

Delayed Visual and Haptic Feedback in a Reciprocal Tapping Task

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Abstract

To make optimal use of distributed virtual environments (DVEs), we must understand and quantify the effects that latency has on user performance. Although the effects of visual lag have been subject to considerable investigation, far less is known about the consequences of delayed haptic feedback. The current study investigates whether delaying haptic, and/or visual feedback in a simple reciprocal tapping task impairs performance or makes the task appear more difficult to the user. Results indicate that in reciprocal tapping, haptic latency has a small effect on performance, but is considerably less disruptive than a lag in visual feedback, providing evidence that in simple operations, such as reaching out to touch surfaces, users of DVEs may be able to tolerate a considerable amount of lag.

1. Introduction

There is great interest in the use of distributed virtual environments (DVEs) and telerobotics for applications such as teleconferencing, training and the control of objects in space. Unfortunately, such environments are blighted by one major problem: information travelling a large distance over a network is inevitably subject to a significant amount of lag. In order to make optimal use of DVEs, it is important to understand and quantify the effect that this latency has on human performance.

There have been many studies investigating the effects of lag in visual feedback, and several that have had success in systematically quantifying its effects on performance [1][2][3]. A simple, yet extremely useful, study in this area examined the effects of lag in a Fitts' Law target acquisition experiment [1]. The experiment showed that the threshold at which visual lag started to affect performance was approximately 75 msec, and that movement times and error rates increase linearly with lag and task difficulty. Other models of performance deterioration according to visual lag that

have been proposed include an extension of the model described in [1] to account for 3D reaching movements [2], and an explanation of the effects of delay in a remote driving task in terms of working memory disruption [3].

In the field of haptics, however, there has been considerably less research. It has been reported that a lag in haptic feedback can be disruptive to the user [4][5][6] but so far no one has managed to produce a robust, quantitative model of the effects of haptic delay as [1] did for the effects of visual delay.

The current authors attempted to address this lack of systematic quantification with a target acquisition experiment analogous to the one used by [1], but with the addition of haptic feedback over the target area [7]. As haptic feedback had previously been shown to enhance performance in such a task [8], it was anticipated that delaying haptic feedback may disrupt performance, or that providing it in real time may mitigate the effects of visual latency (a result already produced in a telesurgery task [4]).

However, it was actually the case that delaying haptic feedback had no effect on either performance or the participant's perception of task difficulty, nor did keeping it in real time aid participants when visual feedback was delayed. The lack of an effect of haptic lag could be attributed to the fact that haptic feedback was not crucial to the task in question. Participants had to rely on visual feedback to see the position of the cursor in relation to the target, whilst haptic feedback merely provided another signal that the cursor had reached the target. Its inferior status was confirmed by a follow up study. The performance enhancement provided by haptic feedback that was originally found by [8] and replicated in [7] (where providing synchronized visual and haptic feedback led to slightly quicker movement times than providing visual feedback alone), declines as users gain more practice at performing the task [9].

Another simple task is examined in the current study: reciprocal tapping between two targets. In this case, haptic feedback is far more important to the user than it was in target acquisition, as it provides the primary indicator that he or she has hit the target – if

we know we should be able to touch a surface, we continue to reach towards it until we actually come into contact with it.

The current study sets out to assess whether delaying haptic feedback has any effect on movement times, error rates or the user's perception of task difficulty in a simple reciprocal tapping task, and to compare this with the effects of visual lag. As the motion that users must perform to accomplish the task could be viewed as analogous to performing an operation such as reaching towards a target, or pressing a button, the results from this experiment will provide an indication of how feasible it is to attempt such tasks in a DVE where lag is present.

2. Method

2.1. Design

The experiment used a 3 x 5 within-subjects factorial design. Factors were level of delay (0, 25, 50, 75, 150 msec on top of the system delay – see 2.2) and type of feedback that was delayed (visual delayed, haptic in real-time; haptic delayed, visual in real-time; both visual and haptic delayed).

