TONAL INTENSITY AND THE AUDITORY KAPPA EFFECT

by

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A Thesis submitted to the Faculty of Graduate Studies of

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RUNNING HEAD: TONAL INTENSITY

THE UNIVERSITY OF MANITOBA

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ABSTRACT

The current study examined a temporal illusion called the auditory kappa effect. It has been demonstrated that a large change in frequency between successive tones elicits the perception of a greater duration time interval. The set of experiments followed an AXB paradigm, with tones A and B at intensity levels 55 and 70 dB, while tone X varied in intensity. Participants judged the durations of the inter-stimulus intervals as 'long-short' or 'short-long' to test whether kappa effects occur for intensity change. Experiment 1 determined that participants perceive similar intensity level tones as occurring closer together in time. Experiment's 2 and 3 tested the auditory motion hypothesis for the kappa effect by presenting participants with a 3-tone stable-intensity context sequences and a varying-intensity context sequences respectively prior to each AXB pattern. Kappa effects were disrupted when context sequences consisted of stable-intensity tones and were maintained when they consisted of varying-intensity tones.

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Time Perception and the Kappa Effect

How people perceive the passage of time has continued to be an area of scientific interest. Previous research has demonstrated the susceptibility of a person's time judgments to non-temporal sources of bias. These studies have found that contextual elements can influence the perceived duration of a time interval (reviewed by Fraisse, 1984). One famous example is that of the filled duration illusion, where the perceived length of an interval is increased by presenting stimuli within the interval (Block, 1974; Buffardi, 1971; Ornstein, 1969). Stimulus meaning can also influence perceived duration. For example, faces displaying emotion are judged as longer than neutral faces (Effron, Niedenthal, Gil, & Droit-Volet, 2006) while words are judged as longer than non-words (Reber, Zimmerman and Wurtz, 2004).

The degree of spatial discrepancy between successive stimuli is one of the most studied non-temporal dimensions found to bias temporal perception (in which larger distances are perceived as having longer durations). Similarly, it has been found that duration length can bias spatial perception (in which longer durations are perceived as indicating greater distances). These perceptual illusions have been termed kappa and tau effects respectively. The tau effect was defined by Helson (1930) and Helson & King (1931) in an experiment where three points were stimulated on a participant's arm. These points were equidistant and touched in succession with a blunt fiber-tipped rod. Participants misperceived points one and two as being further apart when the duration separating them was longer than the duration separating points two and three. Additional studies have found tau effects in both vision (Benussi, 1913; Bill & Teft, 1969; Geldreigh, 1934) and audition (Christiansen & Huang, 1979).

The kappa effect was initially defined by Cohen, Hansel & Sylvester (1953) in order to differentiate it from the tau effect. In a series of experiments, participants witnessed a sequence

of three lights that were spatially and temporally distinct. The distances separating the lights (called inter-stimulus intervals) were either equal (30 mm each) or unequal (50 mm & 30 mm). When timing was held constant, the spatially larger interval was misperceived as having a longer duration. This effect persisted even when the duration of the spatially larger interval was made significantly shorter than the smaller interval. The kappa effect, like the tau effect, has been widely demonstrated in both vision (Abe, 1935; Casasanto & Boroditsky, 2008; Cohen, Hansel & Sylvester, 1953; Lebensfeld & Wapner, 1968; Matsuda, 1974; Newman & Lee, 1972) and audition (Allan, 1984; Boltz, 1998; Cohen, Hansel & Sylvester, 1954, Crowder & Neath, 1994, Sarrazin, Giraudo & Pittenger, 2007; Shingeno, 1986; Shingeno, 1993).

In early studies, the standard procedure for eliciting kappa effects involved a temporal bisection task. Cohen, Hansel and Sylvester (1953), for example, had participants view a repeating sequence of three spatially distinct lights. Across trials the experimenters positioned the middle light so that it was spatially closer to either the first or third light. The participants were tasked with adjusting the second light's timing until they reported it as occurring at the halfway point. The experimenters found that when lights one and two were placed in close spatial proximity, the interval separating them were perceived by participants as short in duration (even when it equaled the duration separating lights two and three). Cohen, Hansel and Sylvester (1954) went on to apply this procedure to auditory perception, finding similar results. Participants were presented with a repeating sequence of three tones that varied in frequency. On each trial the first and third tones were set at fixed frequencies (1,000 & 3,000 Hz), while the middle tone had one of three possible frequencies (1,676 Hz, 1,874 Hz & 2,068 Hz). Participants were told to adjust the tone's timing until they perceived two equal duration inter-stimulus

intervals. When the middle tone was closer in frequency to a bounding tone the time interval between them was misperceived as short.

Shingeno (1986; 1993) modified this procedure in her experiments by using an AXB paradigm. Participants listened to patterns composed of three successive tones and then judged whether the middle occurring tone (tone X) was closer in time to either the first tone (A) or the third tone (B). The middle tone (X) varied in frequency across trials (ranging from 1350 to 2150 Hz), while tones A and B were set at 1000 and 2500 Hz respectively. When the middle tone was closer in frequency to the first tone, participants reported it as closer to Tone A in time. The reverse occurred when the middle tone was closer in frequency to the Tone B. Crowder and Neath (1994) replicated this finding, showing that participants perceived inter-stimulus interval durations as 'long' when successive tones were separated by a greater degree of frequency. Interestingly, this result was found despite having the middle tone (X) fall outside of the frequency-interval defined by tones A and B (tone X was always higher in frequency than both tones A and B, while B was higher in frequency than A). Therefore, it can be concluded that maintaining continuous pitch change across successive tones is unnecessary to elicit auditory kappa effects.

A number of recent studies have demonstrated auditory kappa effects by varying the location of a tone's physical spatial location rather than its frequency. Sarrazin, Giraudo and Pittenger (2007) presented participants with patterns composed of eight identical tones that proceeded horizontally from left to right. The experimenters used four pattern types, 1) a constant spatial + constant temporal condition, in which the distances separating each tone was 26.36 cm with durations of 373 ms, 2) a constant spatial + varying temporal condition in which the distances separating each tone was 26.36 cm, with varying durations (from 191 ms to 560

ms), 3) a varying spatial + constant temporal condition in which the distances separating each tone varied across the pattern (from 13.5 cm to 39.58 cm) with constant durations of 373 ms, and 4) a varying spatial + varying temporal condition in which the distance and the timing between each successive tone varied. Participants were instructed to recreate the timing of each sequence by pressing a button eight times (each press denoting the onset of a tone in the previous pattern). Participants exhibited kappa effects only for patterns that had constant time intervals with varying spatial distances. In these cases, participants recreated the pattern's timing so that it reflected the pattern's varying spatial attributes.

In a similar demonstration Grondin and Plourde (2007) had participants listen to a sequence of four tones. The first three tones in each pattern were emitted from a single speaker placed directly in front of the participant, while the last tone was presented from a speaker located to either the left or right side. All of the inter-stimulus interval durations were held constant except for the final interval (separating tones three and four). Participants were tasked with judging whether the final interval was 'shorter' or 'longer' than the preceding intervals. Across trials, the researchers manipulated the spatial distance the tone travelled on the final interval, defined as either large (2.2 m) or small (1.1 m). Lastly, participants fell into one of two between-subjects conditions, a group that knew what direction the final tone would move to (certainty condition) and a group that was unaware what direction it would move to (uncertainty condition). It was found that only participants in the uncertainty condition exhibited kappa effects, where participants were biased to report large distances as 'long' in duration and small distances as 'short' in duration. Additionally, a study discussed by Hoopen et al. (2008) may provide additional evidence for auditory kappa effects existing for variations in physical space. In this study, isochronous tonal sequences presented in one ear were judged as faster than

sequences which alternated between ears. The added physical distance caused by alternating the sound from one speaker to another increased the perceived duration of the intervals, resulting in a perceptually slower pattern.

The Illusory-Motion Hypothesis

The most referenced theory for the kappa effect is called the illusory-motion hypothesis. This theory is based on apparent motion experiments concerning the phi phenomenon (Koffka, 1963; Wertheimer, 1912). The phi phenomenon occurs when a sequence of spatially and temporally distinct visual stimuli are presented in succession at a velocity that causes the illusion of a single moving object, also called stroboscopic motion (Koffka, 1963). Koffka noted that when perceiving stroboscopic motion people are formulating estimates concerning phenomenonal velocity. By his definition, the perceived stroboscopic velocity is the speed that a stimulus would have to maintain to travel between two successive points were it a single object in motion. Koffka discusses the potential limits of the stroboscopic phenomenon as being determined by the duration of the interval (t) demarking two successive stimuli "If t becomes too great or too small, no stroboscopic motion is seen; in the first case the two objects appear as two in *succession*, in the second as two in *simultaneity*. Between these two stages of succession and simultaneity lies the stage of optimal motion, surrounded on either side by intermediate stages." (Koffka, 1963, P. 292).

Price-Williams (1954) and Cohen, Hansel & Sylvester (1955) suggested that the kappa effect may result from perceiving motion-like properties into a sequence of static stimuli. This theory has since been revised into the constant velocity or imputed-velocity theory (Anderson, 1974; Collyer, 1977; Jones & Huang, 1982). It is hypothesized that the visual kappa effect is the result of participants making automatic calculations about the velocity at which a stimulus

sequence is traveling. According to Collyer (1977), people expect that stimuli will maintain a constant velocity across a defined inter-stimulus interval. Therefore, the expected time is reached by dividing the distance traveled (d) by velocity (v), $E(t) = d/v$. The intervals separating each stimulus can be defined by their duration, or time (t) and their distance, or spatial separation (s) which is quantified as ($t1$, $t2$) and ($s1$, $s2$). The kappa effect is said to arise when the space/time ratio defining the two intervals is equated ($s1/t1 = s2/t2$). Put simply, if people perceive velocity as constant, it can be expected that it will take longer to travel between two points that are further apart in space than to travel between two points that are closer together (Jones & Huang, 1982). A duration judgment is said to reflect a weighted average of the actual objective interval duration and the expected duration given a constant velocity (Anderson, 1974). The expected duration is based on the contextual connection between time and a related non-temporal dimension (i.e. physical space, pitch, etc.). An expected duration is formed when the timing task becomes too difficult to assess through objective estimates (i.e. mental counting). Research has shown that objective methods tend to fail as the estimated durations are made shorter (Fraisse, 1963; Poynter, 1989). This indicates that imputed-velocity occurs for sequential stimuli within a narrow range of interval durations.

The illusory-motion theory has only recently been applied to the auditory kappa effect in what is called the auditory motion hypothesis (reviewed by Hoopen, Miyauchi & Nakajima, 2008). This theory states that people impute constant velocity into auditory patterns exhibiting continuous frequency change (Henry & McCauley, 2009; M. R. Jones, 1976; MacKenzie, 2007; MacKenzie & Jones, 2005). For instance, M. R. Jones et al. (1978) suggests that people actively anticipate 'where' a tone should exist within perceptual pitch-space and 'when' it should occur based on the expectation that the sequence is maintaining a constant velocity and moving in a

continuous direction (i.e. gradually increasing in pitch). According to this theory, if a pattern exhibits very large or very small changes in frequency between successive tones, multiple contour changes between tones, or variations in velocity, the ability to anticipate a tone's space/time trajectory will break-down causing the kappa effect sizes to diminish. Research has supported this theory, demonstrating that kappa effects are modulated by the velocity of the stimulus pattern (as determined by the duration of the inter-stimulus intervals). Collyer (1977) found this to be the case for visual stimuli, where kappa effects disappeared when inter-stimulus intervals were less than 160 ms (reviewed by Fraisse, 1984). Henry and McAuley (2009) recently found further evidence for this in audition, demonstrating that kappa effects disappeared when inter-stimulus intervals were made relatively long in duration (total interval lengths = 1600 ms).

