Audiovisual Prior Entry: Evidence from the Synchrony Comparison Judgment Task

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Abstract

Prior entry refers to the notion that attended stimuli are perceived sooner than unattended stimuli due to a speed up in sensory processing. The century long debate regarding the prior entry phenomenon's existence has always been grounded in the degree to which the methods applied to the problem allow for cognitive response bias. This thesis continues that trend by applying the synchrony comparison judgment method to the problem of audiovisual prior entry. Experiment 1 put this method into context with two other common psychophysical methods – the temporal order judgment and the synchrony judgment – that have been applied to the prior entry problem. The results of this experiment indicated that the temporal order judgment method was out of step with the other two methods in terms of the parameter estimates typically used to evaluate prior entry. Experiment 2 evaluated and confirmed that a specific response bias helps explain the difference in parameter estimates between the temporal order judgment method and the other two. Experiment 3 evaluated the precision of the synchrony comparison judgment method. The results indicated that the method was precise enough to detect potentially small prior entry effect sizes, and that it afforded the ability to detect those participants with points of subjective synchrony that deviate substantially from zero. Finally, Experiment 4 applied the synchrony comparison judgment method to a prior entry scenario. A prior entry effect was not realized. Overall, this thesis highlights the drawbacks of all previous methods used to evaluate audiovisual perception, including prior entry, and validates the use of the synchrony comparison judgment. Further, due to the resistance of this method to response bias, this result now stands as the most convincing evidence yet against the prior entry phenomenon.

General Introduction

Order perception of closely occurring bimodal events has a long and rich past in the field of psychophysics, and has been of interest to researchers since astronomers began investigating the problem of the personal equation over 200 years ago (Mollon and Perkins, 1996; Boring, 1957). The personal equation referred to how much one observer's estimates of the stellar transit time of a star had to be adjusted to bring it into line with the estimates of others. Stellar transit times were estimated using the "eye and ear" method, which involved viewing the passage of stars past crosswires while counting the beats of a clock (Boring, 1957). At the time, an explanation was sought for the sometimes positive and sometimes negative values of the personal equation.

While explanations appealing to methodological deviations or inter-observer differences in relative rate of auditory and visual nerve conduction held some sway at the time, it was the ideas of Friedrich Bessel and Johannes Müller that foreshadowed the explanation that still maintains theoretical influence today (Boring, 1957). In 1822, Bessel stated that one could not simultaneously appreciate the impressions from two different senses. He believed that one first had to appreciate one impression and then carry it over (i.e., switch attention) to the other, and that differences originated from which impression was chosen to be appreciated first and the time taken to carry over this impression (Boring, 1957). Similarly, Müller, in 1834, thought that there were differences between observers in their ability to "take cognizance of impressions" that are presented simultaneously, and he hinted that variation in this ability was a matter of one's "range of attention" (Boring, 1957). But it would be E. B. Titchener who would offer the explanation for these and other observations concerning order perception that still stands today – albeit controversially – and is the central topic for this thesis.

In 1908 Titchener formalized his seven laws of attention, the fourth of which was termed the *law of prior entry*. This law stated that "the object of attention comes to consciousness more quickly than the objects that we are not attending to," (p. 251). That is, the law implies that attention results in a speed up of perceptual processing for the attended stimulus. However, both before and after this formalization, there have been competing explanations for the personal equation and results from similar situations of bimodal order perception. In addition, results contradictory to the predictions of the law have also been seen. Indeed, the issue is now over 100 years old and controversy over the existence of prior entry continues to exist. The issue with the law of prior entry that this thesis will address regards whether prior entry is a true perceptual phenomenon or simply a response bias associated with the methods used to measure it.

The Complication Situation

While the law of prior entry provided an explanation for the personal equation, Titchener (1908) described his fourth law in the context of order perception observations from formal investigations of the personal equation that employed what was termed a complication situation (e.g., Stevens, 1904; Geiger, 1902, as cited in Frey, 1990; Angell & Pierce, 1891; Von Tchisch, 1885, as cited in Frey, 1990). A complication was the term used to describe a situation in which more than one sensory system was stimulated at the same time. Stellar transit estimations are an example of a complication in a non-experimental setting, but a more typical complication experiment in Titchener's time involved viewing a rotating pointer or a swinging pendulum and observing the position of the pointer at the time of some auditory event. It was often found that observers would report the position of the pointer as being prior to its actual position at the time of the auditory event. Some observers also reported the position at a later point, but a negative error was more typical.

The law of prior entry was born out of the effort to try to explain the typically negative errors seen in the complication experiment (Boring, 1957). Titchener (1908) believed that the observers were predisposed to focus more attention on the auditory stimulus. He seemed to suggest that over the course of several oscillations of the pendulum observers would gradually be narrowing the range in which the auditory event could have taken place. Over time, an accommodation of attention to the sound would result, such that the observer becomes predisposed to hear the bell at a certain instant. That is, attention becomes focused on the auditory stimulus. Because attention to the auditory stimulus would speed up its sensory processing, instead of being matched to the actual position of the pointer, it would be matched with a prior position, resulting in a negative error. In other words, at the moment the auditory stimulus is registered, the *actual* position of the pointer will have yet to be registered, thus, attention would be shifted to the last visual input that had been registered, which would be a position prior to the actual position. Stevens (1904) provided direct evidence for this law of attention (Titchener had mentioned the law prior to his 1908 text). Stevens used a pendulum apparatus with a scaled background in which a click was fixed to occur when the head of the pendulum passed 22° on the scale. Testing himself, Stevens found that the perceived position of the pendulum when the click occurred happened at 30° when he attended to the pendulum arrow, and between 10° and 15° when he attended to the click, thus, directing confirming the predictions of the law of prior entry.

While the law of prior entry would become one of Titchener's seven fundamental laws of attention, not everyone at the time subscribed to this view. Von Tchisch (1885) ascribed the negative localization errors of his complication experiments to an anticipatory response. He reasoned that just as a reaction time to some regularly occurring stimulus will approach zero with repeated trials due to a fine tuning of anticipation, so will one begin to anticipate the occurrence of the auditory stimulus in the complication experiment. Thus, the perception of the auditory stimulus occurring sooner is a sort of illusion brought about by the anticipation of the event. Titchener easily discounted this suggestion and he referenced a comment by William James (1890) to support his rejection. James noted that what von Tchisch was suggesting was that a participant was experiencing a regularly occurring hallucination prior to each auditory stimulus, and further, that the *actual* stimulus was not being registered. Other alternative explanations were not so easily discounted. For instance, Geiger (1902, as cited in Frey, 1990) obtained both positive and negative errors in his complication experiment. He suggested that results were likely not due to perceptual factors, but could rather be explained by things such as the speed of the pointer sweep, practice effects, or localization effects of a circular apparatus that are the result of gravity working with and then against the occulomotor muscles. He further suggested that observers might produce the seeming prior entry effect due to their desire to perform as well as their colleagues (Titchener, 1908). In addition, the complication experiments of Angell and Pierce (1891) produced results showing a mix of negative and positive localization errors. They explained negative errors as a result of an after-image, while explaining positive errors as a result of the interference of auditory processing brought about by the transformation of the click into the motor act of stopping eye movement in order to localize the point of occurrence of the pointer at the time of the click. Supporting these explanations, Dunlap (1910) found that localization errors – positive or negative – were eliminated when observers fixated their vision. Thus, his conclusion was in line with those of Geiger (1902, as cited in Frey, 1990) and Angell and Peirce (1891) in that localization errors were due to eye movements rather than the attentional set of the observer.

These criticisms are noteworthy in the sense that they represent the beginning of what will become a series of criticisms of the methods used to test the law of prior entry, resulting in a century long evolution of the manner in which the problem is investigated. The first major criticism which needed to be controlled for was the potential contribution of localization effects associated with a moving stimulus (e.g., Geiger, 1902, as cited in Frey, 1990; Angell & Peirce, 1891; Dunlap, 1910). Since eye movements were a potential confounding factor, a method that didn't invoke eye movements was required. However, this much had already been accomplished by Dunlap's investigation in which he had his participants fixate their focus. But Dunlap still used the standard complication pendulum apparatus in which the visual stimulus is in motion, which was the focus of another early explanation of positive and negative errors. James (1890) suggested that the errors could be a result of the problem of mentally substituting the experience of a visual stimulus in motion with that of the visual stimulus in a finite position. Thus, in order to remove this confound, an alternative method that did not involve motion was needed to yield a more ideal investigation of the problem.

The Temporal Order Judgment Method

The temporal order judgment (TOJ) method was introduced to the problem of prior entry to avoid the criticisms associated with the complication situation. To remove the potential confounding effects of a moving visual stimulus, a stationary stimulus was substituted for the moving one. Because there were no longer several positions of a moving stimulus, the previous relative judgment of the occurrence of the click to a position of the visual stimulus could not be made. Thus, a new relative judgment appropriate to a static visual stimulus was required. A bimodal TOJ consists of a complication situation in which the observer makes a judgment concerning the *order* of two stimuli from different modalities (i.e., "visual stimulus first" or "auditory stimulus first"). Compared to the typical complication situation in which a temporal displacement is inferred from a spatial displacement, the TOJ task measures temporal displacement directly. That is, the law of prior entry suggests that the visual spatial displacement of the arrow of a swinging pendulum relative to an auditory event is due to the relative processing time associated with each modality, insofar as they are influenced by attentional disposition. Given the spatial displacement and the rate of movement of the arrow, the temporal displacement can be derived. In contrast, the TOJ task provides a direct estimate of the temporal displacement.

The temporal displacement is quantified by the difference between the points of subjective simultaneity (PSS) when attending to the visual modality and when attending to the auditory modality. The PSS represents the relative physical temporal displacement of the two stimuli required for them to be experienced as simultaneous. In other words, it represents the average amount of time that one stimulus has to precede the other in order for them to be perceived as maximally simultaneous. To obtain a PSS, an observer would perform TOJs at a variety of stimulus onset asynchronies (SOAs) from which a psychometric function could be generated that represents the number of "visual first" (or "auditory first") responses relative to the SOA. The mean of the psychometric function then represents the average relative timing of the stimuli that brings about maximal simultaneity. In other words, the mean represents the point at which the observer is maximally uncertain about the order of the stimuli, and will be marked by an equal number of 'light first' and 'sound first' judgments (see Figure 1A). According to the law of prior entry, the PSS should shift relative to the attentional disposition. In order to experience maximal simultaneity, the visual stimulus should have to be delayed relative to the auditory stimulus when attending to the visual modality compared to a situation of divided attention. That is, since the act of attending to the visual modality would speed up its processing relative to the auditory stimulus, its presentation would have to be delayed in order for the observer to experience the maximal simultaneity that they would experience in a divided attention situation. The same is true for the auditory modality. The difference between the PSS of the attend-audition and the attend-vision conditions represents the prior entry effect (Figure 1B).

Because of the equally plausible explanations of the cause of spatial displacements in complication situations, it could not be said with any certainty that attention acted to speed up sensory processing. In order for this certainty to exist, it was necessary to provide evidence for the prior entry law in a situation free from the confounds inherent to the complication situation. Evidence of this nature was provided by Stone (1926) who used the TOJ method to test the prior entry hypothesis with auditory and tactile stimuli. Stone used stationary stimuli to circumvent the suggestions regarding eye-movement contributions (Geiger, 1902, as cited in Frey, 1990; Angell & Peirce, 1891; Dunlap, 1910). A further confound that was alleviated by using stationary stimuli was the problem of what Stone called "temporal accommodation". This referred to the fact that, due to the rhythmic nature

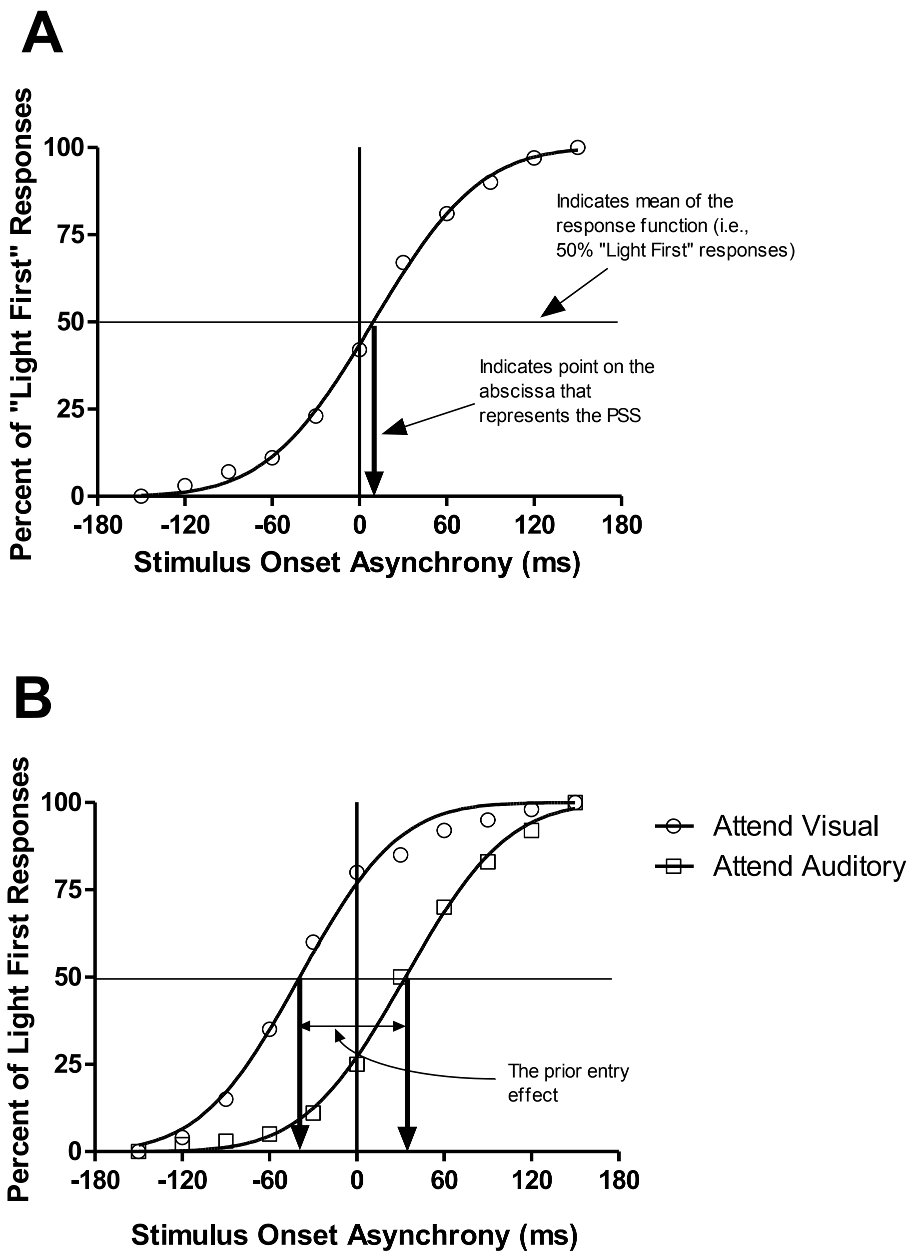

Figure 1. Both figures represent hypothetical data from a temporal order judgment task (TOJ). Figure 1A indicates the determination of the point of subjective simultaneity (PSS), as indicated by the point on the abscissa that corresponds to the point on the function at which 50% of responses are "Light First". Figure 1B indicates the prior entry effect as the difference between the PSSs from "Attend Visual" and "Attend Auditory" conditions of a TOJ task.

of the swinging pendulum, and concomitantly the click, a participant will reflexively engage in a temporal preparation. That is, since the click tends to occur within a particular range of the swinging pendulum, the participant's anticipation of the click will necessarily increase throughout the trial until the event occurs. This results in the participant cumulatively accommodating his attention towards the coming event of coincidence. Thus, she reasoned, the effects of the attentional predisposition will be confounded by the effects of temporal accommodation.

Stone presented her observers with auditory-tactile complications at five SOAs (±60, ±30, 0 ms) using the method of constant stimuli. The tactile stimulus consisted of the contact of a brass rod with the forefinger of the participant. The auditory stimulus was a sharp click, created by having a brass rod make contact with a hard rubber cap. Participants were to report which of the stimuli they thought occurred first or if they thought they occurred simultaneously. Observers were given verbal instructions to attend preferentially to either the auditory or the tactile stimulus in alternating series. Psychometric functions – one each for the attend-tactile and attend-audition conditions – were then constructed from the probabilities of either response (auditory first or tactile first) at each SOA, and the PSSs were estimated from these functions. Stone's participants produced a mean prior entry effect of approximately 45ms. Stone concluded that the effect seen was a true prior entry effect and not an artifact of the introspective note-taking process. She considered the possibility that because the attentional disposition would result in the attended stimulus being "noted" first, it could be the case that participants are simply reporting which stimulus was noted first. She defended this conclusion by noting that while one may argue that reporting successiveness when the two stimuli are actually simultaneous could be due to the fact that the introspective note-taking process were successive, this would not explain how physically successive pairs are judged as simultaneous when the same successive note taking process is taking place. Thus, prior entry would be a better explanation. The results from this method of examining prior entry were the strongest evidence to date in support of the effect.

While Stone would find direct support for the prior entry hypothesis using the TOJ method, several previous researchers had failed to find such an effect using similar methods to study multisensory perception. For example, Hamlin (1895) used various combinations of stimuli (flash of a Geissler tube, click of a telephone sliding induction coil or the snap of an induction spark, shock to the finger) presented at several SOAs with the order of stimuli varying from trial to trial. Participants were instructed to focus their attention on a single modality and to judge which modality they thought occurred first. The attentional manipulation had no effect on the proportions of judgments of which stimulus occurred first, leading Hamlin to conclude that attention does not cause the stimulus to which attention is directed to seem to lead the alternate stimulus. In addition to Hamlin, Drew (1896) also used the TOJ task to investigate the effects of attention on order perception. Drew used similar stimuli to Hamlin (click of a telephone sliding induction coil, shock to the finger), but presented one stimulus to the right side of the participant and the other stimulus to the left side, and had the participants respond as to whether the first stimulus occurred on the right or the left. Giving participants instructions to attend to one modality over the other, Drew also failed to find an influence of attention on the order perception of bimodal stimuli. The fact that with the TOJ method the prior entry effect could not be reliably demonstrated made the standing of the law uncertain. While in 1959, Boring would describe the law of prior entry as "good psychological doctrine," (p. 143), the failure of some investigations to find an attentional effect would cause future investigators to continue to question the methods used to test the law.

The Concurrent Temporal Order Judgment-Reaction Time Paradigm

Although Stone's (1926) study was seen as strong evidence in favour of the prior entry hypothesis due to the fact that it bypassed the criticisms associated with the complication situation, it would eventually be recognized that there were flaws with the TOJ method as well. In the Stone study as well as the studies by Hamlin (1895) and Drew (1896), participants were simply given instructions to focus their attention on one of the two modalities. Thus, there was an assumption that the participants were following the instructions. Given that a participant could potentially choose to ignore the instructions, the methodology would be improved by using a strategy that provides validation that participants were following the instructions and focusing attention on one stimulus over the other. A temporal order judgment does not, in itself, provide any motivation to selectively prepare for one stimulus modality over the other. In fact, the TOJ task could provide an incentive to purposely avoid selectively attending if doing so makes the TOJ task easier to perform (in fact, both Hamlin and Drew reported that accuracy was superior in divided attention conditions). Thus, an ideal method for studying prior entry would include an element that both encourages selective attention, and that also provides independent feedback as to the success of the encouragement.

Sternberg, Knoll, and Gates (1971; as cited in Spence, Shore, & Klein, 2001, and Frey, 1990) tried to replicate the results of Stone (1926) with a more controlled attentional manipulation. Sternberg et al. improved on the original TOJ method by combining the TOJ task with a reaction time (RT) task in which the participants were required to perform a speeded response to the signal which was to be attended. It was assumed that requiring the participants to perform a speeded response to a signal would bias attention towards that signal. In addition to serving as a means of inducing selective attention, this auxiliary element to the methodology allowed them to confirm that the attentional manipulation was successful by comparing RT performance during the concurrent TOJ-RT task to results from a control procedure. That is, if participants were anticipating the imperative signal, then RT performance should be similar under both baseline RT and TOJ-RT conditions. The RT performance of the participants confirmed that the manipulation was successful. Additionally, to ensure that participants were not adopting a strategy of reacting to either signal but only responding to the imperative signal, catch trials in which only the alternate signal was presented (50% of trials) were randomly mixed in with other trials. Relatively few responses to catch trials provided evidence that participants were responding to the imperative stimulus only.

Further efforts were employed to facilitate the participant's selective attention. Prior to each stimulus presentation, a series of three signals was initiated. The first signal was a bimodal warning signal. This signal was followed by a unimodal signal which reminded the observer of the modality on which to focus their attention during that session. The final signal was another bimodal warning signal which indicated that the trial was about to be presented. Following this third signal, participants were presented with either an experimental trial in which both signals at one of several SOAs were presented or a catch trial, in which only the stimulus which is not to be attended is presented. On experimental trials participants were to respond as quickly as possible when they noticed the cued stimulus, and then to provide an unspeeded response as to which of the signals occurred first.

On catch trials, they were simply to withhold their response. Motivation to produce fast reaction times and avoid reactions to the unattended stimulus was provided by a reward system. The authors reported that RT and accuracy performance were maintained despite the concurrent TOJ_RT task. Further, their participants evidenced prior entry effects of approximately 55ms in the auditory-cutaneous pairing, and 30ms in the auditory-visual pairing. With independent evidence of a successful attentional manipulation, this now represented the strongest evidence to date in favour of the prior entry effect.

Although Sternberg et al. (1971) had seemed to provide strong evidence in favour of the prior entry hypothesis, several subsequent studies with similar methodologies would fail to find a prior entry effect, still leaving the effect's existence in doubt. For example, Vanderhaeghen and Bertelson (1974) implemented a similar strategy of requiring participants to produce a RT prior to making a judgment about the order of two stimuli. However, in this study the reaction was a choice reaction. As in the Sternberg et al. study, there was a warning signal prior to each trial (neon lamp flash), however, the warning signal did not predict the modality of the uncertain stimulus. Each trial contained two of a possible three stimuli. A tactile stimulus was presented on every trial (the "reference stimulus"; direct physical contact with the right index finger) and, unpredictably, either a visual (1 ms LED impulse) or an auditory signal (1 ms impulse from speaker) served as the "uncertain stimulus". Participants were required to respond as quickly as possible as to whether the uncertain stimulus was either visual or auditory (choice reaction; Donder's b-type), following which they would make a judgment concerning which of the two stimuli occurred first. To induce selective attention for either the visual or auditory stimulus, the authors implemented a strategy of providing an unbalanced relative frequency of the two uncertain stimuli. That is, three separate series were run in which the auditory-visual ratios were 25:75, 50:50, and 75:25. This modification was added because prior research had shown that this type of manipulation induced selective preparation, such that RT performance will improve for the stimulus towards which one is biased (Fitts, Peterson, & Wolpe, 1963), which will be the stimulus that is presented more frequently. Thus, in order to confirm that the attentional manipulation was successful – that participants are selectively preparing – one should expect to see RTs decrease as the relative frequency of a stimulus increases. For four out the five participants, this pattern of reaction times was observed. However, these four participants showed an inconsistent pattern of results in terms of the PSS. While a prior entry trend was observed for the auditory-tactile pairing (approximately 13ms; interpolated from the graph as no data or statistics were provided), the opposite of a prior entry trend was observed for the visual-tactile pairing (approximately 15ms). This inconsistency led the authors to conclude that selective preparation for a Donder's b-type reaction to a stimulus does not affect the perception of the time of occurrence of that stimulus. However, they cautioned that this result does not necessarily mean that the PE effect does not exist. They note that the reaction task in the Sternberg et al. (1971) study was a Donder's c-type (go/no go), which may induce a selective preparation that will affect the perception of the time of occurrence of a stimulus.

In spite of this qualification, several other investigations at the time were obtaining similar results. Cairney (1975) also used the TOJ method, but modified the secondary task used to allocate attention differentially. Instead of requiring a RT to the signal from a particular modality, Cairney had his participants make a judgment about a feature of the stimulus to which the participant was to attend. In a first experiment, participants were presented with an auditory stimulus from a set of headphones and a visual stimulus consisting of two lines via a tachistoscope. Only two audio-visual intervals were tested, one where the visual signal preceded the auditory by 70 ms, and one where the auditory preceded the visual signal by 30 ms. There were three judgment conditions. In the first condition the participants simply had to make a TOJ, while in conditions two and three they had to first make a judgment concerning which of the two lines was longer (24 vs. 48mm & 35 vs. 37mm, respectively). Cairney applied signal detection analysis to the relative number of visual first (hits) and auditory first (misses) responses. Since the secondary task necessitated attention to the visual signal, support for prior entry would be provided by a tendency to report the visual stimulus as occurring first more in the second and third conditions compared to the first. This result was not realized as the signal detection analysis revealed no difference in the bias measure of the tendency to say visual first.

Further experiments from this study supported the results of the first experiment. For example, the second experiment was the same as the first, save that the third condition was modified. The line length difference was the same as condition two of experiment one (24 vs. 48mm), however, a speeded response was required this time. The results again indicated that there was no increased tendency to report the visual signal as occurring first in conditions two and three. A third experiment required the participants to make a judgment about the auditory signal this time (high vs. low pitch), and again, there was no difference in the bias measure. The results from these three experiments led Cairney to conclude that attending to one signal over the other does not lead to that signal being perceived earlier.

