Effect of Touch Latency on Elementary vs. Bimanual Composite Tasks

Elie Cattan
University of Grenoble
LIG, UJF
Grenoble, France
elie.cattan@imag.fr

Amélie Rochet-Capellan
University of Grenoble
Gipsa-lab, CNRS
Grenoble, France
amelie.rochet-capellan@gipsa-lab.grenoble-inp.fr

François Bérard
University of Grenoble
LIG, Grenoble-INP
Grenoble, France
francois.berard@imag.fr

ABSTRACT

Touch latency has been shown to reduce users' performances but most studies focus on one-handed elementary tasks such as pointing or tracking a single object. The everyday use of touch devices is made, however, of more complex "composite" tasks combining several objects with potential bimanual interaction. Such a composite task may increase users' cognitive load which makes latency less perceivable [2]. We thus expected that the impact of latency on users' performances should be smaller in composite tasks than in elementary tasks.

We tested this hypothesis by comparing the degradation effect of latency on users' performances in an elementary vs. a composite task. The elementary task consisted in positioning a single object. The composite task involved sorting and positioning objects with a two-handed interaction, inducing more complex planning and motor strategies that could be seen as an additional cognitive load. Contrary to expectations, the degradation effect was comparable in the two tasks. This study indicates that the substantial hindrance of latency, demonstrated on elementary tasks, also exists in more complex tasks that better represent the every day use of touch devices. This strengthens the motivation to question the interaction between the task properties and latency effect and to adapt commercial devices and applications accordingly.

Author Keywords

latency; direct-touch; dragging task; composite task; bimanual interaction; target acquisition; user performances

ACM Classification Keywords

H.5.2 User Interfaces: Input devices and strategies (e.g., mouse, touchscreen)

INTRODUCTION

Touch latency, the delay between a user's action on a touchscreen and the corresponding feedback, has been proved to deteriorate users' performances, even at levels as low as 25ms [5, 10]. These results were obtained with target acquisition tasks, following the Fitts' law paradigm [6]. Target acquisition, as well as the tracking and steering studied in the mouse-latency literature, are elementary tasks: they involve the independent repetition of a single gesture. Elementary tasks are implicitly considered to be the building block of everyday interaction. However, out of the lab, interactions happen in complex contexts with multiple items and targets. When available, users also perform bimanual interactions, which supports some degree of parallelism and improves performance [11]. Everyday interactions can thus be seen as "composite tasks" in which the elementary tasks studied in the literature are interleaved with other higher level cognitive tasks, such as dealing with distractors [3], planning the order of execution of the subtasks, or allocating the dominant and non-dominant hand to the subtasks. All could be seen as an increase of cognitive load.

Recent studies have shown that, as the cognitive load of a task increases, participants' ability to perceive latency decreases [2]. In addition, if the non-dominant hand is engaged in accurate gestures, its motions are slower than those of the dominant hand [12], which also makes latency less perceivable. When less perceivable, the effect of latency on users' performances is expected to be milder. The main motivation of this work is to study how the strong negative effect of touch-latency, measured on simple laboratory tasks, applies to a more complex task that is similar to the tasks performed in everyday use. In particular, a weaker effect of latency on composite tasks could account for the widespread use of touch devices despite having high levels of latency, i.e. significantly higher than the latencies tested in the lab studies.

We studied the difference of the effect of touch-latency on users' performances between an elementary dragging task and a composite sorting task. The composite task is made of several dragging actions, similar to those of the elementary task, but performed with the two hands. We considered that it increases the cognitive load, compared with the elementary task, as it requires sorting decisions and planification in relation with the coordination of the two hands. We expected latency to have a smaller effect in the composite task than in the elementary task, but the results did not reveal any significant difference. We discuss the results in relation to possible

ISS 2016, November 6–9, 2016, Niagara Falls, ON, Canada.

ACM ISBN 978-1-4503-4248-3/16/11 ...$15.00.
http://dx.doi.org/10.1145/2992154.2992160

Figure 1. Display at the beginning of an elementary task (left) and at the beginning of a composite task (right). Users have to drag the disc objects located in the top half of the display within the targets located in the bottom side. The composite task is executed with the two index fingers and requires matching the color of objects and targets.

explanations and consider the general implication for touch interaction.

RELATED WORK

The effect of latency on users' performances in *mouse* interaction was studied using various elementary tasks such as pointing [7, 13], 2d tracking [17], 3d aiming [9] or steering [7]. All these studies reveal a clear negative impact of latency on users' performances. In the case of *touch* interaction, the effect of latency on users' performances was only investigated using Fitts' target acquisition tasks [6]. The degradation is demonstrated even at latency levels smaller than 25ms [5, 10]. The effect of latency on users' performances was always considered on elementary tasks, i.e. the repetition of a task requiring a single gesture, but not studied for more demanding tasks. In particular, the effect of latency was not studied in the case of two-handed multi-touch interaction on composite tasks.