MacKenzie and Jones (2005) and MacKenzie (2007) reported further evidence for the auditory motion hypothesis. In their procedure, participants listened to a three tone context sequence prior to an AXB sequence. It was hypothesized that context sequences should initiate motion-based expectancies about how a pattern was unfolding in pitch-space that would influence how participants made timing judgments on the following AXB sequence. It was found that Kappa effects were reduced when context sequences were stable in frequency or changed in frequency in the opposite direction of the AXB sequence (i.e. decreasing vs. increasing in pitch).

While studies have yet to deal directly with the possibility that sound intensity may be susceptible to auditory motion, it has been discussed as a theoretical possibility. Fraisse (1984) suggested that the perception of motion is dependent on the property of continuous change along the dimensions of spatiality, quality and intensity, provided that the difference between the stimuli is large enough to define them as distinct events. However, this would only apply to a

certain magnitude of difference, that being the point where two successive tones are no longer perceptually grouped together, but are perceived as distinct auditory events (Bregman, 1990). Leboe and Mondor (2008) demonstrated this showing that a relatively large abrupt change within a steady tone's frequency had no influence on perceived duration, while a small abrupt change did. This finding would also presumably apply to abrupt changes in a steady tone's intensity. Critically, Divenyi and Danner (1977) found that the degree of intensity change across an inter-stimulus interval influences the accuracy of duration judgments. They presented participants with two unfilled inter-stimulus intervals defined by two successive tones (four tones in total). The task was to judge which interval was longer in duration. When the tones were identical (86 dB SPL tone bursts) performance was not affected. When the tones differed in intensity (second tone = 25 dB SPL or below), accuracy was significantly influenced.

In the current study, the primary goal was to determine whether auditory kappa effects occur for changes in tone intensity (holding frequency constant) and to test the applicability of the auditory motion hypothesis to my findings. A thorough understanding of the limitations of the kappa effect is needed in order to allow for a more general understanding of the psychological mechanism through which time is perceived, and whether or not that mechanism exists across different sensory modalities and within different stimulus dimensions. For the auditory motion theory to be considered valid it will need to demonstrate modulating kappa effect sizes for both changes in auditory frequency and intensity.

An increasing number of experiments have demonstrated kappa effects for stimuli that do not exhibit motion (perceptual or otherwise). Casasanto and Boroditsky (2007) for example found that spatially larger stationary line segments are judged as longer in duration than smaller segments. Additional research has demonstrated that high intensity/pitch tones are judged as

longer in duration than low intensity/pitch tones. Allan (1984) found that participants judged high frequency continuous tones as longer in duration than low frequency continuous tones. This finding has also been demonstrated in visual intensity studies, where bright lights are perceived as longer in duration than dim lights (Brigner, 1986; Goldstone et al., 1979; Kraemer, Brown & Randall, 1995; Wilkie, 1987) and auditory intensity studies, where greater intensity tones are perceived as longer in duration than lesser intensity tones (Oléron, 1952). Several recent studies have shown that fluid changes in tone intensity equally influence perceived duration, where sounds that gradually become louder are perceived as longer in duration than sounds that gradually become quieter (Grassi & Darwin, 2006; Schlauch, Ries, & DiGiovanni, 2001). Additionally, Fraisse and Oléron (1950) found that sounds that increase in intensity rapidly are judged as shorter than sounds that increase in intensity slowly. In total, these studies suggest that intensity information can influence temporal judgments with a variety of experimental paradigms using continuous stimuli. Therefore, it is of primary interest to determine whether changes in auditory intensity will cause kappa effects using a standard AXB paradigm. Xuan, Zhang, He and Chen (2007) recently accomplished this for visual intensity. They manipulated three different visual intensity continua: quantity, size and luminance (e.g. a single dot, a small square, a dim light vs. nine dots, a large square, and a bright light) that gradually decreased in intensity over a sequence of three stimuli. The middle stimulus intensity level was more similar to either the first or the third occurring stimuli. Interestingly, participants demonstrated a strong tendency to perceive visual stimuli of similar intensity levels as being closer together in time. This procedure has yet to be applied to auditory intensity while holding frequency constant using a standardized AXB paradigm.

The aim of Experiment 1 was twofold; to determine if kappa effects occur when tones are kept at a stable frequency and varied in intensity using an AXB paradigm, and to determine whether or not auditory kappa effects are influenced by the direction in which intensity changes across the pattern. There is a possibility that intensity-direction may mediate the effect (Guski, 1992). Neuhoff (2001), for example, found that participants reported an increasing intensity tone as exhibiting a greater degree of change than an equivalent decreasing intensity tone. Additionally, participants reported an approaching (rising-intensity) sound as stopping at closer distance relative to them than the starting point of receding (decreasing-intensity) sound, despite the location of both being held constant. This suggests that there may be a fundamental difference in how people make temporal judgments concerning an increasing intensity auditory sequence versus a decreasing intensity auditory sequence, a difference which is examined in Experiment 1. Experiments 2 and 3 were intended to test the auditory motion hypothesis by applying the context sequence procedure developed by MacKenzie and Jones (2005). The auditory motion hypothesis predicts that kappa effects will diminish when three stable intensity tones precede an AXB pattern. Additionally, it predicts that kappa effects will be maintained when the context sequence and AXB pattern exhibit the same degree of intensity change. This research will provide an important and novel contribution to the literature on the auditory kappa effect, as it has yet to be shown that intensity change can influence 'motion-based expectancies' in audition (Narmour, 1990).

Experiment 1A: AXB (Intensity Decreasing)

Method

Participants

Seventeen students at the University of Manitoba volunteered to participate in the study in exchange for partial course credit in an Introduction to Psychology course (9 males, 8 females, mean age = 19.24). The participants were required to have normal hearing according to self-report.

Materials

Computer and sound system. The experiment was administered on a Dell Precision 390, Intel Core 2 Duo computer with a 17 inch colour monitor. E-prime software (Psychology Software Tools, Inc., 2002) was used to present the auditory patterns and record response accuracy. All sounds were presented binaurally through two Dell A225 speakers which deliver up to 1.2 Watt (RMS) output power with a frequency response between 100-20000 Hz.

Sounds. Adobe Audition 1.5 (Adobe Systems Incorporated, 2004) was used to synthesize the sounds. Each individual tone had a sampling rate of 22,050 Hz and was 100 ms in duration with 5 ms onset and offset amplitude ramps to eliminate clicks. All tones used in this experiment were based on a sine wave and had a frequency of 500 Hz.

The tones were arranged using an AXB paradigm. The first tone (A) was always set at 70 dB SPL and the third tone (B) was always set at 55 dB SPL. The intensity of the middle tone (X) in each pattern was manipulated across trials and could have one of four possible intensities (67 dB SPL, 64 dB SPL, 61 dB SPL, and 58 dB SPL). The amount of intensity change across a pattern was defined according to the absolute difference in intensity between the first and second, and second and third tones. For example, when the middle tone was set at 67 dB SPL,

the pattern was defined as exhibiting a 3:12 intensity change structure. In this example there is an intensity difference of 3 dB SPL between Tone A (set at 70 dB SPL) and Tone X and an intensity difference of 12 dB SPL between Tone X and Tone B (set at 55 dB SPL). In total there were four levels of intensity change corresponding to each of the intensity levels that tone X could assume: 3:12, 6:9, 9:6 and 12:3.

All of the stimulus patterns were 1300 ms in total duration containing two inter-stimulus intervals (inter-stimulus intervals were always 1000 ms in total duration). The interval durations in a pattern were never equal, 50% were long-short time structure (where the first interval was longer in duration than the second) and 50% were short-long time structure (where the first interval was shorter in duration than the second). There were eight total interval durations used in the experiment, four of which were long-short (580-420 ms, 560-440 ms, 540-460 ms, 520-480 ms) and four of which were short-long (480-520 ms, 460-540 ms, 440-560 ms, 420-580 ms).

Procedure

The participants were instructed to make timing judgments of the relative durations of the two inter-stimulus intervals in each presented pattern. If the middle tone (X) was perceived to be closer in time to the first tone (A), they were instructed press the short-long button labeled 'SL'. If the middle tone (X) was perceived to be closer in time to the third tone (B), they were instructed to press the long-short button labeled 'LS'. Each trial began with a fixation cross that remained on screen for 1000 ms followed by a three-tone auditory sequence. Once the sequence had elapsed a new screen was displayed reading: "Was the pattern Short-Long or Long-Short?" The participants were given as much time as was needed to make a classification judgment. E-prime (Psychology Software Tools, 2002) was programmed to record their responses. Each session included 320 experimental trials. All participants performed 10 blocks of 32

experimental trials. Each block contained one trial of each of the 8 interval timing levels at each of the 4 levels of intensity change. The order in which the patterns were presented within each block was randomized.

Data Analysis

Kappa effects were investigated using a procedure detailed by Henry and McAuley (2009). In this analysis, the point of subjective equality (PSE) was determined for each participant at each level of Intensity Change (the interval timing required for participants to answer 'long-short' 50% of the time). This was accomplished by calculating the proportions of long-short responses at each of the eight timing levels, at each Intensity Change level, collapsed across the ten experimental blocks. An estimate of PSE was determined using the z-transformation method (Macmillan & Creelman, 1991; pp. 218-220). To quantify the degree of response bias occurring at each level of Intensity Change a directional constant error (CE) value was calculated. Constant error measurements have been used in time perception studies to quantify the degree of temporal bias occurring when participants compare a test interval to a standard interval (Brown, 1995; Nakajima, 1979). In the following experiment, the standard was defined as a hypothetical pattern in which both inter-stimulus intervals would be perceived as equivalent in duration (500 ms). To calculate a directional CE, the difference was computed between the standard and PSE, yielding a positive or negative value (Grondin, 2008). Using this metric, negative values indicate the existence of a 'short-long' response bias, while positive values indicate a 'long-short' response bias. The mean directional CE values were calculated for each level of Intensity Change in all of the experiments.

Results

The mean proportions of long-short responses for the eight timing levels across the levels of Intensity Change (3:12; 6:9; 9:6; 12:3) are detailed in Table 1. These values were submitted to a 2 x 4 x 4 within-participants ANOVA treating Pattern Type (long-short, short-long), Interval Durations (580 + 420, 560 + 440, 540 + 460, 420 + 580) and Intensity Change (3:12, 6:9, 9:6, 12:3) as independent factors and the proportion of long-short judgments as the dependent measure. The results of this analysis are listed in Appendix A. The central question posed in the present experiment was whether the participant's responses would be biased by the relation of the middle tone's intensity to the bounding tones. To investigate this question, directional CE values for each participant were computed using the procedure detailed above (The mean PSE scores and mean directional CE scores are shown in Table 2). The directional CE values were submitted to a one-way within-participants Analysis of Variance (ANOVA) treating Intensity Change (3:12, 6:9, 9:6; 12:3) as the independent factor and mean directional CE as the dependent measure.

Table 1

Participants' mean proportion of long-short responses in Experiment 1A for Intensity Change (3:12, 6:9, 9:6, 12:3) across the eight timing levels. Standard errors in parentheses.

Pattern Type	Interval Durations	Intensity Change			
		3:12	*6:9*	*9:6*	*12:3*
Long-Short	*580-420 ms*	.712 (.057)	.812 (.043)	.818 (.035)	.882 (.025)
	560-440 ms	.612 (.064)	.724 (.050)	.729 (.052)	.829 (.032)
	540-460 ms	.565 (.071)	.741 (.037)	.735 (.036)	.753 (.036)
	520-480 ms	.541 (.061)	.565 (.037)	.653 (.043)	.718 (.038)
Short-Long	*480-520 ms*	.353 (.054)	.441 (.055)	.529 (.041)	.618 (.040)
	460-540 ms	.247 (.046)	.371 (.032)	.500 (.051)	.412 (.046)
	440-560 ms	.200 (.042)	.276 (.035)	.341 (.036)	.412 (.044)
	420-580 ms	.141 (.029)	.206 (.044)	.288 (.046)	.300 (.051)

Table 2

Participants' mean Point of Subject Equality (PSE) and Constant Error (CE) and standard error in Experiment 1A across the levels of Intensity Change (3:12, 6:9, 9:6, 12:3).