Cairney’s conclusion was consistent with that of Vanderhaeghen and Bertelson (1974), as well as with the conclusion of another investigation that was conducted around the same time, using similar methods. Frey and Wilberg (1975) attempted to replicate the results of Sternberg et al. (1971), but they intentionally modified one aspect of the method that they hypothesized might provide an explanation for the inconsistency in finding support for the prior entry hypothesis. Frey and Wilberg had observed that whenever an investigation had found positive support for the prior entry phenomenon, the participants had either been the experimenters themselves (e.g., Von Tchisch, 1885, as cited in Frey, 1990; Angell & Pierce, 1891; Geiger, 1902, as cited in Frey, 1990; Stone, 1926), or had had the prior entry phenomenon explained to them a priori (Sternberg et al., 1971). When this observation was coupled with the null results of Vanderhaeghen and Bertelson (1974) and Cairney (1975) – who both used student participants who were naïve to the prior entry hypothesis – an alternate explanation for the prior entry phenomenon emerged. To Frey and Wilberg, this observation suggested that an a priori knowledge of the phenomenon could contribute to all or some of the production of the effect, which implicitly suggests that the prior entry effect may be a cognitive effect, rather than a perceptual one. They tested this suggestion by approximating the procedure of Sternberg et al. (1971), with the pivotal replacement of aware (of the prior entry hypothesis) with naïve participants. The participants in this investigation failed to produce a prior entry effect. This led Frey and Wilberg to conclude that previous support for the prior entry phenomenon was merely a reflection of an artifact of the expectations of the prior entry effect that participants possessed prior to their testing.

In a personal communication to Frey, Sternberg suggested alternate reasons for the conflicting results. In addition to the modification regarding the participant's awareness of the prior entry hypothesis, several other modifications to the Sternberg et al. (1971) procedure were implemented. These included removing a reward for fast reaction times, removing the cue (and second warning signal) that reminded the participants which modality on which to place their attention, and reducing the catch trial ratio from 50 to 10%. It was these modifications that Sternberg pointed to as potential explanations for the lack of a prior entry effect, rather than the hypothesized a priori awareness.

Given that these three methodological elements are all designed to encourage the participants to optimally bias their attention, it was a reasonable claim that deviance from these elements could be the cause of the null results. Thus, in order to provide stronger evidence to support their notion that a prior knowledge of the phenomenon was necessary for its realization, Frey and Wilberg performed an additional study using naïve participants that conformed more closely to the Sternberg et al. (1971) method. Wilberg and Frey (1977) performed a series of three experiments that served to eliminate the confounding differences between the methods of Sternberg et al. (1971) and Frey and Wilberg (1975). After implementing a reward system for fast reaction times, adding a cue signal (plus the second warning signal), and increasing the catch trial ratio to 50%, the first two experiments conformed precisely to the methods used by Sternberg et al. (1971). Experiment 1 used an auditory-cutaneous stimulus pairing, while Experiment 2 used an auditory-visual pairing. Following these modifications, the results began to more closely resemble those of Sternberg et al. (1971). While neither effect reached statistical significance, participants in these two experiments evidenced what the authors referred to as "prior entry trends" of magnitude 22ms and 39ms for the auditory-cutaneous, and auditory-visual pairings, respectively. Thus, the authors noted, while a shift in responding indicated a tendency to favour the attended stimulus, the prior entry hypothesis was not statistically supported. However, they also noted that the magnitude of the effects from both experiments still make the results "psychologically provocative". However, the authors still did not seem convinced that the effect was due to divided attention, per se, as evidenced by the third experiment in the series.

The third experiment explored an alternative explanation for the shifts in the PSS seen in the first two experiments, and specifically, why the shift is seen in the direction predicted by the prior entry hypothesis. As with the theory of prior entry, this alternative explanation was concerned with the influence of the secondary task. The prior entry hypothesis suggests that the secondary task induced participants to attend selectively to one stimulus over the other, which in turn results in a difference in the speed of perceptual processing for the different signals. However, Wilberg and Frey (1977) suggested the alternative possibility that the RT task resulted in an unequal amount of *post-detection processing* which may have an effect on a central temporal order decision mechanism. The authors note that while the occurrence of the attended signal inherently carries information regarding its time of occurrence, this occurrence further carries with it a "directive to initiate a response". In contrast, the occurrence of the unattended signal will initiate no more processing than that needed to note its occurrence. Thus, the response initiation processing (i.e., the search for and execution of a motor program) resulting from the occurrence of the attended signal will be associated with only that signal and not the other, resulting in an unequal amount of post-detection processing, which may in turn affect a temporal order decision mechanism. This suggestion continued to imply that the authors were skeptical of the theory that attention sped up sensory processing, and essentially amounted to a re-characterization of the shift seen in the PSS to a cognitive or decision-making effect, rather than a perceptual effect. They tested this notion by attempting to equalize the post detection processing of the two signals.

The authors reasoned that if the unequal post-detection processing was the catalyst for the shift in PSS, then any relative equalization of the post-detection processing should either eliminate or at least reduce the magnitude of the effect. The method for this third experiment was similar to Experiment 2 (visual-auditory stimulus pairs), but with an addition. The participants still performed a manual response to a designated signal, and reported which of the two signals they thought occurred first. However, between these two tasks was a third task concerning the nature of one of the two stimuli, selected at random by the experimenter. Specifically, participants had to judge if the visual stimulus was either red or amber, or if the auditory stimulus was either 750 or 1500 Hz (a white light and a 1000 Hz tone were used for the cue stimuli). Thus, when the signal chosen for analysis was that signal which was opposite to the one to which the participants had to manually respond, the post-detection processing should be relatively equalized. This time, a large, statistically significant shift in the PSS of 116ms was evidenced. However, the large increase in the difference between the PSSs from Experiments 1 and 2 to Experiment 3 was not explained by either the prior entry hypothesis or the post-detection processing hypothesis. If the prior entry hypothesis were true – that the shift in PSS was due to an increase in speed of sensory processing due to attention – then the magnitude of the effect should have been approximately the same between experiments, while if the post-detection processing hypothesis were true – that the shift was due to the effect of post-detection processing on a central temporal order decision maker – then the magnitude of the shift should have been reduced or eliminated all together. This result thus required an alternative explanation, which was forwarded by Wilberg and Frey (1977), but was not addressed experimentally for several years. The alternative explanation forwarded by Wilberg and Frey (1977) was concerned with the fact that the processing that would occur for both signals was of a different kind. That is, while the unattended signal required an identification of its nature, the attended signal required a speeded motor response. It was suggested that the requirement of a speeded response, in contrast to a simple identification, could be the factor that influenced a central timing mechanism.

Thus, Frey (1990) continued the investigation with a series of four more experiments (the three experiments from Wilberg and Frey, [1977], were included as Experiments 1, 2, and 3 of this study). Experiment 4 tested the notion that a *response directive effect* was responsible for the shift in the PSS. Since it would not be possible to require a speeded response to both signals on a single trial – which might be expected to equalize any response directive influence on a temporal order mechanism – Frey (1990) altered the method of Experiment 3 in such a way as to make the response to the attended stimulus more difficult. Frey reasoned that if a response execution was responsible for the prior entry effect, then an increase in the processing of the response itself should cause the magnitude of the effect to be exaggerated relative to that seen in Experiment 3. Thus, the previous go/no go reaction was replaced with a choice reaction. Specifically, while still only reacting to one modality and not the other within a session, participants now reacted with different hands depending on the nature of the stimulus (as with Experiment 3, either a red or amber light for the visual stimulus or a high or a low tone for the auditory stimulus). So that direct comparisons with Experiment 3 could be made, participants were still questioned regarding the nature of one of the two stimuli, chosen randomly by the experimenter. While the participants in this experiment did yield an estimate of the prior entry effect (139ms) that was somewhat larger than that seen in Experiment 3 (116ms), Frey described these results as being similar to those from Experiment 3, and reasoned that this may have been the result of a ceiling effect reached by the demands of the Experiment 3 task.

However, it was from Experiment 4 that Frey harvested other pieces of information which he would use to forward another hypothesis about the nature of the PSS shifts seen with these experiments. The first bit of information that caught the attention of Frey was the self reports of the participants from Experiment 4. During debriefing, all participants reported being overwhelmed by the demands of the task, such that they felt they were guessing on a large number of trials. Frey recalled that this same observation was reported by several of the participants from Experiment 3. What was important to Frey about these comments was that they seemed to suggest that while his experiments did yield a "prior entry" effect, the effect was manifested at least partially when the observers were in a state of uncertainty. Thus, Frey reasoned, while it can be said that the responses from the participants were biased, it could not be said that their judgments were related to any sort of subjective certainty. To Frey, this seemed to open wider a window of doubt about the nature of the prior entry effect. Frey noted that the formal expression of the law of prior entry stated that, "The stimulus for which we are predisposed requires less time than a like stimulus, for which we are unprepared, to produce its full conscious effect," (p. 251). And since the responses of observers were not based on a "full conscious effect", Frey felt that the veracity of the claim that the effect was a purely perceptual phenomenon was questionable. Thus, this piece of evidence threw doubt not so much on the *existence* of the effect as it did on the *nature* of the effect.

A further piece of evidence added weight to the notion that the prior entry effect may not be a purely perceptual phenomenon. This next piece of evidence was centered on an evaluation of the RT data from the previous experiments. The RT data was used as a means of confirming that participants were, in fact, focusing their attention on one stimulus over the other. The fact that the participants in the study by Frey (1990), as well as Sternberg et al. (1971), produced mean RT estimates that were equal in magnitude to baseline reaction times seemed to provide such evidence. However, Frey performed a more comprehensive analysis of the RT data. He analyzed RT by SOA, and he found that the RT profile of participants conformed to a u-shaped function. That is, as the SOA increased, so did the magnitude of the RTs. This is not what one would expect if participants were doing as instructed and basing their RT on only one signal. If they were following the instructions, then one would expect the RTs to be stable across SOAs. However, Frey noted, if participants were to withhold their response until *both* signals had been presented, then one would expect to the see the u-shaped functions that were generated.

Frey also pointed out that there is a logical reason for why participants would employ such a strategy, and this was related to the demands of the task. Recall that fast RTs were rewarded, and that responses on catch trials were punished, in both the baseline and experimental conditions. Catch trials involved trials in which only the unattended signal was presented. In order to avoid making responses on catch trials, a participant could simply respond to trials in which both signals are presented, while withholding a response to trials in which only one signal is presented. That is, they could react to the signal ensemble rather than to the stimulus to which they were instructed to react. If this were the case, then one would see reaction times get faster as one approaches their PSS. Frey concluded, then, that participants were not attending in the manner in which they were instructed. And if they were not dividing their attention in such a way as to favour one signal, then the prior entry effect must be due to some factor other than attention. It was at this point that Frey suggested that participants were not reporting that the “attended” stimulus was occurring first more often because it had a processing advantage, rather, that they were choosing that option as a result of the task demands operating in a situation of uncertainty.

Frey further provided a theoretical context in which one might expect a human operator to behave in such a way. He invoked the ecological theories of Goodson (1973) and Ashby (1968) to provide the theoretical context in which the proposed response bias could at least conceivably, and perhaps probably, operate. Frey cited Ashby’s (1968) notions of variety and constraint in relation to a biological organism. In the simplest and most general terms, Ashby noted that any response that an organism will make will be the response from the organism’s repertoire of potential responses which best suits the current environmental conditions. Further, the variety of responses that an organism can make will be constrained by the environmental conditions. Thus, when an organism makes a response, that response will be the one that seems the best choice from the repertoire of constrained alternatives.

Now, regarding the criteria that the organism is going to use to choose a response, Frey cited Goodson’s (1973) thoughts about the equilibrium state of the organism and the functional utility of selective attention. Goodson (1973) characterized the human as an organism that, like all organisms, tries to maintain a general state of equilibrium. While we are more familiar with the concept of equilibrium in terms of physiology (e.g., blood composition, body temperature), this characterization also applies to our mental states as affected by ecological conditions. For example, if one is faced with a large predator, this will place the individual in a state of disequilibrium, which must be corrected for by some behavior. In this current example, finding an immediate haven from the predator will bring the human to a state of safety. Thus, a particular behavior results in a return to a state of mental equilibrium. Goodson also talks about the function of selective attention. His ecologically inspired point about selective attention that is of concern here is that whatever information is presently the focus of attention is likely to be that information that is – or at least has been in the past – most relevant to survival. Or in other words, the information that is most relevant to easing disequilibrium.

Frey then applied the concept of equilibrium to the ecological conditions encountered by a participant in a prior entry study in which a RT is employed to cause selective attention. Frey suggested that the ecological conditions may favor certain responses as more compatible with the reduction of disequilibrium. Given that participants are typically told that the point of the experiment is to study the effects of distraction on RT, and that participants are only given feedback related to RT performance and not TOJ performance, it would be reasonable for a participant to conclude that the response to the attended signal is the primary task. Thus, whatever response maximizes response time while minimizing false alarms would be the response that results in a return to a state of equilibrium. Now, given that many of the judgments about the temporal order of the two stimuli are extremely difficult due to the small SOAs, the participant, forced to guess, may be more likely to choose the option that is highlighted in attention. That is, the stimulus to which a response previously resulted in a reduction of disequilibrium. Thus, in terms of the theories of both Goodson and Ashby, participants may not tend to respond with the attended signal because of a sensory advantage, rather, because it seemed like the best option given the ecological conditions.

This perspective demonstrated a change in how the human participant is viewed within the context of a prior entry experimental situation. While previous research has implicitly treated the participant as a passive collector of information who is simply and objectively expressing what he experiences when he responds as to which of two stimuli occurs first, the perspective forwarded by Frey puts the human operator into an environmental context. This perspective characterizes the human participant as a subjective decision maker who is guided by evolutionarily acquired heuristics when forced to make choices with incomplete information or in situations of uncertainty.

While these ecological suggestions do not prove that participants are biased by the demands of the task, they do indicate a plausible alternative to the suggestion of sensory acceleration. Frey noted that if participants were to choose the stimulus highlighted in perception more often when in situations of uncertainty, this would result in a shift in the PSS relative to a divided attention condition in which neither stimulus is assigned priority. In other words, the response profiles of a true perceptual effect and a response bias would be similar. Thus, the concurrent TOJ-RT paradigm can not differentiate between a perceptual effect and response bias. However, Frey reasoned that a slight modification to the paradigm would lend itself to this purpose. Frey noted that for the TOJ part of the task, participants are required to respond as to which of the two stimuli occurred first. If there is a sensory acceleration due to attention, then the attended stimulus will actually reach consciousness first more often resulting in it being chosen more often. Also, if there is a response bias related to the attended stimulus, then again, the attended stimulus will be the one chosen more often. However, if one changes the response requirement from having to choose which stimulus occurred first to having to choose which stimulus occurred *second*, then one should expect to see different response profiles for the different explanations. If there is a true sensory acceleration, then participants would choose the unattended stimulus more often as the stimulus occurring second due to its relative delay in perceptual processing, and the response profile would be the same as that seen when asked which stimulus occurred first. However, if the PSS shift is a response bias, then participants should do the same thing that they would do if you asked them which came first. That is, in times of uncertainty, they will choose the option that is highlighted in attention as the one that is occurring second. Thus, if participants are engaging in a response bias, then one would expect a response profile that is the opposite to that which would be expected if the bias were in fact perceptual.

As a final experiment (Experiment 7), Frey made this simple adjustment. The procedure for Experiment 7 was identical to that of Experiment 3, save that participants were required to respond as to which of the two stimuli occurred second, as opposed to which occurred first. As with Experiments 3 and 4, a large effect was realized with the PSSs from the attend-visual and attend-auditory conditions differing by a statistically significant 123ms, which was comparable to the shifts seen in Experiments 3 and 4 (116 and 139 ms, respectively). However, in this instance the difference between the PSSs was in the opposite direction predicted by the prior entry hypothesis. That is, participants now seemed to favour the attended stimulus as the one occurring second, thus, they were now choosing the unattended stimulus as the one occurring first more often. Thus, in terms of a perceptual explanation, it would appear that the unattended stimulus was now being accorded a processing advantage such that it reached consciousness more quickly than the attended stimulus. Of course, this explanation would be opposite to the expectations of the theory of prior entry. Not surprisingly, Frey suggested that this result was better explained by a response bias. In terms of the previously presented ecological frameworks, Frey concluded that given the constraints of the task situation (i.e., a difficult dual-task judgment, a primary task of responding to one stimulus while withholding a response to another, assigning the quality of firstness to one of two stimuli), participants were forced into an environmental context in which they had to make a decision in a situation of uncertainty. Given that many trials within an experiment will occur at SOAs that are beyond the individual's ability to discriminate, this will frequently force the individual to make a guess. The choices are constrained such that one can not respond with what would be the truth on many trials, that he does not know which came first, or that they appeared to occur at the same time. Thus, the variety of responses is constrained such that the participants must make a choice between two undesirable alternatives. According to Goodson (1973), they are more likely to make the choice that will bring them back to a state of equilibrium. Thus, given the attended stimulus' highlight in perception due to either the instructions to attend to this stimulus or the RT response to it, this stimulus is more likely to meet the criterion of acceptability and be chosen as the participant's response. So, while the participant may not have actually had a clear perception of the temporal order, they will be more likely to make the response that would be predicted if attention had actually provided a perceptual advantage. Thus, it was the constraints on the response of the observer that contributed to the response bias.

Support for this notion has been provided by several other investigations using two-alternative, forced choice procedures like a TOJ. Experiments 5 and 6 of Frey (1990) demonstrated that making this same small alteration in method can affect participant's judgments of numerosity and size. In Experiment 5, participants were presented with two visual fields, left and right, of varying numbers of darkened circles. The task was to judge which side had more circles. In separate series, they were to perform a RT (i.e., attend) to the appearance of the circles on the left or on the right. As with the TOJ experiments, catch trials (50%) including only the non-reaction side were included, and a point system rewarding fast RTs and penalizing false alarms was implemented. That participants were optimally dividing their attention was confirmed by a comparison of RT performance to a baseline condition in which the stimulus presentation was the same but numerosity judgments were not required. Points of subjective equivalence (PSE; akin to a PSS but represents the relative amount of circles of the two sides such that they will be judged as containing an equal number) were computed for both right and left attentional conditions. The shift in PSEs indicated that the attended side could contain on average 26% fewer circles and still be judged as equivalent to the unattended side. The same participants also performed the same experiment with the one difference being that they now responded as to which side contained fewer circles. As with the PE experiment, altering the response criterion reversed the effect such that the unattended side could contain on average 31% fewer circles and still be judged as equivalent to the attended side. Under the same catch trial and reward system, Experiment 6 had participants judge the relative length of two lines and a similar reversal was seen. When judging which line was longer, the attended side could be 39% shorter and be judged as equivalent to the unattended side, whereas when judging which line was shorter, the unattended side could be 42% shorter and be judged as equivalent to the attended side.

The fact that responses in a TOJ can be altered by varying the response instructions is further evidenced in a study by Bertelson and Tisseyre (1969). Participants were required to make TOJs concerning the order of an auditory click and a tachistoscopically presented word. They were also required to enunciate the presented word. In one condition, they were required to make the enunciation prior to the TOJ, and the responses were to be given in the opposite configuration for the other condition. While no effect magnitude was reported, participants were more likely to respond that the visually presented word occurred first in the condition where the word needed to be enunciated prior to making the TOJ. This result is consistent with Frey's notion that requiring a secondary task to be performed on one of the stimuli highlights that stimulus in consciousness and makes it more likely to meet the criterion of acceptability.

Jaskowski (1993) also found that changing the response criteria resulted in a change in responding. Jaskowski performed an experiment examining a visual prior entry effect. Two adjacent visual stimuli were presented on each trial, and participants were instructed to attend to one or the other in separate blocks, and respond as to which they thought occurred first. When the response alternatives were restricted to choosing only one of the two stimuli, a prior entry effect was observed. However, when a third option was offered – that the two stimuli occurred simultaneously – the prior entry effect disappeared. It should be noted however, that Stelmach and Herdman (1991) performed a similar prior entry investigation with visual stimuli and also varied the response option variable. Participants in this study continued to evidence a prior entry effect even when the 'simultaneous' option was made available. However, it has been noted by Shore, Spence, and Klein (2001) that participants in this study used the simultaneous option far less often than the participants from the Jaskowski (1993) study. This may have been a result of the fact that all observers in the Stelmach and Herdman study had first participated in at least two experiments without the simultaneous response option. This lack of counterbalancing could have affected the degree to which the participants were willing to use the simultaneous option. Thus, as noted by Shore, Spence and Klein (2001) simply adding this response option can not convincingly rule out a response bias explanation of a shift in PSS.

What Frey has done is show that the TOJ method is flawed, and that there is no way to tell how much the shift in PSS is due to a speed up of perceptual processing versus response bias. Thus, a useful method would be one that could either eliminate the potential for response bias completely, or a method that while it allows for response bias, can estimate the relative contribution of any such bias.

The Orthogonal Temporal Order Judgment

In an effort to combat this confound of response bias elucidated by Frey (1990), Spence, Shore and Klein (2001) reintroduced a variation of the TOJ to the study of prior entry. As Drew (1896) had done, Spence et al. had participants respond along a dimension that was orthogonal to the attentional manipulation. In the majority of TOJ studies of multi-sensory prior entry, participants are induced – through instruction, secondary task or both – to attend to one stimulus modality over another stimulus modality, and then to respond as to which modality came first (or second). In this situation, it is not difficult to imagine that a participant might be influenced to be biased to respond with the modality to which attention was directed, particularly in a situation where he is uncertain. As Frey mentioned, in terms of the ecological theories of Ashby (1968) and Goodson (1973), the response most likely to reach the criterion of acceptability would be the response that seems consistent with what the experimenter is expecting. Further, even if the participant is not actively trying to figure out the hypothesis of the experiment and feels as though they are making random choices when uncertain, the fact that they were directed to attend to one modality over the other will work to highlight that modality in consciousness and make it more likely to be expressed as the judgment. However, the orthogonal temporal order judgment (O-TOJ) design requires participants to respond along a different dimension from that of the attentional manipulation. For example, in a visual prior entry study – where the competing visual stimuli are presented from different locations – Shore, Spence and Klein (2001) manipulated the orientation, vertical or horizontal, of a line that was acting as the visual stimulus. While the participants were induced to attend to either the left or the right location through the presentation of exogenous or endogenous cues, they were required to respond as to which *orientation* was presented first. Thus, the dimension along which participants responded, horizontal or vertical, was orthogonal to the attentional manipulation, left or right. This works to reduce the likelihood that a participant will default to one particular response in situations of uncertainty, as there is no clear reason why a 'horizontal' or 'vertical' response should be activated by a 'left' or 'right' attentional manipulation. This method then has the potential to eliminate or at least reduce the contribution of response bias to the shifts in PSS seen with focused attention.

Shore et al. obtained reliable visual prior entry effects for both the exogenous and endogenous cuing conditions. They further reported converging evidence for the obtained prior entry effects by analyzing the distribution of unspeeded RTs across SOAs. While participants were informed that the TOJ judgment was unspeeded, the RTs were slower at some SOAs compared to others. The rationale for this analysis is based on the intuitive notion that a participant should respond the most slowly when he is the most unsure about the judgment, that is, at his PSS. While a particular response when uncertain could be argued to be biased by the demand characteristics of the task, the uncertainty about the judgment itself should be exclusively a result of perceptual processing. Thus, a RT analysis would provide converging evidence for a prior entry effect if a shift in the slowest RTs corresponded to a shift in the PSSs as measured by the TOJ responses, and as predicted by the prior entry hypothesis. While RT peaks were not as clear in the exogenous cuing conditions, clear shifts in peak RT corresponded in both direction and magnitude to PSS shifts between the different attentional conditions. While the authors noted that an increased emphasis on the speed of the TOJ judgment might reduce the noise in the exogenous-cuing RT distributions and, thus, better elucidate correspondence between shifts in peak RTs and shifts in PSSs, this procedure still represented a bias-free measure of a visual prior entry effect.

Spence, Shore and Klein (2001) applied this procedure – except for the RT analysis – to a bimodal situation (visual and tactile) by creating a spatial dimension along which to respond. The majority of previous bimodal prior entry studies using the TOJ method have utilized a single stimulus source for each modality. However, with Spence et al.'s orthogonal design, both modalities had a left and right source. Thus, if a participant's attention was focused on a particular modality, she could respond as to whether it was the stimulus on the left or the stimulus on the right that occurred first. Conversely, if attention was focused on either the left or the right, then she could respond as to which modality occurred first. In other words, in either case the response dimension is orthogonal to the attentional dimension, thus, participants can not, for example, simply respond with the attended stimulus in times of uncertainty. It is important to note that while this procedure is designed to eliminate the type of first-order response bias proposed by Frey (1990, i.e., choosing the attended stimulus in times of uncertainty), Spence et al. (2001) concede that a second-order response bias is still possible. For example, consider the situation when participants have their attention focused on a particular modality, but are required to respond as to which side had a stimulus appear first. While in a situation of uncertainty they could not choose the modality to which they were predisposed, they could simply choose the side that contained the stimulus from the attended modality. Further, while they propose that this type of bias is less likely than a first order bias, Shore et al. (2001) have devised a method for estimating the contribution of this potential second-order response bias, and have concluded that the contribution of response bias is low (more on this below). Thus, they contend to offer a relatively bias free measure of the prior entry effect.

In addition to infusing the TOJ paradigm with an alternate, orthogonal response dimension, Spence et al. (2001) also altered the method of inducing divided attention. Frey had noted the problem with using RTs to induce attention. Participants simply adjusted their strategy such that they maximized their reaction times while minimizing their false alarms, without actually focusing their attention on one stimulus over the other. Instead, the participants in the Spence et al. (2001) study were presented with an uneven balance in the relative number of visual and tactile stimuli presented in the experiment. Intermixed with the bimodal TOJ trials were unimodal TOJ trials. To induce attention to the tactile signal, 50% of the trials contained two tactile signals from either lateral source, while the remaining 50% were equally divided between trials with a left tactile signal and right visual signal, and the opposite configuration. A separate session was conducted using visual unimodal trials. Participants were aware that there would be an uneven balance in the relative number of stimuli, and were instructed to focus their attention on the more frequently occurring modality. The results from the PSS data indicated that the visual signal had to lead the tactile signal by 155 ms in the attend-touch condition while only having to lead by 22 ms in the attend-vision condition. Thus, verbal instructions to attend and the probability manipulation within their O-TOJ design generated a 133 ms prior entry effect. Given the ability of the orthogonal design to eliminate first-order response bias, and an additional study (Shore et al., 2001) whose results indicated a relatively small contribution of second-order response bias, the authors concluded that the results reflected a genuine processing acceleration of the attended signal.

