Selective attention and the perception of visual-haptic asynchrony

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Abstract

This paper demonstrates that the perceived simultaneity of a visual-haptic stimulus pair is influenced by selective attention. The results provide an explanation for the individual differences in the perceived simultaneity, as found in a previous study.

1. Introduction

Multimodal information is of great advantage in the daily perception and manipulation of our environment compared to information obtain through a single sensory modality. Because of this, it is often desirable to use multimodal displays in man-machine interaction. To benefit from multimodal displays, users must be able to experience a coherent perception of the (virtual) environment by integrating input from multiple modalities. One perceptual attribute that provides an important basis for intersensory integration is temporal synchrony. Synchronisation is, however, a well-known problem in multimodal interfaces. Due to physical and technical constraints, such as computer processing time, interface signals are often delayed with respect to each other and/or the action of the user. Asynchronous feedback can seriously disrupt many aspects of virtual environment simulations, e.g. it impedes the completion time of manipulation tasks (Ferrell, 1966). Knowledge about temporal sensitivities of the human perceptual system is therefore essential in the design of man-machine interfaces.

This research focuses on the sensitivity of human observers to time delays between visual and haptic stimuli. In a previous study (Vogels, 2001) we measured how large the temporal delay between visual and haptic stimuli may be before participants start noticing that the stimuli are asynchronous. Participants moved a force-feedback joystick such that a graphical object on a monitor would hit a virtual wall. The collision of the object with the wall was felt through the joystick, which generated a counter force slightly before, after or at the moment of collision. The maximum visual-haptic delay that participants tolerated was on average 45 ms. The range in which stimuli were judged to be synchronous was centered around a visual delay of about 7 ms. However, this so called point of subjective simultaneity (PSS) was liable to individual differences.

It was suggested that one of the factors that might play a role in the variability of the PSS is the way in which participants divide their attention between the two modalities. Researchers have shown that manipulating the attention of the participant can influence the perception of simultaneity. The stimulus cued by the experimenter is usually perceived earlier. This effect has been shown for stimuli presented to the auditory and tactile modalities (Stone, 1926), stimuli presented within the auditory modality (Needham, 1936) and stimuli presented within the visual modality (e.g. Stelmach and Herdman, 1991). However, some studies failed to find an effect of attention (Cairney, 1975; Jaskowski, 1993) and claimed that the shift in the PSS was an effect of response bias rather than attention. Spence and Driver (1997) showed some appropriate methods for distinguishing attention from other confounding factors.

In this research the influence of attention to one modality on the perceived simultaneity of visual-haptic stimuli was studied. In order to assess whether participants were indeed directing their attention to the cued modality, we used a reaction time procedure. On each trial either a visual stimulus, a haptic stimulus or an asynchronous visual-haptic stimulus pair could be presented. When one stimulus was presented participants were required to make a discrimination response regarding the modality of the stimulus. When both stimuli were presented participants were required to make a temporal order judgement. Attention was manipulated on each trial by presenting a cue that predicted which modality would be presented or which modality would be presented first. To ascertain that a possible effect of cue on temporal order judgement was due to attention and not to a criterion shift, we tested whether participants reacted faster on validly cued trials than on invalid trials without being less accurate.

2. The experiment

This experiment investigated the influence of selective attention to one modality on the perception of visual-haptic asynchronies.

2.1. Participants

Participants were eight students, which were being paid for their participation. The mean age was 20 years. All participants were right handed.

2.2 Procedure

Participants were seated behind a computer screen and held a force-feedback joystick (SideWinder Force Feedback Pro) in their right hand. Participants were instructed to focus on a fixation cross on the middle of the screen. At the beginning of a trial an arrow was displayed for 2.0 s. After an empty time interval of 1.0 to 1.5 s a stimulus or stimulus pair was presented. The stimulus could be a black square of 20 pixels wide on the middle of the screen or a counter force of 5.5 N generated by the joystick. When both stimuli were presented they were separated by a delay that ranged from –240 ms to 240 ms. The delay was defined to be negative when the visual stimulus was delayed and positive when the haptic stimulus was delayed. Participants were asked to respond as soon as possible by pressing a key that corresponded to the modality that was presented or the modality that was presented first.

The arrow at the beginning of the trial predicted which modality would be presented or which modality would be presented first. An upward arrow pointing to the fixation cross corresponded to the visual modality and an arrow pointing to the right, where the joystick was located, corresponded to the haptic modality. Participants were instructed to direct their attention to the cued modality.

The experiment actually consisted of two types of trials: reaction time trials (RT) in which one stimulus was presented and temporal order trials (TOJ) in which two stimuli were presented. In the RT condition the two within-subjects factors were stimulus modality (visual or haptic) and cue validity (valid or invalid). There were 224 (70%) valid trials, where the stimulus modality was correctly predicted by the cue, and 96 (30%) invalid trials. Cue validity was the same for both modalities, which were presented equally often. In the TOJ condition the within-subjects factor was cue modality. There were 160 trials with a visual cue and 160 trials with a haptic cue. In each cue condition 16 different delays were presented, 10 times each.