	Intensity Change			
	3:12	*6:9*	*9:6*	*12:3*
Mean PSE	527.77	497.51	464.59	457.84
Mean CE	-27.77	2.49	35.41	42.16
Standard Error (PSE & CE)	12.77	9.39	7.09	6.43

Mauchley's test indicated that the assumption of sphericity had been violated (χ^2 = 15.883 $p < .05$). Greenhouse-Geisser sphericity estimates were used to correct the degrees of freedom ($\varepsilon = .613$). A significant main effect of Intensity Change $F(1.840, 29.444) = 14.723, p < .001$ was found. Trend analysis revealed a significant linear trend operating for Intensity Change $F_{lin}(1, 16) = 21.946, p < .001$. Figure 1 illustrates the degree with which the proportion of long-short and short-long responses changed across the levels of Intensity Change, with negative values indicating a larger proportion of short-long responses and positive values indicating a larger proportion of long-short responses (a value of 0 on this scale indicates equal amounts of 'short-long' and 'long-short' responses). To investigate this result further, a post-hoc test was carried out using Fisher's Least Significant Difference (LSD) t-test for pair-wise comparisons. All pair-wise comparisons were significant (all $p \leq .017$) with the exception of 9:6 versus 12:3 conditions, which did not significantly differ ($p = .312$).

Figure 1

Experiment 1A: Mean directional CE (with standard error bars) for each level of Intensity Change (3:12, 6:9, 9:6, 12:3).
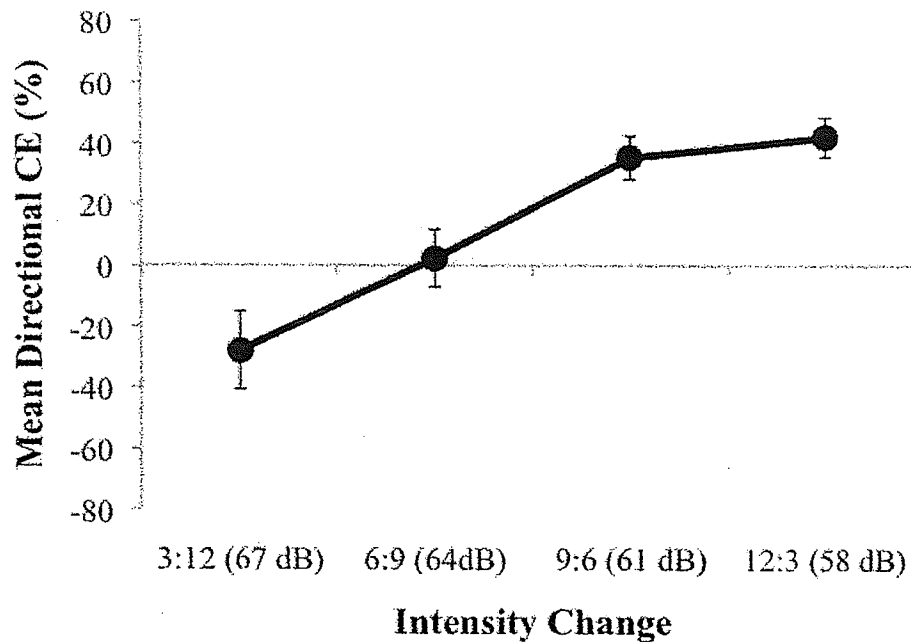
Discussion

In Experiment 1A a kappa effect was found to occur according to the intensity structure of the presented patterns. When the middle tone was closer in intensity to the first tone (3:12) participants were biased to respond 'short-long'. When the middle tone's intensity was closer to the third tone (12:3) participants were biased to respond 'long-short'. When Intensity Change was less salient (6:9) participants exhibited no response bias. One possibility discussed previously is that the potential influence that overall intensity change direction may have on the kappa effect. In Experiment 1A all patterns gradually decreased in intensity (From 70 dB SPL to 55 dB SPL). Experiment 1B was designed to eliminate this potential confound and replicate the findings of Experiment 1A.

Experiment 1B: AXB (Intensity Increasing)

Method

Participants

Seventeen students at the University of Manitoba volunteered to participate in the study in exchange for partial course credit in an Introduction to Psychology course (9 males, 8 females, mean age = 23.06). The participants were required to have normal hearing according to self-report.

Materials

Computer and Sound System. The same computer and sound system used previously were used in Experiment 1B.

Sounds. The sounds and patterns used in Experiment 1B were similar to those used in Experiment 1A. The only difference was the overall direction in which intensity changed across each pattern. In Pilot Experiment 1B, tone A was always set at 55 dB SPL and tone B at 70 dB SPL.

Procedure

The procedure used in Experiment 1B was identical to Experiment 1A, participants responded 'short-long' and 'long-short' by pressing 'SL' and 'LS' on the keyboard respectively. Each session included 320 experimental trials. All participants performed 10 blocks of 32 experimental trials. Each block contained one trial of each of the 8 interval timing levels at each of the 4 intensity change levels. The order in which the patterns were presented within each block was randomized.

Results

The mean proportions of long-short responses for the eight timing levels across the levels

of Intensity Change (3:12; 6:9; 9:6; 12:3) are detailed in Table 3. These values were submitted to

a 2 x 4 x 4 within-participants ANOVA treating Pattern Type (long-short, short-long), Interval

Durations (580 + 420, 560 + 440, 540 + 460, 420 + 580) and Intensity Change (3:12, 6:9, 9:6,

12:3) as independent factors and the proportion of long-short judgments as the dependent

measure. The results of this analysis are listed in Appendix A. A one-way within-participants

ANOVA was run treating Intensity Change (3:12, 6:9, 9:6; 12:3) as the independent factor and

mean directional CE as the dependent measure (mean PSE and directional CE values are shown

in Table 4).

Table 3

Participants' mean proportion of long-short responses in Experiment 1B for Pattern Type (Short-Long, Long-Short) and Intensity Change (3:12, 6:9, 9:6, 12:3) across all of the timing levels. Standard errors in parentheses.

Pattern Type	Interval Durations	Intensity Change			
		3:12	*6:9*	*9:6*	*12:3*
Long-Short	*580-420 ms*	.747 (.046)	.771 (.045)	.788 (.043)	.800 (.035)
	560-440 ms	.682 (.054)	.706 (.033)	.729 (.049)	.782 (.037)
	540-460 ms	.594 (.060)	.606 (.042)	.688 (.043)	.706 (.045)
	520-480 ms	.512 (.037)	.565 (.024)	.624 (.046)	.682 (.043)
Short-Long	*480-520 ms*	.365 (.041)	.353 (.043)	.494 (.034)	.529 (.047)
	460-540 ms	.288 (.036)	.318 (.044)	.335 (.051)	.465 (.039)
	440-560 ms	.218 (.040)	.271 (.048)	.300 (.052)	.388 (.044)
	420-580 ms	.218 (.049)	.200 (.045)	.282 (.041)	.288 (.051)

Table 4

Participants' mean Point of Subject Equality (PSE) and directional Constant Error (CE) and standard error in Experiment 1B across the levels of Intensity Change (3:12, 6:9, 9:6, 12:3).

	Intensity Change			
	3:12	*6:9*	*9:6*	*12:3*
Mean PSE	528.44	508.96	495.31	466.79
Mean CE	-28.44	-8.96	4.69	33.21
Standard Error (PSE & CE)	19.27	7.13	10.22	10.91

Mauchley's test indicated that the assumption of sphericity had been violated (χ^2 = 13.536 $p < .05$). Greenhouse-Geisser sphericity estimates were used to correct the degrees of freedom ($\varepsilon = .638$). The analysis revealed a significant main effect of Intensity Change $F(1.915, 30.637) = 6.280$, $p < .01$. A trend analysis revealed a significant linear trend across the levels of Intensity Change $F_{lin}(1, 16) = 10.821$, $p < .01$. The results demonstrated that temporal judgments are significantly influenced by the degree of intensity change within the pattern, where 3:12 patterns were susceptible to a 'short-long' response bias, and 12:3 patterns a 'long-short' response bias (see Figure 2). To investigate these findings further a post-hoc test was carried out using Fisher's LSD t-test for pair-wise comparisons. Significant differences occurred between 3:12 and 12:3 ($p < .01$), 6:9 and 12:3 ($p < .001$) and between 9:6 and 12:3 ($p < .01$) (all other *p*'s > .063).

Figure 2

Experiment 1B: Mean directional CE (with standard error bars) for each level of Intensity
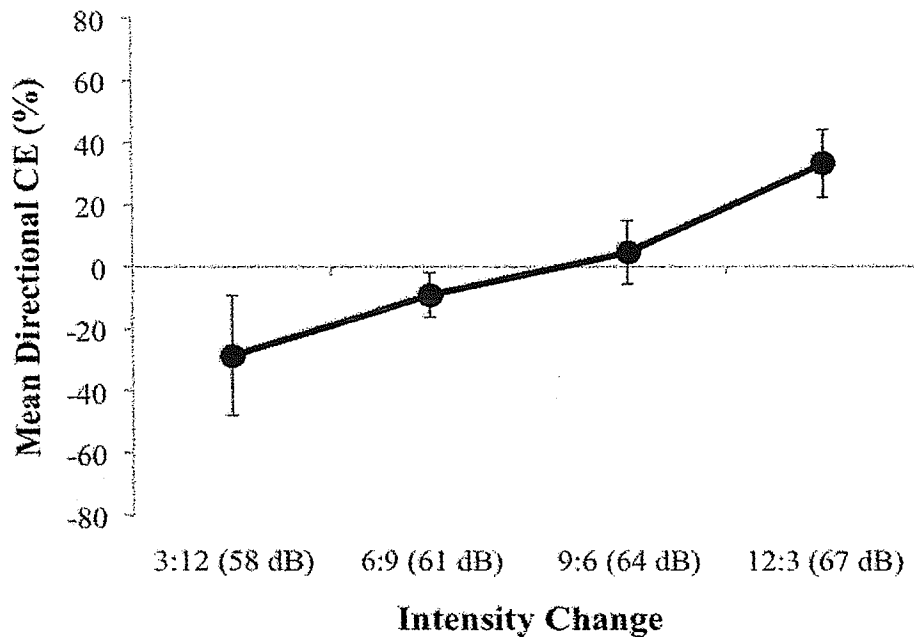
Change (3:12, 6:9, 9:6, 12:3).

In addition, a 2 x 4 Mixed ANOVA was run treating Intensity Direction (Decreasing vs.

Increasing) as the between-participants factor and Intensity Change (3:12, 6:9, 9:6, 12:3) as the

within-participants factor. This addressed the question over whether the direction of intensity

change across the pattern significantly influenced the effect. Mauchley's test indicated that the

assumption of sphericity had been violated for Intensity Change, $(\chi^2 = 25.273 \ p < .05)$.

Greenhouse-Geisser sphericity estimates were used to correct the degrees of freedom ($\varepsilon = .657$).

A main effect for Intensity Change was found, $F(1.970, 63.054) = 18.376, p < .001$. Critically,

the interaction between Intensity Direction and Intensity Change was non-significant ($p = .406$).

This indicates that there was no between-participants influence of Intensity Direction on the

pattern of temporal responding at each Intensity Change level.

