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INTERDEPENDENCE OF SPATIAL AND TEMPORAL JUDGMENTS
IN VISUAL PERCEPTION

by

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A thesis submitted to the Faculty of
Graduate Studies in partial fulfilment
of the requirements for the degree of
Doctor of Philosophy

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December 1980

Of making many books there is no end,
And much study is a weariness of the flesh.

Ecclesiastes XII, 12

- then on the shore
of the wide world I stand alone, and think
till love and fame to nothingness do sink

John Keats

爸爸
妈妈

献
给

(Dedicated to Papa and Mama)

ABSTRACT

This thesis examines a general problem in cognitive integration of information in the context of two illusory effects, tau and kappa, in spatial and temporal judgments. Evidence is presented for a theory, incorporating the constant velocity hypothesis, which takes into account a person's usual perceptual expectancies in laboratory tasks.

The tau effect designates the phenomenon whereby the temporal dimension of a stimulus display influences the subject's spatial judgment. A distance demarcated by two successive signals tends to be judged shorter if temporal separation between the two is short, and longer if temporal separation is long. The kappa effect refers to the converse influence of the spatial dimension on temporal judgments. The constant velocity hypothesis states that movements are imputed across successive signals and that the movements are assumed to have equal velocities, thus giving rise to judgments of greater distance for intervals associated with greater temporal separation (tau) and judgments of greater duration for intervals associated with larger extent (kappa).

Experiment 1 replicated a previous study (Collyer, 1977) which failed to demonstrate either effect when the total duration of the display was very brief. It was found that both effects and their reverse could be observed for a single subject. It was argued that results reflect subjects' response strategy and one possible strategy responsible for the occurrence of reverse tau and kappa effects was suggested.

Experiment 2 examined the effect of systematically lengthening the total display duration (T). It was hypothesized that both tau and kappa effects would be more marked as the primary discrimination was made more difficult. As T increased from 160 msec to 1,500 msec, the tau effect became progressively stronger while the kappa effect showed signs of diminution. Examination of stimulus discriminability confirmed the hypothesis that both effects were more pronounced when discriminations were more difficult.

Experiments 3 and 4 were direct tests of some of the implications of the constant velocity hypothesis. In Experiment 3, induction of equal and unequal velocities was built into the stimuli to be judged. While tau and kappa effects were evident, induction of constant velocity did not yield greater effects than the two non-induction conditions. It was argued that strong subject expectancy obliterated the laboratory manipulation.

The expectancy notion of the constant velocity hypothesis was tested in Experiment 4 using an absolute judgment task (distance). While the tau effect was observed, induction of acceleration before the judged stimulus yielded greater judged distance than an induction of deceleration.

From a review of literature in related areas of motion perception, attention, illusion, it is suggested that any theory of the interdependence of spatial and temporal judgments must take into account a person's ordinary experience.

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Above all, DEO GRATIA.

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I. INTRODUCTION

I.1 Spatial judgments in temporal context

Benussi (1913) seems to have been the first to demonstrate experimentally that visual spatial judgments may depend upon the temporal context. He presented his subjects with three successive lights which defined two spatial intervals and two temporal intervals and found that the spatial distances were made to look longer or shorter according to the duration of the temporal intervals (Note 1). Gelb (1914) demonstrated the same phenomenon in the tactile modality (Note 1) and Scholz (1924) showed that the phenomenal size of a spatial interval, whether it be auditory, visual or tactile, seems to depend upon the associated temporal interval (Note 2). Scholz employed three constantly illuminated lights to define the standard intervals and three intermittent lights to define the intervals which were to be compared to the standards. In general, he found that greater perceived spatial extents were associated with longer duration. In a second, auditory experiment, two successive tones were presented and the subject had to indicate their positions on a measuring stick. Similar temporal effects were found. In this situation, an auditory phi phenomenon was also reported, ~~in~~ the subjects perceived a moving auditory stimulus and not two isolated tones. A series of tactile stimuli were also applied to the subject who had to indicate where on the forearm the last stimulus had been applied. Again, a shorter temporal interval was paired with a shorter extent and perceived phenomenal distance increased with the temporal separation of the defining stimuli.

In both the Benussi (1913) and the Gelb (1914) studies, "phenomenal movement appeared during the optimal time for maximal shortening [of the spatial distance]" (Helson, 1925, p.513). In other words, when the phi phenomenon appeared, the distortion of spatial distance perception associated with the temporal interval was greatest. Helson (1925) therefore concluded that "movement, extent and time are related, for all the spatial modalities, vision, hearing and touch (p.513)."

In 1931, Helson and King reported an extensive quantitative study on the effect of time upon phenomenal extent in touch (see also, Helson, 1930). They presented the subject with three successive tactile stimuli produced by blunt fibre-tipped rods weighing 11.54 grams, falling from a height of 2 mm on either the dorsal or the ventral surface of the subject's right forearm. Each stimulus rested on the skin for 100 msec. Various temporal intervals were used, from a range between 250 and 500 msec, such that either $t_1=t_2$ or $t_1>t_2$ or $t_1<t_2$, where t_1 was the temporal interval between the first and the second stimuli and t_2 the temporal interval between the second and the third stimuli. In a series of trials, one of two spatial intervals (s_1 and s_2) was fixed (from a minimum of 30 mm) and the other, varied in steps of 5 mm. The subject reported whether s_2 was equal to, shorter or longer than s_1 .

For the condition when $s_1=s_2$ and $t_1>t_2$, s_1 was typically judged to be longer than s_2 (e.g., on 100% of trials for the 500-200 msec pair and on over 75% of trials for the 500-350 msec pair), and vice

versa. However, when $s_1 < s_2$ (or $s_1 > s_2$) and $t_1 > t_2$ (or $t_1 < t_2$), within limits, s_1 was judged either equal to or greater than s_2 (or equal to or less than s_2). The temporal context therefore not only influenced spatial judgment when the two spatial distances were physically equal, but also had an overriding effect when they were not. A similar effect was found when the first and third stimulus points were identical, i.e., the longer temporal interval was associated with an impression of greater spatial separation even though the two distances were the same. In this case, the third stimulation was perceived to be different from the first. Finally, when the three points were arranged to form an equilateral triangle (with sides of 40 mm), a distorted figure was perceived when the time intervals were 300 msec and 200 msec although a symmetrical figure was recognizable when the temporal intervals were the same.

Helson (1930) designated this dependence of spatial judgment upon time the tau effect in order, as he put it, "to avoid the use of names which might suggest that we are dealing with an 'illusion', error in judgment, some effect of attention or suggestion" (Helson and King, 1913, p.202). Since this assertion runs counter to the position I wish to take here, I shall examine Helson's suggestion in some detail before reviewing the literature further.

Assuming that the tau effect did not arise merely as a result of explicit suggestions to the subject (though see below, p.14), it may nevertheless be useful to treat the effect as an illusion related to the subject's focus of attention. In the first place, as Helson and King themselves pointed out, if a subject does not comply with the

instruction to judge "quickly and naturally" but "attempts to isolate the spatial from the temporal aspect, his results may be more often 'objectively' correct but, less consistent than those of [the subjects] who follow the instructions and get the effect (p.215)." It follows that the tau effect occurs with the immediate percept of the spatio-temporal event and as such is probably related to the subject's focus of attention.

Secondly, Helson and King (1931) regarded the tau effect as not due to error in judgment, presumably because the subjects' judgments were highly consistent. They also objected to the concept of "illusion" for no other reason than "the objectivity of the phenomenon". However, it could be argued that all illusions are perceptual errors which are consistent and persist despite a person's knowledge of them. In Over's (1968) review, in which 'illusions' and 'perceptual errors' are used interchangeably, three classes of theories were examined: physiological theories, which emphasize input distortion in the neural information provided by the peripheral systems on spatially adjacent contours, information-sampling theories, which emphasize selectivity of attention to different parts of a figure, and finally judgmental theories which place importance on those experimental factors which lead to erroneous interpretation of input information. An important feature underlying all three theories is that they attempt to deal with influences of one part of the stimulus pattern on the other. In other words, illusions are, in theory, context-induced. Given inward and outward fins, two equal sections of a straight line in the Muller-Lyer illusion are perceived as unequal. In the

Poggendorff illusion, two sections of a straight line are seen to be displaced because of an interrupting rectangle. Therefore, if we regard the spatial stimuli of Helson and King (1931) as stimuli placed in a temporal context, there is no reason not to treat the tau effect as an illusion and an analysis of the context of the illusions could prove useful (see below).

The tactile tau effect was further investigated by Lechelt and Bochart (1977). They presented the standard (10cm) and the comparison interval, separated by a 1,500 msec delay, on the right and left forearms, with a fixed total duration (T) of 1,000 msec. Since they used four signals, the two spatial extents and temporal intervals did not share a common boundary. As t_2 (duration associated with the comparison interval, s_2) varied from 200 to 800 msec, s_2 was found to decrease from about 15 to 7 cm. Thus the tau effect was found using bilateral presentation. No laterality effect was apparent, i.e., the site of the standard and the comparison extents on either forearm had little effect.

Geldreich (1934) has also demonstrated the tau effect in the visual modality and more recently, Bill and Teft (1969) have attempted a more quantitative treatment of the effect. Using a 3-stimulus paradigm, the subject was required to adjust the spatial extent of a visual interval defined by two signals from 1 to 7 sec apart such that it appeared equal to a standard interval (35 cm and presented at 4 sec separation). As the time interval increased from 1 to 7 sec, the adjusted extent decreased from about 43 cm to 29 cm, showing a tau effect. Further, the first interval was shown to be

consistently underestimated relative to the second interval, indicating a negative time-order error (TOE, see below). Again, there was no laterality effect in that the left to right presentation did not differ from the right to left presentation. In a further experiment, Bill and Teft (1972) varied stimulus duration from 0.1 to 4 sec and found that the tau effect decreased as signal duration increased. They suggested that "as the visual information is increased [with greater signal duration, the subject] weigh this information more heavily than the correlated temporal cues in making perceptual responses."

Cohen and his colleagues (Cohen, Hansel and Sylvester, 1953, 1954, 1955; Cohen, Christensen and Ono, 1974; also, Christensen and Huang, 1979) have employed the 3-stimulus paradigm throughout. Cohen, Hansel and Sylvester (1954) examined whether or not the tau effect would occur with pitch which they regarded as non-spatial (Note 3). They presented three tones repeatedly to the subject over headphones. The first and the third tones were of fixed frequencies, either 1000 Hz and 3000 Hz or 2000 Hz and 4000 Hz. The two temporal intervals defined by the tones were adjusted by the experimenter while the subject adjusted the frequency of the middle tone so that it appeared to be intermediate in pitch between the first and the third tones. The total time interval was 1.47 sec while t_1 was set either equal to, twice that of, or half that of the t_2 duration. It was found that the pitch of the middle tone was adjusted to be closer to the tone which was further away temporally. For instance, when the first tone was set at 1000 Hz and the third at 3000 Hz, the middle tone was adjusted, on average, to be 1676 Hz

when $t_1 > t_2$, and 2068 Hz when $t_1 < t_2$. Comparable effects were found for the 2000 Hz - 4000 Hz pair of end tones. The adjusted values for the two orders of presentation exhibited a hysteresis effect which, Stevens (1957) has suggested, is a typical result in bisection or equisection experiments with metathetic continua. (Hysteresis refers to a "lagging-behind" of the bisection point in the descending order from that in the ascending order. That is, values adjusted in the ascending order were higher.)

I.2 Temporal judgments in spatial context

If spatial extension is dependent on time, an obvious question is to what extent are temporal judgments dependent upon the spatial context. It has long been known that the perception of brief temporal intervals is influenced by the context in which they are presented (see, e.g. Fraisse, 1963) and conceivably time perception may be influenced by a parallel spatial dimension.

Shortly after Helson and King's (1930) report, Abe (1935) carried out an investigation which established that temporal judgments may be dependent upon the spatial context. The set-up of Abe's (1935) experiment was similar to Helson and King's, except that he used three light flashes to define two spatial (s_1 and s_2) and two temporal (t_1 and t_2) intervals. The following pairs of values were used for s_1 and s_2 : 30 mm - 30 mm, 50 mm - 30 mm and 30 mm - 50 mm. Temporal intervals were also varied, sampling from a range between 250 msec and 2.5 sec. The subjects' task was to judge whether t_2 was equal to, greater or lesser than t_1 . In general, it

was found that "if spatial intervals and all factors except the temporal intervals are equalized, the temporal judgments tend to follow the actual temporal distances between successive stimuli, and that if temporal and all other factors are equalized, the temporal judgments tend to follow the spatial distances between the stimuli. A longer (or shorter) temporal interval can be made to appear shorter (or longer) by decreasing (or increasing) the spatial interval (p.61)." Abe (1935) designated this dependence of temporal judgment on space, the S-effect (see also Suto, 1955). Following Cohen, Hansel and Sylvester (1953), we now know the phenomenon as the kappa effect.

In the Cohen et al. (1953) experiment, a slightly different methodology from that of Abe (1935) was employed. Three lights were repeatedly presented and the subject had to adjust the temporal position of the middle light in relation to the first and the third lights such that the two temporal intervals appeared equal, the total duration, T, being fixed at 1.47 sec. The spatial separations of the lights were independently manipulated by the experimenters with the ratios ranging from 10:1 to 1:10 and the shorter distance fixed at 1 foot. An effect comparable to Abe's effect of spatial separation on temporal judgment was found. The effect reached its maximum when the first distance was three times as large as the second. In this condition, the second temporal interval was underestimated, on average, by 26%. On the other hand, when the second spatial distance was five times that of the first, the second temporal interval was adjusted to be 25% longer than that of the first.

Cohen et al. (1953) also observed negative TOEs. TOEs refer to the overestimation (negative) or underestimation (positive) of the second of a successive pair of stimuli (e.g., physical extents, durations) relative to the first (see Fechner 1860/1966). Helson and King (1931) and Abe (1935) failed to discuss this problem, perhaps because it was less obvious with the frequency responses they obtained. Cohen et al. (1953) used a correcting factor derived from the temporal discrepancy under the equal-distance condition. The adjustments for all distance pairs were multiplied by this factor, i.e., they considered the TOE to operate as a constant proportion of one of the interval pairs. This practice is, however, questionable for it assumes a particular and perhaps inappropriate model of TOE. For instance, if TOE is due in part to a response bias (see Allan, 1977), then an additive factor might have been more appropriate. Further it is known that TOEs are affected by various factors, such as stimulus range (Jamieson and Petrusic, 1975), feedback conditions (Jamieson and Petrusic, 1978), and also, the length of the duration itself (see Hellstrom, 1977; Woodrow, 1951). It is not certain therefore that any single correcting factor could appropriately eliminate the TOE effect. However, it is clear from Cohen et al.'s data that the kappa effect, a dependence of temporal judgment on space, operates over and above any TOE effects, since the independent spatial variable could have completely reversed whatever TOE effect there may have been.

Cohen et al. (1953) claimed that the kappa effect is present when T is between 0.6 and 6.4 sec with the effect diminishing as T increases. However, Price-Williams (1954) observed a kappa effect

with T as great as 11 sec. In his experiment, two lights were set horizontally in front of the subject. One was flashed after the other with an interval of 7, 8, 9, 10 or 11 sec between them. The subject was required to reproduce the temporal interval by a Morse key. It was found that the greater the physical separation of the lights, which ranged from 8 to 32 inches, the greater was the mean reproduction time (i.e., less underestimation). Further, if both flashes were present on the one light, the mean reproduced time was less than if the second flash was physically separated from the first. Thus, whether investigators make use of successive comparisons or a reproduction paradigm, temporal judgment is affected by the spatial variable. Of course, the two procedures are not exactly comparable and the range of duration over which the kappa effect is observed may be specific to a particular methodology.

Early studies sought to demonstrate optimally the occurrence of tau and kappa effects rather than define the boundary conditions. Only Cohen et al. (1953) suggested any temporal range in which the kappa effect should be found ($0.6 \text{ sec} \leq T \leq 6.4 \text{ sec}$) though in view of Price-Williams' (1954) the effect may be observed above this range. A recent study by Collyer (1977) does, however, provide some idea as to the lower limit of the total temporal (T) and spatial distance (S) ranges. In Collyer's study, T and S were fixed at 160 msec and 4 deg of visual angle respectively. The signal duration was 10 msec. During any one trial, one of the 9 combinations of spatial and temporal arrangements was used (randomly chosen such that one of $s_1 > s_2$, $s_1 = s_2$ and $s_1 < s_2$ and one of $t_1 > t_2$, $t_1 = t_2$ and $t_1 < t_2$

were selected). Under one condition, the subject was to judge which temporal interval was longer (kappa effect) and under another, which spatial interval was longer (tau effect). The kappa effect was observed in only one of the three subjects and no tau effect was observed in any of the three. If anything, Collyer observed the reverse of the tau and kappa effects, e.g., if $s_1 > s_2$, there was some tendency to judge t_1 to be longer than t_2 when $t_1 < t_2$ rather than when $t_1 > t_2$.