System latency was also considered in more complex situations, but to evaluate users' ability to *perceive* latency rather than to measure the effect of latency on users' performances. Meehan et al. studied the effect of latency on the feeling of immersion in stressful virtual environments; they found that immersion was better at 50ms of latency than at 90ms [14]. Anderson et al. asked users to rate the usability of various desktop applications at different levels of latency [1]. Usability was rated low at high levels of latency, but with a clear effect only over 280ms, a latency higher than those of current commercial devices. Annett et al. used drawing and writing tasks to show that the ability to perceive system latency decreases with an increase of task complexity [2]. The perception threshold jumps from 6ms for dragging a square with a pen [15] to 61ms when drawing a star [2]. These studies indicate that, when performing a task with a high cognitive cost, the threshold of *latency perception* is higher than when performing a simple task. As latency becomes less perceivable, we expect users' performances to be less affected.

In our *composite* experimental task, one way to increase participant's cognitive load is the requirement for bimanual interaction. Kabbash et al. demonstrated that the use of two hands could improve performances for direct manipulation tasks [11]. However, the addition of a second hand does not simply double users' performances. Two-handed interaction engages a complex behavior where the partition of the work performed by the dominant and non-dominant hand is not symmetric [8, 12]. In a bimanual sorting task, attention, decision making and fine motor control has to be phased with the coordination of the two hands. Together with the slower motion of the non-dominant hand, this should increase the threshold of latency perception.

USER STUDY

The main objective of this experiment is to examine if and how the strong negative effect of latency on users' performances, previously measured on elementary tasks, applies to more demanding composite tasks. An "in the wild" study would provide a faithful depiction of everyday use. However, "in the wild" studies are not well suited for an accurate measurement of users' performances variations, which is best performed with repeated measurement of a controlled task. We thus designed a laboratory study, which included an elementary task and a composite task. Our rational was that the composite task, even if not an actual everyday use of the system, is more similar to everyday use than the elementary task.

For the elementary task, we use the dragging of an object to a target. For comparison purposes, we chose the composite task to be very similar to the elementary task in term of movements trajectory and indices of difficulty. However, in the composite task users are presented with *a set* of objects instead of a single object, and they must drag each object in a bimanual interaction to one of two targets depending on their color. Examples of the graphical display in the elementary and composite tasks are shown in Figure 1.

Compared to the elementary task, the composite task adds a simple sorting subtask (objects go to targets of matching color), a planning subtask (participants optimize the sequence of drags of the objects), the planning of hand allocation to objects and the motor coordination of the two hands in a two-handed interaction. The composite task is designed explicitly to impose more cognitive load on the subjects. It is an "orthogonal assemblage" [11] where each hand executes independent subtasks which could "impose a considerable cognitive load on subjects" [11]. Parallelizing actions also adds a lot of visual diversion: users visual focus constantly switches between the two hands, which can also affect the cognitive load [11] and reduce the attentional ressources available to perceive latency.

As a first step, we test both tasks in a low vs high latency design. We selected two latency levels: 25ms is the lowest achievable latency of our system, and 100ms is a relatively high level where a clear effect of latency should appear, at least on the elementary task [5, 10]. By choosing two values that are clearly apart (a 300% increase from low to high latency), we expect to enhance the difference between the tasks and make a potential effect clearly visible. We test both the elementary and composite tasks at 25ms and 100ms, and we assess users' performances degradation in both cases.

Apparatus

Current commercial touch devices exhibit latency in the order of 80ms or more. Custom made low-latency devices are thus used to experiment with low levels of latency [2, 5, 16]. Following Cattan et al. [5], we use optical tracking to reproduce a system with 25ms of baseline latency. A 24 inches screen is set horizontally on the desk and touch is simulated with optical tracking. Five cameras track the position of markers taped on participants' index fingers. We use custom developed C++ software for rendering. In addition to the 25ms baseline latency of the system, idle time is used in the event queue to simulate a 100ms latency system. Latency levels are regularly controlled using a predictive method [4].