Discussion

In combination, the findings of Experiments 1A and 1B demonstrate the existence of kappa effects for intensity change when frequency is held constant. Participants in both experiments were found to over-respond 'short-long' for 3:12 intensity change patterns, and 'long-short' for 12:3 intensity change patterns. Interestingly, when the pattern of intensity change was less noticeable (6:9 and 9:6 conditions) participants were less likely to employ intensity change as a method for judging duration, and were less susceptible to perceptual bias. Additionally, the kappa effect was not influenced by the overall direction in which intensity changed across the pattern (increasing vs. decreasing conditions). Experiment 2 was intended to further replicate this finding in addition to testing the auditory motion hypothesis.

Experiment 2A: Stable Intensity/Stable Frequency Context

In Experiment 2A I examined the existence of auditory kappa effects when AXB patterns were preceded by stable intensity/stable frequency context sequences. The auditory motion hypothesis states that participants will impute velocity into a sequence based on the spatial properties of the sequential stimuli. The theory states that participants extrapolate motion continuously throughout a temporal sequence and form expectancies about where the next tone should occur in pitch-space. MacKenzie (2007) demonstrated that kappa effects were disrupted on an AXB sequence when it was preceded by a context sequence that did not convey motion-like properties (i.e. stable frequency tones). If the auditory motion hypothesis can be applied to intensity change, then a similar reduction in kappa effect size should be found when AXB sequences are preceded by a stable intensity context sequence. This was the purpose of Experiment 2A.

Method

Participants

Seventeen students enrolled in an Introduction to Psychology course at the University of Manitoba took part in the experiment (10 males, 7 females, mean age = 19.47) for their participation they received partial course credit. All participants were required to self report normal hearing.

Materials

Computer and sound system. The computer and sound system used previously were used in Experiment 2A.

Sounds. The sounds were synthesized using the previous procedure. Each pattern was composed of a stable intensity three-tone context sequence followed by an AXB sequence. The context sequence tones were 100 ms in duration with 5 ms onset/offset ramps, with an intensity of 70 dB SPL and a frequency of 500 Hz. The inter-stimulus intervals had constant durations (500 ms). After the third context tone there was a 500 ms delay before the onset of first tone in the AXB sequence. For the AXB sequences, the first tone (A) was always set at 70 dB SPL, and the third tone (B) at 55 dB SPL. The middle tone (X) had one of four different intensity levels, conveying an Intensity Change of 3:12, 6:9, 9:6 or 12:3, and 8 different timing levels (4 long-short, 4 short-long). Each pattern had a total duration of 3100 ms.

Procedure

Participants were informed that they would hear auditory patterns composed of six tones. They were told to pay attention only to the last three tones, where the timing of the inter-stimulus intervals would convey either a short-long or a long-short pattern type. The participants made their judgments by pressing either 'SL' or an 'LS' button on the keyboard. Each session included

320 experimental trials. All participants performed 10 blocks of 32 experimental trials (one trial for each level of intensity change at each of the eight timing levels). The order with which trials were presented in each block was randomized.

Results

The mean proportions of long-short responses for the eight timing levels across the levels of Intensity Change (3:12; 6:9; 9:6; 12:3) are detailed in Table 5. These values were submitted to a 2 x 4 x 4 within-participants ANOVA treating Pattern Type (long-short, short-long), Interval Durations (580 + 420, 560 + 440, 540 + 460, 420 + 580) and Intensity Change (3:12, 6:9, 9:6, 12:3) as independent factors and the proportion of long-short judgments as the dependent measure. The results of this analysis are listed in Appendix B. A one-way within-participants ANOVA was run using Intensity Change (3:12, 6:9, 9:6; 12:3) as the independent factor and mean directional CE as the dependent measure (mean PSE and directional CE values are shown in Table 6).

Table 5

Participants' mean proportion of long-short responses in Experiment 2A for Intensity Change (3:12, 6:9, 9:6, 12:3) across the eight timing levels. Standard errors in parentheses.

Pattern Type	Interval Durations	Intensity Change			
		3:12	*6:9*	*9:6*	*12:3*
Long-Short	*580-420 ms*	.824 (.040)	.871 (.031)	.900 (.031)	.912 (.026)
	560-440 ms	.800 (.037)	.853 (.029)	.806 (.035)	.824 (.028)
	540-460 ms	.635 (.048)	.782 (.042)	.782 (.035)	.824 (.042)
	520-480 ms	.576 (.055)	.635 (.042)	.706 (.041)	.771 (.041)
Short-Long	*480-520 ms*	.468 (.043)	.486 (.046)	.473 (.058)	.568 (.052)
	460-540 ms	.423 (.063)	.473 (.056)	.441 (.061)	.500 (.057)
	440-560 ms	.395 (.061)	.386 (.049)	.341 (.060)	.423 (.060)
	420-580 ms	.327 (.065)	.373 (.069)	.391 (.059)	.382 (.064)

Table 6

Participants' mean Point of Subject Equality (PSE) and directional Constant Error (CE) and standard error in Experiment 2A across the levels of Intensity Change (3:12, 6:9, 9:6, 12:3).

	Intensity Change			
	3:12	*6:9*	*9:6*	*12:3*
Mean PSE	499.52	480.91	479.65	469.52
Mean CE	.484	19.08	20.35	30.48
Standard Error (PSE & CE)	7.90	6.36	7.42	7.88

Mauchley's test indicated that the assumption of sphericity had been violated (χ^2 = 12.547 p < .05). Greenhouse-Geisser sphericity estimates were used to correct the degrees of freedom (ε = .613). A one-way within-participants ANOVA revealed a significant main effect for Intensity Change $F(1.909, 30.542) = 3.525, p < .05$. Trend analysis revealed a significant linear trend $F_{lin}(1, 16) = 5.250, p < .05$. Post hoc comparisons were carried out using Fisher's LSD t-test for pair-wise comparisons. Significant differences were found comparing the conditions 3:12 versus 6:9 (p < .05) and 3:12 versus 12:3 (p < .05), all other comparisons were not significant (all $p \geq .124$).

Figure 3

Experiment 2A: Mean directional CE (with standard error bars) for each level of Intensity

Change (3:12, 6:9, 9:6, 12:3).

3:12 (67 dB)   6:9 (64 dB)   9:6 (61 dB)   12:3 (58 dB)
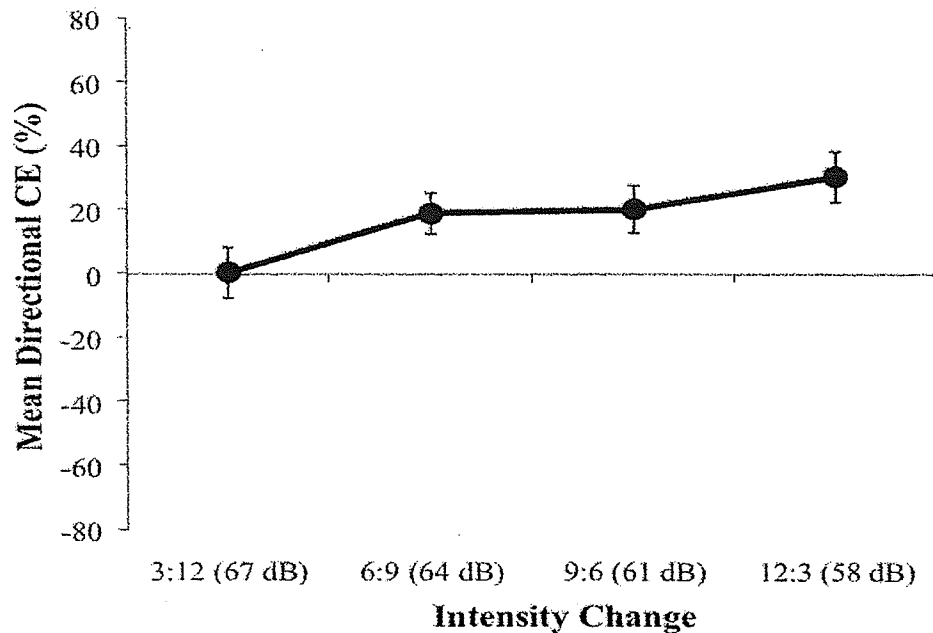
Intensity Change

Discussion

The findings of Experiment 2A indicate the presence of a 'long-short' response bias for

6:9, 9:6 and 12:3 intensity change patterns. In addition to that finding, 3:12 patterns exhibited no

significant response bias. This increase in 'long-short' responses is due to a separately occurring

temporal illusion referred to as positive time-order error. Time-order error occurs when people

make comparison judgments concerning two successive stimuli. Studies on Time-order error

(Hellstrom, 2003; Hellstrom, 1985) have demonstrated the existence of presentation order effects

on temporal judgments, where the first of two stimuli is systematically judged by participants as

'longer' (called positive time-order error) or 'shorter' (called negative time-order error) than the

second occurring stimulus (Fechner, 1860). It has been demonstrated that kappa and time-order

error are separately occurring illusions (see discussion by Huang & Jones, 1982), therefore if

kappa effects are diminished, time-order error effects should be more prevalent. This provides an explanation for why participants over-estimated the number of long-short patterns in the majority of the Intensity Change conditions.

In summary, the results of Experiment 2A support the auditory motion hypothesis. The decreased kappa effect size was evident in the decreased variation between the mean directional CE scores at each level of intensity change, which indicates that participants did not use intensity change as a temporal indicator. Experiments 1A and 1B demonstrated that when kappa effects exert a strong influence, 3:12 and 12:3 pattern types will exhibit the largest degree of bias in both negative and positive directions respectively. This pattern of results was disrupted with the addition of a three tone serial context sequence conveying no intensity change. The purpose of experiment 2B was to extend the procedure used by MacKenzie (2007) by testing the influence of context sequences that conveyed stable-intensity/varied-frequency.

Experiment 2B: Stable Intensity/Varied Frequency Context

Method

Participants

Twenty-one students enrolled in an Introduction to Psychology course at the University of Manitoba were recruited to be in the experiment (11 females, 10 males, mean age = 20.38). The students received partial course credit for their participation. All participants were required to self-report normal hearing.

Materials

Computer and sound system. The same computer and sound system used previously were used in the following experiment.

Sounds. The sounds were synthesized using the procedure used previously. All tones had durations of 100 ms with 5 ms onset/offset ramps. As in Experiment 2A, each AXB sequence was preceded by a context sequence. The context sequence tones were 100 ms in duration with 5 ms onset/offset ramps. Each tone in the context sequence had an intensity of 70 dB SPL. In Experiment 2B, the frequency of the context sequence tones varied (500 Hz − 650 Hz − 800 Hz respectively). The middle context tone's frequency was set at the midpoint between 500 and 800 Hz. The durations of the inter-stimulus intervals separating the three context tones were held constant (500 ms). The AXB sequences used were identical to those in Experiment 1A.

Procedure

The same procedure used in the previous experiments was used in the Experiment 2B. Each session included 320 experimental trials. All participants performed 10 blocks of 32 experimental trials. Each block contained one trial of each of the 8 interval timing levels at each of the 4 intensity change levels. The order in which the patterns were presented within each block was randomized.

Results

The mean proportions of long-short responses for the eight timing levels across the levels of Intensity Change (3:12; 6:9; 9:6; 12:3) are detailed in Table 7. These values were submitted to a 2 x 4 x 4 within-participants ANOVA treating Pattern Type (long-short, short-long), Interval Durations (580 + 420, 560 + 440, 540 + 460, 420 + 580) and Intensity Change (3:12, 6:9, 9:6, 12:3) as independent factors and the proportion of long-short judgments as the dependent measure. The results of this analysis are listed in Appendix B. A one-way within-participants ANOVA was run using Intensity Change (3:12, 6:9, 9:6; 12:3) as the independent factor and

mean directional CE as the dependent measure (mean PSE and directional CE are shown in

Table 8).

Table 7

Participants' mean proportion of long-short responses in Experiment 2B for Intensity Change (3:12, 6:9, 9:6, 12:3) across all of the eight timing levels. Standard errors in parentheses.