This estimate of the prior entry effect is noticeably larger than the previous estimates of Stone, and Sternberg et al, and this may be related to the use of the tactile modality. Larger bimodal attention shifting effects occur between the tactile and auditory modalities than between other modality pairings (Spence & Driver, 1997; Spence, Nicholls & Driver, 2001). It is unclear if comparisons between multimodal studies using different modalities are appropriate. This is also true of comparisons between unimodal and bimodal studies. It is possible that the prior entry effect only applies to competition between signals from different modalities and not within a single modality (cf., Schneider and Bavelier, 2003). Further, it is also possible that this is the case only for competition between signals from two particular modalities (e.g., visual-auditory, or visual-tactile). Thus, the purpose of detailing the Spence et al. (2001) study is not to make a direct comparison between the large prior entry effect generated here, and that of previous multimodal prior entry studies, rather, the importance of this study is in the methodological advancement relative to previous prior entry studies. These advancements included the elimination of potential first-order response biases, and the application of a method of orienting attention that didn't require a reaction time task.

An additional improvement is related to the notion of whether unimodal studies are comparable to multimodal studies. With unimodal studies there is only a single modality, thus, the difference in attentional focus is between the spatial sources of the signals from that modality. With bimodal studies performed prior to Spence et al. (2001), the sources of the two different signals had been from different locations. Thus, it is unclear if the prior entry effects seen in multimodal studies that have used separate locations for presenting the different stimuli are due to attention to the modality or attention to a point in space. If, for example, it is the case that prior entry is a phenomenon that only exists due to competition between signals from different points in space, then previous bimodal prior entry investigations may have falsely concluded that the effect is due to competition between signals from different modalities. Spence et al. (2001) have eliminated this potential confound by presenting the signals from the different modalities from the same point in space. Therefore, this study has provided the next jump in methodological rigor, and it could be argued that this study now represented the best manner for obtaining an estimate of the prior entry effect.

However, there are potential flaws with this method also. As previously mentioned, the O-TOJ method eliminates first-order response bias, but still allows for more sophisticated second-order response bias. However, if one has a method for reliably estimating the relative contribution of second-order response bias to any shift in the PSS, then this factor is not an issue. According to Shore et al. (2001), the O-TOJ task lends itself to this end. In their visual prior entry study, Shore et al. had one group make a judgment about which line orientation came first, while another group judged which orientation came second. According to the authors, if the shift in PSS seen with the "which came first" judgments were due entirely to a response bias effect, then the shift in PSS seen with the "which came second" judgments should be equal in magnitude but in the opposite direction (as in Frey, 1990). Further, if the PSS shift were due completely to a prior entry effect, with no influence of response bias, then the shift should be equal in terms of both magnitude and direction. Thus, they contended, averaging the shifts from both tasks should yield a shift that represents only the influence of the prior entry effect with any response bias effect removed.

While this rationale may seem reasonable on first pass, a closer inspection reveals a shaky assumption. This assumption resides in the first premise of the argument which states that if there is no prior entry effect, then the shift seen with the two judgments will be the same. That is, if there is a bias in the "which came first" judgment, then there will be a bias in the "which came second" judgment that will be equal in magnitude, if different in direction. It is the assumption that the bias will be equal in both cases that is unfounded. Firstly, the Shore et al. comparison was between subjects. Assuming that some participants will show bias and some won't, or at least that people will show a response bias to varying degrees, then a difference in the degree to which the PSS shifts could be explained as a difference in the degree to which the different participant pools engaged in a response bias. Secondly, if the comparison were performed within-subject, it is conceivable that a participant could react differently to the instruction to respond as to "which came first" versus "which came second". The aspect of the two judgments that stands out as different is their coincidence with typical discourse. As an illustration, consider situations in which one inquires about the outcome of some competition. If one were to inquire about the outcome of a sporting competition between two teams, would you expect that person to ask you who won or who lost? If one were to inquire about the results of a 100 m track event, would you expect that person to ask you who came fifth or who came first? The point is that when receiving an inquiry about the results of some sort of competition, we expect to be questioned regarding who won or who came first. In other words, in typical discourse, we inquire about the winner of competitions and inquiries about the loser of the competition might seem awkward, thus, attracting attention and thoughts concerning why the question was phrased in such an atypical manner. This is the situation that a participant is put in when they are asked to report which of two events – which are competing, as is implied by the investigator's query into the order of their appearance – came second. This manner of query could be seen as a demand characteristic, which may inadvertently cue the participant into trying to figure out the hypothesis, or trying to figure out how they are being 'tricked' by this odd question (Orne, 1962). The question of "which came first" on the other hand, is relatively less likely to draw attention.

In his 1998 review of research on attention, Pashler stated that the evidence for the existence of prior entry was unconvincing. Several seemingly valid studies had failed to demonstrate prior entry effects (e.g., Cairney, 1975; Van der Haeghan & Bertelson, 1974). Additionally, while some studies had demonstrated an apparent prior entry effect, these results were susceptible to response bias explanations. He stated that in order to provide "convincing" evidence for the effect, careful consideration must be given to controlling for potential response bias effects. While the O-TOJ is an improvement over a standard TOJ in that it eliminates its susceptibility to first-order response biases, it is still susceptible to second order response biases. And given that the degree to which this method attenuates response bias has not been validly estimated, this method also falls short of the criterion of providing convincing evidence. However, another method not yet utilized seems to have the characteristics required to provide convincing evidence. This is the synchrony judgment (SJ) method.

The Synchrony Judgment Method

With the SJ method, instead of judging which of two stimuli (or which side) occurred first (or second) participants judge whether the two stimuli occurred at the same time or at different times. In other words, they judge whether the stimulus pair was presented synchronously or sequentially. The proportion of synchronous responses as a function of SOA can be plotted and the PSS can be estimated from the mean of the psychometric function (Figure 2). The pivotal factor that makes the SJ task promising for application the prior entry problem is the orthogonality of the attentional and response dimensions. As with the O-TOJ task, the response dimension (synchronous or asynchronous) is different from the attentional dimension (modality or side), thus, potential first-order response biases are eliminated. But the element that makes the SJ superior to the O-TOJ resides in its ability to also eliminate potential second-order response biases, which is due to the fact that its orthogonality is of a different kind than that of the O-TOJ method. With the O-TOJ, while the attentional and response dimensions are different, they are related. They are related in the sense that each individual stimulus possesses each of the two characteristics (e.g., modality and side), and this is what makes it possible for observers to cross reference the dimensions and engage in a second-order response bias. In contrast, with the SJ task, the response dimension does not apply to only a single stimulus. Rather, the response requires the observer to make a judgment about the stimulus ensemble. The fact that the response dimension can not be cross referenced with the attentional dimension establishes the SJ task as a task with a higher-order of orthogonality.

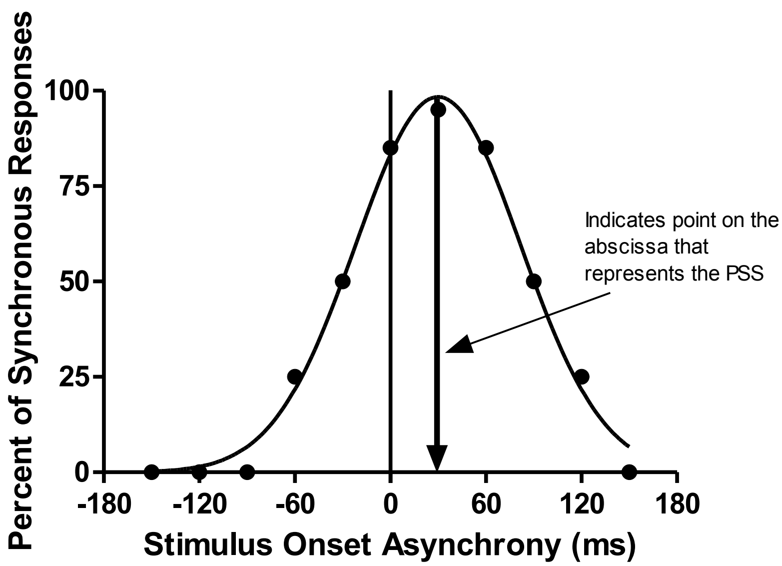

Figure 2. Hypothetical data from a synchrony judgment (SJ) task. Illustrates the determination of the point of subjective simultaneity (PSS), as indicated by the point on the abscissa that corresponds to the peak (mean) of the function.

The first study that applied a higher-order orthogonal design to the study of audio-visual prior entry was by Zampini, Shore, and Spence (2005). In this study, the SJ task was used to estimate the PSS under different attentional conditions. The authors utilized the Spence et al. (2001) strategy of manipulating the stimulus probabilities in order to encourage participants to direct their attention to one stimulus modality, as a supplement to instructions to focus their attention on the more frequently occurring modality. As with the Spence et al. (2001) study, each trial consisted of two stimuli presented from both a left and a right location, with the auditory and visual stimuli again presented from the same location. When participants were to attend to the visual modality, 50% of the trials contained only a left and right visual stimulus, while the remaining 50% were audio-visual trials, evenly split between auditory left-visual right and visual left-auditory right trials. When attending to the auditory modality, the 50% visual only trials were replaced with auditory only trials. On all trials, participants judged if the two stimuli were presented simultaneously or successively, with the bimodal trials being the trials of interest. The results indicated a moderate – relative to previous estimates of audio-visual prior entry – but statistically significant prior entry effect of 14 ms. While visual stimuli had to lead auditory stimuli by 46 ms at the PSS when attending to the visual stimulus, it only had to lead by 32 ms when attending to the auditory stimulus. This result represented the first estimate of the prior entry effect that was free from response bias influences.

However, a noted drawback (Spence, Shore & Klein, 2001; Newman & Albino, 1979) to the SJ method is related to the fact that it is up to the observer to establish their own criterion for what constitutes synchrony. That is, participants can vary how liberal or conservative they are in deeming a dual stimulus event as synchronous or not. If an observer is conservative in reporting the event as synchronous, this will have the effect of flattening out the distribution of synchronous responses and resulting in an estimate of precision that is less than a precision estimate of an observer who is liberal in their synchrony judgments. In this scenario, precision of judgment is not an absolute estimate, but is relative to the participant. Further, any tendency to try to equalize the two responses will also lead to falsely over or underestimated precision estimates (Erlebacher & Sekuler, 1971; Sekuler & Erlebacher, 1971). While this type of criterion bias will affect the estimated precision of the judgment, it will not affect the estimation of the PSS.

In addition to this drawback, there is a potential bias with the SJ judgment that has yet to be considered. As was mentioned earlier, the response dimension for the SJ task is orthogonal to the attentional dimension, thus, the SJ method is not susceptible to the same types of first order and second order biases to which the TOJ and O-TOJ methods are susceptible, respectively. However, there is an alternative cognitive bias that may apply that relates to a potentially false unspoken assumption. The assumption is that the criterion for judging the stimulus as synchronous or not synchronous is the same regardless of whether the visual stimulus precedes the auditory stimulus, or vice versa. Consider the following example. Suppose that a participant decides that as long as the two signals are close enough together that one could have caused the other, she will call them synchronous. Now, consider whether this will result in any differences for the two potential signal orders. As has been mentioned by van Eijk, Kohlrausch, Juola, & van de Par (2008), many studies (but mostly those that use the TOJ method) that investigate the audio-visual PSS estimate that the auditory stimulus must precede the visual stimulus in order for optimal synchrony to be perceived. They point out that this outcome is somewhat counterintuitive, given that in the natural environment, a visual stimulus will always precede its associated auditory component. In other words, the auditory component will never precede its visual counterpart, given that it is the motion of the visual component that *causes* the auditory component. It is the sense of causation that could lead an observer to judge an auditory-preceding-visual (A-V) stimulus configuration differently from a visual-preceding-auditory (V-A) configuration. While in the natural environment a sight that minimally precedes a sound can still be seen as a unitary event – given the experience we have with events that are at a distance – the opposite is not the case. That is, a visual stimulus that minimally precedes an auditory stimulus may be more likely to be judged as synchronous than an auditory stimulus that minimally precedes a visual stimulus. Thus, if an observer chooses causality as her criterion for deeming a dual stimulus event as simultaneous, then the criterion could be different for the A-V and the V-A configurations. This will result in the observer choosing 'synchronous' more often on the V-A side of the SOA distribution, thus shifting the PSS in a direction that suggests more of a visual advance in order to perceive synchrony. This result is common with SJ studies (see Table 1 from van Eijk et al., 2008).

Now, while this potential bias would affect the accuracy of PSS estimation, it is not a problem for the study of prior entry, as long as this bias (or any other bias for that matter) is equivalent for the different attentional conditions. However, if it is not, then this could also lead to falsely identifying a difference in PSS estimate between attentional conditions as a prior entry effect. For illustration, consider an observer who has a PSS that falls exactly at physical synchrony (0 ms SOA) when it is estimated using a method that allows absolutely no room for response bias. Further, consider the case where this observer exhibits this bias while attending to the auditory stimulus, but not while attending to the visual stimulus. For simplicity, imagine that there is no actual prior entry effect. In the attend-vision condition, where no bias is operating, the PSS estimate will be at or near physical synchrony. However, in the attend-audition condition, the bias will result in a PSS estimate that suggests an earlier onset of the visual stimulus for maximal synchrony to be perceived. Thus, the data will appear to show that an earlier onset of the visual stimulus is necessary for maximal synchrony perception when attending to audition versus attending to vision. This happens to be the prediction of the prior entry hypothesis. Thus, this bias could potentially falsely demonstrate a prior entry effect.

While this type of bias may seem less likely than the first and second-order biases associated with the TOJ method, it is still plausible, and thus, presents a potential problem with the SJ method. The point to be taken from this criticism is that the SJ method gives the observer the opportunity to conceive of their own criterion. But when studying something such as prior entry, we are interested in the perceptual effect, not the conceptual effect. Thus, the problem still exists of applying a method to the study of prior entry that only measures what the observer perceives and not what they conceive.

The Present Study – The Synchrony Comparison Judgment Method

Given the potential problems with participants choosing their own judgment criterion, it is difficult to describe the SJ method as an ideal method for testing the prior entry hypothesis. And, as previously mentioned, the TOJ and O-TOJ methods are also tainted by issues of response bias. In order to generate an estimate of the prior entry effect which will be convincing, a method is needed that obstructs both response bias and personal criterion determination. It is with this in mind that it is suggested here that the application of what could be called the synchrony comparison judgment (SCJ) method to the study of prior entry could achieve this end.

The SCJ method differs from the previous methods in that two audio-visual pairs of stimuli are presented on each trial. One of the pairs is always physically synchronous (the standard), while the other pair is asynchronous (the comparison) at one of a series of SOAs. The observer judges whether it was the first pair or the second pair of stimuli that was the synchronous one. The proportion of correct judgments/errors is then plotted as a function of the SOA and the PSS is estimated from the mean of the psychophysical function (Figure 3). As with the SJ and O-TOJ methods, the response dimension (first or second pair) is orthogonal to the attentional dimension (attend vision or audition). Further, like the SJ method, this orthogonality is of a higher-order than that of the O-TOJ. In addition, the criterion for what represents synchrony is established a priori by the physically synchronous standard stimulus pair, thus, individual criterions can not play a role in either the PSS estimation or the precision of judgment.

The purpose of Experiment 1 was to compare the parameter estimates from the SCJ method to those of the SJ and TOJ methods. Specifically, the estimates of the PSS and the precision, in terms of the interval of uncertainty (IOU), were compared. In a within-subjects design, participants made judgments about audiovisual stimuli utilizing the three different judgment tasks. The PSS estimates – and the variability of these estimates – from the SCJ and SJ tasks were different from that of the TOJ task. Experiment 2 sought to identify a particular reason for the differences between the tasks. Specifically, several participants had PSS estimates and IOUs that were startlingly different in the TOJ task compared to the other two tasks. We had participants in Experiment 2 purposely employ a particular response bias

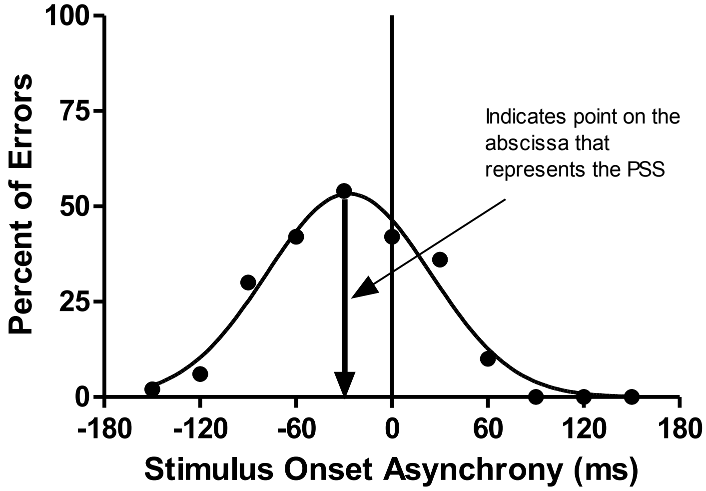

Figure 3. Hypothetical data from a synchrony comparison judgment (SCJ) task. Illustrates the determination of the point of subjective simultaneity (PSS), as indicated by the point on the abscissa that corresponds to the peak (mean) of the function.

in a TOJ paradigm to compare the response profiles of those we know are employing a bias to those who we suspect are employing a bias. The results indicated a consistency in the psychometric functions and parameter estimates between our biased participants in Experiment 2 and several participants from Experiment 1.

Prior to applying our SCJ method to the study of prior entry, we endeavored to validate the use of the method in Experiment 3. A potential criticism of the method concerns those participants who may have a large natural offset in terms of their perception of simultaneity (i.e., they need one of the stimuli to be presented considerably earlier than the other to perceive simultaneity). If the natural offset was large enough, then this would make the synchronous reference stimulus actually appear asynchronous, and thus, inappropriate as a comparison stimulus. By altering the timing of the stimuli, we mimicked what one would experience if one did have a naturally large offset. The results demonstrated that our method was sensitive enough to identify any such participants, and that these participants would display characteristic results.

The final experiment applied the SCJ method to a prior entry situation. Participants made secondary judgments about the auditory or visual stimuli in separate alternating series in order to induce selective attention. No significant difference between the PSSs from the two attentional conditions were obtained, thus, the prior entry hypothesis was not confirmed. In the general discussion it is suggested that the present finding represents the most bias free measure of the prior entry effect to date, but also suggests that further inquiry is required.

Experiment 1

Introduction

Currently, the method of testing that can claim to be the least influenced by response bias and, thus, provides the most accurate estimate of audio-visual PSSs is the SJ method. Despite the superiority of this method compared to the TOJ method, the TOJ method has also frequently been applied to the investigation of audiovisual perception. Van Eijk, Kohlrausch, Juola, and van de Par (2008) investigated the existence of methodological effects on PSS estimation and have compiled a review of studies that have investigated perceived timing relations between auditory and visual stimuli under what they call "normal conditions" (i.e., excluding studies that attempt to manipulate synchrony perception, e.g., attentional or asynchrony-adaptation manipulations). To van Eijk et al. (2008), the most striking observation from the compilation was the numerous instances of negative PSSs, which refer to auditory-preceding-visual (A-V) configurations. As mentioned previously, the authors consider this kind of result as counterintuitive given the lack of A-V configurations in the natural environment. In other words, according to the results of these studies, ideal conditions for perceiving synchrony will *never* occur in our everyday events. The authors also noted that although individual observers displayed both negative and positive PSS values in both SJ and TOJ tasks, negative *mean* PSS values were predominantly reported in TOJ studies, while SJ studies predominantly reported positive values. As has been previously suggested (e.g., Shore, Gray, Spry & Spence, 2005; Zampini, Shore & Spence, 2003; Allan, 1975; Hirsh & Sherrick, 1961), Van Eijk et al. (2008) forwarded that it was possible that the two tasks might be measuring different things.

The goal of van Eijk et al. (2008) was to provide a within-subjects comparison of the SJ and TOJ methods, along with a hybrid of the two tasks which included response options of “audio first”, “synchronous”, or “video first.” The typical SJ task with “synchronous” or “asynchronous” options was referred to as an SJ2 task, while the hybrid task was referred to as an SJ3. While some studies had carried out comparisons of the SJ and TOJ tasks, they were mostly either between-subjects designs (Smith, 1933; Vroomen, Keetels, de Gelder & Bertelson, 2004), or in the context of a temporal recalibration study (Fujisaki, Shimojo, Kashino & Nishida, 2004; Vatakis, Navarra, Soto-Faraco & Spence, 2008). The results from these studies provided inconsistent results. The one study that had looked at the two tasks in a within-subjects design did find a difference in the PSS estimates. Smeele (1994) found significant differences in PSS estimation between SJ and TOJ tasks for 9 out of 10 speech stimuli (nonsense syllables). While the mean PSSs from both tasks were negative, the PSSs from the TOJ task were far more negative. Further, even though the PSS values were different, she found that there was a significant correlation between the PSSs from the two tasks. This was a reflection of the fact that there was a relatively consistent shift of about 94 ms between the PSS values.

Van Eijk et al. (2008) reported results that were somewhat consistent with those of Smeele (1994). They had participants make SJ2, SJ3, and TOJs about both a simple flash-click stimulus pair (white disk and white noise burst) and a more complex bouncing-click ensemble (a moving white disk that bounces up off a horizontal bar). In terms of the PSS estimates, their results indicated that the TOJ task was producing different estimates than either the SJ2 or the SJ3 tasks. While no statistical differences were found when collapsing across stimulus type or when looking at the flash-click estimates alone, the PSSs estimated from the moving stimulus condition did reveal that the TOJ estimates were more negative – i.e., required an earlier onset of the auditory stimulus for ideal synchrony perception – by 35 and 28 ms compared to both the SJ2 and SJ3 tasks, respectively. In addition, while it was found that the PSS values from the two SJ tasks correlated highly, the PSS values from the TOJ task correlated with neither of the PSSs from the SJ tasks. This was the case for both the static and bouncing stimuli. Thus, while both van Eijk et al. (2008) and Smeele (1994) found that TOJs produced PSS estimates that required an earlier onset of sound compared to estimates from SJ tasks, van Eijk et al. did not find a reliably consistent relationship between PSS estimates from the two tasks. Van Eijk et al. concluded that their results were consistent with the suggestion that the different tasks may be measuring different underlying perceptions.

The purpose of Experiment 1 was to directly compare our SCJ task with the SJ and TOJ tasks in a within-subjects design. Seventeen participants made judgments about simple audiovisual stimuli under all three task conditions. Our primary interest was whether the PSSs generated from the SCJ task would line up more closely with the similarly bias resistant SJ task or the TOJ task. Further, we were interested in whether we would see the same reliable relationship between PSS estimates from the different tasks as seen by Smeele (1994), or the lack of such a relationship as reported by van Eijk et al. (2008).

Method

Participants

Seventeen undergraduate students from an introductory psychology class participated in the experiment for class credit. A within-subjects design was implemented such that all observers participated in all three methods of judgment. The mean age of the three male and 14 female participants was 19.0 years. All participants reported normal or corrected vision and normal hearing. In addition, all were naive as to the purpose of the experiment.

Apparatus and Stimuli

The apparatus consisted of a stimulus driver attached to a desktop computer. The stimulus driver included the timing circuitry for the stimuli, housed in a 36 x 22 cm Hammond® case (see Figure 4). A 12.7 x 12.7 cm white plastic panel was mounted on top of the stimulus driver, sloped back 30° from vertical. A single, circular, dual-colour, light emitting diode (LED) measuring 3 mm in diameter was embedded within the panel such that the surface of the LED was flush with the surface of the panel. Two speakers were situated out of view behind the panel at the same approximate position as the LED. Thus, the sound was co-located with the visual stimulus. Five horizontally aligned capnuts (6 mm in diameter, and 3.2 cm apart) were situated on the stimulus driver 6.5 cm in front of the display panel. These capnuts – working as capacitance detectors – acted as response buttons for registering participant responses. The two response buttons adjacent to the central response button were labeled according to the particular responses required by each of the three conditions (see procedure).

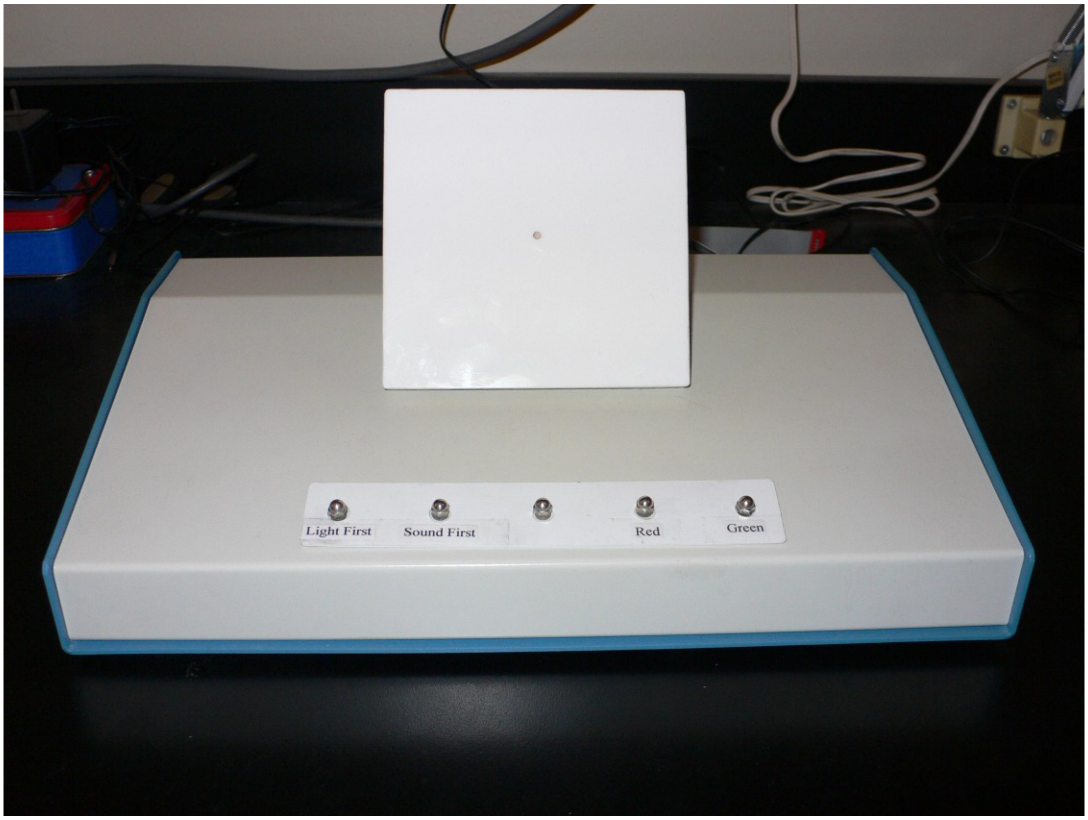

Figure 4: Apparatus from Experiment 1. Note that the labels on the response buttons do not correspond to those used in Experiment 1.

