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Increasing Task Difficulty Enhances Effects of Intersensory Redundancy: Testing A New Prediction of the Intersensory Redundancy Hypothesis

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Abstract

Prior research has demonstrated intersensory facilitation for perception of amodal properties of events such as tempo and rhythm in early development, supporting predictions of the Intersensory Redundancy Hypothesis (IRH). Specifically, infants discriminate amodal properties in bimodal, redundant stimulation but not in unimodal, nonredundant stimulation in early development, whereas later in development infants can detect amodal properties in both redundant and nonredundant stimulation. The present study tested a new prediction of the IRH: that effects of intersensory redundancy on attention and perceptual processing are most apparent in tasks of high difficulty relative to the skills of the perceiver. We assessed whether by increasing task difficulty, older infants would revert to patterns of intersensory facilitation shown by younger infants. Results confirmed our prediction and demonstrated that in difficult tempo discrimination tasks, 5-month-olds perform like 3-month-olds, showing intersensory facilitation for tempo discrimination. In contrast, in tasks of low and moderate difficulty, 5-month-olds discriminate tempo changes in both redundant audiovisual and nonredundant unimodal visual stimulation. These findings indicate that intersensory facilitation is most apparent for tasks of relatively high difficulty and may therefore persist across the life-span.

Infants perceive the world of multimodal events through a unified perceptual system and are able to detect information that is common to stimulation across the senses (Bahrick & Pickens, 1994; E. J. Gibson, 1969; J. J. Gibson, 1979; Lewkowicz, 2000). This information, such as temporal synchrony, rhythm, tempo, and changing intensity is considered “amodal” (i.e., not specific to a particular sensory modality) and can be redundantly specified across the senses. Redundantly specified amodal information is highly salient to both human and non-human animal infants (see Bahrick & Lickliter, 2002; Lewkowicz, 2000 for reviews). Amodal properties are available in all events and can be considered “building blocks” of perceptual development, facilitating perception of unitary multimodal events (such as a person speaking), and serving as the gatekeeper to further processing of the event as a whole (see Bahrick, in press; Bahrick & Lickliter, 2002 for discussion). One of the most fundamental and earliest detected amodal properties is temporal synchrony (Lewkowicz, 2000, in press; Lewkowicz, Leo, & Simion, in press). Research demonstrates that synchrony guides and constrains further perceptual processing of more specific information (Bahrick, 2001) and amodal properties such as synchrony are detected developmentally prior to modality specific properties of events (properties that can be detected through only a single sense modality, such as color, pattern, pitch, or timbre; see Bahrick, 1992, 1994, 2001; Lewkowicz, 2000).

Bahrick & Lickliter (2000, 2002) have proposed a model of selective attention, the Intersensory Redundancy Hypothesis (IRH), to explain how and under what conditions attention and perceptual processing are promoted to different aspects of events (amodal versus modality specific). Intersensory redundancy refers to the temporally synchronous and spatially collocated occurrence of the same information (e.g., rate, rhythm, duration, intensity shifts) across two or more senses. According to the IRH, intersensory redundancy is highly salient and directs selective attention to the amodal aspects of events that are redundantly specified across the senses at the expense of nonredundantly specified information within the same event, particularly during early development.

The IRH makes three specific predictions: 1) Multimodal stimulation selectively recruits attention and promotes perceptual processing of redundantly specified amodal properties of events (at the expense of nonredundantly specified properties) to a greater extent than does unimodal (e.g., visual or auditory) stimulation. This is termed “intersensory facilitation”. Studies of human and nonhuman animal infants have provided converging support for this prediction. For example, rhythm, tempo, and affective expressions are more easily detected when they are conveyed redundantly through synchronous audiovisual stimulation rather than nonredundantly, through asynchronous stimulation or through visual or auditory stimulation alone (Bahrick & Lickliter, 2000; Bahrick, Flom & Lickliter, 2002; Flom & Bahrick, 2007; Lickliter, Bahrick, & Honeycutt, 2002, 2004). 2) Information presented nonredundantly to one sense modality alone selectively recruits attention and promotes perceptual processing of modality specific properties of stimulation to a greater extent than does multimodal stimulation. This is termed “unimodal facilitation”. This occurs in part because salient redundancy is not available to compete for attention in unimodal stimulation. Accordingly, infants have shown heightened discrimination and memory for the orientation of a moving object in unimodal visual and asynchronous audiovisual stimulation (which provide no redundancy) as compared with synchronous audiovisual stimulation where intersensory redundancy competes for attention (Bahrick, Lickliter, & Flom, 2006; Flom & Bahrick, under review). 3) As attention becomes more efficient and flexible with experience, detection of both amodal and modality specific properties emerges in both redundant, multimodal and nonredundant, unimodal stimulation. This is the developmental prediction of the IRH. Thus, detection of amodal properties including rhythm, tempo, and affect extends from multimodal stimulation in young infants, to unimodal stimulation in older infants (Bahrick & Lickliter, 2004; Flom & Bahrick, 2007; Lickliter, Bahrick, & Markham, 2006) whereas detection of nonredundantly specified properties such as orientation, extends from unimodal stimulation in young infants to multimodal stimulation in older infants (Bahrick, Lickliter, & Flom, 2006).