Pattern Type	Interval Durations	Intensity Change			
		3:12	*6:9*	*9:6*	*12:3*
Long-Short	*580-420 ms*	.852 (.042)	.848 (.031)	.862 (.026)	.886 (.029)
	560-440 ms	.752 (.041)	.829 (.036)	.857 (.025)	.867 (.025)
	540-460 ms	.690 (.041)	.781 (.036)	.710 (.040)	.790 (.028)
	520-480 ms	.633 (.050)	.705 (.037)	.652 (.045)	.657 (.045)
Short-Long	*480-520 ms*	.419 (.031)	.490 (.043)	.414 (.043)	.467 (.035)
	460-540 ms	.243 (.030)	.338 (.044)	.300 (.046)	.348 (.034)
	440-560 ms	.167 (.031)	.181 (.027)	.200 (.037)	.238 (.036)
	420-580 ms	.119 (.032)	.171 (.035)	.148 (.035)	.186 (.045)

Table 8

Participants' mean Point of Subject Equality (PSE) and Constant Error (CE) and standard error in Experiment 2B across the levels of Intensity Change (3:12, 6:9, 9:6, 12:3).

	Intensity Change			
	3:12	*6:9*	*9:6*	*12:3*
Mean PSE	507.41	487.67	492.09	481.77
Mean CE	-7.41	12.33	7.91	18.23
Standard Error (PSE & CE)	8.37	6.44	7.30	3.82

Mauchley's test indicated that the assumption of sphericity had not been violated for any

of the conditions. A significant main effect was found for Intensity Change $F(3, 60) = 3.175, p <$

.05. Trend analysis revealed a significant linear trend $F_{lin} (1, 20) = 5.498, p < .05$. Post hoc

comparisons were made using Fisher's LSD t-test for pair-wise comparisons. This analysis

demonstrated that 3:12 and 12:3 conditions were significantly different ($p < .05$). The remaining

pair-wise comparisons were not significant (all $p \geq .061$).

Figure 4

Experiment 2B: Mean directional CE (with standard error bars) for each level of Intensity

Change (3:12, 6:9, 9:6, 12:3).
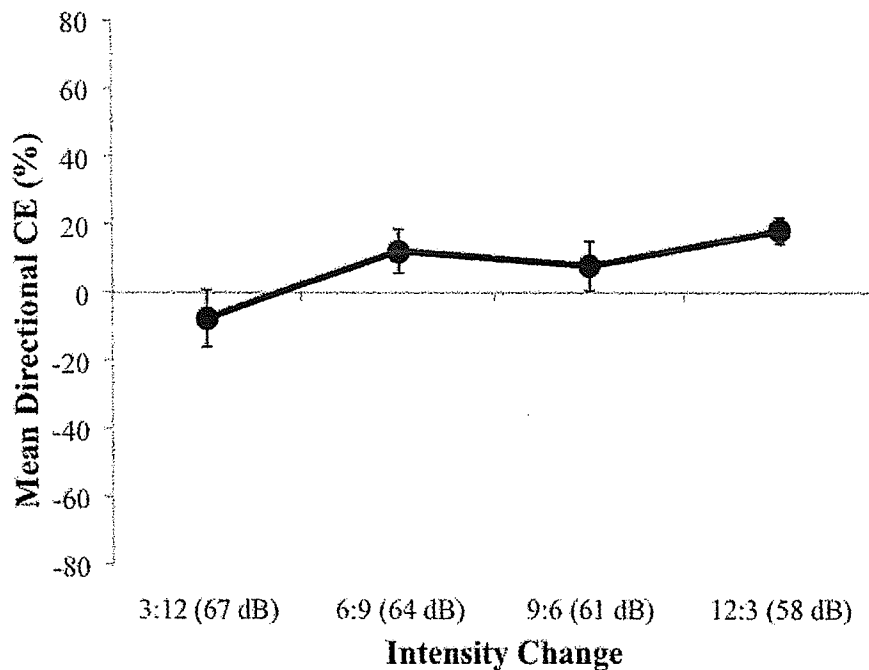
Discussion

In combination, the findings of Experiment 2A and 2B indicate that auditory kappa

effects are determined, in part, by the motion-based expectations that a participant forms prior to

the presentation of an AXB sequence. In Experiment 2A and 2B participants did not demonstrate

a short-long response bias at all for 3:12 items. In addition, participants demonstrated little

variation in the size of their response biases measured on 6:9, 9:6 and 12:3 intensity change

levels (where Experiment 1 demonstrated significantly larger 'long-short' response biases for the

12:3 condition versus 6:9 condition). In Experiment 2A, intensity was stable across the context

sequence, promoting a condition where motion-based expectancies were unlikely to be formed.

In Experiment 2B, intensity remained stable while frequency changed across the context

sequence. I designed this experiment to determine whether perceived motion along a different stimulus dimension (in this case frequency) would promote an auditory kappa effect. In both Experiments 2A and 2B it was found that participants were less likely to factor intensity change into duration judgments (see Figure 4). Additional evidence suggests that kappa effects will be maintained when perceived auditory pitch-motion is preserved across a context sequence (MacKenzie & Jones, 2005; MacKenzie, 2007). The purpose of Experiment 3 was to investigate conditions in which context sequences conveyed intensity change. If the auditory motion hypothesis is correct, I anticipate that there will be a pattern of kappa effect sizes across the levels of Intensity Change similar to those witnessed in Experiment 1A and 1B.

Experiment 3A: Varied Intensity/Stable Frequency Context

Method

Participants

Seventeen students enrolled in an Introduction to Psychology course at the University of Manitoba were recruited to take part in the experiment (10 males, 7 females, mean age = 19.65). The students received partial course credit. All participants were required to self-report normal hearing.

Materials

Computer and sound system. The same computer and sound system used previously were used in Experiment 3A.

Sounds. The sounds were synthesized using the previous procedure. All tones used had durations of 100 ms with 5 ms onset/offset ramps and a frequency of 500 Hz. Each AXB sequence was preceded by a three tone context sequence. The first and third tones in the context

sequence had the same intensity levels as the first and third tones in the AXB sequence (70 dB SPL and 55 dB SPL respectively). The middle context tone did not vary in its intensity across trials, and was always set at the mid-point intensity level (62.5 dB SPL). The durations of the inter-stimulus intervals separating the context tones were held constant (500 ms).

Procedure

The same procedure used previously was used in Experiment 3A. Each session included 320 experimental trials. All participants performed 10 blocks of 32 experimental trials. Each block contained one trial of each of the 8 interval timing levels at each of the 4 intensity change levels. The order in which the patterns were presented within each block was randomized.

Results

The mean proportions of long-short responses for the eight timing levels across the levels of Intensity Change (3:12; 6:9; 9:6; 12:3) are detailed in Table 9. These values were submitted to a 2 x 4 x 4 within-participants ANOVA treating Pattern Type (long-short, short-long), Interval Durations (580 + 420, 560 + 440, 540 + 460, 420 + 580) and Intensity Change (3:12, 6:9, 9:6, 12:3) as independent factors and the proportion of long-short judgments as the dependent measure. The results of this analysis are listed in Appendix C. A one-way within-participants ANOVA was run using Intensity Change (3:12, 6:9, 9:6; 12:3) as the independent variable and mean directional CE as the dependent measure (mean PSE and directional CE are shown in Table 10).

Table 9

Participants' mean proportion of long-short responses in Experiment 3A for Intensity Change (3:12, 6:9, 9:6, 12:3) across the eight timing levels. Standard errors in parentheses.

Pattern Type	Interval Durations	Intensity Change			
		3:12	*6:9*	*9:6*	*12:3*
Long-Short	*580-420 ms*	.716 (.061)	.816 (.034)	.893 (.025)	.929 (.022)
	560-440 ms	.592 (.060)	.746 (.049)	.847 (.032)	.876 (.036)
	540-460 ms	.528 (.054)	.699 (.048)	.811 (.035)	.839 (.030)
	520-480 ms	.427 (.054)	.525 (.052)	.696 (.041)	.772 (.044)
Short-Long	*480-520 ms*	.265 (.039)	.466 (.031)	.613 (.043)	.627 (.052)
	460-540 ms	.233 (.036)	.261 (.036)	.430 (.033)	.569 (.044)
	440-560 ms	.153 (.045)	.224 (.042)	.295 (.054)	.443 (.055)
	420-580 ms	.101 (.045)	.171 (.035)	.254 (.049)	.412 (.047)

Table 10

Participants' mean Point of Subject Equality (PSE) and directional Constant Error (CE) and standard error in Experiment 3A across the levels of Intensity Change (3:12, 6:9, 9:6, 12:3).

	Intensity Change			
	3:12	*6:9*	*9:6*	*12:3*
Mean PSE	543.74	502.52	466.21	433.49
Mean CE	-43.74	-2.52	33.79	66.51
Standard Error (PSE & CE)	9.24	8.38	6.00	9.60

Mauchley's test indicated that the assumption of sphericity had been violated in this circumstance ($\chi^2 = 19.919$ $p < .05$). Greenhouse-Geisser sphericity estimates were used to correct the degrees of freedom ($\varepsilon = .588$). A significant main effect was found for Intensity Change $F(1.765, 28.246) = 29.225$, $p < .001$. Trend analysis revealed a significant linear trend F_{lin} (1, 16) = 41.022, $p < .001$. Post Hoc comparisons were made using Fisher's LSD t-test for pair-wise comparisons, all pair-wise comparisons were found to be highly significant ($p \le .002$). The results demonstrate a significant kappa effect, with large 'short-long' and 'long-short' response

biases occurring at the 3:12 and 12:3 Intensity Change levels respectively. The strength of the

linear trend suggests a strong influence of Intensity Change on duration judgments.

Figure 5

Experiment 3A: Mean directional CE (with standard error bars) for each level of Intensity

Change (3:12, 6:9, 9:6, 12:3).
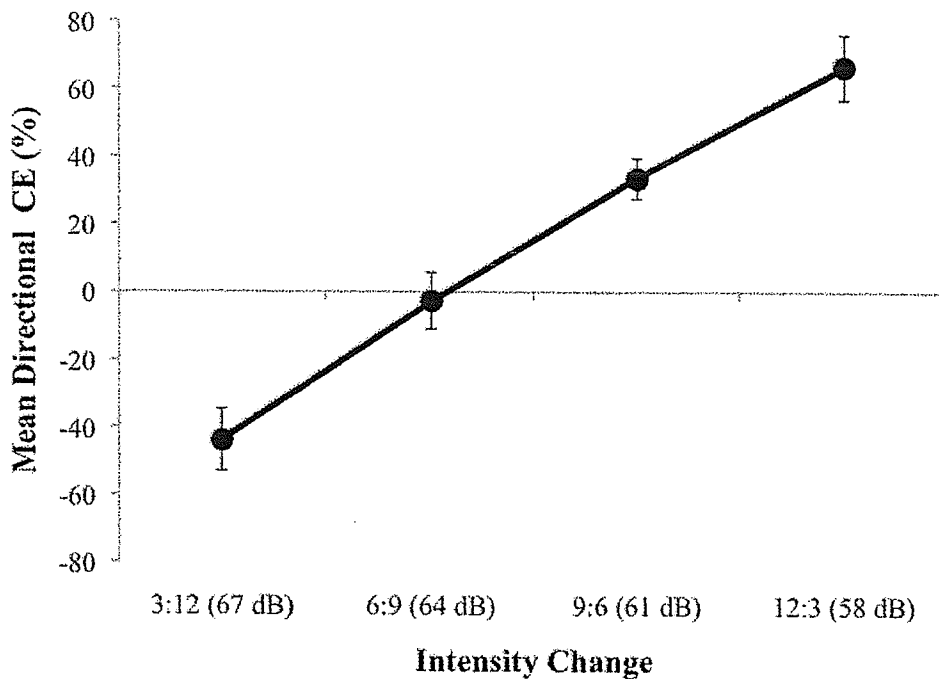
Discussion

Experiment 3A was intended to investigate the influence of a context sequence conveying

intensity change (while keeping frequency stable) on duration judgments. The results showed

that large kappa effects occurred when motion-based expectancies were generated during the

context sequence and repeated in the AXB sequence. This was evident in the finding that

participants were biased to respond 'short-long' on 3:12 pattern types, a finding that disappeared

when context sequences conveyed stable intensity levels (Experiments 2A and 2B). As in

Experiments 1A and 1B, there was a great deal of variation between the mean directional CE values at each level of the intensity change, which suggests that timing judgments were strongly influenced by the pattern of intensity change. Experiment 3B was intended to examine the condition in which intensity and frequency changes co-occurred within the context sequence. The purpose of Experiment 3B was to investigate the possibility that frequency change within a context sequence will interfere with forming motion-based expectancies concerning intensity. If that is the case, Experiment 3B should also demonstrate a decreased kappa effect size across the intensity change levels on the AXB sequences.