Collyer's (1977) paper appears to contain the only report of a failure to observe the tau and kappa effects. One possible reason lies in the methodological differences between his and other studies. In other studies, only one variable (spatial or temporal) was changed in a block of trials; in Collyer's (1977) experiment, both spatial and temporal variables are changed from trial to trial. As I shall argue below, this procedure might deprive the subject of spatial or temporal cues essential for the effects to occur. An additional factor may be the T and S values that Collyer (1977) chose to employ which were considerably smaller than those used in other experiments (T of 160 msec and signal duration of 10 msec.) As Collyer (1977) noted, a different set of perceptual mechanisms might operate for these brief temporal durations. Studies on double-pulse discrimination (see e.g. Boynton, 1972) have shown that a briefly presented single pulse, of say 20 msec in duration (Dunlap, 1915), is likely to be confused with a double-pulse, and vice versa (Cheatham and White, 1952). Collyer's (1977) subjects may perhaps have failed to discriminate the brief flashes from each other. At all events, it seems clear that, when T is reduced, a

variety of factors may affect the subject's performance and obscure interdependencies between temporal and spatial judgment. Consequently, the effect of total display duration on both tau and kappa effects need to be investigated systematically.

I.3 Dependency of judged spatial distance and temporal duration upon velocity of motion

We have seen that apart from Collyer's (1977) study in which a negative result was reported, tau and kappa effects occur over a wide range of spatial extents and durations though studies have rarely employed durations beyond a few seconds. One might wonder if temporal judgments may not be subject to a similar spatial influence for longer durations. Studies along this line have in fact been carried out but in quite a different way.

Cohen and Cooper (1962) experimented on the tau and kappa effects when the subject was in motion. Instead of observing and making judgments on two short distances, blindfolded subjects were moved in a vehicle through a distance of about 12 miles. The journey lasted from 12 to 30 minutes with speeds between 15 and 60 miles per hour. At some point during the journey, a bell rang to demarcate the two portions of the distance travelled. When $t_1 = t_2$ but the distances (s_1 and s_2) as well as the velocities (v_1 and v_2) of the two portions of the journey were varied, then the part of the journey which was travelled at a greater speed for a longer distance seemed to the subjects to be longer in duration. If, however, the two portions of the journey were equal in distance ($s_1 = s_2$) but were travelled at different speeds (and hence for different durations),

then the portion which was travelled at a slower speed for a longer period. seemed to be longer in distance. The former phenomenon has been called the kappa-movement effect and the latter the tau-movement effect.

A related phenomenon in the judgments of velocities was also reported by Cohen and Cooper (1962). If two parts of a journey were travelled at the same speed but for different durations and distances, then the part which was travelled for a shorter time and distance was judged by subjects to have had the greater velocity. This is the so-called kappa-tau effect.

Having established that temporal and distance judgments are interdependent, Cohen and his colleagues (Cohen, Cooper and Ono, 1963; Cohen, Ono and Skelly, 1966) went on to investigate if similar phenomena are present when the subject's motion was voluntary. In a study by Cohen, Ono and Skelly (1966), experienced motorists were directed by the experimenter to drive a distance of about 6 miles during which a bell rang dividing the journey into two portions. An experimental group was required to drive at different speed over the two portions of the journey and was contrasted with a control group who drove at a constant speed. For the experimental group, a kappa-movement effect was found in that at the end of the journey, greater speed was associated with the judgment that the journey was longer in duration. The result also demonstrated a tau-movement effect but only ambiguously a kappa-tau effect. Judgments of velocity were probably less biased by distance and duration since the subjects who were police officers and advanced motorists may have been able to judge velocity accurately.

In another experiment Cohen, Cooper and Ono (1963) had the subjects run half a distance and walk the other half. They found that the walked distance generally seemed longer than the distance run (tau-movement). However, some subjects judged the distance that they had run to be longer than the distance they had walked. Cohen et al. (1963) suggested that the former group (pro-tau) was more sensitive to temporal differences and hence showed the effect, while the anti-tau group was less sensitive to the passage of time and may have focused their attention on the speed thus attributing greater distance to the part of the distance travelled at a greater speed. One might argue, however, that the subjects' responses had very little to do with sensitivity to temporal differences. Given the demand characteristics of the experimental situation (Orne, 1959), subjects might simply have tried to guess the experimenter's hypothesis and given responses based upon their perception of experimenter's perceived wishes rather than their perception of velocity, time or distance.

The three movement effects were also studied by Ono in line-drawing tasks in children (1968a, 1968b) and in adults (1969). The subject was asked to draw two lines successively at different speeds, such that the lines were drawn for either the same duration or for the same distance. Both kappa-movement and tau-movement effects were found. When the durations for the two lines were equal, the duration associated with the longer line drawn at a greater speed seemed longer (kappa-movement). Similarly, when the distances were equal, the distance associated with greater duration, lines drawn at a slower speed, seemed longer (tau-movement).

In a further experiment (Ono and Maruyama, 1971), the subject observed a moving target which stopped for one second before continuing along the same path at a different speed. The subject had to stop the target after it had moved for either the same duration or the same distance as in the first section. Both movement effects were evident. In a different situation (Ono, 1974; Ono and Maruyama, 1971), the subject was required to imagine the second section of the movement. The kappa-tau effect was, in general, observed. The derived speed was greater when the display duration and distance were longer even though the imagined section was to have travelled at the same speed as the real movement section (see review, Ono, 1976).

In short, both tau and kappa effects may be present not only for judgments of short spatial distances and temporal intervals, but also for relatively long ones in a variety of experimental contexts.

1.4 The Constant Velocity Hypothesis (CVH) and related notions

Most discussions of the tau and kappa effects emphasize that they are subject to the influence of phenomenal extent rather than physical extent. For example, Suto (1941) and Lebensfelt and Wapner (1968) both used Muller-Lyer figures which gave the impressions of longer or shorter visual distances depending on whether equal physical distances are bounded by outward fins ($>$ $<$) or inward fins ($<$ $>$). Subjects' judgments were determined by the apparent extent of the stimulus. Under suitable conditions, for example, when s_1 was bounded by outward fins and s_2 inward fins, t_1 (or s_1) seemed longer than t_2 (or s_2) even though t_1 and t_2 and s_1 and s_2 were

physically equal (Lebensfelt and Wapner, 1968). Essentially the same findings have also been made using tactual cues (Suto, 1941).

Newman and Lee (1972) found that the extent to which an individual would exhibit the kappa effect in time judgment correlated with his susceptibility to the influence of background texture surface on distance perception. They used two horizontal surfaces which were painted crosswise to the subject's line of sight with alternating black and white stripes. One had an even texture surface while the other was distorted with increasing density of textual elements towards the end, creating an illusory distance. The subject first made bisection adjustments by moving the middle marker to appear at the midpoint between the first and the third marker. This gave a score indicating the effect of texture surface on the perception of distance in a subject. Then three lights replaced the markers and a kappa experiment was carried out in which the subject had to estimate the duration (9 or 10 sec) between "near" and "centre", and "centre" and "far" lights. The ratio of the durations was defined as the subject's kappa score. A rank-order correlation was obtained between the kappa scores and the distance bisection scores for both texture surfaces and time conditions was above 0.54. Subjects who were more likely to be affected by the background texture surface in distance perception exhibited greater kappa effects, demonstrating that the kappa effect may be based upon apparent rather than actual distance.

Newman and Lee's results suggest that a contextual analysis of the phenomena might bear fruit. In what follows, we shall first

2

examine a cognitive theory and a formal statement of that theory which seeks to explain the tau and kappa effects in terms of the stimulus context and in terms of the subject's expectancy.

Price-Williams (1954) first suggested that in the kappa phenomenon, an "imputed motion" may be experienced by the subject. In everyday experience, we may see a moving object disappear behind some other object and then reemerge at a different location. In the laboratory experiments that we have described, the object may be represented by three points (e.g. light flashes) successively seen at different locations. If subjects assume that the sequence represents constant velocity motion across the visual field, then it would seem reasonable for them to ascribe greater duration to two points which are further apart spatially. Similarly, a greater spatial separation would be supposed between two points that are temporally further apart. Consequently when a subject is asked to adjust the middle stimulus in a 3-stimulus paradigm such that the two spatial (or temporal) distances appear equal, the middle stimulus would be adjusted spatially (or temporally) closer to that stimulus which is temporally (or spatially) further from it. This account has come to be known as the "constant velocity" hypothesis (Collyer, 1977).

We should note that the constant velocity hypothesis applies only when movement is imputed or imagined by the subject. In fact, in one of Mashhour's (1964) experiments where the relationship between subjective distance and the speed with which a dot is moved through a given distance was studied, quite a different result was

obtained. Mashhour (1964) found that subjective distance varied directly with speed (or inversely with time), i.e., a shorter distance was perceived to have been traversed by the dot when the time taken was longer. Mashhour (1964) labelled this the v-effect and noted that it is the reverse of tau effect. His finding is in general agreement with that of Johansson (1962). In both Mashhour's (1964) and Johansson's (1962) experiments, the traverse motion of an object was witnessed by the subject. When motion is imagined by the subject, however, the typical kappa-tau effect appears to occur. Ono (1974), for example, presented subjects with two targets which moved over a fixed distance in the same time (hence $v_1=v_2$). However, he then asked the subject to imagine one target to continue moving over a longer distance than the other, and for a longer interval of time, at the same speed. He found that derived speed (from the subject's duration estimation) for the second target to be greater than the derived speed for the first target.

Anderson (1974) argued that the "imputed movement" effect is an illusion of the positive context. Judgments are based upon both the actual time interval and some expectancy of the time that should be required to traverse the distance at a constant velocity. Anderson also proposed an algebraic integration model in which the subject's judgment is a weighted average of time and expectancy, i.e.,

$$R_{ij} = (w_i)(t_i) + (w_j)(s_j) \quad (w_i + w_j = 1),$$

where R_{ij} is the subject's response to pairings of t_i , temporal duration and s_j , spatial distance. Thomas and Weaver (1975) have similarly argued that temporal judgments are a weighted average of two information processors one of which functions as a conventional

onset-offset timer (see Allan and Kristofferson, 1974; Sternberg and Knoll, 1973) and the other of which derives temporal information indirectly from a stimulus analyser.

Collyer (1977) has suggested a model for spatio-temporal interactions which is, in essentials, very similar to Anderson's. Collyer argues that a subject bases his decision statistically on an internal code Y , where,

$$Y = (W_s)(S^*) + (W_t)(T^*).$$

S^* is a random variable whose expected value is a function of the relative magnitude of s_1 and s_2 , T^* is a random variable, independent of S^* , whose expected value is a function of the relative magnitudes of t_1 and t_2 , and W_s and W_t are their respective weights. This is, of course, a very flexible model. For example, given a positive W_t we could "explain" a tau effect and given a positive W_s a kappa effect. If the reverse of tau effect were observed (c.f. Collyer, 1977), W_t would have a negative sign. Similarly, negative W_s would produce a reverse kappa effect, i.e., a longer spatial interval associated with a shorter apparent duration. Yet despite the apparent ease with which data can be accommodated to the model, a crucial prediction is easy to test. The model implies parallelism or no interaction in a Time x Distance factorial design (see Anderson, 1974; Price-Williams', 1954, study does provide some evidence for parallelism).

In Anderson's model, weights and scale values for temporal (t_i) and spatial (s_j) judgments are treated as functionally independent. However, it has been noted by Schonemann, Cafferty and Rotton, 1973;

see also, Norman, 1976) as a general restriction on Anderson's functional measurement procedure (Anderson, 1974) that when it cannot be assumed that scale values for judgments are equal across factors, in this case spatial distance and temporal duration, it is impossible in principle to unconfound weights and scale values. Nevertheless, it is still possible to test whether or not the integration model can be reasonably said to be linear, or whether or not parameter estimation is possible, since averaging or adding models of the Anderson or Collyer type imply that data from a factorial manipulation of time and distance should plot as a set of parallel curves.

I am suggesting, in other words, that subjects will tend to make judgments about ambiguous perceptual patterns based upon a reasonable assimilation of the ambiguous situation to everyday experience. Specifically, the tau and kappa effects may be explained by reference to our ordinary experience of moving objects and to the expectancies with which this experience should provide us. In the experiments I have reviewed, subjects are required to make a judgment about a primary dimension (spatial or temporal). If the primary judgment is difficult, the background dimension may become salient since the subject can make reasonable assumptions about spatio-temporal dependencies.

The purpose of the present thesis is two-fold. Firstly, an attempt will be made to replicate and extend Collyer's (1977) findings in order to establish lower temporal and spatial bounds for the tau and kappa effects (Experiments 1 and 2). Secondly, two

experiments will be carried out specifically to test the constant velocity hypothesis and the general notion that the subject's expectancies determine in part the tau and kappa effects (Experiments 3 and 4).

In the first two experiments, the classical 3-stimulus paradigm will be employed but the subject will be required to make relative judgments (whether the second presented interval is shorter). In the spatial judgment condition, the mean proportion of "second shorter" (length) responses will be plotted against the temporal variable and in the temporal judgment condition, the mean proportion of "second shorter" (duration) responses will be plotted against the spatial variable. Positive slopes of the plots would indicate the tau or kappa effects and parallelism in the plots would suggest a linear integration model (see above). The present design with the use of proportion plots allows separate examination of what might be called the extent and the magnitude of the effects. The magnitude of the effects is indicated by the slope of the proportion plots: a greater tau/ kappa effect is indicated by a steeper slope. The extent of effects, on the other hand, refers to the range of the s_1/s_2 (or t_1/t_2) ratios for which positive slopes would be observed, for a given T and S pair. Separate examination of the magnitude and the extent of effects is not possible with the adjustment method.

A different response measure will be employed for each of Experiments 3 and 4 and these were discussed in the respective sections.

II. EXPERIMENT 1

As I have noted, Collyer (1977) essentially failed to observe tau or kappa effects when the display was very briefly presented. Collyer (1977) employed the traditional paradigm of a 3-stimulus sequence which defines two spatial (s1 and s2) and two temporal (t1 and t2) intervals. The total separation (S) subtended 4 deg of visual angle and the interval durations always summed to 160 msec (T). On each trial, one of 3 s1 values was paired at random with one of 3 t1 values and the subject had to judge either the spatial or the temporal relation of the intervals (which was longer or shorter).

In the present experiment, an attempt was made to replicate Collyer's (1977) study using a slightly modified paradigm. Five s1 and five t1 values were used instead of three, covering the ranges of values used in Collyer's two experiments. An experimental manipulation, not included in Collyer's design, involved the direction of the stimulus display. With short display durations, eye movements or eye movement tendencies may play a large part in perceptual accuracy (Crovitz and Daves, 1962) and it is possible that different display directions, left to right as opposed to right to left, might induce different spatial (and temporal) judgments since reading habits, for example, may predispose subjects to scan from left to right.

Method

Subjects

Three naive subjects (one male and two females), aged 19 to 30, served in both spatial and temporal conditions and were paid at an hourly rate.

Apparatus

A Data General Nova 1220 computer controlled the timing and generation of signals, which were presented by light-emitting diodes (Texas Instruments TIL209) mounted behind a clear plastic board. A video monitor, positioned behind the signal display, relayed all other instructions. The viewing distance was about 1 m and the display subtended 4 deg of visual angle.

Design and Procedure

On each trial, the subject observed a sequence of three lights, the first and the third of which were fixed at 4 deg of visual angle ($S=s_1+s_2=4$ deg). The five values of s_1 were: 0.67, 1.33, 2.00, 2.67 and 3.33 deg. The total duration was fixed at 160 msec ($T=t_1+t_2=160$ msec). The five values of t_1 were: 20, 56, 80, 104 and 140 msec. The duration of each signal was 10 msec. On each trial, s_1 and t_1 were sampled (without replacement) at random. During each block of 250 trials, there were 10 replications for each of the 25 s_1 - t_1 combinations. There were also 15 practice trials at the beginning of each block which were excluded from analysis. Each subject participated in 20 blocks of trials, with 5 blocks for each display direction (left to right and right to left), under spatial and temporal conditions. Each subject therefore participated in a total of 5,000 trials.

Each trial ran as follows: the word "READY" first appeared on the video screen behind the stimulus display indicating to the subject that he should press any button to initiate the stimulus display. When the subject had pressed a button, the stimulus sequence was presented following a 500 msec delay. The subject responded by pressing one of two response buttons to indicate whether the first or second spatial (or temporal) interval appeared the shorter. A third button was available to the subject to indicate the impossibility of response owing to unclear displays. This response button was rarely used and the trials with such a response were excluded from analysis.

Daily sessions consisted of two to four blocks of trials with rest periods in between. Temporal and spatial conditions were run on alternate days.

Results

Detailed data are contained in Appendix 1. Figures 1.1 and 1.2 plot the mean proportion of responses in which the subject indicated that the second (spatial or temporal) interval was shorter for each s_1-t_1 combination, for the spatial judgment condition (τ) and the temporal judgment condition (κ) respectively. The plots combined both display directions since ANOVA showed no significant effect for the "display direction" factor ($F(1,2)=3.36$ for the spatial condition and $F(1,2)=2.03$ for the temporal condition). This finding is consistent with that of Bill and Teft (1969) who similarly did not find any laterality effect.

Fig. 1.1 Mean proportion of "second shorter" responses for each distance pair as a function of t_1 .

Fig. 1.2 Mean proportion of "second shorter" responses for each duration pair as a function of sl.

For the spatial condition, only two effects achieved statistical significance: the "Space" factor, $F(4,8)=22.96$, $p<0.001$, and the "Space" x "Time" interaction, $F(16,32)=6.92$, $p<0.001$. Figure 1.1 shows good separation between the 5 curves ("Space" factor) indicating that the subjects discriminated well on the judged variable, although there is an indication that the first interval tended to be judged the longer. Take, for instance, the plot for $s_1=s_2$. The mean proportion exceeded 0.5 only when $t_1=20$ msec. This suggests the operation of a negative TOE.