The visual stimulus consisted of a 10ms red flash of the LED at an intensity of 0.5 mcd. The LED was capable of emitting either a red or green flash, but only red stimuli were presented for this experiment. The auditory stimulus consisted of a 10ms stream of 500 Hz rectangular pulses resulting in a sound pressure level of 65 dB at the participant's position.

Procedure

Participants were tested in a 3 x 3 m room dimly lit by two 60 W lamps and the glow of a CRT computer monitor. They were seated at a desk at an unrestrained distance of approximately 45 cm from the stimulus panel, and were asked to maintain this distance throughout the experiment. Participants used the SCJ, SJ, and TOJ methods to make judgments about pairs of auditory-visual stimuli at a series of stimulus onset asynchronies (SOAs) presented randomly using the method of constant stimuli. The SOAs used were ± 15, 30, 60, 100, 160, and 240 ms (negative values indicate that the sound was presented first). Participants performed 24 trials at each SOA for each condition. One *set* of trials contained a single trial at each of the 12 SOAs, and participants performed 12 sets of trials followed by a break, the length of which was participant determined. Following the break, the remaining 12 sets were performed. Participants performed two of the three conditions on the first day of testing – with a five minute break in between – and returned within seven days to complete the final condition. The order of conditions was counter balanced across participants. The SJ and TOJ conditions took approximately 20 minutes to complete, while the SCJ condition took approximately 30 minutes to complete, for a total testing time of about 70 minutes.

At the beginning of each session, participants were provided with instructions concerning the judgment to be made and were given three practice sets to become accustomed to the particular judgment and its associated response options. The first trial of a session was initiated by the experimenter and followed an indication by the experimenter to the participant that the first trial would begin in approximately three seconds. Each successive trial was initiated by the response to the previous trial at a flatly distributed random interval of one to two seconds. Since a subsequent trial would be initiated by the response to the previous trial, participants were also instructed that they could take breaks at any time simply by withholding their response. A token was provided to the participant to place in front of the response button associated with the response that they will make following their break. This procedure rendered the testing self-paced. The pattern and timing of the stimuli were controlled by Visual Basic 4® software on the desktop computer. The computer also served to record the details for each trial, including the responses of the participants.

Synchrony Comparison Judgment

On each trial in the SCJ condition, participants were presented with two audiovisual stimulus pairs, separated by a random, flat distribution of between one and one-and-half seconds. One of the two pairs was always synchronous (the standard), while the other pair was asynchronous (the comparison) at one of the 12 SOAs. Whether the standard pair was presented first or second was random. The participants were instructed to choose the stimulus pair that they felt was the synchronous one (i.e., the response buttons were labeled “First Pair” and “Second Pair”). Participants were instructed to go with their gut instinct if they were uncertain as to which of the pairs was the synchronous one.

Synchrony Judgment

On each trial in the SJ condition, participants were presented with a single audiovisual stimulus pair where the two stimuli were separated by one of the 12 SOAs. The participants were instructed to respond as to whether the two stimuli were presented together or sequentially (i.e., the response buttons were labeled "Synchronous" and "Asynchronous"). Participants were instructed to go with their gut instinct if they were uncertain.

Temporal Order Judgment

On each trial in the TOJ condition, participants were presented with a single audiovisual stimulus pair where the two stimuli were separated by one the 12 SOAs. Thus, the stimuli presented were the same as those presented in the SJ condition. The participants were instructed to respond as to whether the light or the sound occurred first (i.e., the response buttons were labeled "Light First" and "Sound First"). Participants were instructed to go with their gut instinct if they were uncertain as to which stimulus occurred first.

Results

The raw data with fitted curves for all three testing methods, averaged over all participants, are shown in Figure 5. For the SCJ task, the data represent the percentage of errors in choosing which of the two bimodal pairs was the synchronous one as a function of the auditory delay (i.e., the SOA), while for the SJ and TOJ conditions, the data represent the percentage of "synchronous" responses and the percentage of "light first" responses as a function of the auditory delay, respectively. While the data in Figure 5 represent an average over all participants, each participant's data were treated individually for parameter estimates. The parameters of interest were the point of subjective simultaneity (PSS), the auditory-visual (AV) threshold, the visual-auditory (VA) threshold and the interval of uncertainty (IOU). These parameters were estimated from fitted Gaussian (SCJ and SJ) and cumulative Gaussian (TOJ) curves.

The curves were fitted by Graphpad Prism® using least squares criterion. For the SCJ and SJ tasks, the underlying distribution was assumed to be Gaussian, while for the TOJ task, the underling distribution was assumed to be cumulative Gaussian. The TOJ curves were constrained by the maximum value for each data point. The maximum value was determined by the number of trials at each SOA, thus, varied from experiment to experiment.

The basis for AV and VA threshold estimation was dependant upon the method of testing. In terms of the SCJ procedure, one of the two stimulus pairs was always synchronous, thus, participants always had a 50% chance of making the correct choice, and 50% correct choices – or errors, as is presented in Figure 5 and all future figures – is the outcome that would be expected if a participant were entirely unable to differentiate the

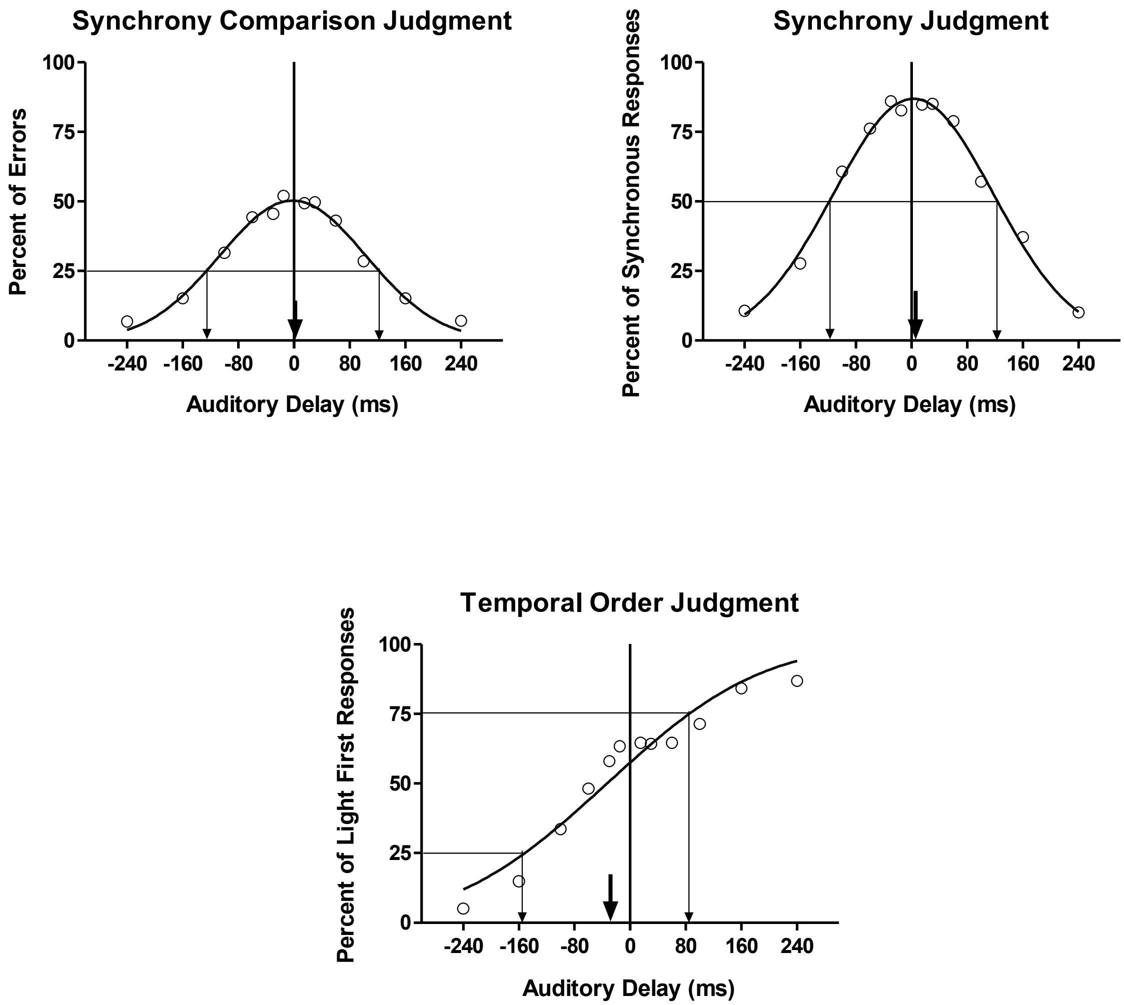

Figure 5. Mean raw scores with fitted curves for the synchrony comparison judgment (SCJ) method, the synchrony judgment (SJ) method and the temporal order judgment (TOJ) method. The data represent the percentage of errors, the percentage of synchronous responses, and the percentage of light first responses for the SCJ, SJ, and TOJ tasks, respectively, as a function of the auditory delay (milliseconds). The two thin vertical arrows indicate the value of the abscissa at which responding crosses the AV (left) and VA (right) thresholds, while the thicker vertical arrow indicates the value of the abscissa that represents the point of subjective simultaneity (PSS). The range of auditory delay between the two thresholds represents the interval of uncertainty (IOU).

standard from the comparison stimulus. Further, if a participant could clearly differentiate the standard from the comparison stimulus, then 100% correct choices (or zero errors) would be the expected outcome. Thus, the thresholds were defined as being represented by the SOAs at which the error rate falls halfway between these two outcome expectancies (i.e., 25 %), one each for auditory-preceding-visual SOAs (AV threshold) and visual-preceding-auditory SOAs (VA threshold).[1] For the SJ procedure, it would be expected that clearly asynchronous stimulus pairs would be judged “synchronous” 0% of the time, while clearly synchronous stimulus pairs would be judged “synchronous” 100% of the time. Thus, the SOA at which the “synchronous” response rate reaches halfway between these two outcomes (50 %) was taken as representing the threshold, one each for auditory-visual SOAs and visual-auditory SOAs. Finally, for the TOJ procedure, 50% of “light first” responses would represent pure guessing, while 0% and 100% of “light first” responses would represent clear order discrimination at the auditory-visual end of the SOA continuum and the visual-auditory end of the SOA continuum, respectively. Thus, AV and VA thresholds were defined as those SOAs that corresponded with “light first” response rates that fall half-way between 0% and 50 % (25 %) and half-way between 50% and 100% (75 %), respectively.

The PSS was defined as the mean of the fitted function, which corresponded to the midpoint between the AV and VA thresholds. Since the two thresholds represent a participant’s ability to make reliable discriminations, the SOA that falls exactly between these points represents the point of maximal synchrony. Finally, the IOU was defined as the

[1]It is typical to have a threshold for perceiving that a visual stimulus precedes an auditory stimulus (i.e., a VA threshold) occur at an SOA in which the visual stimulus does, in fact, physically precede the auditory stimulus (and vice versa for an AV threshold). However, it should be noted that it is possible that a VA threshold could occur when the auditory stimulus physically precedes the visual stimulus if, for example, one has an unusually large delay in auditory processing relative to visual processing. In other words, one *could* have a VA threshold that occurs at an A-V SOA.

magnitude of the SOA range between the two thresholds and was calculated by subtracting the AV threshold from the VA threshold. Since the SOAs between the thresholds represent the range over which participants are unable to make reliable discriminations, the magnitude of this range was taken to represent the participant's sensitivity to the particular discrimination. In this sense, smaller IOUs represent enhanced discriminability.

Sixteen of the 17 participants provided data that was appropriate for analysis. One participant was unable to complete the task sufficiently well enough to reach the criterion level of performance. The criterion for exclusion was set based on the raw data scores. An insufficient level of performance was defined as not having reached the AV threshold in any of the three conditions at the largest SOA administered (-240 ms). This performance restriction was also applied to the VA threshold at the opposite end of the distribution of SOAs (+240 ms). Since this was a repeated measures design, data from all three testing methods for this participant were not included in the analyses. These exclusion criteria were applied to all subsequent experiments.

The mean PSS, AV and VA thresholds, and IOU for the remaining 16 participants are shown in Table 1 (see Appendix A for individually estimated PSSs and IOUs). A one-way repeated measures ANOVA revealed that the means for the PSSs were different from each other, $F(2, 15) = 6.42$, $p = .005$. Further, Tukey's comparisons revealed that while the mean PSSs for the SCJ and SJ conditions were not different from each other, both of these means were different from the mean PSS of the TOJ method (see Table 2 for summary). Pearson correlations between the PSSs of the three methods were also calculated. The correlations between the SCJ and SJ methods ($r = .52$, $p = .04$), and between the SCJ and TOJ methods ($r = .65$, $p = .01$) were statistically significant. The correlation between the

PSSs from the SJ and TOJ methods was not significant ($r = .22$, $p = .42$). The means for the IOU's, AV and VA thresholds were also submitted to one-way repeated measures ANOVAs with no significant differences revealed, $F(2, 15) = 0.85$, $p = .57$, $F(2, 15) = 2.06$, $p = 0.14$, $F(2, 15) = 2.84$, $p = .07$, respectively.

Table 1.
Means and standard deviations of the parameters estimated by each method.

Method	PSS*	AV	VA	IOU
SCJ	1.3 (18.5)	-145.3 (68.3)	147.9 (70.5)	293.2 (133.8)
SJ	4.1 (20.0)	-126.3 (51.1)	134.5 (54.6)	260.8 (97.7)
TOJ	-29.8 (54.7)	-157.6 (72.4)	98.0 (93.5)	255.6 (126.5)

Note. Means (standard deviations) are reported in milliseconds. SCJ = synchrony comparison judgment, SJ = synchrony judgment, TOJ = temporal order judgment, PSS = point of subjective simultaneity, AV = auditory-visual threshold, VA = visual-auditory threshold, IOU = interval of uncertainty.
* Means were significantly different from each other

Table 2.
Details for Tukey's comparisons of mean points of subjective simultaneity.

PSS	**Mean Difference**	**q**	**Significant? p < .05**
SCJ vs. SJ	-2.8	0.38	No
SCJ vs. TOJ	31.1	4.19	Yes
SJ vs. TOJ	33.9	4.56	Yes

Note. Means are reported in milliseconds. SCJ = synchrony comparison judgment, SJ = synchrony judgment, TOJ = temporal order judgment, PSS = point of subjective simultaneity.

Discussion

The results indicate that the TOJ method is out of step with the SCJ and SJ methods. As with the Smeele (1994) and van Eijk et al. (2008) studies, the PSS for the TOJ method was estimated as occurring at an SOA in which the auditory stimulus precedes the visual stimulus (-30 ms). Also consistent with previous within-subject comparisons, the PSS estimated from the SJ method was shifted in a direction favoring a relatively earlier onset of the visual stimulus (+4 ms), compared to the PSS from the TOJ method. The PSS from the SCJ method (+1 ms) was more closely associated with the SJ method.

The correlational analyses also provided evidence for a greater association between the SCJ and SJ tasks relative to the TOJ task, but in a less consistent manner. There was a significant relationship between the PSSs for the SCJ and SJ tasks, and this was expected given that both tasks effectively eliminate response biases associated with favoring one stimulus. However, there was also a significant relationship between the SCJ and the TOJ tasks, while there was not a significant relationship between the SJ and the TOJ tasks. The inconsistency in this pattern of relationships falls in line with the limited results so far reported in these kinds of methodological comparisons. While van Eijk et al. (2008) did not find a significant correlation between the PSSs from the TOJ task with either SJ task, Smeele (1994) did find such a relationship between the TOJ and SJ tasks. In sum, while the results are not entirely consistent, they do support the general finding that TOJs have a tendency to generate PSSs that favor an earlier onset of the auditory stimulus compared to PSSs generated from SJs. Further, the results demonstrate that the PSSs generated by the SCJ method are more closely associated with those from the SJ method.

Despite the results supporting the notion that the TOJ task is different, the inconsistency in the correlational analyses of this experiment and previous methodological comparison studies lends more questionable support to the widely suggested explanation for *why* the TOJ task is different. As mentioned previously, it has been suggested that the reason that the TOJ and SJ tasks generate different PSSs is because the two tasks might measure different things (van Eijk et al., 2008; Shore, Gray, Spry & Spence, 2005; Zampini, Shore & Spence, 2003; Allan, 1975; Hirsh & Sherrick, 1961). The general idea put forward by these authors is that judgments concerning temporal order require different information than judgments regarding successiveness versus simultaneity. Specifically, while the perception of successiveness is a necessary precondition for the perception of temporal order, it is not a sufficient condition. Conversely, the perception of temporal order is sufficient for the perception of successiveness. Thus, more information – hence, more or different processing – is required for the order judgment (Hirsh & Sherrick, 1961). This hypothesis, then, implies that the different types of processing result in a differential relative timing of the two stimuli. However, what is not explicit in this hypothesis is whether one should expect the PSSs from the two tasks to be correlated given the different processing. Whether they should be correlated or not should depend on whether or not the change in the relative timing of the stimuli due to the task has a degree of constancy to it. In other words, the reliability of the relationship will depend on whether the difference in processing results in a somewhat *constant* change in the relative timing of the stimuli, or if one or both of the types of processing add a greater degree of *variability* in PSS estimates such that correlations between the tasks will be fickle. Given the lack of specificity in this differential processing hypothesis, it is not clear whether or not the correlational analyses support the notion of differential processing.

As van Eijk et al. (2008) also note from their results, although the TOJ PSSs are different than the SCJ and SJ PSSs, the PSSs from the TOJ task always fall within the IOU of the other two tasks. Because the PSS is falling within the interval in which observers can not reliably make correct judgments about the stimuli, it should be expected that the PSS as estimated from any task can vary in this range due to variations in random responding. Van Eijk et al. also note that it is within this range that TOJ responses will be most susceptible to response bias. This further source of randomness within the IOU is what they suggest is responsible for the lack of a correlation between their TOJ and SJ PSSs. This explanation can also be applied to the inconsistent correlation results seen in the present experiment, as evidenced by the substantially larger standard deviations of the PSS values estimated from the TOJ method compared to the other two methods (see Table 1). Thus, van Eijk et al. (2008) conclude that while the difference in magnitude of the PSS estimates is due to the fact that the different tasks are underlain by different types of processing, the lack of correlation is due to the randomness of the response bias-affected TOJ PSS estimates.

Despite the fact that the results from Experiment 1 are reasonably consistent with the notion of differential processing, an equally plausible alternative explanation for the disparate results between the tasks is offered here. While response bias was offered by van Eijk et al. (2008) as a suggestion for the lack of correlation between the tasks, it is suggested here that response bias is also responsible for the difference in magnitude of the estimates. As was discussed in the general introduction, the TOJ method is highly susceptible to response bias, while the SJ task (and the SCJ task) is not. Assuming that individuals and groups will vary with respect to how much bias they exhibit, then methods that allow for bias might be expected to show more variability in their estimates, which would explain the lack of correlation between a bias-susceptible and a bias-resistant method. However, random variation in degree of bias does not necessarily explain the relative consistency in which TOJ PSS estimates differ from estimates from other tasks. Out of the 28 PSS estimates from TOJ tasks (as compiled by van Eijk et al., 2008) 12 were negative while 16 were positive. In contrast, out of the 24 studies that used the SJ task, only four provided negative PSS estimates, while the other 20 reported positive estimates. This observation, combined with the fact that all three within-subject methodological comparisons reported thus far resulted in TOJ estimates that favored an earlier onset of the auditory stimulus compared to other methods, suggests that there may be a particular bias that dominates. Given that the two possible biases within an audiovisual TOJ task are a preference for the "light first" or "sound first" options, the more dominant bias would be related to the option that would result in a more negative estimate of the PSS, namely, a response bias favoring the visual signal. Experiment 2 will address this suggestion.

Experiment 2

Introduction

It was suggested that the results of Experiment 1, namely, the tendency for TOJs – compared to SJs and SCJs – to result in estimates of PSSs that require a relatively earlier onset of the sound for the perception of maximal simultaneity, may be related to a bias to choose the "light first" option more often in times of uncertainty. This potential explanation was brought to light by the unsolicited comments of several participants in a pilot version of Experiment 1 and the unusual results of several participants from Experiment 1. Following testing with the TOJ method in the pilot study, three participants admitted that they consistently chose the "light first" option as a default response when they could not discern the order. As an explanation for the differences in PSS estimates between tasks, this bias to favour the "light first" option can explain both differences in correlation and magnitude. As previously mentioned, the degree to which members of a group might execute this bias will vary, making correlations with estimates from unbiased methods erratic. In addition, a tendency to choose the visual stimulus as the leading one more often suggests that the visual stimulus is being perceived first more often, thus, in order to perceive synchrony, the auditory stimulus must be advanced (i.e., a negative PSS).

Figure 6 demonstrates how this strategy might push the response curve of an ideal observer in the negative direction, favoring an earlier onset of the auditory stimulus. The ideal observer in this scenario has a PSS located at physical synchrony, AV and VA thresholds of -67 ms and +67 ms, respectively, and an IOU of 134 ms. Given that a bias will more likely operate in situations of uncertainty, a bias towards the visual signal (or the auditory signal for that matter) would be expected to operate most strongly at the PSS with

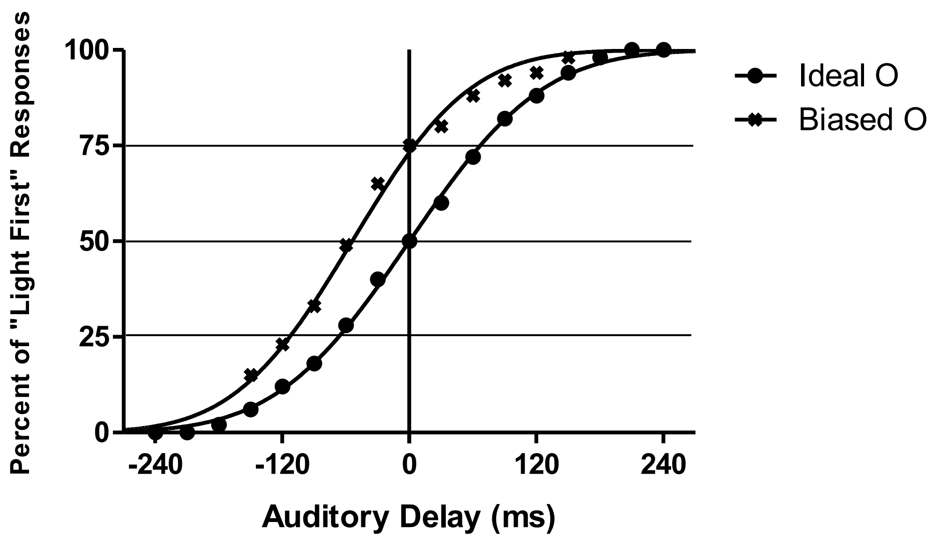

Figure 6. Hypothesized response distributions for an ideal (Ideal O) and a biased (Biased O) observer in a temporal order judgment (TOJ) task. The responses represent the percentage of “light first” responses as a function of the auditory delay (milliseconds). The point on the response functions at which the thin horizontal lines cross represent the locations of the audio-visual threshold (25%), the visual-audio threshold (75%), and the point of subjective simultaneity (50%).

the bias gradually losing strength as one approaches SOAs at which the observer can make the discrimination with certainty. In this illustration, the ideal observer is responding at chance level (i.e., 50% "light first" – 50% "sound first" responses) at his PSS, while the biased observer is biased in such a way as to *guess* "light first" 75% of the time. For both negative and positive auditory delays equivalently, the bias loses strength as it approaches perfect responding, at which point the bias ceases to operate. In this scenario, the PSS of the biased observer has shifted in the negative direction by 54 ms.

The data from three participants who displayed unusual results from the TOJ task relative to the other two methods, and who show differences that are consistent with the hypothetically biased observer are presented in Table 3. In all three cases, the PSS for the TOJ task compared to the other two tasks is shifted considerably in the negative direction (shifts of approximately 91, 175, and 83 ms for P3, P4, and P17, respectively) by a magnitude substantially greater than the mean shift from all participants (approximately 32 ms; see Table 1). In addition, the VA thresholds for all three participants have shifted in the negative direction by substantial amounts. The AV threshold has also shifted in the negative direction for P3 relative to the other two tasks, while the AV threshold for P4 and P17 has remained reasonably close to the estimates from the other two tasks. Finally, the IOUs are also unusually smaller for all three participants, particularly P4 and P17. Thus, these three participants show differences between their parameter estimates from the potentially biased TOJ and the bias-resistant SCJ and SJ tasks, as would be predicted based on the hypothetical effect of a "light first" response bias. The purpose of Experiment 2 was to provide real data for this hypothetical suggestion to provide a profile for identifying participants who might employ such a response strategy.

Table 3.

Parameter estimates from each method for P3, P4, and P17 from Experiment 1.

