"NEARER"	"FARTHER"
Set	Near	2101	2191
	Far	2428	2372

Average RT for triplet formats:
[P: D, D], [P: P, D], [D: D, D].
[D: P, D], [P: D, P], [D: D, P]
Magnitude of SCE: 327 msec

3 O'CLOCK

		Instruction	
		"NEARER"	"FARTHER"
Set	Near	2158	2378
	Far	2665	2629

Average RT for triplet formats:
[D: P, P], [D: D, D], [D: D, P].
[D: P, D], [P: P, P].
Magnitude of SCE: 507 msec

		Instruction	
		"NEARER"	"FARTHER"
Set	Near	2319	2565
	Far	2830	2747

Average RT for triplet formats:
[P: D, P], [P: P, D], [P: D, D].
Magnitude of SCE: 511 msec

Digit (D)

11:00

3:45

7:30

8:23

Picture (P)

ELEVEN

THREE
FORTY-FIVE

SEVEN THIRTY

EIGHT
TWENTY-THREE W_N

WORD

ELEVEN O'CLOCK

QUARTER TO FOUR

HALF PAST SEVEN

TWENTY-THREE MINUTES

 W_P

PAST

EIGHT

FARTHER

Appendix A.

▲ Number within brackets represents number of stimulus pairs

α Comparison-formate : Wn=numeric descriptive word -string;Wp=pictorial descriptive word-string

β Q1=first quadrant; Q2=second quadrant; Q3=third quadrant; Q4=fourth quadrant.

Δ Goolkasian and Park (1980) stimulus pairs

† DIFFERENT pairs:second time differs from first by (i) exactly ± 30 min;(ii) $> \pm 30$ or $< \pm 30$ min (iii) $\pm$ Hrs or $< \pm$ Hrs

Appendix B.

		Block					
		1	2	3	4	5	6
Set	1	W_N -Picture	W_N -Digit	W_P -Picture	W_P -Digit	Picture-Digit	Digit-Picture
	2	W_N -Digit	W_P -Picture	W_P -Digit	Picture-Digit	Digit-Picture	W_N -Picture
	3	W_P -Picture	W_P -Digit	Picture-Digit	Digit-Picture	W_N -Picture	W_N -Digit
	4	W_P -Digit	Picture-Digit	Digit-Picture	W_N -Picture	W_N -Digit	W_P -Picture
	5	Picture-Digit	Digit-Picture	W_N -Picture	W_N -Digit	W_P -Picture	W_P -Digit
	6	Digit-Picture	W_N -Picture	W_N -Digit	W_P -Picture	W_P -Digit	Picture-Digit

END

2|5| 0|5| 93|

FIN