2.2. Equipment

The study was run on a PC with an AMD Athlon XP 2100+ processor (1733MHz) and 512 MB RAM. A 23" Silicon Graphics monitor constituted the visual display. Force feedback was provided by an FCS Control Systems HapticMaster. The haptic response was handled by the haptic controller at 2.5KHz. The frame rate of 27 fps meant that the environment was updated on average every 37 msec. As the function to compute extra lag was inside this rendering loop, this formed the base level of delay in all conditions. The monitor's refresh rate of 76Hz introduced a further 7 msec of visual delay, making a mean system delay of 44 msec for visual feedback.

2.3. Participants

Three male and three female participants, aged between 23 and 29, took part in the study.



Fig 1. Experimental set-up

2.4. Stimuli

The environment used in the experiment consisted of two targets, 5cm in width, positioned 15cm apart (see Figure 2). Visual feedback was provided by an orange sphere which corresponded to the position of the HapticMaster end effector. The target area was haptically rendered to feel like a solid plane; thus touching the target with the end effector felt like hitting a hard surface.

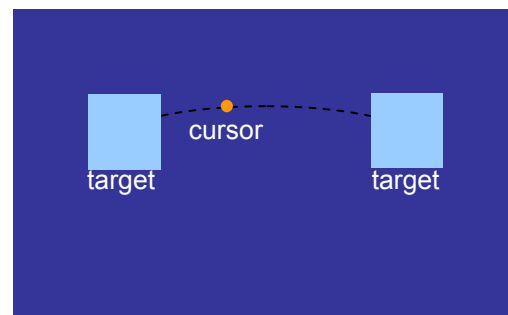


Fig. 2. The stimuli used in the experiment

2.5. Procedure

The participant placed the cursor on the left hand target and then tapped between the targets 30 times as quickly and accurately as possible. Each trial was timed, starting from the point at which the cursor first left the left hand target. Target misses were also recorded.

After completing a short practice session, participants completed a block of 15 trials, one for each combination of lag and feedback, ordered according to a Latin square. After a 15 minute break, participants completed a second block, with the trials in the reverse order.

2.6. Questionnaire

At the end of each trial, participants were asked to rate, on a scale of 1 to 5, how hard they found it to complete the trial, with 1 being very easy and 5 being very difficult. The practice session, in which no feedback was delayed, provided the baseline for their ratings.

3. Results

The results show that, as previously documented, delaying visual feedback seriously degrades performance. It is also the case that a lag in haptic feedback has an effect; however, this is far less pronounced than for visual latency. Analysis of the movement time, error rate and questionnaire data are presented below.

3.1. Movement times

The mean inter-tap interval scores (the time it takes to travel from one target to the other) for each condition can be seen in Figure 3. A repeated measures ANOVA reveals that as in [7], there are significant main effects for both lag ($F_{4,20} = 47.958, p < 0.001$) and type of feedback ($F_{2,10} = 17.514, p < 0.001$).

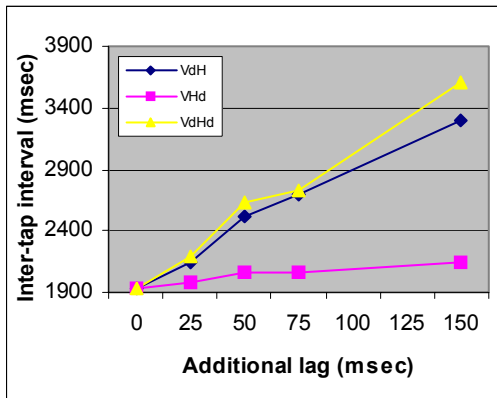


Fig. 3. Mean inter-tap interval as a function of lag. V_dH = visual delayed, haptic real-time; VH_d = visual real-time, haptic delayed; V_dH_d = haptic and visual both delayed

In the V_dH_d condition, pairwise comparisons showed that the main effect of lag ($F_{4,20} = 22.361, p < 0.001$) becomes significant at 69 msec (44 msec already in the system with the addition of 25 msec). In the V_dH condition, movement times are not significantly affected until 94 msec ($F_{4,20} = 31.284, p < 0.001$).