Participant 3

Method	PSS	AV	VA	IOU
SCJ	-18	-144	108	252
SJ	8	-117	132	249
TOJ	-96	-208	16	224

Participant 4

Method	PSS	AV	VA	IOU
SCJ	-10	-300	280	580
SJ	26	-163	214	377
TOJ	-150	-236	-63	173

Participant 17

Method	PSS	AV	VA	IOU
SCJ	-45	-214	124	338
SJ	-41	-260	179	439
TOJ	-124	-196	-51	145

Note. Means are reported in milliseconds. SCJ = synchrony comparison judgment, SJ = synchrony judgment, TOJ = temporal order judgment, PSS = point of subjective simultaneity, AV = audio-visual threshold, VA = visual-audio threshold, IOU = interval of uncertainty.

Method

Participants

Five laboratory members (3 females, 2 males), none of whom participated in Experiment 1, served as participants in Experiment 2. This was again a within-subjects design such that all observers participated in all three judgment conditions. The participant's ages ranged from 21 to 55 years with a median age of 22. All participants reported normal or corrected vision and normal hearing. All participants were aware of the purpose of the experiment.

Apparatus and Stimuli

The apparatus and stimuli were the same as those used in Experiment 1.

Procedure

Participants were tested in the same room as that used in Experiment 1. They were again asked to maintain an unrestrained distance of approximately 45 cm from the stimulus panel. Participants made SCJ and two types of TOJ judgments about pairs of audiovisual stimuli at a series of SOAs presented using the method of constant stimuli. The SOAs used were ±20, 32, 50, 80, 125, and 200 ms. Participants performed 50 trials at each SOA for each condition by engaging in five testing sessions for each condition. A single session consisted of 10 sets of trials, with one set again containing one trial at each of the 12 SOAs. With five sessions for each condition, a total of 15 sessions were completed. A single session took approximately 12 minutes, resulting in a total testing time of approximately three hours. While the order of conditions was counterbalanced across participants, flexibility was allowed in terms of the number of sessions performed per day. Participants were restricted to performing no more than two sessions back to back with a minimum five minute break in between, and no more than three sessions in one day. No restrictions were applied in terms of the number of total days in which the testing sessions were required to be completed. Because of this flexibility, the total amount of time to complete the experiment varied between two to three weeks.

As in Experiment 1, three practice sets were performed prior to the first session for each condition in order to become accustomed to the judgment and the associated response options. Also consistent with Experiment 1, testing was self-paced. The participants themselves initiated a session by clicking a "Start" button on the computer screen. The first trial occurred in approximately two seconds, and each successive trial was triggered by the response to the previous trial at a flatly distributed random interval of one to two seconds. As with Experiment 1, participants could take a break at any time by withholding their response. Participants were given instructions concerning the judgments to be made for each of three conditions prior to their initial testing session.

Tasks

The SCJ method was the same as that used in Experiment 1. The TOJ method was the same as that used in Experiment 1 except for one change. Specifically, participants in the present experiment were required to employ a particular response strategy. As with a typical TOJ, participants were instructed to observe the stimulus pair and report which one they thought occurred first. In Experiment 1, participants were instructed to go with their gut when they were unsure as to the order of the stimuli. However, for this experiment, they were given different instructions for how to deal with trials in which they were uncertain of the order of occurrence. In one TOJ condition, participants were instructed to answer appropriately if they felt as though they could discern the order, but to default to responding that the visual stimulus occurred first every time they were uncertain (TOJ-Default Visual; TOJ-DV). In the other TOJ condition, they were to again respond appropriately if they could discern the order, but to default to the auditory stimulus every time they were uncertain (TOJ-Default Auditory; TOJ-DA).

Results

Raw data scores with fitted curves for Participants 1,2, 4, and 5 are shown in Figure 7. The data for Participant 3 was excluded because AV thresholds could not be drawn for any of the methods. For the SCJ condition, the scores represent the percentage of errors in choosing which of the two bimodal stimulus pairs was the synchronous one, as a function of the auditory delay, while for the TOJ conditions, the scores represent the percentage of "light first" responses, as a function of the auditory delay. The PSS, AV and VA thresholds, and the IOU were estimated for each participant individually from the fitted Gaussian (SCJ method) and cumulative Gaussian curves (TOJ method) as in Experiment 1. The curves were again fitted by Graphpad Prism®.

Table 4 contains the mean PSS, AV and VA thresholds, and IOU for all four participants (see Appendix B for individually estimated PSSs and IOUs). All four of these parameters were submitted to within-subjects ANOVAs. For the PSS, the analysis revealed that the means were different from each other, $F(2, 3) = 48$, $p = .0002$. Tukey's comparisons showed that the PSSs from all three conditions were different from each other (see Table 5 for details). From Table 4, it can be seen that the PSS for the SCJ method is relatively close to zero (-6 ms) while the response bias implemented in the TOJ-DV condition resulted in an estimation of the PSS that is shifted in the negative direction. The response bias implemented in the TOJ-DA condition resulted in a shift of similar magnitude compared to the SCJ method, but in the opposite direction.

For the AV threshold, the analysis also revealed a difference between the groups, $F(2, 3) = 35$, $p = .0005$. Tukey's comparisons (Table 5) showed that the AV threshold from the TOJ-DA condition was different from that of both the TOJ-DV and SCJ conditions. The

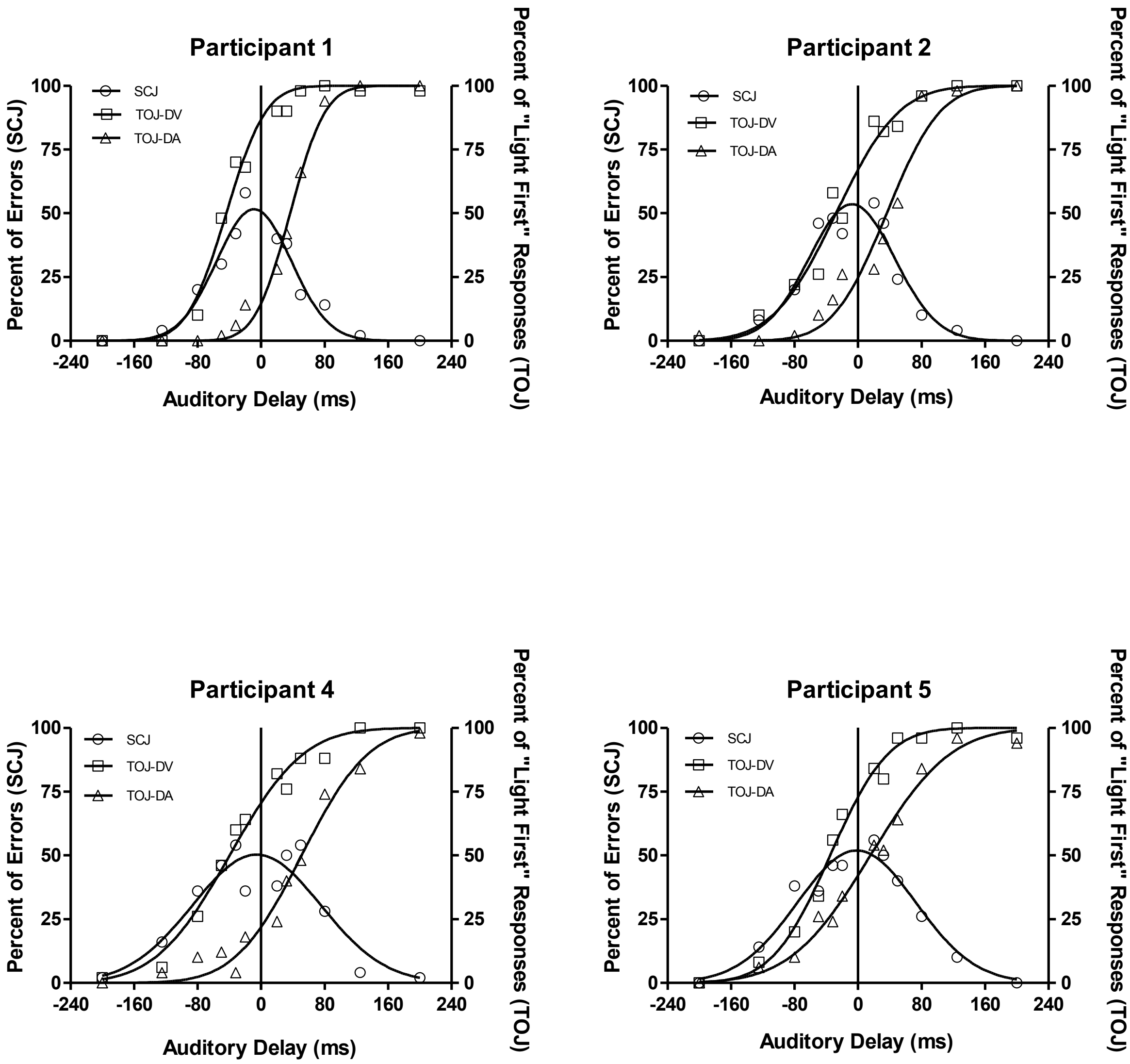

Figure 7. Response functions for all three tasks for participants 1, 2, 4, and 5 from Experiment 2. SCJ = synchrony comparison judgment, TOJ-DV = temporal order judgment-default visual, TOJ-DA = temporal order judgment-default auditory. The SCJ data represents the number of errors as a function of the auditory delay (milliseconds), while the TOJ-DV and TOJ_DA data represent the number of “light first” responses as a function of the auditory delay.

Table 4.
Mean parameter estimates for each method in Experiment 2.

Method	PSS*	AV*	VA*	IOU*
TOJ-DV	-36.8	-75.8	3.0	78.8
SCJ	-6.3	-83.0	70.5	153.5
TOJ-DA	35.0	-4.5	74.3	78.8

Note. Means are reported in milliseconds. TOJ-DV = temporal order judgment-default visual, TOJ-DA = temporal order judgment-default auditory, SCJ = synchrony comparison judgment, PSS = point of subjective simultaneity, AV = audio-visual threshold, VA = visual-audio threshold, IOU = interval of uncertainty.
* Means were significantly different from each other at $p < .05$

Table 5.
Results from Tukey's comparisons for the PSS, AV and VA thresholds, and the IOU from Experiment 2.

PSS	Mean Difference	q	Significant? p < .05
SCJ vs. TOJ-DV	30.5	5.92	Yes
SCJ vs. TOJ-DA	-41.3	8.00	Yes
TOJ-DV vs. TOJ-DA	-71.8	13.91	Yes
AV			
SCJ vs. TOJ-DV	-7.3	1.00	No
SCJ vs. TOJ-DA	-78.5	10.83	Yes
TOJ-DV vs. TOJ-DA	-71.3	9.83	Yes
VA			
SCJ vs. TOJ-DV	67.5	12.58	Yes
SCJ vs. TOJ-DA	-3.8	0.70	No
TOJ-DV vs. TOJ-DA	-71.3	13.27	Yes
IOU			
SCJ vs. TOJ-DV	74.8	9.88	Yes
SCJ vs. TOJ-DA	74.8	9.88	Yes
TOJ-DV vs. TOJ-DA	0.0	0.0	No

Note. Mean differences are reported in milliseconds. SCJ = synchrony comparison judgment, TOJ-DV = temporal order judgment-default visual, TOJ-DA = temporal order judgment-default auditory, PSS = point of subjective simultaneity, AV = audio-visual threshold, VA = visual-audio threshold, IOU = interval of uncertainty.

value of the AV threshold was similar for the TOJ-DV and SCJ conditions (-75.8 and -83.0 ms, respectively), but the response bias implemented in the TOJ-DA condition shifted this threshold substantially in the positive direction (-5 ms).

A similar pattern is seen with the VA threshold, where the analysis also revealed that the means were different from each other, $F(2, 3) = 55$, $p = .0001$. Tukey's comparisons (Table 5) showed that the VA threshold from the TOJ-DV condition was different from that of both the TOJ-DA and SCJ conditions. The value of the VA threshold was similar for the TOJ-DA and SCJ conditions (74.3 and 70.5 ms, respectively), but the response bias implemented in the TOJ-DV condition shifted this threshold substantially in the negative direction (+3 ms).

Finally, the analysis also revealed that the mean IOUs were different from each other, $F(2, 3) = 33$, $p = .0006$. Tukey's comparisons (Table 5) showed that the IOU from the SCJ condition was different from that of both the TOJ-DV and TOJ-DA conditions. While the values of the IOU were identical for the TOJ-DV and TOJ-DA conditions (78.8 ms), the IOU from the SCJ condition was almost twice as large (153.5 ms).

Discussion

The parameter estimates from the participants' "light first" biased responses (Table 4) are similar, but not identical to the hypothetical prediction. While the PSS shift in the negative direction favouring an earlier onset of the sound, and the reduction in the IOU were as expected, the relative shifts in the AV and VA thresholds were different from what was expected. It was hypothesized that the bias would act reciprocally for both auditory-preceding-visual and visual-preceding-auditory signal orders, thus, shifting both thresholds equally in the same direction. However, while in the "light first" bias, it was only the VA threshold that shifted. The "sound first" bias produced reciprocal results. The PSS shifted an equivalent amount in the opposite direction, and only the AV threshold shifted while employing this bias.

This result indicates that the "light first" bias seems to operate more strongly when the visual stimulus is presented first. This could be a reflection of the optimal strategy employed by participants given the environmental constraints. For illustration, consider the condition where participants are employing a "light first" bias. Participants were instructed to answer appropriately given that they could discern the order, and then to default to the "light first" option only when they were unsure. Given that the default response in situations of uncertainty is "light first", trials in which the light did indeed occur first would be highly likely to be judged as such, given that the "light first" judgment will be offered both when the light is actually experienced as occurring first, *and* when the observer is uncertain and defaults to this choice. On the other hand, trials in which the sound occurs first will only be identified correctly given that they are experienced this way. In other words, from a perspective that predicts that an observer's judgments will be influenced by a strategy that maximizes hits while minimizing false alarms (e.g., Signal Detection Theory, Green & Swets, 1966), the observer is likely to infer from the task constraints that the primary goal should be maximizing hits when the auditory stimulus occurs first, and that the attentional set should be adjusted to best achieve this goal.

Since it is known that the participants from Experiment 2 were defaulting to the "light first" option every time they were uncertain, it can not be said with certainty that they employed an attentional set designed to maximize hits of auditory-preceding-visual trials. Moreover, it is even more difficult to say with certainty the precise nature of the bias from the three highlighted Experiment 1 participants. They could have consciously or unconsciously just decided to default to the "light first" option when uncertain, they could have been trying to maximize detection of auditory-preceding-visual trials, or they may have simply been biased towards the response button that was closest to their dominant hand. However, each of these biases will result in a similar pattern of responding. Thus, even though the precise nature of the bias is difficult to confirm, it is important to note that the parameter estimates and response functions for the three participants from Experiment 1 are generally consistent with the response profile generated consistently by all four observers from Experiment 2 that provided usable data.

Figure 8 displays the TOJ data with fitted curves for Participants 3, 4, and 17 from Experiment 1 (parameter estimates for all three methods can be seen in Table 3). While the response profiles from these participants are consistent with those generated by the participants from Experiment 2 in the TOJ-DV condition, a small difference between the profiles does occur at the extreme SOAs. While the participants from Experiment 2 crossed the AV and VA thresholds and then continued to improve their accuracy until responding

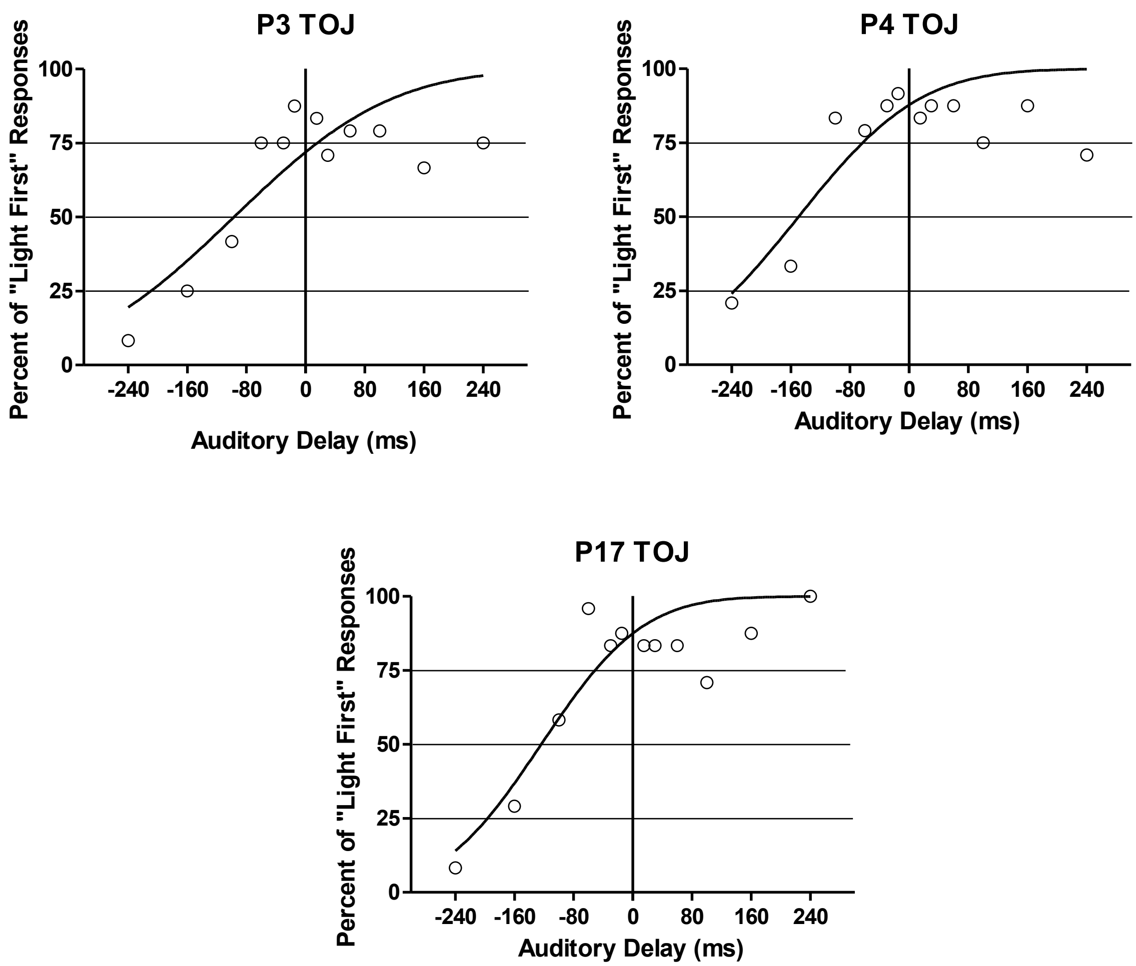

Figure 8. Response distributions for P3, P4, and P17 in the temporal order judgment (TOJ) task from Experiment 1. The responses represent the percentage of “light first” responses as a function of the auditory delay (milliseconds). The point on the response functions at which the thin horizontal lines cross represent the locations of the audio-visual threshold (25%), the visual-audio threshold (75%), and the point of subjective simultaneity (50%).

became perfect at the extreme SOAs, this was not the case for the three participants from Experiment 1 who all never quite reach perfect responding at either end of the SOA distribution. Indeed, as evidenced from the raw data, all three of these participants cross the "VA" threshold on the A-V side of the SOA distribution, but fail to improve to the level of perfect responding. This result is potentially explained by the difference between the judgment precision of the two samples. While the mean IOU is about 154 ms in the SCJ task for the Experiment 2 sample, the mean IOU in the SCJ task for the three biased participants from Experiment 1 is about 390 ms. According to Signal Detection Theory (Green & Swets, 1966), random variation in neural firing will result in some V-A configurations being experienced as A-V configurations and vice versa. That is, random neural activity could give a significantly greater advantage to one stimulus compared to the other such that a signal that entered the nervous system later than an alternative signal could reach a "synchrony center" (a hypothetical brain region responsible for deciding the relative timing of two events) prior to the alternative signal. Further, this potential reversal of signal order will be more likely at SOAs in which the observer can not reliably discriminate the order, and since a wider IOU offers more SOAs at which discrimination is uncertain, the potential for such signal reversals should be greater. Thus, while the biased Experiment 1 participants may be defaulting to a "light first" response when uncertain, not every trial that occurs within the IOU will necessarily elicit an uncertain experience. If a V-A configuration is presented but random firing provides a sufficient enough advantage to the auditory stimulus, then this could be experienced as an A-V configuration, and the participant will respond accordingly. Alternatively, the lack of precision at the extreme SOAs offered by the Experiment 1 participants could be a reflection of the motivation of the sample. While members of a laboratory group – the Experiment 2 sample – are participants by choice, the participants of Experiment 1 were required to participate in order to fulfill a class requirement. Thus, while laboratory members are more likely to be intrinsically motivated to perform well, or motivated by a responsibility to perform well for the research of their peers, participant pool subjects have no such motivation, as their simple attendance and participation satisfy their responsibilities. Thus, there is little motivation to exert a full effort at performing what is often an unexpectedly difficult, attention demanding task.

While these results do not prove definitively that the parameter estimates from the TOJ method differ from other methods because of biased participants, they are certainly consistent with that possibility. Indeed, if these three participants are removed completely from the analysis, the PSS estimates are no longer statistically different (means of +7, +6, and -8 ms, for the SCJ, SJ, and TOJ tasks, respectively). However, the fact that these results can not definitively prove that TOJ estimates are different from the estimates of other tasks is a consequence of the TOJ method's susceptibility to response favoritism. In other words, response bias can never be eliminated as a potential contributor to response functions from TOJ tasks. Further, while this particular bias seems to generate an easily identifiable profile, this may not be the case for any other bias which has yet to be proposed. In fact, a milder version of the bias to choose the attended stimulus in times of uncertainty (e.g., participants choosing the attended stimulus only 60% instead of 100% of the time when uncertain) could be indistinguishable from a true prior entry effect. The crucial point is that with the TOJ method, one can never definitively conclude that its parameter estimates are based on bias-free data. Thus, the application of this method to the study of prior entry – or the use of the method at all – is inappropriate. The appropriateness of the application of the SCJ method is the focus of the next experiment.

Experiment 3

Introduction

The large IOUs exhibited by the participants in Experiment 1 bring to light the question of the precision of the various tasks used to estimate PSSs. Given that the latest and most bias-resistant estimate of the prior entry effect has been estimated as 14 ms (Zampini, Shore, & Spence, 2005), the precision of the testing method must be sensitive enough to be able to catch an effect of this magnitude, and potentially smaller effect sizes. As mentioned in the general introduction, it is this unreliability of precision in the SJ task (due to the participant's freedom to choose their own criterion for simultaneity) that makes it less appealing than the TOJ method for application to the study of prior entry (Spence, Shore & Klein, 2001). In fact, Shore, Gray, Spry, & Spence (2005) have reasoned that given the increased processing demands associated with the TOJ task, this method should be more sensitive to such small effects compared to the SJ task. Given this requirement of being able to detect small effect sizes, the precision of the SCJ method is important to evaluate.

A convenient demonstration of the precision of the SCJ method relative to the SJ and TOJ methods is exhibited in the results of Experiment 1. The results of the statistical analysis revealed that although the SCJ method had the largest IOU (293 ms, compared to 261 and 256 ms for the SJ and TOJ tasks, respectively), no statistical differences between the IOUs for the three different methods, indicating that the precision of the methods was equivalent. However, the confidence that we can put in this comparison is limited. As mentioned previously, the precision of the SJ method will vary according to the individually determined criteria of the participants (Spence, Shore, & Klein, 2001; Newman & Albino, 1979). Further, it has been pointed out that the precision of the SJ method might be underestimated based on a response frequency equalization bias (Spence, Shore & Klein, 2001). In terms of the TOJ method, Experiment 2 demonstrated that the application of a bias to favor one stimulus in times of uncertainty will cause the response distribution to rise quickly through the IOU, thus, providing an underestimation of the magnitude of the IOU, which overestimates the precision of the task. Thus, in terms of both the SJ and TOJ tasks, the susceptibility of these methods to response bias makes estimations of their accuracy spurious. This lack of reliability makes a relative comparison of the precision of the SCJ task to the SJ and TOJ tasks difficult to interpret.

A second concern with the SCJ method is that the standard stimulus may not be an appropriate comparison stimulus for all observers. As mentioned by van Eijk et al. (2008), mean PSS estimates – as well as individual PSSs – vary, sometimes with the auditory stimulus leading, sometimes with the visual stimulus leading, and sometimes with the estimate very close to physical synchrony. Thus, it is not clear if the synchronous comparison stimulus is appropriate for only those individuals with a PSS that is relatively close to zero, or if it will still generate accurate estimates of the PSS for those who require either the visual or auditory stimulus to lead by a considerable amount. The largest PSS deviation from physical synchrony exhibited by a participant from Experiment 1 in either the SCJ or SJ task (the two tasks we can trust to produce accurate PSSs) was approximately 38 ms. This individual had AV and VA thresholds of -116 ms and +191 ms, respectively. Even though for this individual the physically synchronous standard would actually result in the two signals reaching a hypothetical "synchrony center" with a 38 ms delay in one of the signals, this delay is well within his/her IOU, thus, it would be expected that the standard would still be experienced as synchronous on most trials, and thus serve as an appropriate synchronous standard stimulus. However, many other investigations have had participants that have exhibited PSSs that deviate more substantially from physical synchrony (see Table 1 from van Eijk et al., 2008). For example, consider an individual with a PSS of +80 ms and a relatively narrow IOU of 160 ms. For this observer, the “AV” threshold would occur at physical synchrony and the VA threshold at and SOA of +160 ms. Thus, the physically synchronous comparison stimulus would be experienced as asynchronous 75% of the time. In this situation, the appropriateness of a physically synchronous standard stimulus is called into question.