Figure 1.1 also shows that the slopes of the curves change as s_1 increases. Positive slopes indicate that the tau (or kappa) effect is present. Only the lower two curves where $s_1 < s_2$ show any increasing trend. When $s_1 > s_2$ (the upper two curves), there is no indication of temporal influence on the spatial judgment. When $s_1 = s_2$, the curve is clearly decreasing, indicating a reverse tau effect. The results for individual subjects are plotted in Figure 1.3, showing similar trends. However, the overlap in the curves when $s_1 < s_2$, $s_1 > s_2$ for subject 2 and $s_1 > s_2$ for subject 3 shows that the subjects' discrimination of distances in these cases was inaccurate.

For individual subjects, as for the group as a whole, the slopes of the curves tend to be positive when $s_1 < s_2$. Since subjects showed a tendency to judge s_1 shorter than s_2 , it is possible that the TOE might have obscured any temporal effect.

Fig. 1.3 Mean proportion of "second shorter" responses for each distance pair as a function of t_1

Fig. 1.4 Mean proportion of "second shorter" responses for each duration pair as function of s_1

It seems clear, therefore, that when the total time of a display is brief it is difficult to find consistent evidence for the tau effect and we have thus replicated Collyer's (1977) result. It is also obvious that with $T=160$ msec, we observe considerable within- and between-subject variability.

For temporal judgments, Figure 1.2 demonstrates quite surprising results. Although the subjects seem to be able to distinguish between various t_1 values, their mean judgments are an inverse function of t_1 : the longest t_1 was judged to be the shortest, and the shortest t_1 the longest. We shall discuss this point later. In general, all 5 curves are positive in slope showing a kappa effect. However, ANOVA showed that none of the main effects were statistically significant and only the "Space" x "Time" interaction was significant, $F(16,32)=2.33$, $p<0.03$.

Again there is the problem of high between-subject variability. Figure 1.4 is a plot of mean proportions against s_1 at each t_1 for each subject. For subjects 1 and 3, there seems to be little discrimination of the various t_1 values. Rather, the subjects' judgments appear to have been based almost entirely on the spatial attribute of the stimulus sequence. When $s_1 > s_2$, for example, t_1 was judged greater than t_2 (kappa effect), regardless of the actual relationship between t_1 and t_2 . For subject 3, however, mean proportions are typically below 0.50, suggesting a strong negative TOE for the durations and/or the distances.

The curves for subject 2 show both increasing and decreasing trends, for different t_1 . However, for this subject, judgments tended to be in the opposite direction to the actual values and this effect was reflected in the group data (Figure 1.2). Judgmental errors of this kind are rare. One possible reason is that although the subject could discriminate among different duration pairs (t_1-t_2), because the total duration was brief, he was not in a position to impose the correct order upon the 5 pairs.

Discussion

Clearly we find overall, as did Collyer (1977), no evidence for a tau effect with brief perceptual displays. However, for any particular subject, both the tau and the reverse of tau may be observed, depending on the value of s_1 . If anything, the reverse of tau seems to be more prominent when the two distances are equal. That is, when $s_1=s_2$, the longer the first duration, the greater the tendency to judge the first distance as shorter.

Collyer (1977) has suggested that his failure to observe a consistent tau effect may be due to either differences in methodology or alternately that the brief duration of stimulus patterns brings different perceptual mechanisms into play.

A third possibility also suggests itself. The failure to observe a consistent tau effect in the present experiment may be due to a change in the subjects' judgmental strategy for brief displays. The subject came to the laboratory with certain expectations about moving objects. According to the constant velocity hypothesis, when

$s_1=s_2$, the subject makes the implicit assumption of equal velocities across the two distances and hence judges s_1 to be greater, less than or equal to s_2 according to whether t_1 is greater, less than or equal to t_2 (tau effect). On the other hand, when t_1 is very much longer or shorter than t_2 , or when apparent movement is observed in one section of the display and not in the other, then inequality in the derived velocities might have determined the subject's spatial judgment. For example, when $s_1=s_2$ but t_1 is very much larger than t_2 , the subject might have reasonably ascribed a greater distance to the interval associated with greater velocity (and shorter duration). That is, greater distance is associated with shorter duration: a reverse tau effect. Such a strategy can also be applied in temporal judgments when the two judged intervals clearly do not have the same velocities and when $t_1=t_2$, for instance, shorter time is ascribed to the interval with the greater velocity and longer distance, resulting in a reverse kappa effect. There are indications of this strategy in the present experiment and in Collyer's (1977) study. When the derived velocities for the two intervals do not differ markedly, this strategy is not expected to apply.

Since the same subjects were required to make both spatial and temporal judgments, an interesting question arises as to whether the subject made the same judgments regardless of the specific requirements of the task. Figure 1.4 (temporal judgment) has been replotted as Figure 1.5 so that mean proportion is shown as a function of t_1 (rather than s_1) for each distance pair. If we compare Figures 1.3 and 1.5 for subject 1, it is clear that response

Fig. 1.5 Mean proportion of "second shorter" responses for each duration pair as a function of t1, at each distance pair.

patterns for both spatial and temporal judgments are very similar. It seems reasonable to argue, therefore, that this subject made judgments about a pair of intervals in the same way whether the task was spatial or temporal. Since this subject discriminated well in the spatial condition and poorly in the temporal condition, both types of judgments may well have been based upon spatial information. Response patterns in Figures 1.3 and 1.5 for subjects 2 and 3, however, are very different, suggesting independent extraction of spatial and temporal information in the two tasks.

III. EXPERIMENT 2

I have suggested that failure to observe any consistent tau and kappa effects may be due to the subject's strategy faced with a very brief visual display. In the present experiment, I intended to investigate the effect of systematically varying the total display duration (T) and maintaining fixed S on the occurrence of tau and kappa effects. A largely unexplored factor is the effect of stimulus discriminability. As T is increased from 160 msec, there are corresponding changes in the discriminability of spatial and temporal intervals. Spatial tasks may be easier at shorter T and temporal tasks may be more difficult. It is hypothesized that, the tau and kappa effects are more marked when the judgmental tasks are difficult and the subject has to employ secondary cues. Consequently, it is predicted that as T increases and spatial judgments become more difficult, a greater tau effect would be observed. On the other hand, since temporal judgments are most difficult at shorter T's, the kappa effect would be more marked in the lower change.

Apparently no previous experiments have systematically varied T in the lower range of values though as I have noted, Cohen et al. (1954) did investigate the range between 0.6 and 6.4 sec for the kappa effect. In the present experiment, we examined both tau and kappa effects when T was varied from 0.16 to 1.5 sec.

Method

Subjects

One male and two female naive subjects, aged 18 • 25, served in the spatial judgment condition. Two male and one female subjects, aged 19 - 22, served in the temporal judgment condition. All subjects were naive as to the experimental hypotheses. All were paid at an hourly rate.

Apparatus

The apparatus was that used in Experiment 1.

Design and Procedure

The basic design and procedure were as in Experiment 1. All displays were from left to right. There were 8 total durations (T): 160, 320, 480, 640, 800, 1,000, 1,200 and 1,500 msec. This was our main manipulation ("T" factor). For each duration, a set of 5 t_l values was selected such that $t_l/T = 0.3, 0.4, 0.5, 0.6$ or 0.7 ("Time" factor). For all T conditions, S was fixed at 8 deg of visual angle and a set of 5 s_l values was selected such that $s_l/S = 0.3, 0.4, 0.5, 0.6$ or 0.7 ("Space" factor). Each block of trials, with T fixed, consisted of 10 replications of the 25 s_l - t_l combinations. There were 15 practice trials at the beginning of each block which were excluded from analysis. 5 such blocks of trials were presented for each of the eight T conditions. The 40 blocks of trials were randomized in groups of 8, with each group having a block from each of the T conditions. Three subjects made spatial judgments and three subjects made temporal judgments on successive weekdays for 2 to 4 blocks per day. Each subject participated in a total of 10,000 trials.

Results

Detailed data are contained in Appendix 2. Figures 2.1 and 2.2 plot mean proportion of "second shorter" responses for the spatial and temporal judgments, respectively, collapsed across all T conditions. Figures 2.3 and 2.4 plot mean proportions for each T condition. For spatial judgments, ANOVA showed significant "Space", $F(4,8)=356.25$, $p<0.001$ and "Time", $F(4,8)=4.03$, $p<0.05$, main effects and a significant "Space" x "Time" interaction, $F(28,56)=5.69$, $p<0.001$. Figure 2.1 demonstrates that for all T conditions combined, there was a tau effect, for $s1>s2$. When $s1<s2$, however, there was little or no evidence of a tau effect. The detailed plots for each T also make the same point (Fig. 2.3). The differences between $s1>s2$ and $s1<s2$ conditions seems to be responsible for the significant "Space" x "Time" interaction.

The only other significant effect was the "T" x "Space" interaction, $F(28,56)=3.51$, $p<0.001$. Table 2.1 gives the mean proportions for each $s1$ at each T, collapsed across $t1$, i.e., Table 2.1 reflects the change in the influence of $t1$ as T changes. In general, as T increases from 160 msec to 1,500 msec, mean proportions increase for $s1<s2$ but decrease for $s1>s2$. These relationships effectively narrow the range of the dependent measure between the extreme cases, $s1<s2$ and $s1>s2$. The narrow range of values for the dependent measure at larger T suggests greater influence of the temporal factor when T is large. At $T=160$ msec, the subject's spatial judgments were least affected by corresponding changes in temporal relationships. The same narrowing of range of proportions can also be observed in Figure 2.3 where plots for

Fig. 2.1 Mean proportion of "second shorter" responses for distance pair as a function of t_1/T , collapsed across all T conditions.

Fig. 2.2 Mean proportion of "second shorter" responses for duration pair as a function of s_1/S , collapsed across all T conditions.

Fig. 2.3(a) Mean proportion of "second shorter" responses for distance pair as a function of t_1/T , at each T .

Fig. 2.3(b) Mean proportion of "second shorter" responses for distance pair as a function of t_1/T , at each T .

s_1/T	Line Style
0.3	Long Dash
0.4	Short Dash
0.5	Dotted
0.6	Solid
0.7	Long Dash

Fig. 2.4(a) Mean proportion of "second shorter" responses for duration pair as a function of s_1/S , at each T .

Fig. 2.4(b) Mean proportion of "second shorter" responses for duration pair as a function of sl/S , at each T .

	MEAN 1		s1/S					ROW μ
	STD	DEV	0.3	0.4	0.5	0.6	0.7	
T	I	I	I	I	I	I	I	
160 MSEC	I	.04 I	.13 I	.55 I	.86 I	.95 I		.51
	I	.04 I	.10 I	.13 I	.06 I	.06 I		.38
320 MSEC	I	.14 I	.31 I	.61 I	.84 I	.92 I		.56
	I	.11 I	.15 I	.13 I	.05 I	.04 I		.32
480 MSEC	I	.14 I	.32 I	.63 I	.81 I	.89 I		.56
	I	.07 I	.08 I	.09 I	.10 I	.09 I		.30
640 MSEC	I	.16 I	.39 I	.62 I	.76 I	.89 I		.57
	I	.07 I	.09 I	.14 I	.14 I	.12 I		.29
800 MSEC	I	.15 I	.31 I	.61 I	.80 I	.90 I		.55
	I	.08 I	.11 I	.10 I	.12 I	.10 I		.31
1 SEC	I	.12 I	.33 I	.60 I	.80 I	.85 I		.54
	I	.07 I	.08 I	.14 I	.11 I	.13 I		.30
1.2 SEC	I	.09 I	.30 I	.53 I	.70 I	.78 I		.48
	I	.04 I	.12 I	.13 I	.15 I	.12 I		.28
1.5 SEC	I	.19 I	.39 I	.56 I	.70 I	.79 I		.53
	I	.08 I	.14 I	.20 I	.16 I	.17 I		.26
COLUMN			.13	.31	.59	.78	.87	.54
			120	120	120	120	120	600
			.08	.13	.14	.13	.12	.31

Table 2.1 Mean proportion (and S.D.) of "second shorter" responses for the spatial judgment condition at each s1/S and T, summarized across all t1/T conditions.

		t1/T					ROW μ
		0.3	0.4	0.5	0.6	0.7	
T	MEAN I	I	I	I	I	I	
	STD DEV I	I	I	I	I	I	
160 MSEC	I	.47 I	.50 I	.51 I	.53 I	.54 I	.51
	I	.34 I	.35 I	.30 I	.29 I	.26 I	.30
320 MSEC	I	.48 I	.52 I	.60 I	.66 I	.71 I	.60
	I	.28 I	.24 I	.24 I	.25 I	.23 I	.26
480 MSEC	I	.25 I	.43 I	.67 I	.83 I	.89 I	.61
	I	.17 I	.19 I	.19 I	.16 I	.12 I	.30
640 MSEC	I	.14 I	.31 I	.69 I	.87 I	.94 I	.59
	I	.13 I	.16 I	.19 I	.09 I	.06 I	.34
800 MSEC	I	.07 I	.29 I	.69 I	.92 I	.96 I	.59
	I	.08 I	.13 I	.21 I	.07 I	.05 I	.37
1 SEC	I	.03 I	.31 I	.74 I	.91 I	.96 I	.59
	I	.03 I	.14 I	.16 I	.09 I	.05 I	.38
1.2 SEC	I	.02 I	.31 I	.79 I	.95 I	.98 I	.61
	I	.02 I	.12 I	.14 I	.05 I	.02 I	.39
1.5 SEC	I	.02 I	.34 I	.76 I	.93 I	.98 I	.60
	I	.02 I	.20 I	.14 I	.07 I	.03 I	.39
COLUMN	μ	.19	.37	.68	.83	.87	.59
	n	120	120	120	120	120	600
	σ	.25	.22	.21	.21	.20	.34

Table 2.2 Mean proportion (and S.D.) of "second shorter" responses for the temporal judgment condition at each t1/T and T, summarized across all s1/S conditions.

		s1/S					ROW μ
		0.3	0.4	0.5	0.6	0.7	
T	MEAN I	I	I	I	I	I	
	STD DEV I	I	I	I	I	I	
160 MSEC	I	.17 I	.27 I	.55 I	.75 I	.80 I	.51
	I	.06 I	.10 I	.20 I	.22 I	.19 I	.30
320 MSEC	I	.32 I	.47 I	.62 I	.77 I	.81 I	.60
	I	.21 I	.20 I	.16 I	.14 I	.17 I	.26
480 MSEC	I	.44 I	.54 I	.62 I	.70 I	.77 I	.61
	I	.31 I	.30 I	.30 I	.25 I	.22 I	.30
640 MSEC	I	.47 I	.54 I	.59 I	.65 I	.71 I	.59
	I	.36 I	.35 I	.36 I	.33 I	.30 I	.34
800 MSEC	I	.49 I	.55 I	.59 I	.62 I	.68 I	.59
	I	.39 I	.40 I	.38 I	.37 I	.34 I	.37
1 SEC	I	.53 I	.57 I	.57 I	.62 I	.66 I	.59
	I	.39 I	.39 I	.39 I	.39 I	.38 I	.38
1.2 SEC	I	.55 I	.58 I	.60 I	.64 I	.66 I	.61
	I	.40 I	.41 I	.41 I	.40 I	.40 I	.39
1.5 SEC	I	.54 I	.57 I	.59 I	.62 I	.68 I	.60
	I	.41 I	.40 I	.41 I	.39 I	.38 I	.39
COLUMN	μ	.44	.51	.59	.67	.72	.59
	n	120	120	120	120	120	600
	σ	.35	.34	.33	.32	.31	.34

Table 2.3 Mean proportion (and S.D.) of "second shorter" responses for the temporal judgment condition at each s1/S and T, summarized across all t1/T conditions.

smaller T values have shallower slopes. The tau effect increases when T is equal to or greater than 640 msec.

The temporal condition seems to reveal more interesting patterns. All main effects and interactions were significant, apart from the " T " factor, "Time", $F(4,8)=58.78$, $p<0.001$; "Space", $F(4,8)=16.53$, $p<0.001$; "Space" x "Time", $F(112,224)=1.52$, $p<0.001$; " T " x "Space", $F(28,56)=13.73$, $p<0.001$; " T " x "Time", $F(28,56)=16.21$, $p<0.001$, and " T " x "Space" x "Time", $F(112,224)=1.52$, $p<0.005$. Figure 2.2 shows clearly both the "Time" and "Space" main effects, the latter indicating a kappa effect. The plots are roughly parallel and the significant "Space" x "Time" interaction appears due to the greater slope for $t_1/T=0.4$ as compared to other slopes.

Figure 2.4 show the change in the spatial influence on temporal judgments as T was increased from 160 msec to 1,500 msec (as reflected also in all three interactions). When T was small (160 and 320 msec), there was little separation among the t_1 plots and the predominant kappa effects (steep slopes) seem to be the result of the subjects' basing their temporal judgments almost entirely upon spatial relationships. At $T=480$ msec, 640 msec and 800 msec, the subjects were able to make temporal judgments (reflected in clear separation between the curves) though judgments were influenced by the spatial characteristics of the display for all t_1/T ratios.

When T was greater than or equal to 1,000 msec, the kappa effect was present only for the more difficult judgments ($t_1/T = 0.4, 0.5$ or 0.6). Where there was no ambiguity about the temporal relationship of the two intervals ($t_1/T = 0.3$ or 0.7), there was little or no spatial effect. Table 2.2 and Table 2.3 also illustrate the same points. The mean proportions were summarized for each T at levels of t_1/T (Table 2.2) and at levels of s_1/S (Table 2.3). The range of values between extreme t_1/T ratios increases with T while the range of values between extreme s_1/S ratios decreases with T . These two observations taken together suggest decreasing spatial influence with increasing T since mean proportions for t_1/T ratios are more widely separated and mean proportions for s_1/S ratios are more closely clustered.