Experiment 3B: Varied-Intensity/Varied-Frequency Context

Method

Participants

Eighteen students enrolled in an Introduction to Psychology course at the University of Manitoba were recruited to take part in the experiment (10 males, 8 females, mean age = 20.28). The students received partial course credit. The participants were required to self-report normal hearing.

Materials

Computer and sound system. The same computer and sound system used previously were used in Experiment 3B.

Sounds. The sounds were synthesized using the previous procedure. All tones had durations of 100 ms with 5 ms onset/offset ramps. Each AXB sequence was preceded by a three tone context sequence. The context tones for each trial simultaneously conveyed decreasing intensity change (70 dB SPL – 62.5 dB SPL – 55 dB SPL) and increasing frequency change (500

Hz – 650 Hz – 800 Hz) across three tones. The durations of the inter-stimulus intervals

separating the context tones were constant (500 ms).

Procedure

The same procedure used in previous experiments was used in Experiment 3A. Each

session included 320 experimental trials. All participants performed 10 blocks of 32

experimental trials. Each block contained one trial of each of the 8 interval timing levels at each

of the 4 intensity change levels. The order in which the patterns were presented within each

block was randomized.

Results

The mean proportions of long-short responses for the eight timing levels across the levels

of Intensity Change (3:12; 6:9; 9:6; 12:3) are detailed in Table 11. These values were submitted

to a 2 x 4 x 4 within-participants ANOVA treating Pattern Type (long-short, short-long), Interval

Durations (580 + 420, 560 + 440, 540 + 460, 420 + 580) and Intensity Change (3:12, 6:9, 9:6,

12:3) as independent factors and the proportion of long-short judgments as the dependent

measure. The results of this analysis are listed in Appendix C. A one-way within-participants

ANOVA was run using Intensity Change (3:12, 6:9, 9:6; 12:3) as the independent variable and

mean directional CE as the dependent measure (mean PSE and directional CE are shown in

Table 12). A one-way within-participants ANOVA was run using Intensity Change (3:12, 6:9,

9:6; 12:3) as the independent factor mean directional CE as the dependent measure.

Table 11

Participants' mean proportion of long-short responses in Experiment 3B for Pattern Type (Short-Long, Long-Short) and Intensity Change (3:12, 6:9, 9:6, 12:3) across all of the timing levels. Standard errors in parentheses.

Pattern Type	Interval Durations	Intensity Change			
		3:12	*6:9*	*9:6*	*12:3*
Long-Short	*580-420 ms*	.878 (.039)	.828 (.049)	.844 (.041)	.856 (.036)
	560-440 ms	.811 (.034)	.800 (.036)	.817 (.044)	.811 (.040)
	540-460 ms	.667 (.057)	.700 (.057)	.744 (.048)	.828 (.035)
	520-480 ms	.533 (.052)	.578 (.060)	.650 (.068)	.700 (.046)
Short-Long	*480-520 ms*	.339 (.036)	.406 (.059)	.506 (.048)	.550 (.040)
	460-540 ms	.200 (.037)	.278 (.038)	.328 (.050)	.361 (.038)
	440-560 ms	.233 (.044)	.228 (.051)	.206 (.053)	.283 (.053)
	420-580 ms	.178 (.050)	.200 (.045)	.228 (.053)	.144 (.028)

Table 12

Participants' mean Point of Subject Equality (PSE) and directional Constant Error (CE) in Experiment 3B across the levels of Intensity Change (3:12, 6:9, 9:6, 12:3).

	Intensity Change			
	3:12	*6:9*	*9:6*	*12:3*
Mean PSE	507.85	498.56	491.18	476.55
Mean CE	-7.85	1.44	8.82	23.45
Standard Error (PSE & CE)	7.93	9.31	8.13	7.43

A significant main effect was found for Intensity Change $F(3, 51) = 4.509$, $p < .01$. Trend analysis revealed a significant linear trend $F_{lin}(1, 17) = 9.475$, $p < .01$. Post hoc comparisons using Fisher's LSD t-test for pair-wise comparisons revealed that the 3:12 condition significantly differed from 9:6 ($p < .01$) and 12:3 ($p < .01$) conditions. The remaining pair-wise comparisons were non-significant (all $p \geq .056$). These results indicate that kappa effect sizes were again diminished (see Figure 6).

Figure 6

Experiment 3B: Mean directional CE (with standard error bars) for each level of Intensity

Change (3:12, 6:9, 9:6, 12:3).
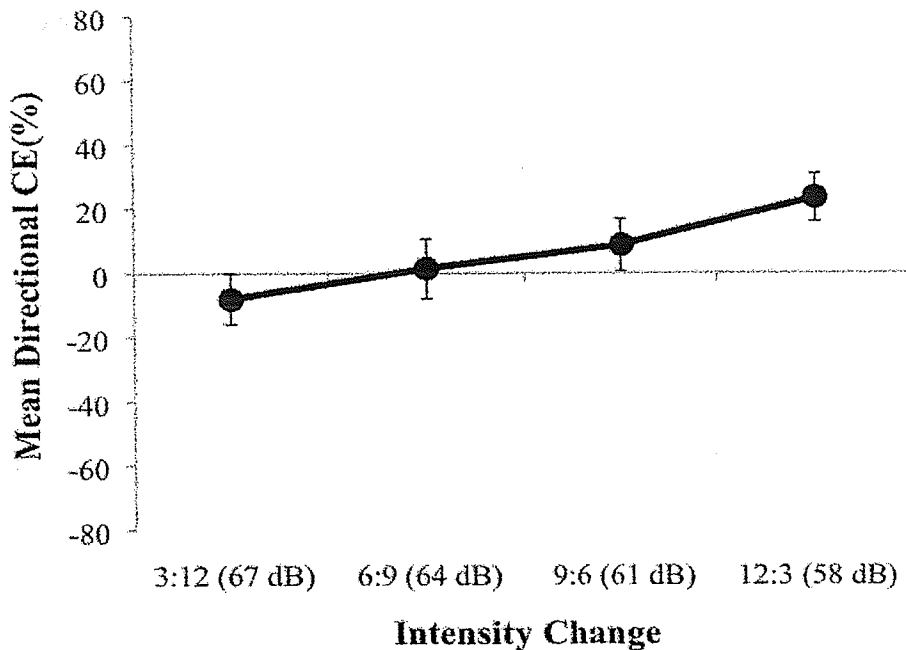
A 4 x 4 mixed ANOVA was used to compare the four context sequence conditions

(Stable-Intensity/Stable-Frequency, Stable-Intensity/Varied-Frequency, Varied-Intensity/Stable-

Frequency, Varied-Intensity/Varied-Frequency). Context sequence type was included as the

between-participants factor while Intensity Change (3:12, 6:9, 9:6, 12:3) was included as the

within-participants factor. The mean directional CE scores were used as the dependent measure.

Mauchley's test indicated that the assumption of sphericity had been violated ($\chi^2 = 25.485$ $p <$

.05). Greenhouse-Geisser sphericity estimates were used to correct the degrees of freedom ($\varepsilon =$

.790). The analysis revealed a significant main effect for Intensity Change $F(2.371, 163.557) =$

34.919, $p < .001$. Critically, a highly significant interaction was found to exist for the factors of

Context Sequence and Intensity Change, $F(7.112, 163.557) = 6.672, p < .001$.

Planned comparisons indicated that the interaction was the result of participants' short-long and long-short response biases being significantly larger in both 3:12 [$F(3, 72) = 5.228$, $p <$ .01] and 12:3 intensity conditions [$F(3, 69) = 8.993$, $p < .001$] respectively for the Variable-Intensity/Stable-Frequency condition (see Figure 7). No significant differences were found between the four Context Sequence types at the other levels of Intensity Change (all $p \geq .052$). In summary, the results show that kappa effects were largest when intensity changed within the context sequence versus being kept stable, and when frequency was kept stable across the sequence versus exhibiting change.

Figure 7

Mean directional CE for each level of Intensity Change (3:12, 6:9, 9:6, 12:3) for the four Context Sequence types (Variable Intensity – Variable Frequency, Variable Intensity – Stable Frequency, Stable Intensity – Variable Frequency, Stable Intensity – Stable Frequency).
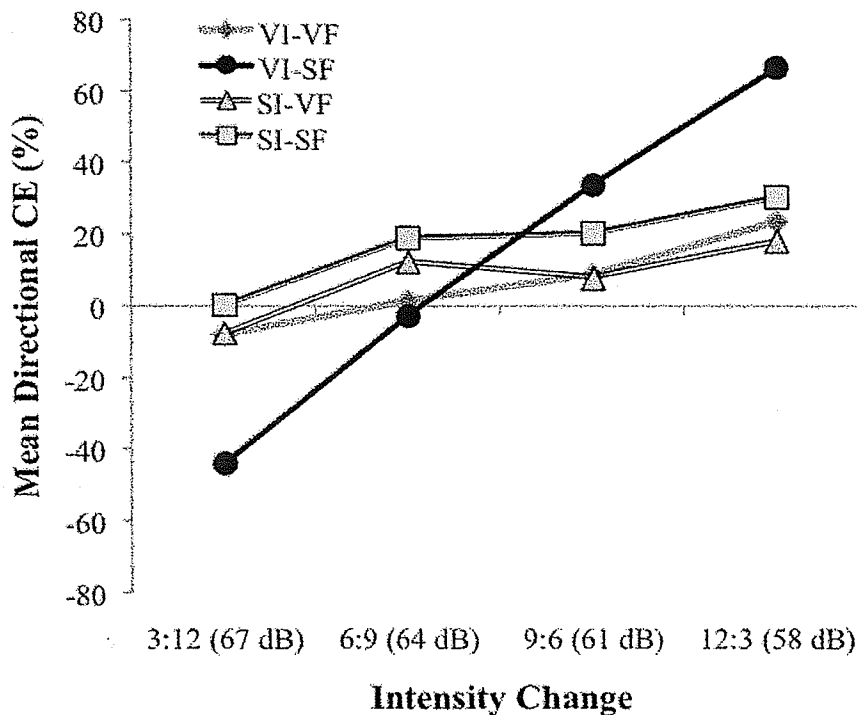
Discussion

The results of Experiments 2 and 3 indicate that the degree of perceived motion across a sequence is inter-related with kappa effects. Therefore participants formulate expectancies concerning the future location of a tone based on intensity change throughout the sequence. When the context sequences were consistent with AXB patterns on the degree of intensity change, auditory motion was preserved and kappa effects were uninfluenced. However, when a series of stable intensity or changing frequency tones preceded an AXB pattern, auditory motion was not conveyed, and participants subsequently no longer formed temporal expectancies based on the degree of intensity change throughout the pattern. These results are consistent with the auditory motion hypothesis, which proposes that participants assume constant velocity between tones changing along a spatial dimension and anticipate the location of a sound within a sequence based on the assumption that it is in motion, when perceived motion is interrupted so are the subsequent expectancies.