Design

The main factor of the experiment is TASK_TYPE, which has two conditions: *elementary* and *composite*. In both conditions participants have to drag disc *objects* (radius 1.78cm) into disc *targets* (radius 2.20cm) of the same color. Each time an object is released, i.e. participant lift their finger from the surface, a feedback is given: the color of the target flashes for 0.1s to green (resp. red) if the drag succeeds (resp. fails). A drag is successful if the object is released when entirely within the target's boundary. Participants are asked to execute the tasks "as fast as possible while attempting to avoid failures". Pauses are offered regularly to avoid fatigue effects. During pauses, a turtle or a rabbit is displayed to announce whether the next block will be with low or high latency. This warning reduces the surprise effect of a change of latency and avoid outliers at the beginning of a block. Participants choose when to end the pause by touching a button in the elementary task, or two buttons in the composite task. The buttons are displayed at the targets' locations to ensure that the participants' fingers are at the same position at the beginning of each trial.

In the elementary condition a blue target is displayed at a fixed position at the bottom center of the screen. Blue disc objects appear sequentially at pseudo-random locations in the upper half of the screen. A *trial* consists of dragging the object on top of the target with the index of the dominant hand and lifting the finger from the display. As soon as the object is released and the feedback provided, a new disc appear for the next trial. Trials are grouped by *blocks* of 40, each trial having a unique initial position of the object (Fitts' indexes of difficulty range from 5.08 to 6.19). Blocks of 40 trials are presented first with low latency, then with high latency. This sequence is repeated five times for a total of 400 dragging actions: [40 (drags) x 2 (latencies)] x 5 (repetitions). Hence, latency conditions were interleaved, always starting with the smallest latency as it allows training with the task in "natural condition". Interleaving blocks is then a way to control for order effect as in this design, low latency occurs 5 times before and 4 times after the high latency and conversely. The initial positions of the objects are also randomized within each block to avoid sequence learning. A pause is offered between each block.

For the composite condition, two targets, one purple, one blue, are displayed 7cm apart in the bottom half of the screen. At the beginning of each trial, 10 disc objects, 5 purple and 5 blue, appear simultaneously in the upper half of the screen. A trial consists of dragging the 10 objects to the appropriate target. The index fingers of the two hands are used. A trial ends when the 10 objects have been moved and released. There are 4 different starting sets of 10 objects, which, grouped together, include the 40 object-to-target relative positions used in the elementary task. The four sets are presented first with low latency, then with high latency. This sequence is repeated five times for a total of 400 dragging actions: [10 (drags) x 4 (sets) x 2 (latencies)] x 5 (repetitions). Hence, latency conditions were interleaved as in the elementary condition. A pause is provided between each trial to ensure that participants' hands go back to the initial position before the next trial.

In a within subject design, 12 participants (3 females) executed both conditions of TASK_TYPE in *two parts* of the experiment. They were all right handed with an average age of 28.3 years old (range [24..38]). In the first part, half of the participants started with the elementary task and the other half with the composite task.

Measurements

Our goal is to assess the *impact of latency* depending on TASK_TYPE. This requires a delicate choice of the measured variable as different tasks inherently yield different durations: if the same duration increase, expressed in seconds, is observed for a long vs. a short task, then it denotes a latency impact that is actually stronger for the short task than for the long task. In order to compare the latency impact across tasks of various durations, we have to measure the *relative* increase of *dragging time*, in percentage, from the low to the high levels of latency.

For the *error*, measuring the increase of failed targets as an absolute value or as a percentage of the total number of target is similar since the number of targets to acquire in each "latency x task type" condition is the same (200 targets). Hence, we measure the impact of latency on *error* as an absolute difference between the two latency conditions that we can compare across TASK_TYPEs.

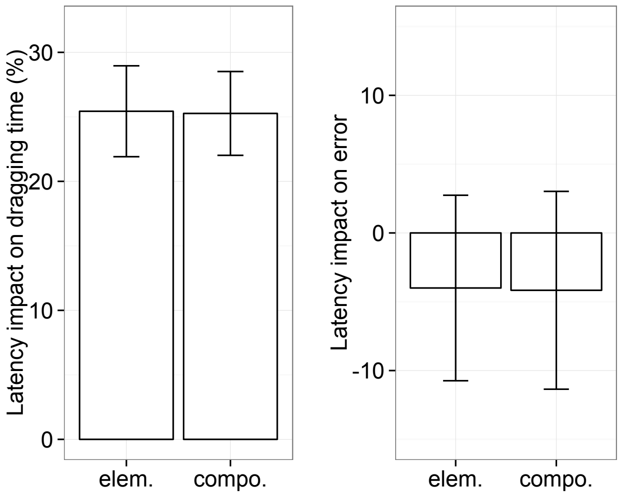

Figure 2. Effect of the task type (elementary vs. composite) on the latency impact on dragging time (left) and errors (right).