Discussion

Collyer (1977) suggested that procedural differences between his forced-choice procedure and the adjustment methods typically used to demonstrate tau and kappa effects might have accounted for his negative results. The present demonstration of both effects in a forced-choice paradigm suggests that such procedural differences may be largely irrelevant. Rather, the total display duration appears to be the salient factor. Within the range of T employed in the present experiment (160 - 1,500 msec), the tau effect seems to increase with increasing T while the kappa effect seems to decrease.

Use of the relative judgment method and response proportion plots also permits us to examine the subject's ability to discriminate spatial and temporal magnitudes. At $T=160$ msec,

temporal discrimination of the interval pairs was poor. It could therefore be argued that the subjects did not in fact make genuine temporal judgments, and responses were entirely based upon spatial cues. Temporal judgments do seem to be particularly difficult for short durations. For example, even successiveness information may not be available for very short onset-offset intervals between two spatially close but distinct lights (see Allan, 1979; Allan and Kristofferson, 1974; and Sections VI.4 and VI.6). At the same time, however, spatial judgments seem to be easier with short durations (T). In order to code distance, the subject must remember the location of the initial light and it is reasonable to expect that location memory becomes more diffuse over time (c.f. Allan, 1968; Kinchla and Smyzer, 1967). Given easy spatial discriminations, it is unlikely that we should observe much temporal (tau) effect on the spatial judgments.

For longer T (1,000 to 1,500 msec). the kappa effect was observed only when the two temporal intervals were similar. There was no spatial (kappa) effect for judgments. On the other hand, temporal influence on spatial judgment appeared to be greater as T was increased. Possibly at longer T's, spatial distances defined by successive flashes may be difficult to remember so that subjects must increase their reliance on temporal cues.

Our observation of a kappa effect is consistent with that of Cohen et al. (1953) who reported a decreasing kappa effect over the range 0.6 - 6.4 sec. We should note, however, that Cohen et al.'s results are somewhat ambiguous since it is not clear whether Cohen

et al's data concern the magnitude of the kappa effect or the extent of the effect. In the present experiment, the extent for kappa effect narrows with increases in T but perhaps not the magnitude. On the other hand, both the magnitude and the extent of the tau effect seem to be relatively stable for $T > 480$ msec.

The hypothesis that tau and kappa effects are likely to be more marked when either the temporal (kappa) or the spatial (tau) judgment is more difficult is supported. Spatial judgments seem to have been more influenced by the temporal dimension when the spatial task was difficult (T long) and relatively uninfluenced when the spatial task was easy (T short). When temporal judgments were very difficult ($T \leq 320$ msec), the subjects' responses seemed to have been entirely based on the spatial cue.

In short, a subject may comply with the experimenter's demands for a spatial or temporal judgment in a number of ways. The judgment may be based entirely upon the primary cue if sufficiently unambiguous information is available. When primary cues are more difficult to interpret, subjects may rely more heavily on the context, temporal or spatial, of a judgment and give responses in conformity to reasonable expectations about spatio-temporal relations.

The following two experiments aim to examine more closely the degree to which a subject's expectancies might influence spatial and temporal judgments.

IV. EXPERIMENT 3

In a general way the constant velocity hypothesis is one of a class of theories which assert that perceptual judgments depend upon expectancies as much as upon immediately available perceptual information. Subject to the boundary conditions demonstrated in Experiments 1 and 2, the tau and kappa effects arise, according to the hypothesis, because (i) subjects impute movement across successive retinal stimuli and (ii) this movement is assumed to have constant velocity. When a constant velocity cannot be assumed, the subject may fall back upon another reasonable experiential strategy such as the one outlined above.

In the present experiment, I attempted to reduce the tau and kappa effects by manipulating the perception of constant velocity in the display. Instead of a 3-signal sequence, a 4-signal sequence was used which defined 3 spatial (s1, s2 and s3) and 3 temporal (t1, t2 and t3) intervals and the subject was required to make either spatial or temporal judgments on the first and the third interval. The derived velocities across the first two intervals was either equal or unequal. For equal velocities, we sought to induce a perception of constant velocity (induction) which should produce greater tau and kappa effects than if the derived velocities were unequal (non-induction).

Method

Subjects

Twelve naive subjects (nine male and three female), aged 15 to 22, participated in the experiment, 6 making spatial judgments and 6 making temporal judgments. Each subject was paid at an hourly rate.

Apparatus

The apparatus was as that used in Experiment 1.

Design and Procedure

In the induction condition (I), the spatial and temporal separations between the first and the third signals were kept constant at 8 deg of visual angle (s_1+s_2) and 1,600 msec (t_1+t_2), respectively. s_1 was sampled from 3 values: 2, 3 and 4 deg. Three values of t_1 : 400, 600 and 800 msec were selected such that $s_1/t_1 = s_2/t_2 = 5$ deg/sec. There were nine s_3 - t_3 combinations for the third interval with s_3 sampling from 2, 3 and 4 deg and t_3 sampling from 400, 600 and 800 msec.

Two non-induction conditions were run. The set-up of the two conditions were essentially the same as the I condition, with the exception that t_2 was fixed at either 400 msec (NI-short) or 1,000 msec (NI-long). The procedure was therefore a 3 (" s_1 - t_1 ") x 3 (" s_3 ") x 3 (" t_3 ") x 3 ("Induction") completely factorial design.

Each block of trials was based upon one induction condition consisting of 10 replications of the 27 combinations of the first three factors. The subject participated in all 3 induction conditions on consecutive weekdays, the 3 blocks of trials being selected at random.

Each trial proceeded as follows: the word "READY" first appeared on the video screen behind the stimulus display indicating to the subject that he may press any button to initiate the trial. When the subject had pressed a button, the stimulus sequence was presented following a 500 msec delay. The subject responded by pressing one of six buttons, labelled 1 to 6, where 1 to 3 indicated that the first interval (whether spatial or temporal) was shorter and 4 to 6 indicated that the third interval (whether spatial or temporal) was shorter. Buttons 1 and 6, 2 and 5, and 3 and 4 indicated high, medium and low confidence of judgment, respectively. The dependent measure was the mean of the confidence ratings. Notice that the subject was required to indicate not the size of the stimulus difference but rather their confidence that a particular interval was shorter than another. The use of confidence ratings provides a finer-scale measure than the proportional measure used in Experiments 1 and 2.

Results and Discussion

Detailed data are contained in Appendix 3. Separate ANOVA's were performed for spatial and temporal conditions using the mean confidence rating as the dependent measure. Mean confidence rating serves similar function as mean proportions, but is a more efficient measure, in that a higher confidence rating indicates a greater proportion of "second shorter" responses. For the spatial condition, the "s1-t1" factor and the "s3" factor were both significant, at $p < 0.001$ $F(2,10)=84.42$ and $F(2,10)=34.23$, respectively, indicating overall significant separation between the spatial curves (see Figure 3.4). The t3 factor was significant only

Fig. 3.1 Mean confidence rating of "s3 shorter" as a function of t_3 for each induction condition.

Fig. 3.2 Mean confidence rating of "s3 shorter" as a function of s_1 for each induction condition.

beyond the 0.01 level, $F(2,10)=3.45$, $p<0.075$. Figure 3.1 plots mean confidence rating against t_3 for each induction condition. The curves are clearly monotonically declining indicating the tau effect. However, neither the "Induction" factor nor the "Induction" x " t_3 " interaction was significant. Therefore, the constant velocity induction (I) did not yield greater tau effect (greater negative slope) than the two non-induction conditions (NI-long and NI-short).

The following interactions were significant: "Induction" x " s_1-t_1 " $F(4,20)=2.95$, $p<0.05$, "Induction" x " s_3 ", $F(4,20)=8.94$, $p<0.001$, and "Induction" x " s_1-t_1 " x " s_3 ", $F(8,40)=2.88$, $p<0.02$. In Figures 3.2 and 3.3, mean confidence rating is plotted against " s_1-t_1 " and " s_3 " respectively for each induction condition. The plots show that while the induction of constant velocity (I) and the NI-long condition did not differ, the NI-short condition differs from them in having progressively shorter perceived s_1 as s_1 increased and progressively longer s_3 as s_3 decreased. It is not clear why this is so although the fact that I and NI-long conditions do not differ in this respect suggests that shorter ISI ($t_2=400$ msec) between the judged distances interacted with the subject's perceptual or memorial mechanisms. This is also reflected in Figure 3.1 where NI-short produced overall shorter mean ratings. The significant "Induction" x " s_1-t_1 " x " s_3 " interaction, with its low F-value (2.88), seemed to be the result of a single deviation point for "NI-short" at $s_1=4$ deg and $s_3=3$ deg (Figure 3.4).

Fig. 3.3 Mean confidence rating of "s3 shorter" for each induction condition.

Fig. 3.4 Mean confidence rating of "s3 shorter" at each s1 for each induction condition.

Overall, similar trends are evident for temporal judgments. Main effects "sl-tl" and "t3" are significant, both at $p < 0.001$ $F(2,10)=83.96$ and $F(2,10)=19.64$, respectively, as would be expected. The "Induction" factor was statistically significant, $F(2,10)=4.34$, $p < 0.05$ but not the "Induction" x "s3" interaction, $F(4,20) < 1$. Although the "s3" main effect was only marginally significant, $F(2,10)=3.46$, $p < 0.075$, the kappa effect is evident in Figure 3.5 which plots mean confidence rating against s3 for each induction condition. The parallel curves also show that the induction manipulation did not produce a greater kappa effect in the constant velocity induction condition (I) as compared with the non-induction conditions but that shorter ISI (NI-short) produced lower mean ratings.

The only other significant interaction was the "sl-tl" x "t3" interaction $F(4,20)=3.81$, $p < 0.02$. Figure 3.6 plots mean rating against t3 at each sl-tl showing slightly varying (negative) slopes as t1 varied in duration.

Unlike the results of Experiments 1 and 2, no TOE was observed for either the spatial or the temporal judgment in the range of values we used. The mean rating was 3.5 and 3.35 for the temporal and the spatial condition, respectively and for the 3 induction conditions separately: the mean ratings for temporal judgments were 3.58, 3.54 and 3.37 and for spatial judgments were 3.42, 3.40 and 3.22 for the I, NI-long and NI-short conditions, respectively.

Fig. 5 Mean confidence rating of "t3 shorter" as a function of s3 for each induction condition.

Fig. 3.6 Mean confidence rating of "t3 shorter" at each t1.

Although both tau and kappa effects were observed, the attempt to manipulate the subject's expectancies of constant velocity was without significant effect. Conceivably, subjects may have brought with them such strong expectancies about successively presented stimuli that an attempt to induce unequal velocities within a trial did not yield lesser tau or kappa effects than an induction of constant velocity.

V. EXPERIMENT 4

Although we did not find different response patterns under induction and non-induction conditions in Experiment 3, the presence of tau and kappa effects in all three conditions indicates that induction and non-induction procedures within a block of trials in an experimental session were not effective in bringing about a change in the subject's imputation of constant velocity movements across comparison intervals. As a further test of the constant velocity hypothesis and its "expectancy" notion, the following experiment was devised.

As an extension of constant velocity hypothesis, it is reasonable to expect tau and kappa effects to operate similarly if a subject is induced to assume acceleration for movements imputed between successive signals. In the present experiment, acceleration (positive, negative or zero) was induced by varying the temporal separation between a sequence of equidistant lights. The subject was required to make an absolute judgment of the distance between the last of the series of induction lights and a subsequent light. The subject was first trained to make absolute identification on 5 different distances, defined by pairs of simultaneously presented lights. In the experiment proper, the distance to be judged was separated by a time interval which was varied from trial to trial. The subject's judgments were expected to vary according to the associated time interval (tau effect). Moreover, it was hypothesized that his judgments would be greatest under an induction of positive acceleration and least under an induction of negative

acceleration, since a positively accelerating sequence should magnify the final perceived distance of the display, a decelerating sequence should diminish the perceived distance and the control condition, with zero-acceleration induction, should not influence absolute judgments.

Method

Subjects

Five naive subjects (three male and two female), aged 16 to 23, participated in the experiment. Each subject was paid at an hourly rate.

Apparatus

The apparatus was that used in Experiment 1.

Design and Procedure

Training

The subjects were trained to make absolute judgments of 5 distances, $d=2.67, 3.33, 4.00, 4.67$ and 5.33 deg of visual angle which were assigned labels 1, 2, 3, 4 and 5, respectively. During the initial 15 viewing trials, in which the 5 distances were presented three times at random, the phrase "LENGTH = x" (where $x = 1, 2, 3, 4$ or 5) was first presented on the video screen for 1 sec. Then the corresponding distance was presented, by two simultaneous lights, for 500 msec. The subject initiated the next trial by pressing a response button.

Immediately following the viewing trials, the subject participated in an absolute judgment task. A trial began with the presentation of a distance, by means of the two lights, for 500

msec. The subject responded by pressing one of 5 response buttons corresponding to the distance. No feedback was provided. The proportion of correct responses was computed following each block of 50 such trials. The whole training procedure was repeated until the subject attained between .50 and .65 accuracy. No more than two training sessions were needed by any of the 5 subjects.

The Experiment

A sequence of 7 equidistant (0.66 deg) lights spanning a total of 4 deg served as the inducting sequence. An eighth light at a variable distance along the same horizontal meridian defined the distance which the subject was required to judge. The 3 acceleration conditions were constructed as follows: for positive acceleration, the six temporal separations were, in the following order, 1,200, 850, 600, 400, 325 and 225 msec; for negative acceleration, they were, 225, 325, 400, 600, 850 and 1,200 msec; for zero acceleration, each was 600 msec. The constraint was imposed that the total duration for the inducting sequence should be the same for all three conditions and the temporal separations were chosen to allow for clear perception of acceleration (whether positive, negative or zero). The subjects were informed of this arrangement and were able to distinguish among the acceleration conditions.

There were also 5 temporal intervals between the two lights which defined the distance to be judged: $t = 600, 700, 800, 900$ and $1,000$ msec. The procedure was therefore a 5 ("d") $\times$ 5 ("t") $\times$ 3 ("Acceleration") completely factorial repeated measures design.

Each block of trials consisted of 5 replications of the 75 combinations of the 3 factors. The subject participated in 2 blocks of trials on consecutive weekdays, following initial training.

Each trial proceeded with a "READY" message displayed on a video screen. The subject initiated a trial by pressing a response button and 500 msec later the display was presented from left to right. The subject responded by pressing one of 5 response buttons corresponding to the distances. The dependent measure was the mean absolute judgment.

Results

Detailed data are contained in Appendix 4. ANOVA indicated three statistically significant effects: "Acceleration", $F(2,8)=5.26$, $p<0.04$, "Distance", $F(4,16)=72.40$, $p<0.001$, and "Time", $F(4,16)=6.52$, $p<0.003$.

Figure 4.1 plots mean judgment against the "Distance" variable for each acceleration condition. The "Distance" effect under ANOVA indicates that slopes in Figure 4.1 are significantly greater than zero indicating good discrimination of the various distances. The curves have slopes less than one but this is generally observed in absolute judgment tasks because of compression on the response scale. Bearing in mind the fact that the subject obtained only 0.50 - 0.65 accuracy during the training sessions, with the additional manipulation here on the temporal separation between the signals demarcating the judged distance, the slopes obtained were reasonably steep.

Fig. 4.1 Mean distance judgment for each acceleration condition.

Perhaps the most important finding in Figure 4.1 is the effect of the acceleration manipulation on mean judgments. A positive acceleration in the induction sequence gave rise to greater mean judgment of distances, confirming our hypothesis that a positive acceleration magnifies a subject's perceived distance while a negative acceleration reduces it. Further, the trend with zero and negative acceleration inductions are also in accordance with the specification of our hypothesis.

Figure 4.2 plots the mean judgment for each distance against the temporal intervals, collapsing across "Acceleration". It is clear that a tau effect is present, mean judgments increasing with greater temporal separation for each distance.

Discussion

The traditional finding of a tau effect (significant "Time" factor) is replicated here, using a different paradigm. We involved a subject in an absolute judgment task as opposed to the subjective adjustment or the relative judgment method. This demonstration of tau is new. Moreover, the present experiment vividly demonstrates the effect of an induction sequence on the perceived distance of a subsequent interval. While an induction of positive acceleration magnified the perceived distance, an induction of negative acceleration produced a reduction in the perceived distance, as compared to the control condition (zero acceleration). Our hypothesis that distance judgment can be modified by changing the subject's expectancy in the judgmental context is strongly supported.

Fig. 4.2 Mean distance judgment as a function of temporal separation (t).

The parallel curves in Figure 4.1 (insignificant "Acceleration" x "Distance" interaction) further suggest that the induction effect may be best represented by a linear integration model:

$$R_{ij} = f(t_i) + g(s_j) + I + e$$

where R_{ij} is the subject's judgment of the distance s_j for a given t_i , temporal separation between the demarcating signals. I is a variable representing the effect of the induction condition which can be set to zero for the zero acceleration condition. Values for the other two conditions could then be determined from the re-scaled intercepts in Figure 4.1. The function, $f(t_i)$, is some monotonically increasing function of the temporal separation, t_i , between the demarcating signals. Figure 4.2 shows that the curves for each value of s_j are approximately constantly separated suggesting that $g(s_j)$ is a linear function. Finally, e is an error term with zero expectation.