Experiment 3 was implemented to provide insight into both of these issues. Two participants who had previously performed SCJ tasks and were known to have PSSs that deviated only moderately from physical synchrony participated. They performed a typical SCJ task with a physically synchronous standard and equivalent comparison stimuli on both the AV and VA sides of the SOA distribution. In addition to this condition, the participants also performed SCJ tasks in which a constant advancement of either the visual stimulus or the auditory stimulus was applied to both the standard and comparison stimuli. Applying a large advancement to one of the two stimuli serves the purpose of mimicking what a participant with a PSS that deviates considerably from physical synchrony would experience, thus, providing a template for identifying such participants. The second purpose served by Experiment 3 was to provide an evaluation of the precision of the SCJ method. Given that the constant advancement of one of the stimuli will mimic that which is experienced by someone with a PSS that is a combination of the true PSS of the observer plus the advancement, then if the SCJ task is reasonably accurate, the difference between the estimated PSSs from the different conditions should reflect the magnitude of the constant advancements.

Method

Participants

Two male laboratory members – ages 33 and 56 – both of whom participated in Experiment 2, served as participants in the present experiment. Both participants reported corrected vision and normal hearing. In addition, both participants were aware of the purpose of the experiment.

Apparatus and Stimuli

An alternate apparatus was used for Experiment 3. While the stimulus driver and desk-top computer were the same, an alternate stimulus panel was mounted on top of the driver (Figure 9). The stimulus panel consisted of two rows of seven rectangular, red LEDs, one above the other. Each LED consisted of a 5.7 x 3.3 mm flat lense with a thin white bracket that made the total outer dimension of each LED 6.2 x 3.6 mm. With the longer side of each LED oriented horizontally, the total length of each row of LEDs was 43.4 mm. The two rows were lined above, below and in between by 7 mm high white plastic, and this LED arrangement was bracketed by a 5 mm thick dark grey plastic boarder. This total assembly was set in a 14.1 x 12.5 cm white plastic panel that was mounted on top of the stimulus driver, sloped back 30° from vertical. As with the previous stimulus panel, two speakers were situated out of view behind the panel, thus, the sound source was co-located with the visual stimulus.

The visual stimulus consisted of a 10ms flash of the top, middle LED at an intensity of 0.5 mcd. The auditory stimulus was the same as that used in the previous experiments, a 10 ms stream of 500 Hz rectangular pulses resulting in a sound pressure level of 65 dB at the participant's position.

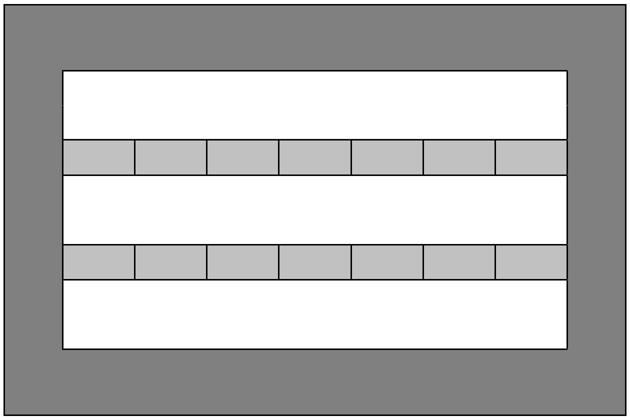

Figure 9. Diagram of stimulus panel from Experiment 3.

Procedure

Participants were tested in the same room as the previous two experiments, and were once again asked to maintain the approximately 45 cm unrestrained distance from the stimulus panel. Participants made SCJs about pairs of auditory-visual stimuli presented using the method of constant stimuli. While previous experiments manipulated the type of judgment made while keeping constant the timing of the stimuli, the present experiment had the participants make the same type of judgment in all five conditions, with the timing of the stimuli being manipulated for each condition. The first condition (0offset) was a typical SCJ condition with a synchronous standard stimulus and comparison stimuli of 150, 120, 90, 60, 30, 0 -30, -60, -90, -120, and -150 ms. The other four conditions took the standard stimulus and this same range of comparison SOAs and either added a constant advancement of the auditory stimulus to each, or added a constant advancement of the visual stimulus to each. Auditory advancements of 30 (-30offset) and 80 ms (-80offset) were applied to the 0offset standard and comparison stimuli, as well as visual advancements of 30 (+30offset) and 80 ms (+80offset). Thus, for example, in the +30offset condition, the standard stimulus had an actual SOA of +30 ms, and the comparison stimuli were 180, 150, 120, 90, 60, 30, 0 -30, -60, -90, and -120 ms.

Participant 2 performed 50 trials at each SOA of each condition, while participant 1 performed 30 trials. The lab members completed five and three sessions of 10 sets for each condition, respectively. One set again contained one trial at each one of the 11 comparison stimuli. Thus, a total of 25 and 15 sessions were completed, respectively. A single session took approximately 13 minutes for a total testing time of approximately five and a half and three hours, respectively. The order of conditions was counterbalanced between the two participants, and they were awarded the same flexibility as seen in Experiment 2 in terms of the number of sessions performed per day. The restriction in terms of number of sessions performed back to back and per day was also maintained from the previous two experiments. Data collection took approximately one week.

As in all previous experiments, familiarity with the judgments prior to data collection was attained by performing three practice sets prior to the first session for each condition. Also consistent with all previous experiments, testing was self-paced. This again included a participant-initiated first trial, and all subsequent trials occurred automatically as a result of the response to the previous trial with a random one to two second delay. Both lab members were given instructions prior to their first session and were experienced with regards to the SCJ method.

Results

Raw data scores with fitted curves for all conditions for both participants are shown in Figure 10. The scores represent the percentage of errors in choosing which of the two bimodal stimulus pairs was the synchronous one, as a function of the nominal auditory delay. The PSS was estimated for both participants individually from the fitted Gaussian curves, as in previous experiments. The curves were again fitted by Graphpad Prism®. PSSs could not be estimated for the +80offset condition because VA thresholds could not be obtained (see discussion). The vertical arrows at the peaks of the distributions indicate the value of the abscissa that represents the point of subjective simultaneity (PSS).

Table 6 displays the PSSs for each condition for both participants. The table also indicates the deviations of the PSSs from the 0offset condition for each condition.

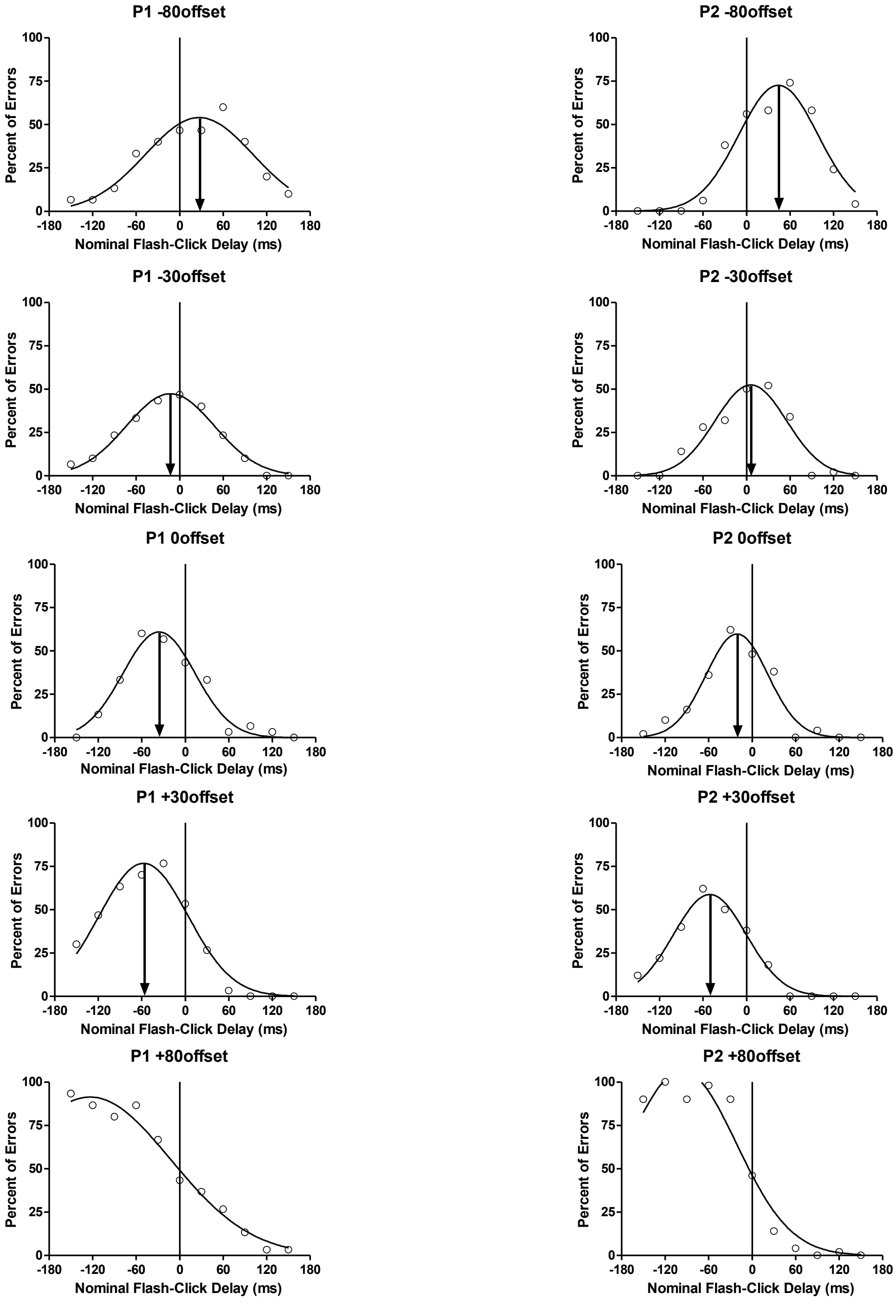

Figure 10. Raw data with fitted curves for both participants in all five synchrony comparison judgment conditions. Data points represent the percentage of errors as a function of the nominal auditory delay (milliseconds). The vertical arrows at the peak of the distributions mark the point of subjective simultaneity (PSS) for each condition. In the individual graph titles, positive values represent advancement of the visual signal while negative values represent the advancement of the auditory signal.

Table 6: PSS deviations relative to the offsets for both participants.

Participant	Magnitude of Offset	PSS Deviation From 0offset Condition	PSS	Participant	Magnitude of Offset	PSS Deviation From 0offset Condition	PSS
P1	-80	**-63**	+27	P2	-80	**-63**	+44
	-30	**-20**	-13		-30	**-27**	+6
	0	**0**	-36		0	**0**	-21
	+30	**+21**	-57		+30	**+30**	-51
	+80	*	*		+80	*	*

Note. Values are reported in milliseconds. PSS = point of subjective simultaneity.
* unable to estimate PSS

Discussion

In terms of the problem of using a synchronous standard for those participants with a PSS that deviates substantially from physical synchrony, the results of this experiment exhibit the response function that should be expected in this scenario. Taking Participant 1 (P1) as an example (everything that is said for P1 can also be said for P2), the effect of a large absolute PSS can be seen in the +80 ms-advancement condition. For this participant, his baseline PSS, as estimated from the typical SCJ task with a synchronous standard stimulus, is -36 ms. As can be seen in Figure 10, in the +80 ms-advancement condition, an AV threshold can not be obtained, as the participant never comes close to reaching the 75% correct response threshold. This result makes sense when we consider what the standard and comparison stimuli truly are.[2] For simplicity, consider just the data point that falls at the -150 ms point of the abscissa, where the participant performs the seemingly unusual behavior of choosing the *comparison* stimulus as the synchronous one almost every time. While in Figure 8 this point is labeled as -150 ms (auditory preceding visual), because of the 80 ms visual stimulus advance, what is actually presented is a -70 ms offset. Further, the 80 ms visual advantage has also been applied to the standard stimulus, thus, the standard stimulus is actually a +80 ms offset (visual preceding auditory). From the 0 ms-advance condition we know that this individual perceives synchrony most strongly at a -36 ms offset. Thus, given a -70 ms offset comparison stimulus, which deviates from his PSS by 34 ms, and a +80 ms standard stimulus, which deviates from his PSS by 116 ms, it is not surprising that this

[2]Notice that the SOA distributions on the abscissas in Figure 10 are labeled the same for all conditions, even thought this distribution was only used for the 0 ms-advancement condition. This was done to illustrate a realistic experimental situation. Specifically, given that the observer's PSS is not known prior to estimating it from the results of the completed task, in an experimental situation all one knows is what was physically presented. Thus, while a researcher may be presenting a physically synchronous standard, they will be ignorant to the fact that an observer with a large absolute PSS may actually experience the standard as asynchronous. In this sense, the advancements of the signals serve to mimic what would be experienced by an observer with a PSS equal to the magnitude of the advancement (plus or minus their own PSS) when the stimuli displayed on the abscissa are presented to them.

individual feels that the -70 ms comparison stimulus is more synchronous than the +80 ms standard. Supporting this interpretation, notice in the 0 ms-advance condition that at the -70 ms SOA – which corresponds to a 34 ms deviation from his PSS, just like the -150 ms SOA from the +80 ms-advancement condition – this participant is responding randomly (i.e., is well within his IOU), indicating that he can not reliably discriminate this stimulus from the synchronous standard. Additionally, at the + 80 ms SOA in the 0 offset condition – which corresponds to a 116 ms deviation from his PSS, just like the 0 ms SOA from the +80 ms-advancement condition – the participant has clearly crossed threshold and is approaching perfect responding, indicating that this SOA is clearly asynchronous compared to the synchronous standard. Thus, again, the fact that P1 chose the comparison stimulus almost exclusively as the synchronous stimulus at the -150 ms SOA is what should be expected.

This can also be thought about in another way. The -36 ms PSS in the typical SCJ task implies that P1 requires the auditory stimulus to be presented 36 ms before the visual stimulus in order to perceive maximal synchrony. In other words, his sensory processing apparatus provides a 36 ms advantage to the visual stimulus that must be corrected for by the presentation offset for ideal synchrony perception. Again, for simplicity, consider just the data point that falls at the -150 ms point of the abscissa in the +80 ms-advancement condition. The manipulation in this condition applied an 80 ms advantage to the visual stimulus, making the actual physical offset -70 ms. Now, P1's brain gives a 36 ms advantage to the visual stimulus, thus, at this SOA the auditory stimulus will reach a "synchrony center" 34 ms (-70 ms + 36 ms) before the visual stimulus. The visual signal in the standard stimulus has been given an 80 ms physical advantage, and in combination with the 36 ms "sensory processing" advantage, will arrive at the synchrony centre 116 ms before the auditory stimulus. Again, it is not surprising that P1 consistently chooses the 34 ms A-V configuration as being the synchronous stimulus over the 116 ms V-A configuration. Moreover, this same explanation applies to the adjacent SOAs in the +80 ms-advancement condition that are also reliably judged as more synchronous than the standard, as well as to the equivalent results of Participant 2.

The fact that one does not see this reliable selection of the comparison stimulus at the opposite end of the distribution in the +80 ms-advancement condition makes sense when one again considers the standard and comparison stimuli that are actually presented and P1's natural PSS. Considering the +150 ms comparison SOA, the actual SOA is +230 ms, and the 0 ms standard SOA is actually +80 ms. Applying the 36 ms visual advantage from sensory processing, the comparison stimulus will consist of the visual stimulus reaching the synchrony centre 266 ms before the auditory stimulus, while the standard stimulus will have the visual stimulus arriving 116 ms prior to the auditory. Given these two choices, it should be expected that the smaller offset of the standard stimulus will result in it being experienced as the synchronous one the vast majority of the time.

Given P1's -36 ms PSS and the 80 ms visual advantage, this condition with this participant represents what would be seen with a participant in an SCJ task with a PSS of -116 ms. From this, it can be concluded that the physically synchronous standard stimulus would not be appropriate for an individual with a PSS as large as 116 ms. While this issue could be avoided by widening the range of SOAs presented (i.e., this issue does not occur in the ±30 ms conditions because), if one is considering the extensive amount of time and effort that must be put forth by a participant in such experiments, then adding more test points may not be desirable.

The same response pattern seen at the -150 ms SOA in the +80 ms-advancement condition is not seen at this same SOA in the -80 ms-advancement condition. If one again looks at the actual offsets given the applied advancement and the sensory advancement, then this pattern is what would be expected. However, if an observer with a PSS of +36 ms (as opposed to the -36 ms of P1) were to perform this task, then a reverse would be seen in terms of the condition which shows the unusual response pattern.

Using the same rationale that was used to assert that the +80 ms-advancement condition with P1 mimicked a situation in which a person with a -116 ms PSS was performing a typical SCJ, the +30 ms-advancement condition with P1 represented the pattern that would be seen with an observer that has a -66 ms PSS. Even given this seemingly large offset, thresholds were still obtained in this condition, and the same can be said for the -30 ms-advancement condition. Further, the location of the PSS in this condition relative to the other conditions also supports the contention that a physically synchronous standard would be appropriate for such an observer (see next paragraph). Thus, for an observer with a natural PSS of -66 ms or +66 ms, the physically synchronous standard would be an appropriate standard stimulus.

In terms of the issue of the sensitivity of the SCJ method, the relative PSSs generated by each condition provide support for the notion that the method is reasonably accurate (see Table 6). Essentially, if the method is accurate, then one would expect the PSS estimates from each condition to change relative to the applied advancements. For example, if an observer has a PSS of 0 ms in the typical SCJ situation, then when a +30 ms advancement is applied to the standard and comparison stimuli, the estimated PSS from this condition should reflect the fact that the visual stimulus has been given a 30 ms advantage. That is, the participant should exhibit a PSS that suggests that he needs the auditory stimulus advanced by 30 ms in order to perceive synchrony maximally. In other words, he should now generate a PSS of -30 ms.

P2 demonstrates this expected effect quite accurately at the +30 and -30 ms-advancement conditions (Table 6). The PSS of P2 in the 0 ms-advancement condition is -21 ms. In the +30 and -30 ms-advancement conditions, his PSS is estimated as -51 ms, and +6 ms, respectively. This corresponds to shifts of 30 and 27 ms, respectively, which follows almost precisely what would be expected given a sensitive testing measure. P1 shows a similar but less precise pattern, as the PSS shifts are in the correct direction, but only amounted to 20 and 21 ms in the +30 and -30 ms-advancement conditions, respectively. The -80 ms-advancement condition demonstrates a similar pattern of apparently slightly reduced accuracy, as both P1 and P2 exhibit a PSS shift of 63 ms in the expected direction. As mentioned previously, a PSS could not be generated for either participant in the +80 ms condition.

To be able to assert that the SCJ method is accurate, the ideal result for this experiment would have been for all PSSs to shift to a degree that is exactly equal to the applied advancements. However, there is reason to believe that this result should not be expected to be so precise. This reason is related to the variability of PSS estimation seen with repeated testing. That is to say, some variability in the estimation of the PSS should be expected with multiple estimations. An estimation of how much variation should be expected is provided by Fouriezos, Capstick, Monette, Bellemare, Parkinson, and Dumoulin (2007). Using the SCJ method, the authors investigated the effect of motion on the estimation of the PSS. Over the course of five experiments, judgments of the synchrony of flash-click pairs were compared to judgments of the synchrony of an apparent bounce of a moving visual stimulus with a click. Two observers in this study participated in all five experiments, thus, this provides an indication of the variability that one might expect with repeated testing. For the sake of comparison, only the PSSs estimated from the conditions that used a static visual stimulus are considered here. S1 from Fouriezos et al. (2007) exhibited PSSs of 0, -2, -8, -12, and -3 ms, while S2 showed PSSs of -21, -33, -35, -25, and -32 ms. These values amount to ranges of 12 and 14 ms for S1 and S2, respectively, suggesting that PSSs from the same observer can be expected to vary by 12 to 14 ms between measurements. The 17 ms deviations between the 0 ms and -80 ms-advancement conditions is slightly beyond this range, but the estimates from the -80 ms may be influenced by another source of variability related to the difficulty of the judgments. In the 0 ms-advancement condition, at least one of the stimuli (i.e., that standard) will seem synchronous on every trial, thus, the observer simply has to perceive one of the two stimuli as asynchronous in order to make the judgment. However, as was explained previously in context of the +80 ms-advancement condition, in the -80 ms-advancement condition, there will be some trials where both stimuli are substantially asynchronous, thus, the observer must judge which of the two was less asynchronous (or which was the most synchronous), rather than just identifying the one asynchronous stimulus. This increased difficulty will add to the variability, which could account for the 17 ms deviation seen in both participants in the -80 ms-advancement condition.

Experiment 4

Introduction

The purpose of Experiment 4 was to apply the SCJ method to a prior entry scenario. Experiment 3 provided evidence for the accuracy of the SCJ method, thus, given the drawbacks associated with the SJ and TOJ methods, the next logical step in the evolution of the methodological application to the study of prior entry was the application of the SCJ method. Five laboratory members participated in both forced attention conditions.

In choosing the method for inducing differential attentional allocation, the goal was to maximize the likelihood that the manipulation would be successful while minimizing the difficulty of the overall task. Frey (1990) had demonstrated that difficult secondary tasks such as reaction times can induce the participant to adopt a strategy that maximizes performance on the secondary task, but that alters the goal of the manipulation (i.e., reacting to the stimulus ensemble). Thus, the strategy applied here was to employ a task that forced the observer to favor one stimulus over the other, but that did not make the overall task excessively difficult. Recall that with the SCJ method, there are two bimodal stimulus pairs on each trial, thus, each trial contains two visual and two auditory stimuli. In the “attend visual” condition of Experiment 4 the two visual stimuli of one trial were randomly either both red, both green, or one of each. The task of the participant was to respond as to whether the visual signals were the same or a different colour. In the “attend auditory” condition, the two auditory stimuli were randomly either the same low pitch, the same high pitch, or one of each, with the task to again judge whether they were the same of different. To supplement this manipulation, participants were instructed to focus their attention on the signal to which a judgment was to made. The accuracy of these judgments was recorded to provide evidence that the participants were performing the task accurately.

Method

Participants

Five laboratory members (4 males, 1 female), two of whom participated in Experiments 2 and 3, served as participants in the present experiment. All observers participated in both conditions in a within-subjects design. The participant's ages ranged from 20 to 55 years with a median age of 21. All participants reported normal or corrected vision and normal hearing. All participants were aware of the purpose of the experiment.

Apparatus and Stimuli

The apparatus was the same as that used in Experiments 1 and 2, however, there were additional stimuli utilized in the present experiment. The visual stimulus again consisted of a 10ms flash of the LED at an intensity of 0.5 mcd, however, while in previous experiments the flash was always red, the flash was either red or green for the present experiment. In addition, while the auditory stimulus was again a 10 ms noise burst with a sound pressure level of 65 dB at the participant's position, in the present experiment the stimulus was either 500 Hz (low pitch) or 1000 Hz (high pitch). Whether a red or green visual stimulus or whether a high or low auditory stimulus was presented was random.

Procedure

Participants were tested in the same room as that used in Experiments 1, 2 and 3, with the same requirement of maintenance of an unrestrained distance of approximately 45 cm from the stimulus panel. Participants made two types of SCJs about pairs of audiovisual stimuli at a series of SOAs presented using the method of constant stimuli. The SOAs used were ±30, 60, 90, 120, 150, and 0 ms. Participants performed 50 trials at each SOA of each condition. As with Experiment 3, participants performed five testing sessions for each condition. A single session consisted of 10 sets of trials, with one set again containing one trial at each of the 11 SOAs. A total of 10 sessions were completed. A single session took approximately 13 minutes for a total testing time of approximately two hours. While the order of conditions was counterbalanced across participants, flexibility was again allowed in terms of the number of sessions performed per day. The restriction concerning the maximum number of back to back and daily sessions performed was maintained from Experiments 2 and 3. The total amount of time to complete the experiment varied between two to three weeks.

As in all previous experiments, three practice sets were performed prior to the first session for each condition to ensure that participants were comfortable with the judgment. Also consistent with previous experiments, testing was self-paced. Following a first trial that was participant-initiated by clicking a “start” button, the successive trials were again triggered by the response to the previous trial at a flatly distributed random interval of one to two seconds. Lab members were given instructions concerning the judgments to be made for both conditions prior to their initial testing session, but were not re-instructed prior to each session. All lab members were experienced with regards to the SCJ method.

There were two conditions in the present experiment that both required the participants to make SCJs. However, the two conditions differed in terms of the participant’s attentional focus. In one condition, the participants were instructed to focus their attention on the visual stimulus (SCJ-V), while in the other condition they were instructed to focus their attention on the auditory stimulus (SCJ-A). In order to further encourage participants to focus their attention on one stimulus over the other, a secondary task was implemented. In the SCJ-V condition, the visual stimulus for both stimulus pairs (i.e., the standard and comparison stimuli) could have been either red or green, and participants had to first respond as to whether the two visual stimuli were the same or a different colour. In the SCJ-A condition, the auditory stimulus for both stimulus pairs could have been either high pitched or low pitched, and participants had to first respond as to whether the two auditory stimuli were the same or a different pitch. Whether the stimuli were the same or different was random. As with the responses to the SCJ, the participants "same" or "different" judgments were also recorded on the desk-top computer so that error rates for each participant could be calculated.

Results

Raw data scores with fitted curves for all participants are shown in Figure 11. The scores represent the percentage of errors in choosing which of the two bimodal stimulus pairs was the synchronous one, as a function of the auditory delay. The PSS, AV and VA thresholds, and the IOU were estimated for each participant individually from the fitted Gaussian curves. The curves were again fitted by Graphpad Prism®.

Discrimination error rates were low for all participants with mean error rates of 0.8 and 2.2 % for the SCJ-V and SCJ-A conditions, respectively. Table 7 contains the mean PSS, AV and VA thresholds, and the IOU for all five participants for both conditions (see Appendix C for individually estimated PSSs and IOUs). The PSS data were submitted to a within-subjects *t*-test. The analysis revealed that the means were not different from each other, $t(1, 4) = .9024$, $p = .42$. From table 7, it can be seen that the difference between the means from the two conditions was only 5 ms.