The purpose of the present study was to test a new, fourth prediction of the IRH: 4) Intersensory facilitation is most pronounced for tasks of relatively high difficulty in relation to the expertise of the perceiver. In early development, perceivers are more naïve, events are relatively novel, and attentional resources are more limited, making perceptual processing rather difficult and effortful. During this time, effects of intersensory redundancy should be most pronounced. However, because perceptual learning and differentiation occur throughout the lifespan, effects of intersensory facilitation should also be evident in later development, particularly when cognitive load is high, perceivers develop new areas of expertise, or learn to perceive finer distinctions in familiar stimuli (e.g., learning a new language, playing a musical instrument, or identifying birds). Under these conditions, when expertise is low in relation to task demands, older perceivers should also experience intersensory facilitation.

Underlying this prediction is the assumption that more salient information receives earlier, longer, and deeper processing than less salient information (see Adler & Rovee Collier, 1994; Bahrick, in press; Bahrick & Newell, 2008; Craik & Lockhart, 1972). Exposure to an event promotes perceptual differentiation in order of attentional salience such that more salient properties are differentiated first and less salient properties are differentiated later (E. J. Gibson, 1969). Thus, in multimodal stimulation, the salience of intersensory redundancy should promote earlier, longer, and deeper processing of amodal properties. Infants should therefore differentiate amodal properties first, and modality specific properties later during exploration of an event. Processing biases consistent with such salience hierarchies have been documented for young infants for a variety of other event properties (see Bahrick, Gogate, & Ruiz, 2002; Bahrick & Newell, 2008; Bahrick & Pickens, 1995; Frick, Colombo, & Saxon, 1999; Oakes & Madole, 2008). Further, because older infants process information more rapidly and efficiently than younger infants (e.g., Colombo & Mitchell, 1990; Colombo, Mitchell, Coldren & Freeseman, 1991; Frick, Colombo, & Saxon, 1999; Hale, 1990; Hunter & Ames, 1988; Rose, Feldman, & Jankowski, 2001) they should also progress through this salience hierarchy more rapidly than younger infants. This would increase their likelihood of processing less salient properties of an event following processing more salient properties. Further, effects of task difficulty should parallel those of age and experience. If task difficulty is increased, requiring further perceptual differentiation, older infants should progress through the salience hierarchy more slowly, eliciting performance similar to that of younger, less experienced infants.

Similar interactions among task difficulty, age and exploratory time have also been documented for preferences for familiarity versus novelty. Consistent with our attentional salience view, older infants progress through a familiarity-to-novelty preference sequence faster than do younger infants. Similarly, for tasks of low difficulty, infants progress through the sequence faster than for tasks of high difficulty (e.g., Hunter & Ames, 1988; Rose, Gottfried, Carminar, & Bridger, 1982). Moreover, studies across various domains have demonstrated that performance of older infants can revert to patterns characteristic of younger infants when task demands, task difficulty, or cognitive load are increased (Adolph, 1997, 2002; Adolph & Berger, 2005; Berger, 2004; Corbetta & Bojczyk, 2002).

In keeping with the logic outlined above, we reasoned that if the improved performance of older infants in our prior study of tempo discrimination (Bahrick & Lickliter, 2004) is a result of greater experience, attentional resources, and increased perceptual differentiation, then increasing task difficulty should require additional differentiation, and older infants should revert to patterns of intersensory facilitation observed in younger infants. That is, they should show better detection of amodal properties in bimodal, redundant stimulation than in unimodal, nonredundant stimulation.