In Experiment 3 we found that manipulating the subject's perception of constant velocity did not differentially affect expectancy. We suggested that subjects bring with them firm expectations which were not modified in the laboratory. The induction manipulation in the present experiment, on the other hand, has been effective. The differences between the two experiments may be due to the many factors which differentiate the two experiments. One factor, however, seems to be more important than others. In Experiment 3, the induction manipulation was built into the stimulus sequence whereas the induction manipulation in the present experiment was devised before the judged variable. The additivity observed for the tau and "expectancy" effects in the present

experiment (see above) leads us to expect that if in Experiment 3, the induction and non-induction of constant velocity had been planted before the judged intervals, a difference might be observed for the induction conditions. Such a reasoning is consistent with theories of attention (see Kahneman, 1973) with the notion, in other words, that allocation of attention determines in large part the availability of information for perceptual analysis (see Section VI.5). Building the induction into the judged stimuli (in Experiment 3) may have resulted in lesser allocation of attention to the induction sequence per se.

VI. GENERAL DISCUSSION AND CONCLUSIONS

VI.1 Summary of main findings

Our experiments have yielded some consistent results which demonstrate the clear interdependence of spatial and temporal judgments, the tau and kappa effects, previously observed by a number of investigators. However, our results also show some interesting features which were not observed in previous studies. Experiment 1 shows, that there is intra-subject variability when T, the total duration of display, is relatively short. Both tau and kappa effects and their reverse may be observed within a single subject, depending on the particular combinations of s_1 - t_1 values. While it can be argued that at short total display duration of 160 msec, a different set of (as yet unknown) perceptual mechanisms is brought into play (Collyer, 1977), plausible changes in the ways in which the subject interprets the situation could explain the presence of both tau and the reverse of it within an experimental block.

Experiment 2 systematically varied the total display duration over the range 160 - 1,500 msec. Progressive changes over this range were observed for both tau and kappa though the two effects were not mirror images. Spatial judgments were increasingly more dependent on the temporal context as display duration was increased whereas, while the kappa effect was still observed for the 1,500 msec display, temporal judgments become increasingly less dependent on the spatial context with increasing T.

This finding may be explained in terms of the different requirements of the two (spatial, temporal) judgmental tasks. At shorter display durations, the spatial judgment approximates the limiting case of distance judgment between intervals defined by simultaneously presented lights, whereas at longer display duration, the temporal judgment may be comparatively easier for the subject and need not be based upon the spatial cues. Our analysis of the discriminability of stimuli in terms of separation of the curves in Figures 2.3 and 2.4 also suggests that interdependence increases with decreasing discriminability. This effect was not noted in previous studies using the subjective adjustment method and has not previously been investigated. Further experiments are needed to investigate the effect of stimulus discriminability on the interdependence of spatial and temporal judgments, or the degree of spatio-temporal integration of information. For example, a separate experiment could first be carried out without the secondary dimension to establish the sensitivity (as measure by d' , for instance) on the primary dimension (judged variable). Then, the magnitude of the effects can be examined in relation to such a sensitivity measure.

Experiment 3 went on to test the constant velocity hypothesis in relative judgment on 3 distances (2, 3 and 4 deg visual angle) and 3 time intervals (400, 600 and 800 msec). Both tau and kappa effects were so dominant, or at least it is reasonable to believe the subject's expectancies to have been so dominant, that an induction built into the stimuli themselves did not yield greater effects compared to the two non-induction manipulation.

We then tested the expectancy notion, in Experiment 4, by introducing induction of acceleration before the stimulus sequence. This experiment has two noteworthy features. First, we used a different judgmental task: the subject was first trained to make absolute identification of 5 distances (2.67, 3.33, 4.00, 4.67 and 5.33 deg of visual angle) defined by stationery lights and then participated in judgments of distances defined by successive lights. Secondly, and perhaps more importantly, we manipulated the subject's expectancy with respect to judged distances by a preceding series of lights which were accelerating, decelerating or moving with constant velocity. The results confirmed the hypothesis that an "acceleration" induction should magnify the subject's perceived distance, and a "deceleration" induction should reduce it. This seems to constitute a strong test of the expectancy notion as all other factors are controlled in the induction sequence of lights, including the total duration and display distance. We shall return to this point later.

VI.2 Real, apparent and imputed movements

Since Hubel and Wiesel's (1959, 1962) discoveries, it is now accepted that some neural cells may function as motion detectors. Grusser-Cornehlis, Grusser and Bullock (1964), moreover, found units in the frog's optic tectum responding to both real movement and possibly, apparent movement. Apparent movement (beta movement or stroboscopic movement) occurs, under specific conditions, when two (or more) spatially distinct stimuli are presented in rapid succession. Richards (1971), in an ingenious experiment using the

spiral after-effect, has found the motion detection system in man to operate within a range of parameters comparable to that of lower animals and further suggested the mid-brain as a site for such a system as in the lower animals (Richards and Smith, 1969). Recent psychophysical models of motion detection have also included such analysers (e.g. Bonnet, 1978).

While real and apparent movements seem to invoke similar perceptual judgments, they may still be based upon different underlying mechanisms. For instance, apparent movements are much slower than real movements and yet apparent movements occur under conditions of greater (derived) velocity than do real movements (Kolars, 1963, 1964). This latter point has led Rock (1975) to suggest that apparent movement might reflect a system which takes over for higher velocity motions beyond the analysing capabilities of the real motion detection system since rapid real movements are essentially stroboscopic (though see Frisby, 1972).

What concerns us here is neither real nor apparent movement, but "imputed" movement. The foregoing discussion serves only to indicate the importance and prevalence of motion perception and the possibility and in fact, necessity of imputation of movements for successive visual stimuli. Newman and Lee (1972) suggested that in the tau and kappa phenomena, the subject imputes movement across successive visual signals and the imputed velocity aids the subject in making temporal judgments. Such an imputation process is also consistent with the artificial intelligence approach to the study of visual motion. Ullman (1979), for instance, postulates two

processes for the interpretation of motion. A correspondence process first matches the constituents of two successive stimuli. If two stimuli correspond, an interpretative process then makes the distinction between a change of structure and a motion relation. Such an interpretative process is also implicit in the stopped frame approach of Kinchla and Allan (1969).

In our study where identical stimuli are presented successively in the dark, and there is neither a change of structure nor real motion, the same interpretative process should suggest an "imputed movement. It is perhaps obvious, but worthy of repeated emphasis, that no perceived motion (real, apparent or imputed) is automatic or locally (retinally) determined, but each motion is, as Kahneman (1973) describes perception, "the achievement of a set of interpretations." (see e.g. Kolars, 1972).

VI.3 Experience and expectancy

The imputation of movement, and any such interpretative process, is probably the result of learning. As such, we should be concerned with the subjects' expectancies accumulated from experience. It is perhaps not surprising that when their expectancies are being manipulated, as the results of Experiment 4 show, perceptual judgments are modified. Cross-cultural studies on susceptibility to visual illusions also indicate a strong connexion between experience and perception (Segall, Campbell and Herskovits, 1960).

The influence of a subject's expectation on perception is also evident in related area of research. Wertheimer (1912), for

example, reported that if two lines intersecting each other were alternately presented, an apparent motion was perceived between them, usually motion over the shortest distance, i.e., through the acute angle. However, if on successive trials the angle was increased, the motion would continue to be seen through the same path, though it may now cover a longer distance (through the obtuse angle rather than the acute angle). Given sufficient prior experience, motion would continue to be seen for a few additional trials though only one line was presented. Zapparoli and Reatto's (1969) sensory interaction studies provide added evidence that in ambiguous situations, a subject may sometimes perceive certain stimulus patterns in the way that he could best interpret, from his everyday experience. They repeatedly presented to a subject a large visual stimulus on the right and a sound stimulus on the left, each of 100 msec duration with an ISI of 300 msec. The visual stimulus was a 100 watt lamp which lit up a 22 x 16 cm white opaque glass screen. In addition, the subject was required to wear dark glasses so that he would see the light flashes as being without definite outlines. The auditory stimulus was a 500 Hz tone. Under suitable conditions for stroboscopic movement, Zapparoli and Reatto (1969) reported that the subject had "a feeling of nausea, giddiness and uneasiness which ceases as soon as the subject succeeds in perceiving either the causal nexus between the two homogeneous stimuli or the feeling of movement". In the "former case, the subject typically described the light as causing the beginning or the end of the sound or the sound as causing the light to be turned on and off. In the latter case when a movement was perceived, the phenomena was described as "something that moves between the sound

and the light a light and a sound tunnel which grows longer and shorter, or a light tunnel which grows longer and shorter while a sound passes through it". Zapparoli and Reatto (1969) described this as "the unification of the action of two stimuli temporally, spatially and sensorially distinct, into a single phenomenic object animated by movement (p. 266)." That such a unification is possible could best be explained by a theory which takes into account the role of learning in the interpretation (integration) of incoming information.

VI.4 Tau, kappa, IAE and the "rabbit"

Collyer (1976) found an induction effect on temporal order judgment which he termed the induced asynchrony effect (IAE). When two lights were extinguished successively in the spatial vicinity of two test lights, then the perception of the onset of the test lights may be influenced by the offset relationship of the first lights. In particular, the test light which is closer (in space) to the first extinguished stimulus would be judged to appear sooner than the other test light, even though the two lights have been presented at the same time. Such an effect is only observed for very brief inter-stimulus intervals, say less than 100 msec.

A different sequential phenomenon was described by Geldard and Sherrick (1972). When 5 pulses, at 20 pulse per second rate say, were delivered to the forearm by each of 3 contactors (10 cm apart) successively, the subject would feel that the 15 pulses were uniformly distributed between the contactors as though a rabbit was hopping along the arm (the "rabbit" effect). Geldard (1975) has

subsequently found comparable effects in the visual and auditory modalities and referred to the effects as showing "metastability" across the senses.

Collyer (1976) has suggested that tau, kappa, IAE and the "rabbit" should be understood as spatio-temporal illusions within the same conceptual framework (see Fig. 5): "the simple IAE and the tau effect have been observed in stimulus patterns where the two spatial intervals separating the three stimuli are equal, but the temporal intervals are unequal. The rabbit and kappa effects have been observed under conditions of equal time intervals but unequal [spatial] intervals (p.54)." Alternatively, we could look at the rabbit effect as the limiting case of tau for perceptual distortion in space and the IAE as the limiting case of kappa for perceptual distortion in time. "In all four phenomena, the perceptual distortion is in the direction that would be expected under the hypothesis that observers have a tendency toward constant velocity in the perception of motion" (Collyer, 1976; p.54).

However, the IAE and rabbit effects typically occur for very short durations while the tau and kappa are difficult to observe at short durations (Collyer, 1977; Experiment 1). We have argued for a cognitive explanation of the tau and kappa effects. The IAE and the rabbit effect are probably sensory effects that have very limited boundary conditions. All four effects can be said to obey the "rule" of constant velocity and it is reasonable to argue that all four may be subserved by the same underlying mechanisms. On the other hand, it may be that the same "rule" is applicable to largely

Figure 5 Space-time diagrams representing four dynamic perceptual "illusions": (a) simple form of LAE, (b) tau effect, (c) kappa effect, (d) simple form of rabbit effect. The paradigms are arranged in the figure as follows: Top row, "even" spacing and "uneven" timing; bottom row, "uneven" spacing and "even" timing; left column, temporal judgment tasks; right column, spatial judgment tasks. Arrows represent the direction of perceptual distortion reported for each paradigm. The observer may have a tendency to judge the spatial positions or times of presentation of the three stimuli in such a way as to preserve constant velocity of apparent motion, which is represented by the dashed line. (Collyer, 1976)

peripheral processes (IAE, the rabbit) as to largely central processes (tau and kappa). Further work is clearly required to establish the nature of the link between these contextual sequential effects.

VI.5 Context, irrelevant attributes and attention

We have previously mentioned that tau and kappa effects can be considered as illusions where perceptual distortions arise as a result of the influence of spatial or temporal background. In the tau effects, spatial judgments are influenced by the temporal stimulus context and in the kappa effects, temporal judgments are influenced by the spatial stimulus context. It would follow that if a subject does not attend to the context, then the effects would diminish or not occur at all (c.f. Carr, 1938). Contextual learning theories also emphasize that non-relevant components play a determining role in producing illusions. Within the framework of these theories, the attitude of a subject is thought to be important in determining, at least in part, the magnitude of an illusion. "Holistic" viewing instructions typically yield larger illusions than those of "partistic" viewing (see Over, 1968, pp.554-556).

With respect to the tau effect, we have also seen that some of Helson and King's (1931) subjects could give spatial judgments more or less independently of the temporal context when they attempted to isolate spatial cues from the temporal element of the stimulus pattern. Similar findings were reported in Abe's (1935) kappa study. One of Abe's subjects in fact said, "It is clear that my time estimation depended upon spatial distance. It is not good.

Therefore I frequently revised some of my naive judgments." Interdependence of spatial and temporal judgments may arise, therefore, from the subject's failure to isolate relevant attributes of the judgment from the irrelevant attributes in the context.

What should be taken as relevant and irrelevant to any judgment is the central concern of theories of attention. In fact, theories have generally included features which account for the findings that irrelevant attributes tend to enter into perceptual analysis (Stroop, 1935; Treisman and Fearnley, 1969). In auditory attention, for instance, Treisman's (1960, 1964) modification of Broadbent's (1958) filter theory suggests that information rejected by a selective "filter" is attenuated, not eradicated. Holding a more extreme position, Deutsch and Deutsch (1963) have proposed that "a message will reach the same perceptual and discriminatory mechanisms whether attention is paid to it or not (p.83)." Kahneman (1973) has summarized the main findings of attention research in the following statement, "The general rule is that it is easy to focus attention exclusively on a single object and difficult to divide attention among objects. Conversely, it is easy to notice several aspects or attributes of an object, but it is difficult or impossible to prevent the perceptual analysis of irrelevant attributes (p.7)." Furthermore, "there is little evidence that an attention to a particular dimension can prevent the perceptual interpretation of other dimensions (p.111)."

VI.6 Cues

Under certain conditions, the inseparability of attributes may not be so much the problem of attention but, in these experiments, may lie in spatial or temporal acuity which is known to be influenced by context. We know, for example, that the simultaneous two-point threshold on the forearm is about 40 mm (Weinstein, 1968). However, when two points are successively stimulated, then the threshold depends very much on the temporal separation between the stimuli. Wieland (1960) showed that the space-time equivalence can be adequately described by the equation: $\log T = a - bD$, where T is the temporal separation, D is the spatial separation and a and b are constants. The limits are 750 msec and 93 mm for T and D respectively. The values for the constants are different for each subject. As an example, two points of stimulation would be felt at a distance of 10 mm if they are separated by 500 msec but they would have to be separated by more than 90 mm if the temporal separation is reduced to 40 msec. Wieland (1960) suggested that this phenomenon of spatio-temporal interaction is related to Helson and King's (1931) tau effect. This argument would, however, tend to confuse the issue of acuity with that of context-induced perceptual errors. Experiments with anaesthetized animals have shown that the responses recorded from primary sensory receiving area of the cerebral cortex to a second stimulus reduced in size when the first stimulus preceded the second by 40 to 150 msec (see e.g. Jarcho, 1949; Towe & Amassian, 1958). Angel (1969) has shown that when the interstimulus interval (ISI) is less than 500 msec, the probability of discharge of single thalamic cells to closely spaced stimuli was a monotone function of the ISI until the ISI is 40 msec at which

point the second signal elicited no response. In other words, there is blocking of information with brief temporal separation between tactile signals. At the least it is difficult to equate this kind of spatio-temporal interaction with perceptual errors at the suprathreshold level.

Wieland's (1960) results, however, raise an interesting question: when should we accept that a subject has made a genuine spatial judgment, whether influenced by time or not? If, for example, points of stimulation in Helson and King's (1931) experiment were close to Wieland's (1960) two-point threshold (in time or in space), it is questionable whether subjects genuinely perceived spatial extension. It is possible that a subject may have reported one spatial interval to be longer than the other simply because the duration of one interval was longer than another. Of course, this is one very reasonable strategy and the result could be described as a tactile tau effect in that longer spatial intervals are associated with longer temporal interval. Our study (Experiments 1 and 2) and Collyer's (1977) seem to indicate, in fact, that response strategy might account for spatial and temporal judgments for brief displays, although strategies could conceivably be different for varied conditions.

VI.7 Constant velocity hypothesis and pitch

It may be questioned how the "constant velocity" hypothesis may be applied to non-localizable auditory stimuli. Numerous examples, however, testify that pitch is a spatialized continuum (Note 3). In the Pollack (1977) study, for instance, a person is able to imagine

a series of brief auditory pulses increasing (or decreasing) in pitch to continue across an empty interval to match another series of auditory pulses. It is therefore quite probable that a similar continuous change in pitch is imputed by the subject from the three stimuli in the auditory tau experiments. The subject would ascribe a greater change in pitch (i.e., greater tonal interval) to two tones that are temporally further apart. When he is asked to equate two tonal intervals, he would tend to move the middle stimulus closer in pitch to the stimulus that is temporally further apart. It is therefore not surprising to note that the experienced musician would not be subject to the influence of the temporal characteristics of the stimulus pattern (Huang, 1976). Following only a few trials, the tonal midpoint would be given for the second stimulus to within 2 or 3 Hz by a musical subject, regardless of the temporal condition. During the initial few trials, however, Huang (1976) noted that a similar tau effect is evident even for a musician.