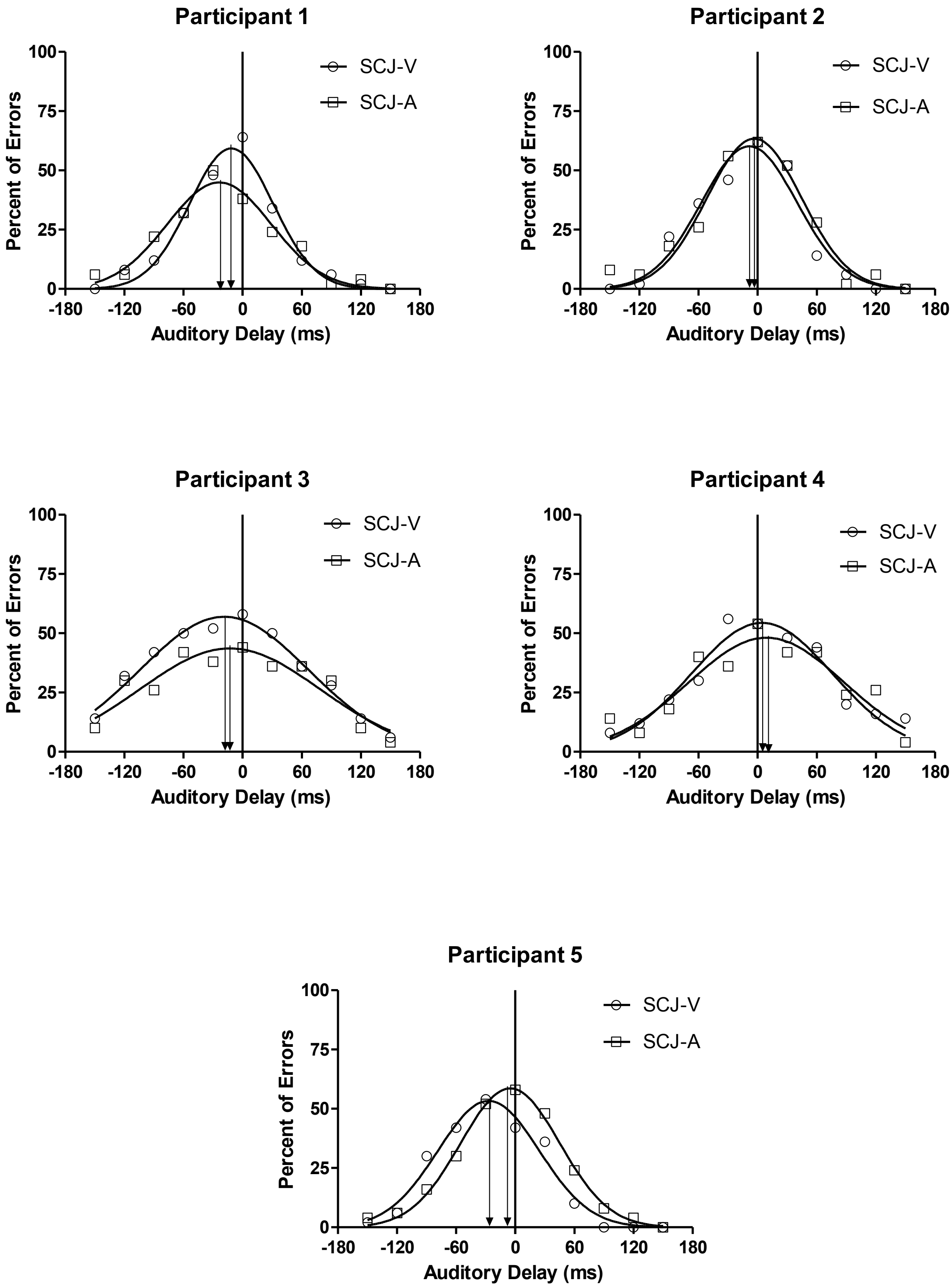

Figure 11. Raw data scores with fitted curves for all participants from Experiment 4. Scores represent the percentage of errors as a function of the auditory delay. SCJ_V = synchrony comparison judgment_visual, SCJ_A = synchrony comparison judgment_auditory. Vertical arrows indicate the SOA on the abscissa that represents the point of subjective simultaneity (PSS).

Table 7.
Mean PSS, AV and VA thresholds, and IOU for both conditions.

Method	PSS	AV	VA	IOU
SCJ-V	-12.2	-88.8	64.2	153.0
SCJ-A	-7.2	-80.0	68.2	148.2

Note. Means are reported in milliseconds. SCJ-V = synchrony comparison judgment-visual, SCJ-A = synchrony comparison judgment-auditory, PSS = point of subjective simultaneity, AV = audio-visual threshold, VA = visual-audio threshold, IOU = interval of uncertainty.

Discussion

Using the SCJ method, an audiovisual prior entry effect was not realized. The magnitude of the difference was only 5 ms. While the non-significant result indicates that there was no difference between the conditions, one might note that the difference was in the direction that would be predicted by the prior entry hypothesis. It might be speculated that the prior entry effect is an extremely small effect and that this same small 5 ms difference from a larger sample that provides more statistical power might then become statistically significant. If one accepts this possibility, then the result obtained here continues the trend of smaller estimates of an audio-visual prior entry effect seen with increasingly rigorous methodologies. Sternberg et al. (1971) obtained an audiovisual prior entry effect of 30 ms using the TOJ-RT paradigm, while Zampini et al. (2005) obtained an effect of 14 ms using an SJ task. Given that the method employed in this experiment is the most resistant to response bias, and thus, provides the most reliable estimation of the PSS, then this result is the most convincing evidence to date against the prior entry hypothesis (at least in terms of the magnitudes previously reported).

General Discussion

Review of Experiments 1 to 4

The purpose of this thesis was to evaluate the appropriateness of applying the synchrony comparison judgment (SCJ) method to the study of audio-visual synchrony perception, and then to apply this method to the study of audio-visual prior entry. The introduction to this thesis first defined the prior entry effect as a speed up of sensory processing of attended stimuli relative to unattended stimuli that can be inferred from differences in the perception of relative timing between attended and unattended stimuli, as indexed by the point of subjective simultaneity (PSS). Following this, the evolution of the methodology applied to the study of prior entry was outlined, with emphasis on the fact that conclusions about the existence or nature of the prior entry effect have been questioned for over 100 years due to criticisms of every method used to test the phenomenon. The four experiments in this investigation have succeeded in providing information concerning the value of the SCJ method relative to the synchrony judgment (SJ) and temporal order judgment (TOJ) methods, a major drawback of the TOJ method, the capacity of the SCJ method to make precise estimates of the PSS, and what the SCJ method says about the existence of audio-visual prior entry. In general, it can be argued that the SCJ method is a superior method for application to audio-visual synchrony perception investigations, and that the results from this method contradict the prior entry hypothesis.

Experiment 1 sought to put the parameter estimates from an SCJ task in context with those from SJ and TOJ tasks. It was believed that both the SCJ and SJ tasks were similarly resistant to any bias favouring one signal over the other compared to the TOJ task, thus, it was expected that the PSS estimates from these two tasks would show a greater degree of correspondence. The results confirmed that the estimates of the PSS from the SCJ task were more consistent with those from the SJ task compared to the TOJ task. A similar pattern of results to that of van Eijk et al. (2008) and Smeele (1994) was obtained. Specifically, the mean PSS for the TOJ task was again a negative value, suggesting the counter-intuitive finding that the optimal environmental configuration for audiovisual synchrony perception occurs when the sound precedes its visual counterpart.

As mentioned, many researchers have argued that the differences in PSS estimates between the two tasks arise from the fact that they require different kinds of processing (van Eijk et al., 2008; Shore et al., 2005; Zampini et al., 2003; Allan, 1975; Hirsh & Sherrick, 1961). In the discussion section to Experiment 1, it was suggested that if this were the case, then one still might expect to see a correlation between the PSS estimates between the two tasks, even if the mean estimates are different. This suggestion relies on the assumptions that the two types of processing would be based on the same initial neural input (i.e., the same signal from the sensory nerves) and that once the signals diverge towards their respective processing areas, the difference in processing would impose a relatively constant change in either delaying or advancing one of the stimuli relative to the other, compared to the other type of processing. Thus, to the degree that one accepts these assumptions, the lack of a consistent relationship between the PSSs estimated from the different tasks may be evidence that contradicts this differential processing hypothesis. Further, the fact that PSS estimates from the TOJ task seem almost equally likely to generate a negative as a positive mean PSS (van Eijk et al., 2008) – while the SJ task generates relatively consistent positive PSS estimates – also suggests that there is some other factor contributing to the lack of correlations between PSSs from the two tasks.

With Experiment 2, the purpose was to illuminate an alternative explanation for why TOJs seem to produce PSS estimates that favour an earlier onset of the sound. Primarily due to the unsolicited comments of participants in a pilot version of Experiment 1 and the unusual response patterns of several participants from Experiment 1, it was suggested that a bias to favour the visual signal in times of uncertainty would lead to the pattern of observed TOJ results. Thus, by purposefully implementing the "light first" bias, Experiment 2 was successful in providing a template for what we would expect from participants employing such a bias. The bias did indeed shift the PSSs in the predicted direction, and the precision, as represented by the IOU, was also reduced, as expected. Also, while the AV threshold remained stable, the VA threshold shifted considerably. While this latter change was not entirely consistent with the prediction from the hypothetical bias, it was consistent with the results of the three unusual participants from Experiment 1. This result is potentially explained by an observer who adjusts his attentional set such that he attempts to maximize his hits of auditory-preceding-visual trials, since hits of visual-preceding-auditory trials will occur both by their experience as such and by "light first" default responses.

The fact that there were no participants from Experiment 1 who produced results from the TOJ task that would indicate a "sound first" bias is consistent with the suggestion that the tendency of the TOJ task to produce mean negative PSS estimates is due to a bias towards the visual stimulus. However, it is interesting to note that a potential candidate for a bias towards the "sound first" response option can be found in the van Eijk et al (2008) study. The authors noted that there were only three instances of individual negative PSSs from either the SJ2 or the SJ3 task (compared to 11 from the TOJ), and that all three came from the same participant. For the stationary stimulus, this individual produced PSSs of -58 ms and -61 ms for the SJ2 and SJ3 tasks, respectively. However, in contrast to the mean result of the PSS from the TOJ task being more negative, this individual's PSS as estimated by the TOJ task was substantially more *positive*, falling at +28 ms. If one were to assume that the PSS estimate from the SJ2 task (and maybe the SJ3 task, more on this later) is reliable, then the estimate from the TOJ task seems unusual. However, if this individual applied a bias towards the "sound first" response option – or employed an attentional set that would maximize hits of light-preceding-auditory trials – then a PSS that shifts in the positive direction would be expected. If this individual also evidenced a reduction in his/her IOU (or an increase in precision as evidenced by some other measure) and a stable VA threshold but a shifting AV threshold (the opposite of the light first bias effect), then strong support would exist for the notion that this individual employed a bias in the TOJ task that skewed the parameter estimates. Taken together, the results from Experiments 1 and 2 highlight the potential hazard associated with using a TOJ task to estimate PSSs.

Experiment 3 acted as a preliminary validation of the SCJ method, prior to applying this method to a prior entry scenario. The two issues that were of interest in terms of the effectiveness of the SCJ method were its precision and the appropriateness of a physically synchronous standard stimulus. In regards to the issue of the physically synchronous standard, the results indicate that this stimulus is appropriate as long as the observer's PSS does not deviate from physical synchrony by an unusually large amount. However, an individual's PSS is often not known prior to testing (absent a preliminary procedure), thus, it is inevitable that participants of this nature will be tested. Fortunately, the results from Experiment 3 profile the response distribution that can be expected given a participant with a large natural offset. Given a 300 ms range of comparison stimuli equally balanced on either side of physical synchrony – as in Experiment 3 – participants with natural offsets as large as 116 ms will not be able to reach threshold performance on both ends of the SOA distribution. However, participants with offsets as large as 66 ms will still be able to obtain threshold performance within this range. Thus, with the largest PSS deviation from physical synchrony in being 38 ms, all of the participants from Experiment 1 were presented with an appropriate comparison stimulus. If, however, one were still uncomfortable with a standard stimulus that varies in terms of how close it is to an observer's PSS, preliminary procedures could be included that estimate the PSS of each participant. From this estimate, standard and comparison stimuli could be tailored to fit each individual participant.

Another reason that it can be asserted that the comparison stimulus is appropriate for those with a natural PSS offset is related to the task's sensitivity to alterations made to the SOAs of the standard and comparison stimuli. The conditions from Experiment 3 consisted of a typical SCJ situation as well as conditions in which constant advancements were added to either the visual or the auditory stimulus with the expectation that a sensitive testing measure would accurately reflect these advancements. The results reflected this expectation with the PSS estimates being accurately related to the applied advancements. Further, insofar as the PSS estimates from the SJ method are accurate, the correlation between the PSSs from the SCJ and the SJ task in Experiment 1 provides additional evidence towards the accuracy of the SCJ method.

Finally, after validating the SCJ method, Experiment 4 applied this method to a prior entry scenario. Participant's attention was manipulated through a combination of instructions and a secondary task. The difference between the mean PSS estimates from the "attend visual" and the "attend auditory" conditions was only 5 ms. Although the difference was in the direction predicted by the prior entry hypothesis, it was not statistically significant. Given the SCJ's resistance to first-order, second-order, and personal criterion biases, this estimate represents the most bias-free measure of prior entry to date.

Is the SCJ method really better than the TOJ and the SJ?

The answer to the question of whether the SCJ task is better than the standard TOJ task for studying audiovisual prior entry (or for studying anything for that matter) is an emphatic yes. The problems with the TOJ method have been documented by several researchers (e.g., Schneider and Bavelier, 2003; Spence, Shore & Klein, 2001; Frey, 1990) and were highlighted in Experiments 1 and 2. Just as van Eijk et al. (2008) noted in their review of studies of audiovisual synchrony, the TOJ method produced a mean estimate of the PSS that was more negative than that estimated by the SJ method. It has now also been demonstrated that the TOJ method produces PSS estimates that are more negative than that estimated by the SCJ method. Further, the observation that the response profile for participants who purposely (or potentially unwittingly for that matter) employ a bias for the visual signal matched the profile for several unusual sets of data from Experiment 1 provides evidence for the fact that the TOJ method inherently provides opportunity for such a response bias or other response strategies. Due to its higher-order orthogonality, the SCJ method is immune to such first-order response biases.

It can not be claimed as confidently that the SCJ task is better than the SJ task for studying audiovisual prior entry because the SJ task is equally resistant to first-order response biases, also due to its higher-order orthogonality. However, if precision is a parameter of interest, then this is where the superiority of the SCJ method comes to bear. As mentioned, the susceptibility of the SJ method to personal criterion and response frequency equalization biases means that estimates of the precision can be either over or underestimated. In contrast, the SCJ method does not invite personal criteria into the testing situation, as the participant makes a judgment about one stimulus relative to another, rather than an absolute judgment about one stimulus (or a dual stimulus ensemble).

In terms of the response frequency equalization bias, this is less of an issue for the SCJ task. With the SJ task, almost all of the stimuli presented to the participant will be asynchronous. That is, there is an imbalance in the number of synchronous to asynchronous stimuli, thus, attempting to equalize each response relies on an incorrect assumption by the participant that there are equivalent numbers of synchronous and asynchronous stimuli. Thus, employing this bias necessarily generates errors, which will have the effect of underestimating the precision of the task (unless the individual has such a wide window of simultaneity that almost all the stimuli actually seem synchronous, then response equalization will result in an overestimation of precision for this individual). In contrast, with the SCJ task employed in this study, a stimulus presentation configuration was implemented such that the synchronous standard had a 50-50 chance of being the first or the second stimulus pair presented. If a participant were to make this assumption, they would be correct, and there equalization would have an effect no different than if they chose the first pair or the second pair consistently. This, of course, relies on the assumption that observes are employing this bias in times of relative uncertainty, and are not actually making a response contrary to their experience simply for the sake of equalization. If this assumption is incorrect, then this equalization bias would also make estimates of the precision inaccurate, and it could not be claimed that the SCJ method is completely resistant to this particular bias.

It was also suggested in the general introduction that in addition to personal criteria affecting the precision of the judgment, it could also conceivably affect the estimation of the PSS. The reasoning for this possibility was based on the notion that an observer's personal criterion might not have the same effect on auditory-preceding-visual configurations, compared to visual-preceding-auditory configurations. Specifically, it was suggested that since we have experience with events at a distance that have the auditory element following the visual element while still seeing the two events as united, one could have more tolerance for deeming as synchronous visual signals that minimally precede their auditory counterparts compared to the opposite configuration. While one might label this suggestion as speculation, the results of the study by van Eijk et al. (2008) potentially provide support for this notion. Recall that van Eijk et al. made a within-subjects comparison of the TOJ task to an SJ2 task (the standard SJ task with "synchronous" and "asynchronous" options) and an SJ3 task ("light first", "synchronous", or "sound first"). The differences between the two SJ tasks are the matter of interest here. If, as is being suggested here, participants are more likely to deem an event in which the visual stimulus minimally precedes the auditory stimulus as synchronous compared to the opposite configuration, then when participants are no longer given the option to say "light first" or "sound first" and have to convert these responses to "synchronous" or "asynchronous" (i.e., the difference between the SJ3 and the SJ2), more "light first" responses will be converted to "synchronous" than "sound first" options. Thus, when the proportions of "synchronous" responses for the two tasks are plotted, one should see an equivalent number for the auditory-preceding-visual SOAs, but a greater number in the SJ2 task for the visual-preceding-auditory SOAs. That is, while all of the "sound first" responses from the SJ3 task should be converted to "asynchronous" responses for the SJ2 task, some of the "light first" responses will be converted to "synchronous". This is precisely the result that van Eijk et al (2008) obtained, for both the static and the moving visual stimuli. Since the proportion of "synchronous" responses will affect the location of the thresholds, then if this difference is significant, it will reveal itself in a statistical difference in the location of the VA threshold. This was indeed the case, as the VA threshold for the SJ3 task – collapsed across both static and moving stimuli – was closer to physical synchrony (+144 ms) than the threshold from the SJ2 task (+160 ms). Therefore, these results support the possibility that participant's personal criteria might apply differently to the two different stimulus orders.

Results demonstrating that more simultaneous responses are given on the visual-preceding-auditory side of synchrony are not confined to this particular study, but are the norm in most studies of audiovisual synchrony using an SJ task (Vroomen & Keetels, 2010; van Eijk et al., 2008). While it is generally assumed that this is due to the slower processing of visual stimuli relative to auditory stimuli (Vroomen & Keetels, 2010), it is also possible that a cognitive bias of greater forgiveness for late sounds could falsely lead to estimates of the PSS that favour an earlier onset of the sound. In other words, just as the TOJ task may result in estimates of the PSS that are too negative, the SJ task may result in estimates of the PSS that are too positive.

What about the O-TOJ and the SJ3?

The orthogonal TOJ was not tested in this study, thus, direct comparisons to the parameter estimates from the SCJ, SJ and TOJ tasks are not possible. Ideally, this method would be evaluated in the same type of within-subjects comparison that was performed here. However, if participants were to engage in the same type of first-order response bias that it appears some participants from Experiment 1 have, its effect on the response distribution would depend on which dimension was chosen to be plotted. For example, if the apparatus was set up like that of Spence et al. (2001) with two separate collocated stimulus sources, and participants were asked which side a stimulus appeared on first, then even if they defaulted to one side in times of uncertainty this would have no effect on the distribution of “light first” or “sound first” responses, assuming that the auditory and visual stimuli were randomly assigned to either side. However, if the distribution of “left side” or “right side” responses were plotted, then one would see the same unusual response patterns as displayed by the three participants from Experiment 1.

But with a prior entry scenario, the O-TOJ would certainly be able to eliminate first-order response biases. If one were interested in audiovisual prior entry, one would simply need to set up the Spence, Shore and Klein (2001) configuration, instruct (and/or use probability manipulation) the participants to attend to either the visual or the auditory signal, and have the participants respond as to which side appeared first. Just as in a divided attention scenario, as long as the visual and auditory stimuli occur randomly on each side, then favouring one side over the other will not affect the response distributions of “light first” or “sound first” judgments, and concomitantly, the PSS estimate. However, the possibility of second-order response biases still casts a shadow over this method. This would involve the participant choosing the side that had the modality to which they were instructed to attend in times of uncertainty. While it seems less likely that a participant would default to this more sophisticated bias compared to the first-order response bias, it is not so sophisticated that it should be discounted as unlikely. Further, while a second-order response bias by a naïve (to the prior entry hypothesis) participant might be deemed possible but unlikely, a person with knowledge of the prior entry hypothesis could easily manipulate their responses to purposely support or contradict the theory. Thus, using this method requires inquiring as to whether or not the participant has knowledge of the prior entry hypothesis. In addition, unless the participant completes his testing in a single session immediately following the inquiry, one can not be sure that he did not research the effect, and then adjust his responses to support or contradict what the researcher is expecting.

If, however, a technique for parsing a PSS shift into sensory and response bias components could be applied to the data, then the O-TOJ method could be included in the category of bias-resistant. As previously mentioned, Shore et al. (2001) have suggested a method for performing this component separation. However, it was also mentioned that this technique relies on the assumption that any response bias will be equivalent in a “which came first” task or a “which came second” task. Due to the fact that asking a participant “which came first” or “which came second” entails different demand characteristics, this assumption is difficult to accept. Thus, the potential for response bias hampers the confidence that one can have in results from the O-TOJ method.

Van Eijk et al. (2008) term the task that offers responses options of “light first”, “sound first” and “simultaneous” as an SJ task, the SJ3. This task has alternatively been characterized as a modified TOJ task (e.g., Stelmach and Hurdman, 1991; Jaskowski, 1993; Stone, 1926) or as a combination of the two tasks (Schneider and Bavelier, 2003). This modification serves the purpose of attempting to alleviate response bias in a TOJ task. This works by giving participants a response option that they can use when they can’t tell whether the visual or auditory stimulus came first, instead of defaulting to either the “light first” or “sound first” option. It could be argued that whether or not this task is more accurately considered an SJ task or a TOJ task is related to how a participant is instructed to make the judgment, or how the participant decides to make the judgment given instructions that don't specify how to make the judgment. Essentially, there are two ways a judgment could be made given this task. A participant could first try to decide if it was the light or the sound that came first, and if they can't tell, then respond that the presentation was simultaneous. Alternatively, they could first try and decide if it was synchronous or asynchronous, and if it seemed asynchronous, then try and decide if it was the light that came first or the sound. If one assumes that the perception of order is sufficient for the perception of simultaneity (Hirsh & Sherrick, 1961), then it makes sense to make the TOJ first, since this will be the only judgment required given that the simultaneous response will be the default response if the order judgment can not be made. On the other hand, if one first makes the simultaneous/successive judgment, then another judgment will be required if they appear successive. And according to the results of Hirsh and Sherrick (1961), they may not necessarily be able to make this judgment. Regardless of how a participant treats this task, it is still a task that allows for response bias, unless one can guarantee that they were successful in getting all participants to use the "simultaneous" option every time they were uncertain of the order. It has even been suggested by Schneider and Baveleir (2003) that adding a third response option actually compounds the problems of the TOJ in that the use of this option might vary among observers. Thus, as with the O-TOJ, response bias effects can not be ruled out with this method.

Limitations of the SCJ method

While it is the contention here that the SCJ method is superior to all methods previously used to study the prior entry phenomenon, there are still issues of concern with the method used in the present study. The first criticism that could be leveled towards the SCJ task is that the extra stimuli needed to be judged could place an undue amount of strain on the participants. Given the same number of trials in any of the other tasks, one would have to judge twice as many stimuli with the SCJ task. In addition, the discriminations that the observers are being asked to make are in many cases difficult, as the stimuli are presented in very close succession, including many trials in which the SOA is so small as to be beyond the resolution power of the average individual. Given that hundreds of trials are required, these testing sessions entail an extended period of effortful selective attention. Since maintaining this selectivity of attention is an integral part of a prior entry investigation, straining the observers beyond their capacity would be an unwanted side effect of the method. This issue is easily side-stepped by administering fewer trials per session to keep the session lengths similar to those used with other methods. In the end this will require a greater number of testing sessions and more total testing time, but if the reward is data that can be trusted to be bias free, then this trade-off does not seem unreasonable.

A second potential drawback of the SCJ method is related to the introduction of a memory component to the task. While in the other tasks participants are given a single dual-stimulus event to judge, with the SCJ task they have two of these events to judge, with a random flat distribution of between 1 and 1.5 seconds between events. Thus, participants must make a comparison between a dual-stimulus event that just occurred and one that occurred in the recent past. This should not be an issue in terms of the location of the PSS. Given that the synchronous standard was randomly either the first or the second pair presented, then any effects that the memory component may have on the judgment will affect all stimuli equally. In terms of the precision of the judgment, it is plausible that the memory component could have an effect on the judgment. This will depend on the degree to which the information about the synchrony of the first pair presented degrades over the course of 1.15 to 1.65 (the time between events plus the largest SOA used) seconds. If the information degrades substantially, then this will make the judgment more difficult and will decrease accuracy. However, given that Experiment 1 did not find a difference between the tasks in terms of precision, this does not seem to be an issue.

A third potential criticism might be related to the attentional allocation method. The method used in Experiment 4 was to apply a secondary task as a supplement to verbal instructions to attend to one modality. This included making judgments about whether the two visual stimuli were the same colour, or whether the two auditory stimuli were the same pitch prior to making the judgment about which was the synchronous pair. This method was similar to the method used by Cairney (1975) who also had participants make judgments about the pitch of the auditory stimulus (whether it was high or low), and judgments about the relative size of elements of the visual stimulus (whether the left or right line was longer). Spence et al. (2001) criticized this approach and suggested that it explained why Cairney did not obtain a prior entry effect. They suggested that because there were no verbal instructions to attend to one modality over the other, that participants could have determined that the TOJ task was the primary or more difficult task. Thus, they may have divided attention equally in order to maximize performance on this task. However, there is reason to believe that participants were indeed applying a significant amount of attention to the secondary task. Cairney (1975) also reported a measure of the sensitivity for the TOJ task exhibited by the participants (2 Arcsine $\sqrt{P[A]}$). He found that participants were significantly less precise on the TOJ task when they had to make the secondary judgment, compared to a baseline condition in which only the TOJ was required. This change in the precision suggests that attention was taken away from the TOJ task, and put onto the secondary task, which requires a favouring of one of the stimuli.