General Discussion

In Experiment 1 there were several important findings. Firstly, auditory kappa effects were found when intensity was manipulated using an AXB paradigm. The results showed that tones with similar intensity levels are perceived as occurring closer together in time (a 'short-long' response bias occurred for 3:12 pattern types and a 'long-short' response bias for 12:3 pattern types). Secondly, auditory intensity kappa effects were not significantly influenced by the overall direction of intensity change within the sequence (decreasing versus increasing). It is concluded that auditory intensity may influence temporal judgments using a standard 3-tone AXB paradigm.

Experiment 2 generated several important findings; firstly it was found that kappa effect

sizes decreased with the addition of a stable-intensity/stable-frequency context sequence

preceding each AXB pattern, a finding that was replicated for stable-intensity/varied-frequency

context sequences. This result supports MacKenzie and Jones (2005) findings, where three

stable-frequency tones diminished kappa effect sizes on preceding AXB patterns. This suggests

that when auditory motion (for both frequency and/or intensity) is not conveyed at the beginning

of a sequence it becomes difficult for participants to form motion-based expectancies later on in

the sequence. This may be the result of a priming phenomenon, where auditory-motion perceived

at the start of a sequence primes motion-based expectancies later on in the sequence.

Experiment 3 demonstrated that varied-intensity/stable-frequency context sequences will

induce a large kappa effect, while varied-intensity/varied-frequency context sequence will not.

There are several possible explanations for this finding; firstly, frequency change may

overshadow perceived intensity change within the context sequence, disrupting intensity-motion

expectancies on the preceding AXB pattern. A second possibility is that it may be determined by

the manner with which frequency and intensity information are perceptually combined when

making motion-based calculations (in the case of Experiment 3B intensity gradually decreased

across the sequence while frequency gradually increased). Studies on a naturally occurring

illusion called the Doppler-effect (Doppler, 1842) have demonstrated that people perceive an

approaching sound source as gradually increasing in loudness (intensity) and pitch (frequency).

This effect is a perceptual illusion, as the wave-form frequency of an approaching sound is

greatest when the sound source is furthest, decreasing in frequency as the sound source nears the

listener. Theoretically people should perceive an approaching sound as decreasing in frequency.

Neuhoff & McBeath (1996) presented participants with Doppler-shifted steady tones

(demonstrating the physical qualities of an approaching sound). These steady tones had a high

frequency low-level intensity at onset and gradually decreased in frequency while increasing in

intensity. Interestingly, participants reported increasing intensity tone as gradually increasing in

pitch. It is therefore possible that kappa and Doppler effects may interact, such that Doppler

effects may reinforce the perception of motion. To examine this possibility, participants could be

presented with increasing-intensity/increasing-frequency context sequences. These sequences

would conform to the perceptual properties of an approaching sound source and theoretically

could cause participants to infer motion, preserving kappa effects on preceding AXB patterns.

<center>Theoretical Issue: Perceived Motion vs. Heuristics</center>

The auditory motion hypothesis was supported by the findings of the current study as the

theory states that both frequency and intensity can induce auditory motion. M. R. Jones (1976)

states that spatiality in audition is conveyed through three subjective dimensions: pitch, loudness

and time, where changes in pitch and loudness are used to indicate duration "Pitch and/or

loudness relations are proportional to corresponding temporal periods identifiable within serial

patterns." (P. 327). Jones states that people anticipate the durations between sequential stimuli

according to their rhythmic form (a large time interval in a 'good' rhythmic form will indicate a

larger pitch or loudness interval between two tones). It is assumed that listeners perceptually

frame a pattern into an optimal pitch/loudness-time structure, "a listener casts a space-time

course into the future and thus heightens a receptive region for forthcoming events" (P. 348).

Kappa effects therefore arise when the expected temporal structure is applied to pattern that

violates those expectancies. As a side note, it is also possible that auditory kappa effects for

intensity are determined by pitch-motion expectancies despite holding frequency constant.

Neuhoff and McBeath (1996) found that when they Doppler-shifted a tone for intensity (the

stimulus started quiet, got louder and then decreased to its original sound level) while holding frequency constant, participants judged the sound as increasing in pitch during its approach. This introduces an interesting possibility for the auditory motion hypothesis, that participants do not formulate motion-based expectancies concerning 'intensity-motion', but rather form expectancies that combine intensity and pitch information (even when frequency change is absent from the experimental manipulation).

One issue the auditory motion hypothesis will likely need to address is that it requires that participants formulate complex expectancies about future events at a completely unconscious level. For example research has shown that participants encode contextual information concerning the temporal order of multiple stimuli under incidental-memory conditions (Hintzman & Block, 1971; Hinztman, Block & Summers, 1973) therefore participants should also encode information concerning spatial context automatically. It is not entirely clear through what mechanisms the auditory motion hypothesis proposes that the automatic imputation of velocity occurs, whether it is attention-based or involves the operation of complex cognitive processes (which MacKenzie's (2007) data would imply).

One possibility is that perceived auditory motion is simply a byproduct of a heuristic being applied, rather than the direct cause of kappa effects. The heuristic approach concerning temporal perception has its roots in early Gestalt psychology. Koffka's (1963) theory of perceived motion, for example, suggests that the perceived duration between successive stimuli is dependent on the level of 'field excitation' occurring between neuronal representations of each stimulus. This field excitation is what determines the law of proximity (Meyer, 1956), where elements occurring closer together in space are perceptually grouped, and the law of common fate (Schiffman, 1990), where stimuli moving in one direction are perceptually grouped. When

these organizational principles are combined it allows a sequence of static stimuli to be perceived as a single stimulus moving in one direction. The gestalt principles of proximity and common fate are similar to heuristics in that they provide a cognitive short-cut for how to perceive the environment, while perceived motion is the result of these combined processes, neither directly attempt to predict a stimulus' location in space as a function of velocity. Koffka's theory has been supported by evidence demonstrating that participants make musical inferences consistently with gestalt principles (Cuddy & Lunney, 1995; Narmour, 1990).

Tversky and Kahneman (1974) were the first to introduce the concept of heuristics as cognitive short-cuts or rules of thumb that are automatically applied when making decisions concerning ambiguous or complex stimuli (such as formulating event probabilities). In short, difficult questions can be answered by using the most accessible information (Goldstein & Gigerenzer, 2002). Auditory kappa effects may be due to participants relying on a similarity heuristic, where it is easier to base timing judgments on the degree of similarity between two tone's fundamental properties (frequency or intensity) when the duration of the intervals are so short that an algorithm cannot be implemented to determine them (i.e. mental counting). This is stated succinctly by Tversky and Kahneman (1974):

"Briefly stated, it appears that whenever some aspect of the environment is made disproportionately salient or 'available' to the perceiver that aspect is given more weight in causal attribution." (p. 11).

Participants may therefore use the similarity of sequential stimuli to make efficient duration judgments without ever perceiving inherent motion in the sequence. Following this reasoning, a recent experiment has found a direct link between event causality and time estimation in which perceived motion would be highly unlikely (Faro, Leelere & Hastie, 2005). In this study it was

found that historical events perceived as having casual connections were judged to have occurred closer together in the historical time-line than events with less or no causal connection.

It was previously discussed how context may influence perceived duration. The psychological mechanism through which this is proposed to occur is referred to as attribute substitution. Kahneman and Frederick (2002) stated that three conditions must be satisfied for attribute substitution to occur:

"(1) the target attribute is relatively inaccessible; (2) a semantically and associatively related attribute is highly accessible; and (3) the substitution of the heuristic attribute is not rejected..." (p. 54).

These conditions appear to be met in the majority of kappa experiments, as most use interval durations that are only milliseconds in length, making them difficult to perceive. The related element of pitch or loudness is highly accessible, and is therefore substituted. Lastly, for the illusion to occur, the person must not thoughtfully reject the substitution of pitch or loudness information to help make a duration judgment. A number of experiments have found that a resulting bias could be reduced or eliminated simply by alerting participants to the fact that an irrelevant variable could bias their judgments (Schwarz & Clore, 1983; Schwarz, 1996). It is therefore possible that a three-tone frequency or intensity stable context sequence may alert participants to the irrelevancy of using frequency or intensity change in later timing judgments.

The change/segmentation model (Poynter, 1983; Poynter, 1989) or contextual-change model (Block & Zakay, 2008) provide the theoretical structure through which frequency/intensity variation may be substituted for duration. The contextual-change model states that people will judge time by assessing the amount of contextual change occurring over an assessed duration, the context is said to include environmental factors that are unrelated to the central task (judging the length of a temporal duration). This model can be applied directly to

kappa effects. Block (1982) for example, demonstrated that a change in the environmental context between study and recognition test could lengthen the perceived duration of the interval separating study and test phases. Brown (1995) demonstrated more evidence, showing that participants perceive a moving visual stimulus exhibiting unpredictable variations in its location as longer in duration than a stationary stimulus. Recently Leboe and Mondor (2008) found that steady tones (500 Hz) are perceived as shorter than glide sounds (sounds that change smoothly in frequency) of equivalent duration and that tones exhibiting abrupt changes in frequency were perceived as having a longer duration than steady tones. These studies suggest that the inferred degree of contextual (i.e. spatial, frequency etc.) change occurring across an inter-stimulus interval will subsequently increase the perceived duration.

Appendix A

Analysis of the Proportion of 'Long-Short' responses from Experiments 1A and 1B

Results (Experiment 1A)

A main effect was found for Pattern Type $F(1, 16) = 91.988$, $p < .001$, which revealed that participants responded 'long-short' more often to long-short patterns (see Table A1). A main effect was found for Intensity Change $F(1.387, 22.188) = 11.323$, $p < .001$. A planned contrast revealed a significant linear trend across the four levels of Intensity Change $F_{lin}(1, 16) = 13.660$, $p < .01$, therefore participants were more likely to respond 'long-short' as the pattern shifted from 3:12 to 12:3 (see Table A1). There was also an Interval Durations x Pattern Type interaction $F(3, 48) = 55.973$, $p < .001$. Planned contrasts demonstrated significant linear trends for long-short [$F_{lin}(1, 17) = 100.439$, $p < .001$] and short-long [$F_{lin}(1, 17) = 76.455$, $p < .001$] patterns across Interval Durations. As the saliency of the interval durations increased the proportion of 'long-short' responses significantly increased for long-short patterns and decreased for short-long (see Table A1).

Table A1

Mean proportion of 'long-short' response each level of Intensity Change and Interval Durations for each Pattern Type in Experiment 1A. Standard Errors in parentheses.

	Intensity Change				
	3:12	*6:9*	*9:6*	*12:3*	
	.421 (.038)	.517 (.025)	.574 (.015)	.615 (.020)	
	Interval Durations				
Pattern Type	*520 + 480*	*540 + 460*	*560 + 420*	*580 + 420*	*Total*
Long-Short	.619 (.029)	.699 (.025)	.724 (.034)	.806 (.027)	.712
Short-Long	.485 (.032)	.382 (.025)	.307 (.025)	.234 (.027)	.353

Results (Experiment 1B)

A main effect was found for Pattern Type $F(1, 16) = 74.796, p < .001$), which revealed that participants responded 'long-short' more often to long-short patterns (see Table A2). A main effect was found for Intensity Change $F(1.633, 26.121) = 8.900, p < .001$. A planned contrast revealed a significant linear trend across the four levels of intensity $F_{lin}(1, 16) = 11.655, p < .01$, therefore participants were more likely to respond 'long-short' as the Intensity Change in the pattern neared 12:3 (see Table A2). Lastly there was a significant Interval Durations x Pattern Type $F(1.876, 30.009) = 34.673, p < .001$. Planned contrasts demonstrated significant linear trends for long-short [$F_{lin}(1, 16) = 47.029, p < .001$] and short-long [$F_{lin}(1, 16) = 35.027, p < .001$] patterns across the Interval Durations. The source of the interaction is due to the fact that as the saliency of the interval durations increased, the proportion of 'long-short' responses significantly increased for long-short patterns and decreased for short-long (see Table A2).