VI.8 Conclusions

We set out to test the validity of a theory which emphasizes the cognitive aspects in the interdependence of spatial and temporal judgments. The main conclusions from the four experiments are as follows:

- (i) For relatively short T, both spatial and temporal judgments are probably strategy-based responses involving a mixture of imputed velocities as well as cues from other (irrelevant) dimensions.

Consequently, the tau and kappa effects and their reverse may be observed for the same subject under different spatio-temporal pairings.

(ii) As the total display duration is increased from 160 msec to 1,500 msec, the tau effect is progressively more evident while the kappa effect shows sign of diminution. This is explicable in terms of the differing requirements and conditions of the two tasks (spatial/ temporal). There is also evidence that the degree of interdependence is inversely related to stimulus discriminability. This point warrants further investigation and is clearly important for theories of information integration in general.

(iii) Direct testing of the constant velocity hypothesis by building induction (and non-induction), of constant velocity within the stimuli failed to yield greater tau or kappa effects. Since both tau and kappa effects were observed, it seems reasonable to conclude that strong subject expectancy obliterates the laboratory manipulation.

(iv) The expectancy notion was supported by an experiment on absolute distance judgment. While the tau effect was present for all conditions, an induction of "acceleration" before the judged stimulus yielded greater judged distance than an induction of "deceleration".

Based on the results of the present experiments, a review of research in related areas of motion perception, attention, illusion,

etc. demonstrates that any theory of the interdependence of spatial and temporal judgments must take into account the person's ordinary experience. The stimulus patterns that we have studied here may be either extension embedded in a temporal context or duration embedded in a spatial context. In cases where extension is not easily perceived, judgment may depend entirely on temporal cues, and vice versa. On the other hand, where it is possible to perceive distance clearly (e.g., when the distance is traversed by a target) or when a subject is sufficiently experienced with the stimuli (e.g., the musician in Huang's, 1976, auditory study), spatial judgments tend not to be distorted by the temporal variable.

We therefore conclude that in questions regarding the interdependence of spatial and temporal judgments, the emphasis should be placed on how a subject would use reasonable everyday expectations to make interpretations of ambiguous information, whether in everyday situation or in the laboratory.

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NOTES

1. These studies were cited by Helson & King (1931).
2. A description of Scholz's (1924) work may be found in Helson (1925) (p.513ff).
3. It is interesting that the tau effect was in fact present for what Cohen et al. (1954) considered to be a non-spatial stimulus. Conceivably, the temporal context may affect any judgment of ordered continua. However, one might argue that pitch is a spatial continuum. Our ordinary use of 'high' and 'lowness' of pitch to denote sounds of greater or lesser frequencies shows one way in which pitch is spatialized. In fact, pitch differences can be seen as tonal distances which could, for instance, be imagined to be distances between keys on a piano.

Subject 1

	S1						ROW μ
	MEAN STD DEV	0.67 DEG	1.33 DEG	2 DEG	2.67 DEG	3.33 DEG	
T1	I	I	I	I	I	I	
20 MSEC	I	.00 I	.08 I	.52 I	.58 I	.78 I	.39
	I	.00 I	.11 I	.11 I	.16 I	.04 I	.32
56 MSEC	I	.00 I	.12 I	.36 I	.50 I	.74 I	.34
	I	.00 I	.16 I	.24 I	.24 I	.13 I	.32
80 MSEC	I	.02 I	.16 I	.22 I	.48 I	.66 I	.31
	I	.04 I	.11 I	.18 I	.16 I	.13 I	.27
104 MSEC	I	.08 I	.12 I	.28 I	.44 I	.70 I	.32
	I	.13 I	.11 I	.19 I	.21 I	.20 I	.28
160 MSEC	I	.14 I	.04 I	.02 I	.30 I	.70 I	.24
	I	.05 I	.09 I	.04 I	.21 I	.16 I	.28
COLUMN	μ σ	.05 25 .08	.10 25 .12	.28 25 .23	.46 25 .21	.72 25 .14	.32 125 .29

Subject 2

	S1						ROW μ
	MEAN STD DEV	0.67 DEG	1.33 DEG	2 DEG	2.67 DEG	3.33 DEG	
T1	I	I	I	I	I	I	
20 MSEC	I	.00 I	.00 I	.34 I	.92 I	.74 I	.40
	I	.00 I	.00 I	.21 I	.04 I	.34 I	.42
56 MSEC	I	.02 I	.00 I	.34 I	.88 I	.68 I	.38
	I	.04 I	.00 I	.21 I	.16 I	.33 I	.40
80 MSEC	I	.08 I	.04 I	.36 I	.74 I	.72 I	.39
	I	.13 I	.05 I	.18 I	.27 I	.29 I	.36
104 MSEC	I	.06 I	.06 I	.30 I	.82 I	.74 I	.40
	I	.09 I	.09 I	.10 I	.16 I	.38 I	.38
160 MSEC	I	.18 I	.04 I	.52 I	.86 I	.82 I	.48
	I	.04 I	.05 I	.19 I	.09 I	.24 I	.36
COLUMN	μ σ	.07 25 .09	.03 25 .05	.38 25 .18	.84 25 .16	.74 25 .30	.41 125 .38

Subject 3

	S1						ROW μ
	MEAN STD DEV	0.67 DEG	1.33 DEG	2 DEG	2.67 DEG	3.33 DEG	
T1	I	I	I	I	I	I	
20 MSEC	I	.00 I	.06 I	.32 I	.50 I	.42 I	.26
	I	.00 I	.05 I	.18 I	.14 I	.08 I	.23
56 MSEC	I	.06 I	.10 I	.52 I	.48 I	.48 I	.33
	I	.13 I	.14 I	.24 I	.13 I	.19 I	.26
80 MSEC	I	.00 I	.12 I	.40 I	.50 I	.42 I	.29
	I	.00 I	.13 I	.14 I	.19 I	.15 I	.23
104 MSEC	I	.08 I	.10 I	.32 I	.60 I	.48 I	.32
	I	.08 I	.07 I	.18 I	.16 I	.15 I	.24
160 MSEC	I	.10 I	.12 I	.28 I	.64 I	.44 I	.32
	I	.10 I	.13 I	.13 I	.19 I	.22 I	.25
COLUMN	μ σ	.05 25 .09	.10 25 .10	.37 25 .18	.54 25 .16	.45 25 .15	.30 125 .24

Appendix 1.1 Mean proportion (and S.D.) of "second shorter" responses for each sl-t1 combination for each subject. Spatial judgments with left to right presentation.

Subject 1

91

MEAN I		S1						ROW
STD DEV I		0.67 DEG	1.33 DEG	2 DEG	2.67 DEG	3.33 DEG		
	I	I	I	I	I	I	μ	
T1	I	I	I	I	I	I		
	I	.02 I	.08 I	.62 I	.72 I	.86 I	.46	
20 MSEC	I	.04 I	.13 I	.13 I	.13 I	.11 I	.37	
	I	I	I	I	I	I		
	I	.02 I	.04 I	.40 I	.58 I	.88 I	.38	
56 MSEC	I	.04 I	.05 I	.19 I	.13 I	.13 I	.35	
	I	I	I	I	I	I		
	I	.06 I	.12 I	.36 I	.70 I	.80 I	.41	
80 MSEC	I	.09 I	.04 I	.11 I	.10 I	.10 I	.32	
	I	I	I	I	I	I		
	I	.14 I	.18 I	.14 I	.48 I	.78 I	.34	
104 MSEC	I	.09 I	.04 I	.09 I	.13 I	.19 I	.28	
	I	I	I	I	I	I		
	I	.22 I	.22 I	.08 I	.60 I	.90 I	.40	
160 MSEC	I	.18 I	.16 I	.08 I	.19 I	.17 I	.34	
	I	I	I	I	I	I		
COLUMN	μ	.09	.13	.32	.62	.84	.40	
	n	25	25	25	25	25	125	
	σ	.12	.11	.23	.15	.14	.33	

Subject 2

MEAN I		S1						ROW
STD DEV I		0.67 DEG	1.33 DEG	2 DEG	2.67 DEG	3.33 DEG		
	I	I	I	I	I	I	μ	
T1	I	I	I	I	I	I		
	I	.00 I	.02 I	.76 I	.80 I	.78 I	.47	
20 MSEC	I	.00 I	.04 I	.18 I	.16 I	.15 I	.40	
	I	.00 I	.06 I	.64 I	.70 I	.72 I	.42	
56 MSEC	I	.00 I	.09 I	.11 I	.19 I	.13 I	.35	
	I	.00 I	.02 I	.46 I	.76 I	.80 I	.41	
80 MSEC	I	.00 I	.04 I	.21 I	.18 I	.12 I	.37	
	I	.04 I	.02 I	.46 I	.86 I	.86 I	.45	
104 MSEC	I	.05 I	.04 I	.23 I	.11 I	.17 I	.40	
	I	.12 I	.00 I	.30 I	.76 I	.88 I	.41	
160 MSEC	I	.13 I	.00 I	.19 I	.17 I	.11 I	.38	
COLUMN	μ	.03	.02	.52	.78	.81	.43	
	n	25	25	25	25	25	125	
	σ	.07	.05	.24	.16	.14	.38	

Subject 3

MEAN I		S1					ROW
STD DEV I		0.67 DEG	1.33 DEG	2 DEG	2.67 DEG	3.33 DEG	
	I	I	I	I	I	I	μ
T1	I	I	I	I	I	I	
	I	.12 I	.14 I	.78 I	.84 I	.78 I	.53
20 MSEC	I	.16 I	.09 I	.15 I	.09 I	.08 I	.35
	I	I	I	I	I	I	
	I	.22 I	.48 I	.56 I	.76 I	.84 I	.57
56 MSEC	I	.15 I	.22 I	.05 I	.13 I	.11 I	.26
	I	I	I	I	I	I	
	I	.10 I	.52 I	.50 I	.82 I	.82 I	.55
80 MSEC)	I	.10 I	.08 I	.19 I	.04 I	.15 I	.29
	I	I	I	I	I	I	
	I	.30 I	.42 I	.56 I	.60 I	.76 I	.53
104 MSEC	I	.20 I	.08 I	.18 I	.24 I	.05 I	.22
	I	I	I	I	I	I	
	I	.28 I	.38 I	.38 I	.40 I	.70 I	.43
160 MSEC	I	.20 I	.22 I	.15 I	.16 I	.10 I	.21
	I	I	I	I	I	I	
COLUMN	μ	.20	.39	.56	.68	.78	.52
	n	25	25	25	25	25	125
	σ	.17	.19	.19	.22	.11	.27

Appendix 1.2 Mean proportion (and S.D.) of "second shorter" responses for each sl-t1 combination for each subject. Spatial judgments with right to left presentation.

Subject 1

92

		T1						Subject 1
	MEAN I	STD DEV I	20 MSEC	56 MSEC	80 MSEC	104 MSEC	160 MSEC	ROW μ
	I	I	I	I	I	I	I	
S1	I	I	I	I	I	I	I	
	I	I	I	I	I	I	I	
0.67 DEG	I	.00 I	.02 I	.06 I	.06 I	.26 I	.08	
	I	.00 I	.04 I	.09 I	.05 I	.23 I	.14	
	I	I	I	I	I	I	I	
1.33 DEG	I	.06 I	.10 I	.12 I	.24 I	.06 I	.12	
	I	.09 I	.12 I	.04 I	.19 I	.09 I	.13	
	I	I	I	I	I	I	I	
2 DEG	I	.68 I	.38 I	.34 I	.28 I	.26 I	.39	
	I	.15 I	.26 I	.29 I	.13 I	.15 I	.24	
	I	I	I	I	I	I	I	
2.67 DEG	I	.76 I	.66 I	.60 I	.42 I	.32 I	.55	
	I	.18 I	.15 I	.21 I	.13 I	.15 I	.22	
	I	I	I	I	I	I	I	
3.33 DEG	I	.80 I	.70 I	.70 I	.76 I	.56 I	.70	
	I	.19 I	.14 I	.16 I	.11 I	.25 I	.18	
	I	I	I	I	I	I	I	
COLUMN	μ	.46	.37	.36	.35	.29	.37	
	n	25	25	25	25	25	125	
	σ	.38	.32	.31	.27	.23	.31	

Subject 2

		Subject 2					
T1							
MEAN	STD DEV	20 MSEC	56 MSEC	80 MSEC	104 MSEC	160 MSEC	ROW
							μ
S1							
0.67 DEG		.98	.64	.42	.50	.40	.59
		.04	.18	.28	.23	.14	.28
1.33 DEG		.86	.48	.26	.12	.20	.38
		.11	.18	.15	.13	.19	.31
2 DEG		.84	.44	.22	.20	.04	.35
		.09	.11	.19	.17	.05	.31
2.67 DEG		.88	.82	.58	.24	.04	.51
		.16	.15	.34	.21	.05	.38
3.33 DEG		.72	.84	.92	.30	.12	.58
		.24	.15	.11	.19	.16	.36
COLUMN	μ	.86	.64	.48	.27	.16	.48
	n	25	25	25	25	25	125
	σ	.16	.22	.33	.22	.18	.34

Subject 3

		T1						ROW	
		MEAN	STD DEV	20 MSEC	56 MSEC	80 MSEC	104 MSEC	160 MSEC	
		I	I	I	I	I	I	I	μ
S1		I	I	I	I	I	I	I	
		I	.08 I	.06 I	.12 I	.18 I	.48 I	.18	
0.67 DEG		I	.08 I	.13 I	.13 I	.15 I	.18 I	.20	
		I	.26 I	.42 I	.30 I	.34 I	.48 I	.36	
1.33 DEG		I	.15 I	.22 I	.19 I	.29 I	.19 I	.21	
		I	.42 I	.58 I	.44 I	.50 I	.40 I	.47	
2 DEG		I	.18 I	.16 I	.17 I	.31 I	.19 I	.20	
		I	.52 I	.40 I	.40 I	.32 I	.42 I	.41	
2.67 DEG		I	.25 I	.31 I	.14 I	.13 I	.18 I	.20	
		I	.36 I	.34 I	.32 I	.36 I	.52 I	.38	
3.33 DEG		I	.30 I	.24 I	.23 I	.09 I	.13 I	.21	
		I	.33	.36	.32	.34	.46	.36	
COLUMN	μ		.25	.25	.25	.25	.25	.125	
	σ		.24	.27	.20	.22	.17	.22	

Appendix 1.3 Mean proportion (and S.D.) of "second shorter" responses for each sl-t1 combination for each subject. Temporal judgments with left to right presentation.

Subject 1

93

		T1						ROW	
		MEAN	STD DEV	20 MSEC	56 MSEC	80 MSEC	104 MSEC	160 MSEC	
		I	I	I	I	I	I	I	
S1		I	I	I	I	I	I	I	
		I	.00	.00	.00	.02	.10	.02	
0.67 DEG		I	.00	.00	.00	.04	.07	.05	
		I	.06	.06	.08	.04	.10	.07	
1.33 DEG		I	.09	.09	.11	.05	.12	.09	
		I	.66	.40	.30	.02	.14	.30	
2 DEG		I	.17	.07	.16	.04	.15	.25	
		I	.86	.72	.58	.46	.50	.62	
2.67 DEG		I	.19	.08	.16	.24	.14	.22	
		I	.98	.96	.84	.88	.92	.92	
3.33 DEG		I	.04	.09	.11	.11	.08	.10	
		I	.51	.43	.36	.28	.35	.39	
COLUMN	μ		.25	.25	.25	.25	.25	.125	
	σ		.43	.38	.34	.37	.35	.38	

Subject 2

		T1						ROW	
		MEAN	STD DEV	20 MSEC	56 MSEC	80 MSEC	104 MSEC	160 MSEC	μ
		I	I	I	I	I	I	I	
S1		I	I	I	I	I	I	I	
		I	.88	.50	.24	.32	.62	.51	
0.67 DEG		I	.22	.22	.26	.13	.18	.30	
		I	.88	.74	.42	.38	.40	.56	
1.33 DEG		I	.22	.34	.16	.20	.21	.30	
		I	.70	.62	.48	.36	.20	.47	
2 DEG		I	.19	.16	.22	.26	.29	.28	
		I	.68	.64	.46	.16	.20	.43	
2.67 DEG		I	.13	.09	.15	.15	.12	.25	
		I	.62	.60	.52	.44	.18	.47	
3.33 DEG		I	.13	.23	.11	.34	.15	.25	
COLUMN	μ		.75	.62	.42	.33	.32	.49	
	n		25	25	25	25	25	125	
	σ		.20	.22	.20	.23	.25	.28	

Subject 3

T1								ROW
MEAN I	STD DEV I	20 MSEC	56 MSEC	80 MSEC	104 MSEC	160 MSEC	μ	
	I	I	I	I	I	I		
S1	I	I	I	I	I	I		
	I	.18 I	.10 I	.24 I	.30 I	.30 I	.22	
0.67 DEG	I	.13 I	.12 I	.11 I	.07 I	.14 I	.13	
	I	I	I	I	I	I		
	I	.38 I	.56 I	.46 I	.48 I	.40 I	.46	
1.33 DEG	I	.11 I	.21 I	.15 I	.27 I	.00 I	.17	
	I	I	I	I	I	I		
	I	.42 I	.64 I	.54 I	.68 I	.50 I	.56	
2 DEG	I	.08 I	.15 I	.18 I	.22 I	.16 I	.18	
	I	I	I	I	I	I		
	I	.50 I	.62 I	.60 I	.64 I	.56 I	.58	
2.67 DEG	I	.30 I	.23 I	.14 I	.21 I	.18 I	.21	
	I	I	I	I	I	I		
	I	.40 I	.52 I	.56 I	.58 I	.48 I	.51	
3.33 DEG	I	.29 I	.26 I	.34 I	.13 I	.18 I	.24	
	I	I	I	I	I	I		
COLUMN	μ	.38	.49	.48	.54	.45	.47	
	n	25	25	25	25	25	125	
	σ	.22	.27	.23	.22	.16	.23	

Appendix 1.4 Mean proportion (and S.D.) of "second shorter" responses for each sl-t1 combination for each subject. Temporal judgments with right to left presentation.