Aside from this initial variation, overall the V_dH and V_dH_d conditions do not differ significantly. There is however, as previously mentioned, a highly

significant difference between these conditions and the VH_d condition (where only haptic feedback is delayed). Although performance deterioration does increase with haptic lag ($F_{4,20} = 3.081, p < 0.05$), this does not take effect until the 187 msec level (37 msec delay already in the system, with an additional 150 msec), indicating that in this task, although haptic lag has an effect, it is far less disruptive to users than visual delay.

3.2. Error rate

The mean number of target misses that occurred in each condition are displayed in Figure 4. In the conditions where visual feedback was delayed, there was a main effect for the number of target misses, becoming significant when lag reached the 94 msec level ($F_{4,20} = 40.1, p < 0.001$). However, a lag in haptic feedback did not lead to an increase in the number of errors participants made.

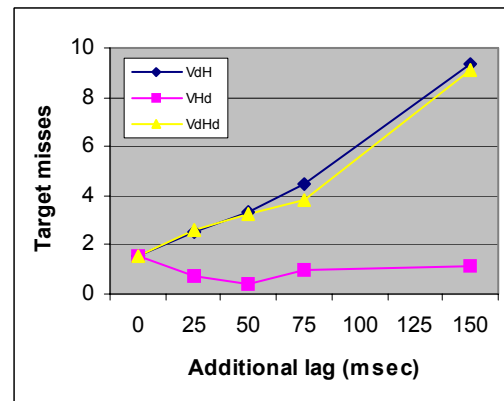


Fig. 4. Mean number of target misses as a function of lag.

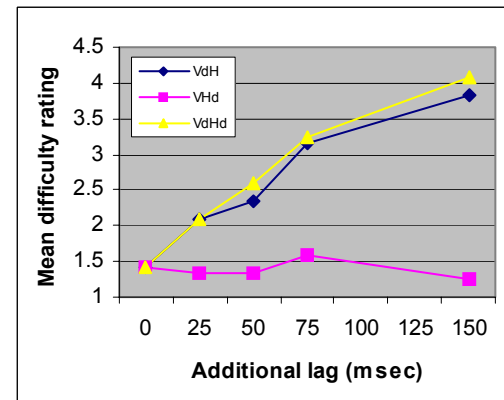


Fig. 5. Mean difficulty rating as a function of lag.

3.3. Questionnaire

The results of the questionnaire broadly reflect the movement time and error rate data (see Figure 5). Participants start to rate the task as significantly harder in the V_dH_d condition when lag reaches 94 msec ($F_{4,20} = 15.178$, $p < 0.001$), and in the V_dH condition when lag reaches 119 msec ($F_{4,20} = 12.528$, $p < 0.001$). In contrast to this, haptic lag has no effect on participants' perception of task difficulty.

4. Discussion

The study set out to determine whether a lag in haptic feedback caused performance in a reciprocal tapping task to deteriorate, and to compare this to the effects of a lag in visual feedback. The results indicate that delaying haptic feedback does make a difference, but only when the delay is considerable: whilst movement times are significantly slowed by a lag of just 69 msec in visual feedback, they do not increase in response to haptic latency until it approaches 200 msec. The increase in movement time also appears to be the only way in which haptic delay effects performance – participants were not more likely to miss the target as lag increased, nor did they find the task more difficult. Again, this contrasted strongly with the results of visual delay, which increased the number of mistakes participants made and their perception of task difficulty.

The consequences of this for DVEs are interesting. While haptic lag may cause great problems in more complex tasks [4], it appears that users may be able to tolerate considerable lag when performing simple operations such as button pressing or reaching out to touch surfaces. It is also the case that users are not disrupted by asynchrony between visual and haptic feedback (indeed, anecdotal evidence indicates that they do not detect it at all). This raises the possibility that if bandwidth is limited, more of it could be used for relaying crucial visual information, in the knowledge that the user will not notice, or be affected by, a delay in haptic feedback of less than 200 msec.

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