We tested this hypothesis by assessing discrimination and intersensory facilitation for the amodal property of tempo in a task identical to that of prior studies in this series (Bahrick, Flom, & Lickliter, 2002; Bahrick & Lickliter, 2004). These studies revealed that 3-month-olds can discriminate a change in the tempo of a toy hammer tapping (from fast to slow, or vice versa) in redundant (synchronous), audiovisual stimulation, but not in nonredundant stimulation (unimodal visual, unimodal auditory, or asynchronous audiovisual). However, by the age of 5-months, intersensory facilitation was no longer evident as infants could discriminate the change in tempo in both synchronous audiovisual and unimodal visual stimulation.

In the present study, we presented 5-month-old infants with more fine-grained tempo contrasts of moderate and high difficulty in redundant (synchronous, audiovisual) and nonredundant (unimodal visual) conditions. Stimulus events and data from Bahrick & Lickliter (2004) served as the condition of low difficulty. We hypothesized that when these older (5-month-old) infants were presented with more difficult tempo contrasts they would revert to the intersensory facilitation shown for the easy contrasts by younger (3-month-old) infants. In other words, they would discriminate difficult tempo contrasts only in redundant, bimodal stimulation and not in nonredundant, unimodal stimulation. Further, if task difficulty affects discrimination of amodal properties, then discrimination of moderately difficult tempo contrasts should fall somewhere between those of low and high difficulty. Thus, a main effect of task difficulty should be found and discrimination should decrease monotonically as task difficulty increases. These findings would provide evidence that intersensory facilitation becomes more apparent as task difficulty increases in relation to the expertise of the perceiver, revealing more about mechanisms for facilitation.

Methods

Participants

Forty-eight 5-month-olds (24 females and 24 males), with a mean age of 155.19 days (SD = 4.61) participated. Infants had a gestation period of at least 38 weeks, were primarily from middle class homes, and had parents with at least a high school education. Thirty-three infants were Hispanic, 9 were Caucasian, 2 were African American, and 4 were of unknown ethnic origin. Eight additional infants participated, but their data were excluded due to fussiness (*n* = 1), experimenter error (*n* = 2), and failure to meet the fatigue criterion (*n* = 5).

The data of thirty-two 5-month-olds from our prior study (Bahrick & Lickliter, 2004, Experiment 1) were also included and comprised the low task difficulty condition for comparison with the data generated from the present sample, which was comprised of conditions of moderate and high task difficulty. The selection criteria, mean age, and ethnic make up of our prior sample were comparable to those of our present sample (M=157.4 days, SD = 6.4; 23 Hispanic, 7 Caucasian, and 2 African American infants).

Stimulus Events

The stimulus events (from Bahrick et al., 2002 and Bahrick & Lickliter, 2004) depicted a red toy hammer tapping one of two rhythms at one of two tempos against a white platform, creating a naturalistic percussive sound. Each rhythm consisted of 4 beats and they differed only in terms of the arrangement of their elements. The tempo contrast used in our prior studies, 110 vs. 240 bpm (a difference of more than 100%) served as the “low difficulty” contrast. Using audiovisual editing software (Adobe Premier 1.5) we modified the speed of the events (while holding the pitch of the impact sound constant) to create more difficult tempo contrasts. After piloting (to establish which contrasts 5-month-olds appeared to detect) tempos of 138 bpm and 129 bpm were selected to yield event contrasts of “moderate difficulty” (110 vs. 138 bpm, an increase of 38% over the standard), and “high difficulty” (110 vs. 129 bpm, an increase of 17% over the standard) for each rhythm. A control display was also used, depicting a green and white plastic turtle whose arms spun, creating a whirring sound, as in our prior studies.

Apparatus

Infants sat in a standard infant seat facing a color television monitor (Sony KV-20520) approximately 55 cm away. An experimenter presented the stimulus events using Panasonic video decks (models DS545 and AG7750). Trained observers, unaware of the infant’s condition, monitored their visual fixations (through apertures in a curtain) by depressing a button on a joystick corresponding to the length of each fixation. The joystick was connected to a computer which collected the fixation time data on line. The observations of the primary observer controlled the video presentations, and those of the secondary observer were used for calculation of interobserver reliability.