T = 160 msec

94

		sl/S						ROW μ
		MEAN STD DEV	0.3	0.4	0.5	0.6	0.7	
t1/T		I	I	I	I	I	I	
		I	I	I	I	I	I	
0.3		I	.05 I	.18 I	.59 I	.87 I	.91 I	.52
		I	.05 I	.16 I	.18 I	.08 I	.12 I	.38
0.4		I	.02 I	.09 I	.59 I	.85 I	.96 I	.50
		I	.02 I	.06 I	.15 I	.03 I	.05 I	.40
0.5		I	.03 I	.15 I	.53 I	.89 I	.96 I	.51
		I	.03 I	.10 I	.18 I	.09 I	.04 I	.40
0.6		I	.03 I	.13 I	.54 I	.87 I	.96 I	.51
		I	.04 I	.10 I	.12 I	.06 I	.03 I	.40
0.7		I	.05 I	.11 I	.51 I	.83 I	.97 I	.49
		I	.05 I	.09 I	.11 I	.05 I	.01 I	.39
COLUMN	μ		.04	.13	.55	.86	.95	.51
	n		15	15	15	15	15	75
	σ		.04	.10	.13	.06	.06	.38

T = 320 msec

		sl/S						ROW μ
		MEAN STD DEV	0.3	0.4	0.5	0.6	0.7	
t1/T		I	I	I	I	I	I	
		I	I	I	I	I	I	
0.3		I	.13 I	.27 I	.64 I	.81 I	.93 I	.56
		I	.14 I	.12 I	.16 I	.02 I	.02 I	.33
0.4		I	.15 I	.32 I	.59 I	.80 I	.90 I	.55
		I	.13 I	.14 I	.08 I	.00 I	.04 I	.30
0.5		I	.10 I	.31 I	.55 I	.87 I	.94 I	.55
		I	.05 I	.19 I	.18 I	.05 I	.05 I	.35
0.6		I	.21 I	.30 I	.64 I	.84 I	.91 I	.58
		I	.16 I	.18 I	.12 I	.07 I	.06 I	.31
0.7		I	.10 I	.36 I	.62 I	.86 I	.93 I	.57
		I	.08 I	.22 I	.17 I	.04 I	.04 I	.34
COLUMN	μ		.14	.31	.61	.84	.92	.56
	n		15	15	15	15	15	75
	σ		.11	.15	.13	.05	.04	.32

T = 480 msec

		sl/S						ROW μ
		MEAN STD DEV	0.3	0.4	0.5	0.6	0.7	
t1/T		I	I	I	I	I	I	
		I	I	I	I	I	I	
0.3		I	.10 I	.30 I	.61 I	.73 I	.83 I	.51
		I	.10 I	.07 I	.16 I	.20 I	.17 I	.31
0.4		I	.11 I	.33 I	.61 I	.81 I	.89 I	.55
		I	.10 I	.06 I	.12 I	.06 I	.07 I	.31
0.5		I	.11 I	.33 I	.65 I	.81 I	.86 I	.55
		I	.06 I	.10 I	.09 I	.02 I	.11 I	.31
0.6		I	.15 I	.31 I	.61 I	.82 I	.93 I	.56
		I	.03 I	.16 I	.05 I	.06 I	.05 I	.31
0.7		I	.21 I	.35 I	.67 I	.89 I	.94 I	.61
		I	.05 I	.06 I	.08 I	.07 I	.02 I	.30
COLUMN	μ		.14	.32	.63	.81	.89	.56
	n		15	15	15	15	15	75
	σ		.07	.08	.09	.10	.09	.30

Appendix 2.1 Mean proportion (and S.D.) of "second shorter" responses for each sl-t1 combination in the spatial judgment condition at T = 160, 320 and 480 msec.

T = 640 msec

95

		s1/S						ROW μ
		MEAN I STD DEV	0.3	0.4	0.5	0.6	0.7	
t1/T		I	I	I	I	I	I	
		I	I	I	I	I	I	
0.3		I	.18 I	.41 I	.51 I	.63 I	.84 I	.52
		I	.07 I	.13 I	.15 I	.20 I	.17 I	.26
0.4		I	.14 I	.39 I	.55 I	.77 I	.83 I	.54
		I	.08 I	.13 I	.10 I	.20 I	.18 I	.29
0.5		I	.17 I	.47 I	.67 I	.77 I	.89 I	.59
		I	.07 I	.03 I	.05 I	.09 I	.10 I	.27
0.6		I	.18 I	.33 I	.66 I	.83 I	.94 I	.59
		I	.12 I	.06 I	.20 I	.05 I	.06 I	.32
0.7		I	.13 I	.37 I	.71 I	.81 I	.95 I	.60
		I	.05 I	.05 I	.09 I	.11 I	.04 I	.32
COLUMN		I	.16	.39	.62	.76	.89	.57
		I	.15	.15	.15	.15	.15	.75
		I	.07	.09	.14	.14	.12	.29
		I						

T = 800 msec

		s1/S						ROW μ
		MEAN I STD DEV	0.3	0.4	0.5	0.6	0.7	
t1/T		I	I	I	I	I	I	
		I	I	I	I	I	I	
0.3		I	.17 I	.23 I	.57 I	.83 I	.85 I	.53
		I	.12 I	.17 I	.15 I	.12 I	.08 I	.32
0.4		I	.14 I	.34 I	.58 I	.68 I	.86 I	.52
		I	.05 I	.16 I	.16 I	.17 I	.16 I	.29
0.5		I	.15 I	.30 I	.63 I	.81 I	.87 I	.55
		I	.06 I	.09 I	.11 I	.14 I	.13 I	.30
0.6		I	.15 I	.36 I	.61 I	.87 I	.95 I	.59
		I	.09 I	.04 I	.03 I	.01 I	.02 I	.32
0.7		I	.13 I	.31 I	.65 I	.83 I	.99 I	.58
		I	.10 I	.03 I	.01 I	.07 I	.01 I	.34
COLUMN		I	.15	.31	.61	.80	.90	.55
		I	.15	.15	.15	.15	.15	.75
		I	.08	.11	.10	.12	.10	.31
		I						

T = 1,000 msec

		s1/S						ROW μ
		MEAN I STD DEV	0.3	0.4	0.5	0.6	0.7	
t1/T		I	I	I	I	I	I	
		I	I	I	I	I	I	
0.3		I	.10 I	.31 I	.42 I	.70 I	.70 I	.45
		I	.08 I	.14 I	.09 I	.11 I	.14 I	.26
0.4		I	.15 I	.31 I	.57 I	.79 I	.78 I	.52
		I	.09 I	.08 I	.10 I	.09 I	.13 I	.28
0.5		I	.12 I	.34 I	.66 I	.76 I	.87 I	.55
		I	.09 I	.11 I	.05 I	.14 I	.01 I	.30
0.6		I	.13 I	.35 I	.65 I	.87 I	.91 I	.58
		I	.03 I	.05 I	.17 I	.09 I	.06 I	.32
0.7		I	.10 I	.34 I	.69 I	.90 I	.97 I	.60
		I	.06 I	.09 I	.11 I	.02 I	.03 I	.35
COLUMN		I	.12	.33	.60	.80	.85	.54
		I	.15	.15	.15	.15	.15	.75
		I	.07	.08	.14	.11	.13	.30
		I						

Appendix 2.2 Mean proportion (and S.D.) of "second shorter" responses for each s1-t1 combination in the spatial judgment condition at T = 640, 800 and 1,000 msec.

T = 1,200 msec

		s1/s						ROW μ
		MEAN STD DEV	0.3	0.4	0.5	0.6	0.7	
t1/T		I	I	I	I	I	I	
		I	I	I	I	I	I	
0.3		I	.10 I	.28 I	.41 I	.59 I	.65 I	.41
		I	.06 I	.07 I	.11 I	.14 I	.09 I	.22
0.4		I	.12 I	.31 I	.45 I	.63 I	.79 I	.46
		I	.05 I	.15 I	.11 I	.17 I	.10 I	.26
0.5		I	.06 I	.29 I	.53 I	.67 I	.74 I	.46
		I	.05 I	.17 I	.05 I	.13 I	.13 I	.28
0.6		I	.09 I	.31 I	.56 I	.76 I	.80 I	.50
		I	.03 I	.15 I	.14 I	.16 I	.07 I	.30
0.7		I	.09 I	.29 I	.69 I	.85 I	.92 I	.57
		I	.02 I	.12 I	.10 I	.03 I	.07 I	.34
COLUMN			.09	.30	.53	.70	.78	.48
			15	15	15	15	15	75
			.04	.12	.13	.15	.12	.28

T = 1,500 msec

		s1/s						ROW μ
		MEAN STD DEV	0.3	0.4	0.5	0.6	0.7	
t1/T		I	I	I	I	I	I	
		I	I	I	I	I	I	
0.3		I	.19 I	.39 I	.41 I	.55 I	.65 I	.44
		I	.11 I	.24 I	.28 I	.18 I	.22 I	.24
0.4		I	.24 I	.39 I	.62 I	.70 I	.75 I	.54
		I	.09 I	.09 I	.16 I	.21 I	.14 I	.24
0.5		I	.15 I	.45 I	.48 I	.73 I	.81 I	.53
		I	.04 I	.17 I	.13 I	.12 I	.20 I	.27
0.6		I	.23 I	.35 I	.63 I	.71 I	.85 I	.55
		I	.05 I	.16 I	.25 I	.16 I	.14 I	.28
0.7		I	.15 I	.37 I	.68 I	.79 I	.88 I	.57
		I	.08 I	.06 I	.09 I	.09 I	.13 I	.29
COLUMN			.19	.39	.56	.70	.79	.53
			15	15	15	15	15	75
			.08	.14	.20	.16	.17	.26

Appendix 2.3 Mean proportion (and S.D.) of "second shorter" responses for each s1-t1 combination in the spatial judgment condition at T = 1,200 and 1,500 msec.

T = 160 msec

97

		t1/T						ROW	
		MEAN	STD DEV	0.3	0.4	0.5	0.6	0.7	
sl/s	I	I	I	I	I	I	I	I	μ
	I	I	I	I	I	I	I	I	
0.3	I	.16	I	.15	I	.15	I	.13	.23
	I	.05	I	.08	I	.05	I	.04	.05
0.4	I	.22	I	.17	I	.31	I	.35	.31
	I	.14	I	.10	I	.08	I	.04	.04
0.5	I	.53	I	.55	I	.53	I	.57	.59
	I	.31	I	.31	I	.19	I	.14	.13
0.6	I	.72	I	.80	I	.69	I	.77	.79
	I	.36	I	.20	I	.31	I	.17	.15
0.7	I	.73	I	.81	I	.85	I	.82	.80
	I	.32	I	.27	I	.11	I	.20	.16
COLUMN		.47		.50		.51		.53	.54
		15		15		15		15	75
		.34		.35		.30		.29	.26

T = 320 msec

		t1/T						ROW	
		MEAN	STD DEV	0.3	0.4	0.5	0.6	0.7	
sl/S	I	I	I	I	I	I	I	I	
		I	I	I	I	I	I	I	
0.3	I	.15	I	.23	I	.36	I	.35	.32
	I	.11	I	.04	I	.24	I	.21	.21
0.4	I	.37	I	.34	I	.40	I	.58	.47
	I	.17	I	.09	I	.17	I	.26	.20
0.5	I	.51	I	.58	I	.63	I	.69	.62
	I	.22	I	.09	I	.06	I	.16	.16
0.6	I	.71	I	.71	I	.81	I	.79	.77
	I	.22	I	.12	I	.12	I	.11	.14
0.7	I	.69	I	.77	I	.80	I	.91	.81
	I	.31	I	.17	I	.13	I	.05	.17
COLUMN	μ	.48		.52		.60		.66	.60
	n	15		15		15		15	75
	σ	.28		.24		.24		.25	.26

T = 480 msec

		t1/T						ROW	
		MEAN I	STD DEV I	0.3	0.4	0.5	0.6	0.7	
sl/S	I	I	I	I	I	I	I	I	
		I	I	I	I	I	I	I	
0.3	I	.11 I	.20 I	.48 I	.65 I	.76 I			.44
	I	.04 I	.06 I	.28 I	.25 I	.18 I			.31
0.4	I	.15 I	.29 I	.58 I	.79 I	.87 I			.54
	I	.10 I	.05 I	.16 I	.15 I	.11 I			.30
0.5	I	.22 I	.37 I	.72 I	.87 I	.91 I			.62
	I	.19 I	.04 I	.14 I	.09 I	.10 I			.30
0.6	I	.33 I	.58 I	.73 I	.89 I	.94 I			.70
	I	.16 I	.05 I	.06 I	.12 I	.08 I			.25
0.7	I	.44 I	.68 I	.84 I	.93 I	.95 I			.77
	I	.17 I	.12 I	.12 I	.08 I	.08 I			.22
COLUMN	μ	.25	.43	.67	.83	.89			.61
	n	15	15	15	15	15			75
	σ	.17	.19	.19	.16	.12			.30

Appendix 2.4 Mean proportion (and S.D.) of "second shorter" responses for each sl-t combination in the temporal judgment condition at T = 160, 320 and 480 msec.

$$T = 800 \text{ msec}$$

T = 1,000 msec

Appendix 2.5 Mean proportion (and S.D.) of "second shorter" responses for each sl-tl combination in the temporal judgment condition at T = 640, 800 and 1,000 msec.

T = 1,200 msec

		t1/T					ROW μ
		0.3	0.4	0.5	0.6	0.7	
s1/S	MEAN I	I	I	I	I	I	
	STD DEV I	I	I	I	I	I	
0.3		.00 I	.21 I	.70 I	.89 I	.97 I	.55
		.00 I	.10 I	.18 I	.05 I	.03 I	.40
0.4		.01 I	.25 I	.73 I	.95 I	.97 I	.58
		.02 I	.15 I	.16 I	.04 I	.03 I	.41
0.5		.02 I	.27 I	.78 I	.96 I	.97 I	.60
		.00 I	.07 I	.15 I	.05 I	.03 I	.41
0.6		.02 I	.39 I	.84 I	.96 I	1.00 I	.64
		.02 I	.10 I	.09 I	.04 I	.00 I	.40
0.7		.02 I	.41 I	.90 I	.99 I	.99 I	.66
		.03 I	.06 I	.06 I	.02 I	.01 I	.40
COLUMN	μ	.02	.31	.79	.95	.98	.61
	n	15	15	15	15	15	75
	σ	.02	.12	.14	.05	.02	.39

T = 1,500 msec

		t1/T					ROW μ
		0.3	0.4	0.5	0.6	0.7	
s1/S	MEAN I	I	I	I	I	I	
	STD DEV I	I	I	I	I	I	
0.3		.02 I	.19 I	.63 I	.91 I	.97 I	.54
		.01 I	.13 I	.18 I	.11 I	.05 I	.41
0.4		.00 I	.25 I	.76 I	.89 I	.97 I	.57
		.00 I	.08 I	.12 I	.10 I	.04 I	.40
0.5		.01 I	.29 I	.75 I	.95 I	.97 I	.59
		.01 I	.24 I	.11 I	.04 I	.03 I	.41
0.6		.02 I	.38 I	.78 I	.94 I	.98 I	.62
		.03 I	.12 I	.18 I	.05 I	.03 I	.39
0.7		.03 I	.58 I	.86 I	.96 I	.99 I	.68
		.03 I	.21 I	.10 I	.02 I	.01 I	.38
COLUMN	μ	.02	.34	.76	.93	.98	.60
	n	15	15	15	15	15	75
	σ	.02	.20	.14	.07	.03	.39

Appendix 2.6 Mean proportion (and S.D.) of "second shorter" responses for each s1-t1 combination in the temporal judgment condition at T = 1,200 and 1,500 msec.