Participants had a lot of practice before the experiment started. They also participated in a control experiment in which only 160 TOJ trials were presented without the cue. This experiment severed as a baseline for the perception of temporal order.

3. Results

We first analyse the RT data to determine whether participants were able to focus their attention to the cued modality. Trials on which an incorrect response occurred were discarded from the analysis. In addition, trials on which the RT differed more than 3 standard deviations from the mean RT were removed. These criteria removed less than 4% of the data. Mean RTs are shown in Table 1. We performed an ANOVA on the RT with stimulus modality and cue validity as within-subjects factors. There was a significant main effect of stimulus modality ($F_{1,7}$=11.47, p=0.012), with participants responding more rapidly to the haptic stimulus (*M*=361 ms) than to the visual stimulus (*M*=414 ms). The effect of cue validity was also significant ($F_{1,7}$=9.38, p=0.018), with participants responding more rapidly on validly cued trials (*M*=362 ms) than on invalid trials (*M*=413 ms). The interaction effect was not significant. When the data for each participant was analysed separately, two participants did not reveal an effect of validity. Therefore, these participants were not included in the following analysis

Table 1: Mean reaction time (in ms) and the standard error for the visual stimulus and the haptic stimulus.

	Cue validity			
	Valid		Invalid	
Target modality	Mean	SE	Mean	SE
Visual	391	52	437	36
Haptic	332	39	391	33

The TOJ data was plotted as in Figure 1 and fitted with a psychometric function to determine the offset of the curve, i.e. the delay at which the percentage ‘visual first’ and ‘haptic first’ are equal. This delay is called ‘point of subjective simultaneity’ (PSS). We performed an ANOVA on the PSS with cue modality as the within-subjects factor. The effect of cue modality was highly significant ($F_{1,5}$=47.7, p<0.001). The mean PSS was –59 ms for the visual cue and 52 ms for the haptic cue. We also compared the PSS values with those obtained in the control experiment. The mean PSS in the absence of a cue was 35 ms and differed significantly from the PSS with a visual cue ($F_{1,5}$=29.5, p<0.003) and with a haptic cue ($F_{1,5}$=35.4, p<0.002). The PSS values for each participant are shown in Figure 2.

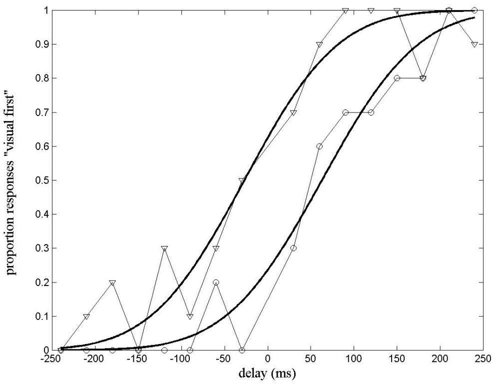

Figure 1: The TOJ data for one participant. The proportion responses “visual first” is plotted against the delay between the visual and haptic stimulus. The modality of the cue was visual (triangles) or haptic (circles). The data was fitted with a psychometric function (dark line).

4. Discussion

The results of this experiment clearly show that the perceived simultaneity of visual-haptic stimuli is influenced by selective attention. The PSS shifted towards visual delays when participants directed their attention to the visual stimulus and towards haptic delays when participants directed their attention to the haptic stimulus. This means that if the visual and haptic stimuli were presented simultaneously, participants would perceive the stimulus to which they were attending as occurring earlier.

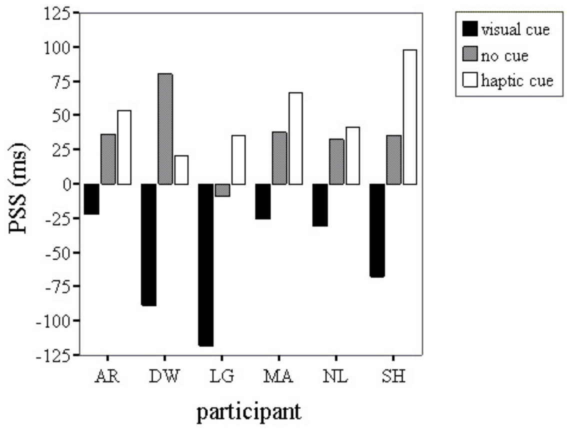

Figure 2: The PSS for each participant in the case of a visual cue (black), no cue (grey) or a haptic cue (white).

Because the visual and haptic stimuli were not presented at the same spatial location, it is impossible to determine whether the effect was due to spatial attention or to attention to one modality. The RT data, however, demonstrated that the shift in the PSS was really an effect of attention. If, for instance, participants had lowered their criterion for the cued modality, they would have made more erroneous responses on trial with an invalid cue.

The results provide an explanation for the individual differences in the perceived simultaneity, as found by Vogels (2001). When participants do not receive any instructions about their attention, they divide their attention between the two modalities in their own preferred way.

5. References

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