Procedure

Using procedures identical to those of our prior study (Bahrick & Lickliter, 2004), infants were tested to determine whether they could detect a change in tempo following bimodal audiovisual (*n*=24) as compared with unimodal visual (*n*=24) exposure to a rhythmic sequence in an infant-controlled habituation procedure (see Horowitz, 1975; Horowitz, Paden, Bhana, & Self, 1972). In the bimodal condition, infants received a synchronous audible and visible presentation of the toy hammer tapping a rhythm, whereas in the unimodal visual condition they received a silent visual presentation of the toy hammer tapping. Within each condition, infants were randomly assigned to one of the two rhythms, and within each of these conditions, they were randomly assigned to one of two tempo contrasts (moderate or high difficulty contrasts). Thus, 12 infants were presented with each tempo contrast under each redundancy condition. Half the infants in each condition were habituated to the slower tempo and tested with the faster tempo and the other half received the opposite arrangement.

The infant-controlled habituation procedure (identical to that of our prior studies, Bahrick & Lickliter, 2004; Bahrick, et al., 2006) began and ended with the control display used for assessing fatigue. Infants were judged to be fatigued if their visual fixation on the final control trial was less than 20% of their initial fixation level. Each habituation sequence consisted of at least 6 trials. Habituation trials were presented when infants visually fixated the television monitor and terminated when infants looked away for 1.5 seconds or when a maximum of 60 seconds had elapsed. Trials continued until the infant's visual fixation decreased by 50% or greater on two consecutive trials, relative to the infant's mean fixation level on the first two trials of the habituation sequence (baseline). Then two additional habituation trials were presented ("post-habituation trials") and served as a basis for calculating visual recovery to the subsequent test trials.

Following successful completion of the habituation phase and the two no-change post-habituation trials, infants received two identical test trials depicting a novel tempo (presented at the familiar rhythm) to assess discrimination of a change in tempo of either moderate or high difficulty. Discrimination of tempo was inferred on the basis of visual recovery to the novel tempo with respect to the familiar tempo presented during the post-habituation trials. Approximately 15% of the infants were monitored by a secondary observer for assessing interobserver reliability. A Pearson product-moment correlation between the visual fixation scores of the primary and secondary observers revealed an average correlation of .99 (SD = .001).

Results

Visual recovery to the change in tempo served as an index of discrimination. This was calculated by subtracting the mean of the two post-habituation trials from the mean of the two test trials. Infants' visual recovery to the change in tempo as a function of condition (bimodal audiovisual vs. unimodal visual) and difficulty (low, moderate, high) are depicted in Figure 1.

To address the primary research question, whether infants who received more difficult tempo contrasts reverted to patterns of intersensory facilitation like those of younger infants, single-sample *t*-tests were conducted on mean visual recovery against the chance value of zero (i.e., no difference between test and post-habituation fixation) to assess tempo discrimination. Results confirmed our predictions. Infants who received tempo contrasts of high difficulty showed intersensory facilitation. They demonstrated significant visual recovery to a change in tempo following redundant, bimodal, audiovisual stimulation ($t(11) = 2.24$, $p = .05$, $\text{eta}^2 = .31$), but not following nonredundant, unimodal visual stimulation ($t(11) = 0.21$, $p > .05$, $\text{eta}^2 = .004$). In contrast, infants who received tempo contrasts of low and moderate difficulty showed discrimination under both conditions. They demonstrated significant visual recovery to a change in tempo in redundant, bimodal audiovisual stimulation ($t(15) = 4.27$, $p < .001$, $\text{eta}^2 = .55$; $t(11) = 3.08$, $p < .05$, $\text{eta}^2 = .46$, respectively), and in nonredundant, unimodal visual stimulation ($t(15) = 3.04$, $p < .01$, eta^2 = .38; $t(11) = 2.17$, $p = .05$, eta^2 = .30, respectively). These findings suggest that discrimination is a function of task difficulty in relation to the age/expertise of the perceiver. They support our prediction that with more difficult tasks, older, more experienced infants revert to the patterns of intersensory facilitation shown by younger, more naïve infants.