This criticism could also apply to the attentional allocation method utilized here. In one sense, the scenario from Experiment 4 is different from that of Cairney in that the secondary task was in addition to instructions which emphasized that the secondary task was an element introduced to encourage participants to selectively attend to that modality. Thus, participants were aware that selective attention was a key component of the experiment. In another sense however, the criticism still applies in that Experiment 4 provided no independent measure of *successful* attentional manipulation. While sensitivity measures are available for the task (IOU), no baseline condition was performed which would have provided a means for comparison.

It could also be argued that the secondary task was overly simple, thus, could have been performed from memory. That is, participants could have divided their attention between the two modalities and focused on the SCJ task, and then accessed the secondary judgment from memory. Again, a comparison to the Cairney study provides support for the notion that even simple tasks can demand enough attentional resources to affect the precision of the other task. As mentioned, judging whether the pitch of the auditory stimulus was high or low (1000 versus 1200 Hz) or judging whether the left or right line was longer (24 vs. 48 mm) resulted in decreased precision in the TOJ task, even though these tasks do not seem overly difficult. Further, making the tasks more difficult by using visual stimuli that are closer together in length (35 vs. 37 mm) or making the secondary judgment a speeded response did not reduce the precision further. That is, there were no differences in the precision for the TOJ task relative to the difficulty of the task. This suggests that even given a relatively simple task, participants were expending a large portion of their attentional resources on it. It might be argued that the secondary tasks from Experiment 4 were simpler than those of Cairney, and may not have demanded enough attentional resources to elicit a prior entry effect. Unfortunately, the lack of a control condition makes this potential contention difficult to confirm. However, this query could be accommodated by comparing the colour and pitch discrimination task applied in Experiment 4 to a more difficult version of the same task by making the stimuli more alike. For example, to make the visual discrimination task more difficult one could use two colours that are more alike than red and green, or further, by using different shades of the same colour. The auditory discrimination task could be made more difficult by closing the gap between the difference in pitches.

To put the issued of attentional allocation method into perspective, it is useful to recall how the study of prior entry began. The original observations that needed to be accounted for were the differences among observers in terms of their estimates of the stellar transit times of stars. In these situations, the observers were attending to both the visual stimulus of the star, and the auditory stimulus from a ticking clock, and it was hypothesized that differences in estimates were due to different observers putting varying proportions of their finite pool of attention on the two signals. In addition to these real-world observations were the laboratory observations of positive and negative errors in complication situations involving a rotating pointer and its perceived location at the time of a click. Again, the locus of attention was offered as the explanation, and the prior entry hypothesis was born. In the former situation, differential allocation of attention was assumed to originate as a characteristic behaviour of the observer. In other words, they put more attention on one signal compared to the other without external influence. In the latter situation, the selective attention was often purposeful, but was not aided by further endogenous or exogenous cues. The common factor is that in neither of these situations are extensive efforts put forward to differentially allocate attention. Rather, these situations more closely resemble the simple, reflexive selective attention one uses in day to day life. Thus, given that it is these types of observations that the law of prior entry was invoked to explain, then criticisms of the method of attentional allocation ignores the original explanatory intent of the law of prior entry.

Electrophysiological Evidence

In 1947, Kohler suggested that, "experienced order in time is always structurally identical with a functional order in the sequence of correlated brain processes," (p. 62). He likened the experience of temporal order to the experience of the spatial ordering of objects or the order of degrees of loudness. Thus, in general, Kohler was suggesting that there is a functional correspondence between that which we experience and physiological events in the brain. More specifically, Libet, Wright, Feinstein and Pearl (1979; Libet, 1981) have suggested that the brain likely uses a "timing signal" represented by the initial cerebral cortex response to a stimulus as a reference point for determining temporal order. While the contention that temporal order is necessarily represented temporally in the brain is not immune to debate (see Roache, 1999; Dennett, 1991; Mellor, 1981; Kohler, 1947), the components of scalp measured event related potentials (ERPs) provide convenient candidates for these potential timing referents. Under this assumption, then, studying the effects of selective attention on the latency of evoked potentials can provide direct evidence to the contention that attention speeds up sensory processing if the latency of ERPs that occur prior to conscious awareness are reduced as a result of this attention.

LaBerge (2000) has provided a non-modality specific account of the cortical effects of the expression of selective attention. The central notion of this framework is that the functional expression of selective attention lies in the relative amplification of neural activity in selected clusters of cortical columns, with the interaction of neurons within individual columns representing the codes that activate particular images, ideas, feelings or actions. While this relative amplification has been conceptualized as complete filtering of irrelevant signals (e.g., Broadbent, 1958), the attenuation of irrelevant signals (e.g., Treisman, 1960), or the enhancement of the target signal (LaBerge & Samuels, 1974), the net result of any of these viewpoints is an enhancement of the target signal relative to the irrelevant signal. The particular interest here that relates to the issue of prior entry is whether this amplification serves to simply enhance ERP signals – that is, make them larger/stronger, thus, improving their signal-to-noise ratio – or if the amplification also results in these ERPs occurring sooner compared to those generated by unattended signals. In other words, enhancement in terms of simple magnitude will support the notion that psychophysical results supporting the prior entry hypothesis may simply be due to response bias influenced by the increased saliency of the attended signal. On the other hand, an enhancement in terms of a decreased latency to occurrence would support the idea that choosing the attended signal more often is due to a genuine speed up in sensory processing.

While LaBerge refers to a general selective attention effect, reviews of the effects of selective attention tend to handle visual (e.g., Correa, Lupiáñez, Madrid & Tudela, 2005; Anllo-Vento, Schoenfeld & Hillyard, 2004; Luck, Woodman & Vogel, 2000) and auditory (e.g., Näätänen & Alho, 2004; Muller-Gass & Campbell, 2002) selective attention separately. In terms of visual selective attention, the general conclusion is that enhancement provided by spatial visual attention (i.e., the attention is focused on a point in space) is manifested in *enlarged* P1 (latency 80–130 ms) and/or N1 (150-200 ms) components of the visual ERP with little to no change in their peak latency. An earlier, positive peak, C1 (50-60 ms), is typically unaffected by attention. The N1 (80-100 ms) component associated with an auditory stimulus has also been found to be enlarged as a result of attention. Enlargements have also been reported in the 20-50 ms mid-latency range of components. According to Woldorff and Hillyard (1991) this enhancement, as well as the N1 enhancement, is due to a selective facilitation of the attended signal. However, according to Näätänen and his colleagues (e.g., Näätänen, Gaillard & Mäntysalo, 1978; Näätänen & Michie, 1979), this enhancement is not a direct facilitation of the attended signal. Rather, it is due to the summation of the original signal with a long lasting endogenous (i.e., voluntary attention) processing negativity (PN) that acts to select input for further processing. This explanation is consistent with the reciprocal attentional effects on positive mid-latency components P1 (50 ms) and P2 (175-200 ms). That is, the PN that causes the N1 to become larger also causes the P1 and P2 to become smaller (Muller-Gass & Campbell, 2002). Thus, while explanations for the cause of the enlarged N1 differ, just as with the visual ERP components, enlargement rather than earlier peak latency is the typical observation.

While the typical result is an enhancement of ERP component strength, modulation of peak latency due to selective attention has also been reported. Schuller and Rossion (2001) used ERPs to investigate the effect of an exogenous dynamic eye gaze cue on visual spatial attention. The authors noted that the typical space cuing paradigm utilized exogenous cues in the same location as the target (e.g., thickening of target area border), or endogenous cueing (e.g., verbal instruction; arrows), thus, they attempted to extend the findings to a socially relevant exogenous cue. The cue consisted of a real face that first had the eyes gazing forward in one frame, followed by another frame in which the eyes are moved such that the gaze is now towards either the left or right visual fields. The results indicated the typical attention related enhancement of the P1 and N1 components in terms of magnitude, but *also* in terms of latency. The P1 component peaked 5 ms earlier, while the N1 component peaked 16 ms earlier for attended stimuli. Two follow-up investigations confirmed these results. Schuller and Rossion (2004) performed the same experiment with a modification to the cue. Instead of being a dynamic cue in which the eye gaze moves from central to peripheral, the cue was now static with the left or right eye gaze existing from the beginning of cue presentation. The P1 and N1 components from the attended stimuli were larger and occurred earlier by 5 ms and 4 ms, respectively. Again using a dynamic eye gaze cue but dividing the visual field into four quadrants instead of just left and right, Schuller and Rossion (2005) again obtained earlier peak latencies for the P1 and N1 components of attended stimuli (no latency shift magnitude reported). It is not clear why this laboratory obtains results that are different from the norm, however, their use of the socially relevant eye gaze cue is the most obvious factor that differentiates this study from the others.

It is questionable as to whether or not the results of any of these attentional studies apply directly to the present investigation of prior entry due to deviations in methodology. Firstly, most of these studies are intramodal, while the present concern is with intermodal (audio-visual specifically) prior entry. Further, while intermodal attentional studies have also been performed (e.g., Eimer & Schröger, 1998; Hackley, Woldorff & Hillyard, 1990), the typical result of magnitude enhancement absent latency enhancement is reported. However, even the applicability of these studies is called into question given that the stimuli in intermodal studies are typically delivered from different spatial locations, thus, as with many previous prior entry studies, one can not be certain as to whether observers are attending to a particular modality or to a particular point in space (although see Karns & Knight, 2008, and Talsma and Kok, 2002, for intermodal studies with collocated stimuli). A further methodological deviation from the typical prior entry investigation is that many ERP studies – particularly auditory studies – tend to use trains of stimuli with the task being to identify and respond to deviant stimuli within this train (while ignoring another train). This is in contrast to the task of determining the temporal order of two stimuli, or whether or not two stimuli were synchronous or not. Thus, in order for ERP studies to provide more applicable data to the study of prior entry, these studies need to be designed such that they adhere to the methodological restrictions detailed in the general introduction.

Several ERP studies have been recently cited as more closely following the prior entry protocol, and thus, contributing more direct evidence to the study of prior entry in general (Spence & Parise, 2010; Shore & Spence, 2005). McDonald, Teder-Sälejärvi, Di Russo and Hillyard (2005) performed a visual prior entry study (i.e., attention was to a location in space) in which ERPs were recorded from participants making TOJs. They used a cross-modal cuing strategy – a sound to reflexively induce attention to one of two visual stimulus locations – thus avoiding the potential local sensory facilitation effect as described by Schneider and Bavelier (2003). They also arranged an orthogonal design by cuing attention to the left or right, but having participants respond as to which color appeared first, red or green. The behavioral results indicated that the stimulus from the uncued side had to be presented 68.5 ms prior to the stimulus from the cued side in order for the two to be perceived as maximally synchronous. This 68.5 ms prior entry effect was not reflected in the latencies of the visual ERP components. Latencies of the C1, P1, N1 and N2 components were not different for cued or uncued stimuli. However, the P2 did occur 5 ms earlier for the cued target. But the authors attributed this to an overlap of the P2 with another positive waveform, rather than a genuine speed up of sensory processing. The authors concluded that the contention that attention speeds up the sensory processing of stimuli was not supported. However, the authors also assumed that their orthogonal design had at least attenuated response bias, thus, the 68.5 shift in PSS was at least partly perceptual. They concluded that the enlarged positivity (80-140 ms) of ERPs from attended stimuli is interpreted as a timing difference by a comparator mechanism located further down the chain of processing.

While the McDonald et al. (2005) result is in direct conflict with the notion that attention to a location in space speeds up sensory processing, it could still be the case that attention to a modality results in a speed up sensory processing for signals in that modality. An intermodal ERP investigation that corresponded to previously executed prior entry methodology was performed by Vibell, Klinge, Zampini, Spence and Nobre (2007). The orthogonal visual-tactile TOJ arrangement utilized by Spence, Shore and Klein (2001) was implemented while ERPs were recorded. While judging which side a stimulus appeared on first following an endogenous cue (instructions plus probability manipulation) to attend to one modality over the other, a behavioural prior entry effect of 38 ms was obtained. In terms of the ERP, typical amplitude enhancements were seen with P1 and N1 components. However, as with Schuller and Rossion (2001, 2004, 2005), earlier peak latencies were also obtained. The latencies for the P1, N1 and N2 components were earlier for attended visual stimuli by 4, 3 and 4 ms, respectively. In addition to these components, the P300 was also found to have peaked earlier by 14ms. The authors concluded that although the shifts in the components were substantially smaller than the behavioural PSS shift, the results provided strong evidence that both modulations of signal strength and timing due to attention were responsible for the behavioural prior entry effect. They also suggested that the failure of McDonald et al. (2005) to detect the small latency effects seen with the P1, N1 and N2 components was potentially due to the fact that they used a lower sampling rate. In addition to noting that different mechanisms may underlie exogenous and endogenous attention, and that McDonald et al. manipulated attention on a trial-to-trial basis compared to their blocked design, they emphasized that the mechanisms underlying attention to space may be different than those underlying attention to a modality.

Spence and Parise (2010) describe a follow-up study by Vibell, Klinge, Zampini, Spence and Nobre (submitted for publication) that investigated whether the difference between their 2007 study and that of McDonald et al. could be attributed to the locus of attention (space versus modality). A similar visual-tactile O-TOJ design was implemented, however, this time attention was oriented to a side with participants reporting which modality occurred first. A behavioural prior entry effect was again obtained (28 ms), as were amplitude and latency effects with the N1, P2 and N2 components (no magnitudes reported; no information concerning the P300 reported). The P1 component showed an amplitude but not a latency effect. The authors concluded that this again provided evidence for a prior entry effect, but that the differences between this result and their previous study may reflect different mechanisms associated with endogenous attention to a location versus endogenous attention to a modality.

Certainly, further studies are required in order to provide clarity to the issue of why some selective attention studies report only ERP component magnitude enhancements, while a few recent studies report latency enhancements in addition to the magnitude enhancements. In terms of ERP investigations of prior entry and selective attention ERP studies in general, careful consideration needs to be applied to certain aspects of the methodology in order to determine if latency enhancements are confined to particular scenarios. For example, consideration needs to be given to whether one employs an endogenous cue such as a target area sensory event (peripheral cue) or a socially relevant eye-gaze (central cue), or an exogenous cue, such as instructions, secondary tasks, probability manipulations or some combination of techniques. The type of task (e.g., SCJ, SJ, TOJ, serial or parallel search) should also be taken into account, including whether or not this task presents a high enough load on the perceptual system needed to elicit the reported attentional effects (Luck, Woodman & Vogel, 2000). Related to the type of task is the type of attention elicited by this task and its associated goals. For example, LaBerge (2000) proposes the selective attention can manifest itself in three forms. These include simple selection (searching tasks where the goal is identification detection), preparation (preparatory attention to an object, attribute or spatial location with the goal of more effective response to the anticipated stimulus) and maintenance (sustained attention to an object or event with the goal being an ongoing “appreciative” processing of the event). Finally, one also needs to recognize whether the selective attention is intramodal versus intermodal.

Vibell et al. (2007) have asserted that their evidence of latency shifts of ERP components due to selective attention to a modality represents the strongest evidence to date in favour of the prior entry hypothesis. However, there are reasons to be cautious about this interpretation. Firstly, at present, the dominant finding in ERP studies of selective attention is that certain components of the attended stimulus are enhanced in terms of magnitude, while only a small number of studies report latency enhancements. Thus, the balance of evidence is currently weighted *against* the notion that selective attention leads to a speed up of sensory processing. It could be argued, however, that the one study that most closely applies to the problem of audio-visual prior entry is the Vibell et al. (2007) study, and that this study reports a latency enhancement. While the collocated visual-tactile design does represent a clear situation of intermodal (and not spatial) attention, as mentioned previously, it is not clear if results from one bimodal pairing can be generalized to all modality pairings.

The small size of the latency shifts further weakens the contention that the shifts seen in the ERP components underlie the psychophysical results. The 3-4 ms shifts seen in the visual P1, N1, and N2 components are far less than the behavioural visual-tactile prior entry effect of 38 ms (or the 133 ms visual-tactile prior entry effect reported by Spence, Shore & Klein, 2001). Of course, the 3-4 ms shifts only represents the shifts seen within the visual stimulus ERP components, and would need to be added to any ERP shifts from the auditory signal to make a fair comparison, since behavioural prior entry magnitudes represent the sum of the shifts between both modalities. Given this, however, the ERP shifts seen with attention to the tactile signal would need to be in the order of 30 ms or more for the behavioural and electrophysiological measures to match up. While Spence, Shore and Klein (2001) report that the shift due to attention to the tactile modality is more than double the shift due to attention to the visual modality, in the Vibell et al. (2007) study, it would need to be ten times the shift seen with the visual modality.

It could be the case that the effects of attention continue to summate after the P1, N1 and N2 components. This would explain the 14 ms shift seen with the P300, which could more favourably match up with the behavioural results, as any shift due to attention to the tactile stimulus would now only need to be about 24 ms. However, it is not clear at what point in the ERP one should expect a match between behavioural and electrophysiological results. Muller-Gass and Campbell (2002) comment that a P300 does not occur unless an observer has consciously detected the target, and its presence “can therefore be used as evidence that a subject was conscious of an external stimulus,” (p. 186). Thus, it can be said that the electrophysiological latency shift should be seen at least by this point. It could further be argued that the latency shift should be seen earlier in the ERP. Indeed, a case could be made for the notion that the relative timing of stimuli is determined at the same time as the relative position of objects. Given that many of the elements in the natural world are in motion, then if the brain were to make a judgment about the relative position of two objects, this will need to be in reference to a point in time, since the relative position will be different for moving objects from one moment to the next. According to Luck et al. (2000), location processing occurs very early in the visual system, thus, one might expect to see the effects well before the P300. While ERP investigations tend to work with stationary flashed visual stimuli, and while it does appear that the cognitive system handles the timing of moving versus stationary visual stimuli differently (Fouriezos et al., 2007), this does not presuppose that they are handled at different times. Of course, this suggestion is somewhat speculative, and belies a need for a more thorough analysis concerning when one should expect to see a latency shift, but this debate is beyond the scope of this paper.

To conclude, the contribution of electrophysiological evidence to the study of prior entry remains to be seen. Currently, the balance of studies conclude that selective attention to either a position in space or to a modality does not result in a speed up of sensory processing. However, a small number of studies do report latency enhancements, thus, further inquiry is warranted. Firstly, as mentioned, further studies with careful consideration of certain methodological factors need to be performed. Secondly, a thorough evaluation of when one should expect to see a latency shift also needs to be addressed.

Future Directions

While it is contended here that a further improvement has been made in the manner in which prior entry is measured, it would be naïve to conclude that the more than 100 year old debate has been resolved. Certainly, future work is required in order to accumulate convincing evidence related to the existence of a prior entry effect. In this sense, given the methodological advantages outlined in this thesis, further replications of prior entry studies utilizing the SCJ method need to be performed. While the conclusion of the present study is in conflict with the prior entry hypothesis, confidence in the contention that prior entry is an artifact of the testing methods previously used to measure the phenomenon would be increased by replications of the present result. Conversely, further prior entry studies that apply the SCJ method but which conflict with the present result may suggest that the elusiveness of the effect is related to some factor other than the method. However, while conflicting evidence from other methods has fueled the debate regarding the contribution of response bias, utilizing this method can rule out response bias as a confounding factor.

It would also be useful to evaluate the parameter estimates of the O-TOJ and SJ3 tasks relative to those of the SCJ task. In particular, this comparison could provide a valuable estimate of the degree of response bias inherent to the O-TOJ task. In addition, van Eijk et al. (2008) obtained mixed evidence regarding whether the SJ3 was more like an SJ2 or a TOJ, thus, further studies could shed light on this distinction.

It is possible that the prior entry effect is a phenomenon that only occurs under particular conditions. As was mentioned in the previous section on the contribution of electrophysiological evidence to the study of prior entry, careful consideration needs to given to certain factors which could define the circumstances in which a prior entry effect is more likely to be elicited. These included factors such as cue type, the type of task, the type of attention, and the particular modality pairing. For instance, it could be the case that the attentional set induced by a TOJ is the set needed to produce a prior entry effect. Since the magnitude of the effect as estimated by the TOJ or O-TOJ method is difficult to trust, this is a situation where the combination of behavioural and electrophysiological measures would be ideally complimentary. In fact, insofar as one can pinpoint the particular ERP component that should evidence a prior entry effect, this combination of measures could be used to estimate the bias inherent to the O-TOJ task. It could even be argued that if it could be reasoned which ERP component(s) is the one that indexes the conscious experience of a stimulus, then this evidence would serve as the strongest indicator of a prior entry effect.

A final suggestion for future audiovisual prior entry studies relates to the type of stimuli used. The visual stimulus in a typical prior entry study is a static flash from either a computer monitor or an LED. Visual stimuli that appear out of nowhere are certainly not ecologically valid. In a natural setting, visual stimuli simply do not materialize from nothing;

rather, they emerge, either from the periphery or from behind some other object. Thus, by using a static flash, one is potentially introducing a confound in that it is not clear if the visual system would handle such a stimulus in the same way it would handle an ecologically valid stimulus. Indeed, evidence that the timing of audiovisual stimuli is modulated by the factor of motion is presented by Fouriezos et al. (2007; and to a lesser extent by van Eijk et al., 2008). Using the SCJ task, they found that a static visual stimulus tended to result in PSSs that favoured an earlier onset of the auditory stimulus compared to a visual stimulus in motion. Thus, it seems that the relative timing of audiovisual stimuli is affected by whether the visual stimulus is in motion or not.

Static visual stimuli were introduced to the study of prior entry due to the suggestion that the results of complication experiments were due to localization effects of a circular apparatus that are the result of gravity working with and then against the occulomotor muscles (Geiger, 1902, as cited in Frey, 1990). Since we can now easily present visual stimuli that only move horizontally, this potential explanation is not an issue. Again, this would more closely approximate the original observations for which the prior entry hypothesis was formed.

Conclusion

As the methods for measuring the prior entry effect have become more rigorous, the magnitude of the effect has been shrinking. The increase in rigor can be said to consist of a steady elimination of opportunities for participants to employ a response bias. The analysis of this investigation points to the conclusion that the SCJ method is a superior method for measuring audiovisual synchrony perception due to its resistance to response bias. Since the debate over the existence of a prior entry effect largely centers on the contribution of response bias to observed prior entry effects, the SCJ method emerges as the paradigm of choice for assessing this issue. Thus, given the results of Experiment 4, it is concluded at this time that either the prior entry effect does not exist, or that it is an extremely modest effect. Replications of this finding using the SCJ task, and with careful consideration of certain methodological factors, would strengthen this conviction.

As a final point of consideration, Frey (1990) points out that in formulating his laws of attention, Titchner's intention was not to have the laws taken as dogma, rather, they represented "a challenge, an appeal to the bar of fact," (p.211). More specifically, he stated that each law should be regarded as "a general statement of the behaviour of conscious contents given in the state of attention," (p. 211). That is, Titchener never makes reference to a speed up of sensory processing, rather, he is only commenting on the *experience*, not the underlying processing, when he asserts that the "object of attention comes to consciousness more quickly than the objects that we are not attending to," (p. 251). Indeed the inference that he was suggesting a speed up of sensory processing seems less valid when one considers the formal (the previous quote is the law in "popular terms") statement of the law of prior entry, "The stimulus for which we are predisposed requires less time than a like stimulus, for which we are unprepared, to produce its full conscious effect," (p. 251). Asserting that an attended stimulus will reach its "full conscious effect" does not necessarily imply that it has priority access to consciousness. It could very simply imply that what we are attending to is more clear (its full conscious effect) than what we are not attending to, even though both enter consciousness at the same time. Thus, if Titchener's intent in formulating these laws of attention was to stir debate and encourage empirical exploration, it is safe to say, over 100 years later, that he was successful.

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Appendix A

Individually Estimated PSSs and IOUs for Each Participant of Experiment 1

Participant	SCJ		SJ		TOJ	
	PSS	IOU	PSS	IOU	PSS	IOU
1	27	239	-6	295	20	306
2	12	277	17	261	-27	280
3	-18	252	8	249	-96	224
4	-10	580	26	377	-150	173
5	24	438	17	420	-28	462
6	6	385	14	135	1	131
8	5	195	6	308	-54	290
9	-20	185	1	118	-29	131
10	16	568	37	307	-11	583
11	-9	211	-21	210	-31	292
12	3	211	-13	196	-2	273
13	6	267	20	234	18	268
14	-2	150	-20	141	-30	97
15	6	198	20	305	66	267
16	20	197	0	178	0	168
17	-45	338	-41	439	-124	145

Note. Values are reported in milliseconds. PSS = point of subjective synchrony, IOU = interval of uncertainty, SCJ = synchrony comparison judgment, SJ = synchrony judgment, TOJ = temporal order judgment.
Note. P7 did not reach criterion performance, thus, parameters could not be estimated.

Appendix B

Individually Estimated PSSs and IOUs for Each Participant of Experiment 2

Participant	SCJ		TOJ-DV		TOJ-DA	
	PSS	IOU	PSS	IOU	PSS	IOU
1	-9	113	-44	53	37	47
2	-8	132	-28	85	36	72
4	-6	191	-40	99	51	89
5	-2	178	-35	78	16	107

Note. Values are reported in milliseconds. PSS = point of subjective synchrony, IOU = interval of uncertainty, SCJ = synchrony comparison judgment, TOJ-DV = temporal order judgment-default visual, TOJ-DA = temporal order judgment-default auditory.
Note. P3 did not reach criterion performance, thus, parameters could not be estimated.

Appendix C

Individually Estimated PSSs and IOUs for Each Participant of Experiment 4.

Participant	SCJ-V		SCJ-A	
	PSS	IOU	PSS	IOU
1	-11	111	-24	103
2	-8	129	-3	131
3	-19	220	-13	193
4	4	179	9	182
5	-27	126	-5	132

Note. Values are reported in milliseconds. PSS = point of subjective synchrony, IOU = interval of uncertainty, SCJ-V = synchrony comparison judgment-attend visual, SCJ-A = synchrony comparison judgment-attend auditory.