Table A2

Mean proportion of 'long-short' response each level of Intensity Change and Interval Durations for each Pattern Type in Experiment 1B. Standard Errors in parentheses.

	Intensity Change				
	3:12	*6:9*	*9:6*	*12:3*	
	.453 (.027)	.474 (.019)	.530 (.021)	.580 (.025)	

	Interval Durations				
Pattern Type	*520 + 480*	*540 + 460*	*560 + 420*	*580 + 420*	*Total*
Long-Short	.596 (.026)	.649 (.029)	.725 (.033)	.776 (.030)	.686
Short-Long	.435 (.024)	.351 (.022)	.294 (.033)	.247 (.039)	.332

Appendix B

Analysis of the Proportion of 'Long-Short' responses from Experiments 2A and 2B

Results (Experiment 2A)

A main effect was found for Pattern Type $F(1, 16) = 65.885, p < .001$, which revealed that participants responded 'long-short' more often to long-short patterns (see Table B1). A main effect was found for Intensity Change $F(1.862, 29.792) = 3.672, p < .05$. Interestingly, a planned linear contrast revealed no significant trend ($p = .064$). Fisher's LSD T-test revealed significant pair-wise differences in the mean proportion of long-short responses between all four levels of intensity change (all $p \leq .035$). Lastly there was a significant Interval Durations x Pattern Type interaction $F(1.921, 30.732) = 15.370, p < .001$. Planned contrasts demonstrated significant linear trends for long-short [$F_{lin}(1, 16) = 29.695, p < .001$] and short-long [$F_{lin} (1, 16) = 4.903, p < .05$] patterns across the Interval Durations. The source of the interaction is due to the fact that as the saliency of the interval durations increased, the proportion of 'long-short' responses significantly increased for long-short patterns and decreased for short-long (see Table B1).

Table B1

Mean proportion of 'long-short' response each level of Intensity Change and Interval Durations for each Pattern Type in Experiment 2A. Standard Errors in parentheses.

	Intensity Change				
	3:12	*6:9*	*9:6*	*12:3*	
	.564 (.036)	.609 (.026)	.589 (.020)	.647 (.021)	

	Interval Durations				
Pattern Type	*520 + 480*	*540 + 460*	*560 + 420*	*580 + 420*	*Total*
Long-Short	.672 (.029)	.756 (.028)	.821 (.021)	.876 (.020)	.781
Short-Long	.494 (.035)	.447 (.048)	.382 (.047)	.368 (.058)	.423

Results (Experiment 2B)

A main effect was found for Pattern Type $F(1, 20) = 154.295, p < .001$, which revealed

that participants responded 'long-short' more often to long-short patterns (see Table B2). A main

effect was found for Intensity Change $F(3, 60) = 5.956, p < .01$. Planned contrasts revealed

significant linear [$F_{lin}(1, 20) = 7.048, p < .05$] and cubic [$F_{cub}(1, 20) = 8.856, p < .01$] trends. As

Intensity Change was manipulated the mean proportion of 'long-short' responses significantly

increased and demonstrated two inflection points (See Table B2). Lastly there was a significant

Interval Durations x Pattern Type interaction $F(3, 60) = 109.208, p < .001$. Planned contrasts

demonstrated significant linear trends for long-short [$F_{lin}(1, 20) = 27.616, p < .001$] and short-

long [$F_{lin}(1, 20) = 85.400, p < .001$] patterns across the Interval Durations. The source of the

interaction is due to the fact that as the saliency of the interval durations increased, the

proportion of 'long-short' responses significantly increased for long-short patterns and decreased

for short-long (see Table B2).

Table B2

Mean proportion of 'long-short' response each level of Intensity Change and Interval Durations
for each Pattern Type in Experiment 2B. Standard Errors in parentheses.

	Intensity Change				
	3:12	*6:9*	*9:6*	*12:3*	
	.486 (.017)	.545 (.013)	.519 (.018)	.557 (.012)	

	Interval Durations				
Pattern Type	*520 + 480*	*540 + 460*	*560 + 420*	*580 + 420*	*Total*
Long-Short	.662 (.036)	.743 (.024)	.826 (.026)	.862 (.024)	.773
Short-Long	.448 (.028)	.307 (.028)	.196 (.025)	.156 (.030)	.277

Appendix C

Analysis of the Proportion of 'Long-Short' responses from Experiments 3A and 3B

Results (Experiment 3A)

A main effect was found for Pattern Type $F(1, 16) = 73.725, p < .001$, which revealed that participants responded 'long-short' more often to long-short patterns (see Table C1). A main effect was found for Intensity Change $F(1.503, 24.051) = 39.808, p < .001$. Planned contrasts revealed a significant linear $F_{lin}(1, 16) = 50.589, p < .001$ trend. As Intensity Change was manipulated the mean proportion of 'long-short' responses significantly increased (See Table C1). Lastly there was a significant Interval Durations x Pattern Type interaction $F(1.851, 29.612) = 42.351, p < .001$. Planned contrasts revealed significant linear trends for long-short [$F_{lin}(1, 16) = 40.282, p < .001$] and short-long [$F_{lin}(1, 16) = 46.550, p < .001$] patterns across Interval Durations. The source of the interaction is due to the fact that as the saliency of the interval durations increased, the proportion of 'long-short' responses significantly increased for long-short patterns and decreased for short-long (see Table C1).

Table C1

Mean proportion of 'long-short' response each level of Intensity Change and Interval Durations for each Pattern Type in Experiment 3A. Standard Errors in parentheses.

	Intensity Change				
	3:12	*6:9*	*9:6*	*12:3*	
	.486 (.029)	.545 (.021)	.519 (.014)	.557 (.023)	
	Interval Durations				
Pattern Type	*520 + 480*	*540 + 460*	*560 + 420*	*580 + 420*	*Total*
Long-Short	.605 (.036)	.719 (.030)	.765 (.034)	.839 (.030)	.732
Short-Long	.493 (.029)	.373 (.024)	.279 (.035)	.234 (.033)	.345

Results (Experiment 3B)

A main effect was found for Pattern Type $F(1, 17) = 77.136, p < .001$, which revealed that participants responded 'long-short' more often to long-short patterns (see Table C2). A main effect was found for Intensity Change $F(3, 51) = 13.690, p < .001$. Planned contrasts revealed a significant linear $F_{lin}(1, 17) = 42.701, p < .001$.trend. As Intensity Change was manipulated the mean proportion of 'long-short' responses significantly increased (See Table C2). There was a significant Interval Durations x Pattern Type interaction $F(1.648, 28.022) = 49.494, p < .001$. Planned contrasts revealed significant linear trends for long-short [$F_{lin}(1, 17) = 20.571, p < .001$] and short-long [$F_{lin}(1, 17) = 22.466, p < .001$] patterns across Interval Durations. The source of the interaction is due to the fact that as the saliency of the interval durations increased, the proportion of 'long-short' responses significantly increased for long-short patterns and decreased for short-long (see Table C1).

Table C2

Mean proportion of 'long-short' response each level of Intensity Change and Interval Durations for each Pattern Type in Experiment 3B. Standard Errors in parentheses.

	Intensity Change				
	3:12	*6:9*	*9:6*	*12:3*	
	.480 (.018)	.502 (.025)	.540 (.022)	.567 (.016)	

	Interval Durations				
Pattern Type	*520 + 480*	*540 + 460*	*560 + 420*	*580 + 420*	*Total*
Long-Short	.615 (.049)	.735 (.042)	.810 (.032)	.851 (.038)	.753
Short-Long	.450 (.038)	.292 (.032)	.238 (.039)	.188 (.040)	.292

An Interval Durations x Intensity Change interaction was found, $F(9, 153) = 5.710$, $p <$ .001. To analyze it the simple effects of Intensity Change at each of the 4 interval durations were examined (see figure C1). When the Interval Durations were 520 + 480 and 540 + 460 significant differences between the Intensity Change levels occured [$F(3, 51) = 12.306$, $p < .001$, and $F(3, 51) = 10.698$, $p < .001$, respectively]. No differences were found at the 560 + 440 or 580 + 420 levels ($p = .481$ and .327 respectively). Post Hoc tests were carried out for 520 + 480 and 540 + 460 Interval Durations using Fisher's LSD. This revealed that at the 520 + 480 level, there were significant differences between all the intensity levels except for 3:12 vs. 6:9 ($p =$ .116) and 9:6 vs. 12:3 ($p = .191$) (remaining $p \leq .046$). At the 540 + 460 level, there were significant differences between all the intensity levels except for 6:9 vs. 9:6 ($p = .129$) and 9:6 vs. 12:3 ($p = .078$).

Figure C1
Interval Duration x Intensity Change Interaction (mean proportion of long-short responses).
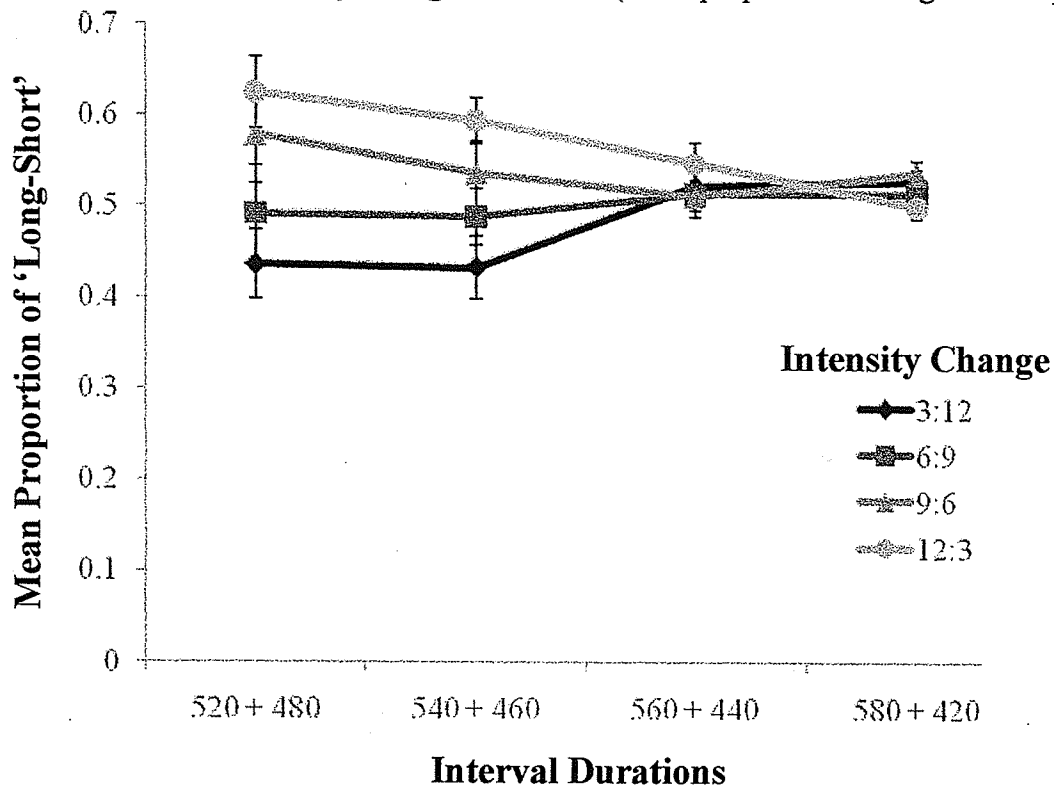
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