What is the nature of the relations among task difficulty, redundancy, and discrimination? Figure 1 reveals that mean visual recovery, our index of discrimination, decreases monotonically as task difficulty increases, for both bimodal, redundant stimulation and unimodal, nonredundant stimulation. Regression analyses revealed a significant linear relationship between task difficulty (defined in terms of bpm) and visual recovery ($F(1, 78) = 12.36$, $p = .001$, $r^2 = .14$). Thus, discrimination of tempo contrasts of moderate difficulty fall between those of low and high difficulty, confirming that task difficulty affects discrimination of amodal properties in a systematic manner. To compare discrimination across conditions, we conducted a two-way analysis of variance on visual recovery with condition (bimodal audiovisual, unimodal visual) and difficulty (low, moderate, high) as between subject factors. Results revealed a main effect of condition ($F(1,74) = 4.47$, $p = .04$, eta^2 = .03), indicating that overall, infants in the bimodal audiovisual condition demonstrated greater visual recovery to a change in tempo than infants in the unimodal visual condition. These results support our predictions and are consistent with previous findings indicating that intersensory redundancy available in bimodal audiovisual stimulation promotes discrimination of amodal properties such as tempo to a greater extent than does nonredundant stimulation (Bahrick & Lickliter, 2000;Bahrick, Flom, et al., 2002). Results also revealed a main effect of task difficulty ($F(2,74) = 6.37$, $p = .003$, eta^2 = .10). Planned comparisons indicated that visual recovery in the low difficulty condition was significantly greater than that of the moderate and high difficulty conditions ($p = .02$, $p = .001$, respectively). No significant interaction of redundancy and task difficulty was found ($F(2,74) = .28$, $p > .05$, eta^2 = .004).

Analyses of simple main effects were also conducted. Although there was no significant difference between redundant vs. nonredundant stimulation for each difficulty level taken alone (likely because of insufficient power), when results of the two more difficult tempo contrasts (moderate and high difficulty) were combined, analyses revealed a significant effect of redundancy on visual recovery ($F(1,76) = 4.26$, $p = .04$; eta^2 =.05). There was no such effect for the easy contrasts ($F(1,76) = .52$, $p > .1$; eta^2 = .007), again indicating that effects of redundancy on discrimination of amodal properties are most evident for more difficult tasks.

Secondary analyses were also performed on each of the four habituation variables (see Table 1) to assess whether infants showed any differences in habituation patterns as a function of condition (bimodal, unimodal) or difficulty level assigned. Results indicated only a significant main effect of condition for mean baseline fixation ($F(1,74) = 9.81$, $p = .002$, eta^2 = .03) and processing time ($F(1,74) = 9.35$, $p = .003$, eta^2 = .02), with infants spending more initial and overall time looking to the bimodal than the unimodal events. To disentangle effects of processing time and redundancy on visual recovery, processing time was used as a covariate in an analysis of variance with condition and difficulty as main factors. Results indicated processing time was not a significant covariate ($F(1, 73) = .43$, $p > .1$, eta^2 = .003) and thus processing time differences for unimodal vs. bimodal stimulation had no significant impact on discrimination of tempo. Taken together, none of the secondary analyses qualified results of our main analyses.

General Discussion

In the present study, we assessed discrimination of moderate and difficult changes in tempo (28 and 19 bpm, respectively) in 5-month-old infants. Consistent with our predictions, results revealed intersensory facilitation for discrimination of difficult but not moderate tempo changes by 5-month-olds. Together with our prior findings, results revealed that for tempo contrasts of moderate and low difficulty, 5-month-olds showed significant discrimination in both unimodal, nonredundant and bimodal, redundant stimulation (i.e. no intersensory facilitation). In contrast, when tempo contrasts were of high difficulty, 5-month-olds showed intersensory facilitation. They discriminated tempo changes only in bimodal redundant stimulation and not in unimodal nonredundant stimulation, paralleling the facilitation shown by 3-month-olds (Bahrick et al., 2002). Thus, when task difficulty was high, older (5-month-old) infants reverted to the patterns of intersensory facilitation shown by younger (3-month-old) infants. They discriminated tempo only when intersensory redundancy highlighted amodal properties. These findings support a new prediction of the IRH and indicate that, in infancy, intersensory facilitation is a function of task difficulty in relation to the expertise of the perceiver.