sl = 2 deg

		S3				ROW μ
		MEAN I STD DEV I	2 DEG	3 DEG	4 DEG	
T3		I	I	I	I	
400 MSEC		I	3.92 I .82 I	2.58 I .63 I	1.70 I .38 I	2.73 1.11
600 MSEC		I	3.50 I .49 I	2.35 I .43 I	1.82 I .41 I	2.56 .84
900 MSEC		I	3.05 I .97 I	1.86 I .39 I	1.52 I .49 I	2.14 .92
COLUMN	μ n σ		3.49 18 .82	2.27 18 .56	1.58 18 .42	2.48 54 .98

sl = 2 deg

		S3				ROW μ
		MEAN I STD DEV I	2 DEG	3 DEG	4 DEG	
T3		I	I	I	I	
400 MSEC		I	3.70 I .64 I	2.58 I .50 I	1.60 I .35 I	2.53 1.01
600 MSEC		I	3.33 I .65 I	2.30 I .46 I	1.57 I .44 I	2.43 .86
800 MSEC		I	3.17 I .67 I	2.38 I .48 I	1.73 I .76 I	2.43 .86
COLUMN	μ n σ		3.40 18 .66	2.42 18 .47	1.67 18 .52	2.50 54 .90

sl = 3 deg

		S3				ROW μ
		MEAN I STD DEV I	2 DEG	3 DEG	4 DEG	
T3		I	I	I	I	
400 MSEC		I	4.68 I .92 I	4.00 I 1.18 I	2.37 I .90 I	3.48 1.38
600 MSEC		I	4.28 I .46 I	3.31 I .64 I	2.32 I .59 I	3.30 .98
900 MSEC		I	4.17 I 1.13 I	3.20 I .69 I	2.20 I .59 I	3.19 1.14
COLUMN	μ n σ		4.38 18 .86	3.50 18 .90	2.29 18 .57	3.39 54 1.17

sl = 3 deg

		S3				ROW μ
		MEAN I STD DEV I	2 DEG	3 DEG	4 DEG	
T3		I	I	I	I	
400 MSEC		I	4.35 I .75 I	3.73 I .67 I	2.68 I .58 I	3.59 .95
600 MSEC		I	4.53 I .40 I	3.25 I .73 I	2.58 I .35 I	3.46 .97
800 MSEC		I	3.90 I .66 I	3.36 I .38 I	2.42 I .70 I	3.23 .84
COLUMN	μ n σ		4.26 18 .64	3.45 18 .61	2.56 18 .54	3.42 54 .92

sl = 4 deg

		S3				ROW μ
		MEAN I STD DEV I	2 DEG	3 DEG	4 DEG	
T3		I	I	I	I	
400 MSEC		I	5.27 I .64 I	4.66 I .92 I	4.05 I .92 I	4.66 .94
600 MSEC		I	4.94 I .78 I	4.38 I .96 I	3.58 I .91 I	4.30 1.01
800 MSEC		I	4.95 I .43 I	4.02 I .53 I	3.55 I .94 I	4.17 .87
COLUMN	μ n σ		5.05 18 .61	4.35 18 .92	3.73 18 .90	4.38 54 .95

sl = 4 deg

		S3				ROW μ
		MEAN I STD DEV I	2 DEG	3 DEG	4 DEG	
T3		I	I	I	I	
400 MSEC		I	5.15 I .63 I	4.47 I .73 I	3.93 I .66 I	4.52 .82
600 MSEC		I	5.00 I .51 I	4.22 I .86 I	3.35 I .63 I	4.19 .94
800 MSEC		I	4.98 I .34 I	4.00 I .69 I	3.40 I .68 I	4.13 .87
COLUMN	μ n σ		5.04 18 .48	4.23 18 .74	3.56 18 .67	4.28 54 .88

Appendix 3.1 Mean confidence rating (and S.D.) on s3 at each temporal separation (t3) for sl = 2, 3 and 4 deg in the Induction and NI - long conditions.

NI - shorts1 = 2 deg

		S3				ROW μ
		MEAN I	2 DEG	3 DEG	4 DEG	
		STD DEV I				
		I	I	I	I	
T3		I	I	I	I	
400 MSEC		I	3.17 I	2.88 I	2.52 I	2.85
		I	1.10 I	.90 I	1.09 I	1.01
		-I	I	I	I	
600 MSEC		I	2.87 I	2.65 I	2.37 I	2.63
		I	.68 I	.93 I	.88 I	.78
		-I	I	I	I	
800 MSEC		I	2.72 I	2.47 I	1.83 I	2.34
		I	.58 I	.50 I	.47 I	.52
		-I	I	I	I	
COLUMN	μ		2.92	2.67	2.24	2.61
	n		18	18	18	54
	σ		.79	.74	.85	.83

s1 = 3 deg

		S3				ROW μ
		MEAN I	2 DEG	3 DEG	4 DEG	
		STD DEV I				
		I	I	I	I	
T3		I	I	I	I	
400 MSEC		I	3.83 I	3.28 I	2.87 I	3.33
		I	.80 I	.90 I	1.00 I	.94
		-I	I	I	I	
600 MSEC		I	3.65 I	3.28 I	2.77 I	3.23
		I	.97 I	.48 I	.75 I	.81
		-I	I	I	I	
800 MSEC		I	3.58 I	2.73 I	2.63 I	2.98
		I	.90 I	.64 I	.51 I	.79
		-I	I	I	I	
COLUMN	μ		3.69	3.10	2.76	3.18
	n		18	18	18	54
	σ		.84	.70	.74	.85

s1 = 4 deg

		S3				ROW μ
		MEAN I	2 DEG	3 DEG	4 DEG	
		STD DEV I				
		I	I	I	I	
T3		I	I	I	I	
400 MSEC		I	4.65 I	4.43 I	3.85 I	4.31
		I	.71 I	.48 I	1.00 I	.79
		-I	I	I	I	
600 MSEC		I	4.18 I	3.98 I	3.10 I	3.76
		I	.41 I	.76 I	.57 I	.74
		-I	I	I	I	
800 MSEC		I	3.99 I	3.58 I	3.02 I	3.53
		I	.75 I	.64 I	.28 I	.59
		-I	I	I	I	
COLUMN	μ		4.28	4.00	3.32	3.87
	n		18	18	18	54
	σ		.66	.70	.75	.80

Appendix 3.2 Mean confidence rating (and S.D.) on s3 at each temporal separation (t3) for s1 = 2, 3, 4 deg in the NI - short condition.

t1 = 400 msec

		T3				ROW	
		MEAN I	STD DEV I	400 MSEC	500 MSEC	800 MSEC	
		I	I	I	I	I	μ
S3		I	I	I	I	I	
		I	4.20 I	2.75 I	2.33 I	I	3.09
2 DEG		I	.24 I	.78 I	1.40 I	I	1.20
		I	I	I	I	I	
		I	3.07 I	2.02 I	1.42 I	I	2.17
3 DEG		I	1.18 I	.69 I	.20 I	I	1.03
		I	I	I	I	I	
		I	2.78 I	1.78 I	1.43 I	I	1.97
4 DEG		I	1.06 I	.54 I	.37 I	I	.90
		I	I	I	I	I	
COLUMN	μ		3.35	2.16	1.73		2.41
	n		18	18	18		54
	σ		1.07	.78	.91		1.14

t1 = 400 msec

		T3				ROW	
		MEAN I	STD DEV I	400 MSEC	500 MSEC	800 MSEC	
		I	I	I	I	I	μ
S3		I	I	I	I	I	
		I	I	I	I	I	
2 DEG		I	4.30 I	2.52 I	2.02 I	I	2.94
		I	.55 I	.90 I	1.12 I	I	1.31
		I	I	I	I	I	
3 DEG		I	3.28 I	2.18 I	1.52 I	I	2.33
		I	.97 I	.44 I	.44 I	I	.98
		I	I	I	I	I	
4 DEG		I	3.15 I	1.62 I	1.27 I	I	2.01
		I	1.22 I	.57 I	.23 I	I	1.12
		I	I	I	I	I	
COLUMN	μ		3.58	2.11	1.60		2.43
	n		18	18	18		54
	σ		1.04	.73	.74		1.19

t1 = 600 msec

		T3				ROW
		MEAN I				
		STD DEV I	400 MSEC	500 MSEC	800 MSEC	μ
		I	I	I	I	
		I	I	I	I	
S3		I	I	I	I	
		I	5.36 I	4.47 I	3.25 I	4.36
		I	.39 I	.84 I	1.59 I	1.34
2 DEG		I	I	I	I	
		I	5.18 I	3.73 I	2.45 I	3.79
		I	.42 I	.44 I	.71 I	1.26
3 DEG		I	I	I	I	
		I	4.17 I	3.17 I	2.10 I	3.14
		I	1.57 I	1.27 I	.62 I	1.44
4 DEG		I	I	I	I	
		I	I	I	I	
COLUMN	μ		4.90	3.79	2.60	3.76
	n		18	18	18	54
	σ		1.05	1.02	1.12	1.41

t1 = 600 msec

		T3				ROW
		MEAN I				
		STD DEV I	400 MSEC	500 MSEC	800 MSEC	
		I	I	I	I	μ
S3		I	1 I	2 I	3 I	
	1	I	5.47 I	4.17 I	3.20 I	4.28
2 DEG		I	.45 I	.71 I	1.50 I	1.33
	2	I	5.00 I	3.48 I	2.57 I	3.68
3 DEG		I	.85 I	.41 I	.64 I	1.20
	3	I	4.48 I	2.90 I	1.95 I	3.11
4 DEG		I	1.54 I	.69 I	.48 I	1.44
		I				
COLUMN	μ		4.98	3.52	2.57	3.69
	n		18	18	18	54
	σ		1.07	.79	1.06	1.39

t1 = 800 msec

		T3				ROW
		MEAN STD DEV	400 MSEC	500 MSEC	800 MSEC	
S3		I	I	I	I	
		I	5.62 I	4.73 I	3.75 I	4.70
2 DEG		I	.55 I	.83 I	1.14 I	1.14
		I	I	I	I	
		I	5.65 I	4.75 I	3.75 I	4.72
3 DEG		I	.19 I	.89 I	.98 I	1.08
		I	I	I	I	
		I	5.08 I	4.27 I	3.37 I	4.24
4 DEG		I	.79 I	.72 I	.39 I	.95
		I	I	I	I	
COLUMN	μ		5.45	4.58	3.52	4.55
	n		18	18	18	54
	σ		.60	.80	.86	1.06

t1 = 800 msec

		T3				ROW
		MEAN I				
		STD DEV I	400 MSEC	600 MSEC	800 MSEC	
		I	I	I	I	μ
S3		I	I	I	I	
		I	5.58 I	4.85 I	3.92 I	4.78
2 DEG		I	.44 I	.72 I	1.19 I	1.06
		-I	I	I	I	
		I	5.53 I	4.57 I	3.82 I	4.44
3 DEG		I	.46 I	.77 I	.99 I	1.02
		-I	I	I	I	
		I	5.08 I	3.78 I	3.35 I	4.07
4 DEG		I	.80 I	.45 I	.34 I	.93
		-I	I	I	I	
COLUMN	μ		5.40	4.40	3.69	4.50
	n		18	18	18	54
	σ		.60	.78	.90	1.03

Appendix 3.3 Mean confidence rating (and S.D.) on t3 at each spatial separation (s3) for t1 = 400, 600 and 800 msec in the Induction and NI - long conditions.

NI - short

t1 = 400 msec

		T3			ROW μ
		MEAN I	STD DEV I		
		400 MSEC	500 MSEC	800 MSEC	
		I	I	I	I
S3	-----	I	I	I	I
		I	I	I	I
		I	I	I	I
2 DEG		I	I	I	I
		I	I	I	I
		I	I	I	I
3 DEG		I	I	I	I
		I	I	I	I
		I	I	I	I
4 DEG		I	I	I	I
		I	I	I	I
		I	I	I	I
COLUMN	μ	3.38	2.13	1.54	2.35
	n	18	18	18	54
	σ	.85	.76	.80	1.11

t1 = 600 msec

		T3			ROW μ
		MEAN I	STD DEV I		
		400 MSEC	500 MSEC	800 MSEC	
		I	I	I	I
S3	-----	I	I	I	I
		I	I	I	I
		I	I	I	I
2 DEG		I	I	I	I
		I	I	I	I
		I	I	I	I
3 DEG		I	I	I	I
		I	I	I	I
		I	I	I	I
4 DEG		I	I	I	I
		I	I	I	I
		I	I	I	I
COLUMN	μ	4.69	3.28	2.79	3.45
	n	18	18	18	54
	σ	1.13	.87	1.09	1.40

t1 = 800 msec

		T3			ROW μ
		MEAN I	STD DEV I		
		400 MSEC	500 MSEC	800 MSEC	
		I	I	I	I
S3	-----	I	I	I	I
		I	I	I	I
		I	I	I	I
2 DEG		I	I	I	I
		I	I	I	I
		I	I	I	I
3 DEG		I	I	I	I
		I	I	I	I
		I	I	I	I
4 DEG		I	I	I	I
		I	I	I	I
		I	I	I	I
COLUMN	μ	5.16	4.36	3.39	4.30
	n	18	18	18	54
	σ	.70	.75	1.11	1.13

Appendix 3.4 Mean confidence rating (and S.D.) on t3 at each spatial separation (s3) for t1 = 400, 600 and 800 msec in the NI - short condition.

Negative acceleration induction

T	MEAN I STD DEV I		S					ROW μ
	I		1 I	2 I	3 I	4 I	5 I	
600 MSEC	I	I	1.72 I .59 I	2.54 I .65 I	2.70 I .57 I	3.50 I .33 I	3.70 I .32 I	2.83 .86
700 MSEC	I	I	2.08 I .66 I	2.18 I .51 I	2.78 I .47 I	3.40 I .28 I	3.95 I .50 I	2.88 .86
800 MSEC	I	I	1.98 I .25 I	2.34 I .43 I	2.97 I .39 I	3.54 I .52 I	4.07 I .48 I	2.98 .87
900 MSEC	I	I	1.90 I .54 I	2.44 I .38 I	3.14 I .19 I	3.60 I .28 I	3.82 I .41 I	2.98 .81
1 SEC	I	I	2.28 I .52 I	2.56 I .52 I	3.03 I .37 I	3.68 I .30 I	4.22 I .20 I	3.15 .82
COLUMN	μ	σ	1.99 25 .52	2.41 25 .48	2.92 25 .42	3.54 25 .34	3.95 25 .41	2.96 125 .84

Zero acceleration induction

T	MEAN I STD DEV I		S					ROW μ
	I		1 I	2 I	3 I	4 I	5 I	
600 MSEC	I	I	1.72 I .63 I	2.42 I .95 I	2.64 I .62 I	3.36 I .62 I	3.88 I .41 I	2.80 .98
700 MSEC	I	I	1.86 I .37 I	2.50 I .56 I	2.68 I .30 I	3.54 I .42 I	4.04 I .33 I	2.92 .87
800 MSEC	I	I	2.04 I .59 I	2.44 I .62 I	2.96 I .55 I	3.66 I .31 I	4.16 I .38 I	3.05 .92
900 MSEC	I	I	2.08 I .63 I	2.56 I .34 I	3.06 I .67 I	3.48 I .39 I	4.12 I .11 I	3.06 .84
1 SEC	I	I	2.23 I .47 I	2.78 I .51 I	3.42 I .50 I	3.80 I .32 I	4.08 I .41 I	3.26 .80
COLUMN	μ	σ	1.99 25 .53	2.54 25 .59	2.95 25 .42	3.57 25 .42	4.06 25 .33	3.02 125 .88

Positive acceleration induction

T	MEAN I STD DEV I		S					ROW μ
	I		1 I	2 I	3 I	4 I	5 I	
600 MSEC	I	I	1.92 I .63 I	2.28 I .52 I	3.26 I .68 I	3.42 I .11 I	3.90 I .52 I	2.96 .90
700 MSEC	I	I	2.08 I .67 I	2.42 I .55 I	3.29 I .63 I	3.70 I .63 I	4.34 I .60 I	3.17 1.01
800 MSEC	I	I	2.31 I .47 I	2.88 I .73 I	3.24 I .46 I	4.05 I .27 I	4.16 I .26 I	3.33 .83
900 MSEC	I	I	2.14 I .62 I	2.88 I .59 I	3.26 I .60 I	3.76 I .61 I	4.46 I .31 I	3.30 .95
1 SEC	I	I	2.13 I .76 I	2.89 I .21 I	3.46 I .30 I	3.78 I .50 I	4.28 I .31 I	3.31 .87
COLUMN	μ	σ	2.12 25 .60	2.67 25 .57	3.30 25 .51	3.74 25 .48	4.23 25 .43	3.21 125 .91

Appendix 4. Mean judgment (and S.D.) on distance (s) at each temporal separation (t) for each of the three induction conditions.

		S					
		MEAN I					
		STD DEV I					
		I					
		I	1 I	2 I	3 I	4 I	5 I
T		I	I	I	I	I	I
600 MSEC	1	I	1.79 I	2.41 I	2.87 I	3.43 I	3.83 I
		I	.58 I	.68 I	.65 I	.39 I	.40 I
		-I	-I	-I	-I	-I	-I
700 MSEC	2	I	2.01 I	2.37 I	2.92 I	3.55 I	4.11 I
		I	.55 I	.52 I	.53 I	.45 I	.48 I
		-I	-I	-I	-I	-I	-I
800 MSEC	3	I	2.11 I	2.55 I	3.06 I	3.75 I	4.13 I
		I	.45 I	.61 I	.46 I	.42 I	.36 I
		-I	-I	-I	-I	-I	-I
900 MSEC	4	I	2.04 I	2.63 I	3.15 I	3.61 I	4.13 I
		I	.56 I	.46 I	.50 I	.43 I	.39 I
		-I	-I	-I	-I	-I	-I
1 SEC	5	I	2.21 I	2.74 I	3.30 I	3.75 I	4.19 I
		I	.56 I	.43 I	.42 I	.36 I	.31 I
		-I	-I	-I	-I	-I	-I
COLUMN TOTAL			2.03	2.54	3.06	3.62	4.08
			.75	.75	.75	.75	.75
			.55	.55	.53	.42	.41

Appendix 4.2 Mean judgment (and S.D.) on distance (s) at each temporal separation (t), collapsed across all induction conditions.

END

1	0	5	H	0	9	H	8	4
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FIN