An attentional salience hierarchy model (see Bahrick, in press, Bahrick & Newell, 2008 for discussion) may account for the effects of task difficulty on intersensory facilitation. Attention is thought to progress from most salient to increasingly less salient characteristics of events across exploratory time. For easy tasks, perceivers may detect both the more and less salient aspects of stimulation resulting in discrimination of amodal properties such as tempo in both bimodal redundant stimulation (where they are highly salient) and in unimodal, nonredundant stimulation (where they are less salient). In contrast, for difficult tasks which require greater perceptual processing and attentional resources, attention progresses more slowly through the salience hierarchy, resulting in processing only the more salient properties at the expense of less salient properties. Thus, amodal properties would be detected only in bimodal, redundant stimulation, where they are most salient, as observed in the difficult tempo discrimination condition of the present study.

This salience hierarchy may characterize not only the sequence of attending and processing properties of events across time within a given episode of exploration, but it may also translate to trends across development. Older infants process information more quickly and efficiently than younger infants and thus would progress through the salience hierarchy more rapidly, demonstrating more flexible attention and processing of both more and less salient properties of stimulation.

The present findings are consistent with the effects of task difficulty, age, and experience on performance in other domains as well. For example, older, more experienced infants also revert to patterns of performance shown by younger infants when difficulty is increased in cognitive and motor tasks (e.g., Adolph, 1997; 2002; Berger, 2004; Corbetta & Bojczk, 2002). This shift has also been discussed in terms of competition for limited cognitive and attentional resources (Berger, 2004).

Our current findings are the first to suggest that intersensory facilitation should be evident across the life span. In particular, effects of intersensory redundancy should be apparent during early phases of learning for a variety of tasks regardless of developmental level, including domains that are novel, problems of relatively high cognitive load, and tasks that require discrimination of fine detail or speeded responses. Such findings across the life span would have important implications for education and interventions. They could serve as a guide for tailoring learning contexts to the nature of material to be learned, maximizing attention and learning of specific aspects of objects and events by manipulating intersensory redundancy.

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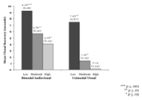

Figure 1.

Mean visual recovery (and standard deviations) to the tempo contrasts of low, moderate and high difficulty for 5-month-old infants following redundant, bimodal, audiovisual habituation and nonredundant, unimodal visual habituation.

Table 1

Means and standard deviation for visual fixation in seconds for baseline (first two habituation trials), final two habituation trials, posthabituation (two no-change trials just following habituation reflecting final interest level), test trials, processing time (total number of seconds fixating the habituation events), and visual recovery (difference between test trial and posthabituation fixation) as a function of the presence vs. absence of intersensory redundancy (bimodal, redundant vs. unimodal, nonredundant) and task difficulty (low, moderate, high).

Condition	**Difficulty Level**	**Baseline**	**Trials to Habituation**	**Processing Time**	**Final Habituation**	**Post-Habituation**	**Test**	**Visual Recovery**
Bimodal, redundant	Low	36.20 *(17.70)*	6.94 *(2.08)*	137.23 *(56.72)*	6.48 *(3.05)*	6.36 *(3.05)*	15.62 *(10.99)*	9.26 *(8.68)*
	Moderate	39.80 *(19.81)*	7.33 *(1.97)*	181.35 *(87.16)*	11.57 *(10.80)*	5.44 *(2.96)*	11.13 *(6.23)*	5.69 *(6.40)*
	High	41.30 *(16.89)*	6.67 *(1.30)*	150.18 *(60.81)*	7.09 *(4.48)*	5.40 *(3.67)*	9.47 *(6.97)*	4.06 *(6.29)*
Unimodal, nonredund	Low	24.48 *(16.08)*	9.25 *(4.87)*	125.76 *(59.96)*	5.59 *(4.33)*	4.97 *(3.02)*	12.47 *(10.60)*	7.50 *(9.87)*
	Moderate	27.56 *(13.39)*	6.25 *(0.62)*	106.73 *(59.35)*	5.12 *(3.26)*	4.78 *(2.26)*	6.17 *(2.76)*	1.40 *(2.23)*
	High	29.23 *(17.47)*	7.25 *(2.18)*	109.29 *(34.77)*	4.88 *(1.85)*	5.16 *(2.62)*	5.30 *(2.99)*	0.14 *(2.34)*