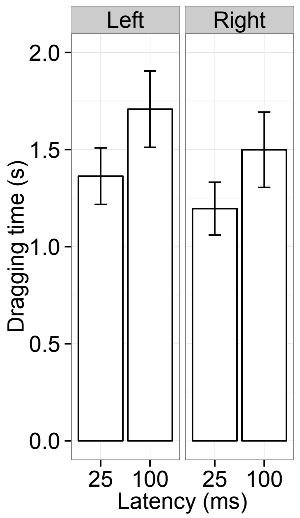

Figure 3. Effect of HAND and LATENCY on the dragging time during the composite task.

	time_impact (%)		*error_impact*	
	elem.	compo.	elem.	compo.
average	25.4	25.3	-4.0	-4.2
min	21.1	16.0	-21	-25
max	40.8	34.9	13	13
stddev	5.54	5.11	10.6	11.3

Table 1. Values measured on the dependent variables depending on the task type (elementary vs. composite).

We thus record two dependent variables:

- the latency *time_impact* on dragging time: the *relative* increase of the average *dragging time* when latency increases from 25ms to 100ms, measured as a percentage.
- the latency *error_impact*: the increase of the number of failed targets when latency increases from 25ms to 100ms.

The expected effects of TASK_TYPE and LATENCY on *dragging time* and *error* were verified with a repeated measure ANOVA. The effect of TASK_TYPE on the two dependent variables was then tested with paired sample t-tests.

Results

As expected, the average dragging time (for a unique dragging action) was higher in the composite condition than in the elementary condition (1.44s. vs 0.94s, $F_{1,11} = 169, p < 1e-07$). This would indicate a greater cognitive demand of the composite condition. There is also a clear effect of LATENCY on the *dragging time* ($F_{1,11} = 255, p < 1e-08$). In the elementary condition, the average *time_impact* across participants was 25.4%. This is consistent with results from the literature [5, 10]. The time_impact in the composite condition was very similar at 25.3%. The difference was not found significant with a paired sample t-test ($t(11) = 0.097, p = .92$).

The number of errors was significantly higher in the composite condition than in the elementary condition (25.6 errors vs 20.9 erros, $F_{1,11} = 5.4, p = .04$), but there was no significant effect of LATENCY ($F_{1,11} = 2.0, p > .18$). In the elementary condition, the average number of failed targets per participant decreased by 4 from 22.9 to 18.9 with the latency increase. In the composite condition, the decrease was 4.2 from 27.7 to 23.5. Less errors at higher levels of latency may be explained by participants being more cautious when they feel that the system does not respond as they expect. The difference between the elementary and the composite task was not found significant with a paired sample t-test ($t(11) = 0.07, p = .95$).

In summary, TASK_TYPE was found to have an effect neither on *time_impact* nor on *error_impact*. An absence of effect can not be statistically proved, but a significant effect with more participants or longer sessions seems unlikely with p-values above 0.9. In any cases, these results indicate that even if a significant difference of the impact of latency could be observed, the impact would still be very similar accross TASK_TYPE.

The results of the influence of TASK_TYPE on the dependent variables is reported in Table 1 and illustrated on Figure 2.

DISCUSSION

Latency has been shown to significantly reduce users' performances, but only in the case of elementary tasks and single-handed interaction. In addition, recent research efforts have demonstrated that users are less capable of perceiving latency as the cognitive demand of the task increases [2]. In this study, we worked on the assumption that when users' perception of latency is reduced, then their performances should be less affected. We attempted to observe such a reduction of latency's influence, but the results don't support this assumption. The higher average dragging time in the composite condition is a sign of a higher cognitive demand compared to the elementary condition. However, latency has a very similar influence in both conditions: a 25.4% vs 25.3% increase of dragging times when going from 25ms to 100ms.

We investigated how the non-dominant hand could have influenced the results. Focusing on the composite task, we performed a repeated measure ANOVA to study how the factors HAND and LATENCY influenced the object dragging time. As all our participants are right-handed, we use the levels *left* and *right* for the non-dominant and dominant hands, respectively. The main effect of HAND supports what is expected: as our dragging task requires a good amount of precision, the dragging time is significantly higher for the left hand (1.54s.) than for the right hand (1.35s.) ($F_{1,11} = 10, p = .009$). More interestingly, latency clearly makes both hands' dragging time increase ($F_{1,11} = 142, p < 1e-06$) but there is no evidence of an interaction between HAND and LATENCY ($F_{1,11} = 1.3, p > 0.25$): the effect of latency on performances appears to be as strong on the left hand as on the right hand. Focusing back to our main result, the introduction of the non-dominant hand cannot explain the stronger than expected influence of latency in the composite task.

We also interviewed participants at the end of the experiment to get their subjective impression. We asked them to rate four sentences on a Likert scale from 1 (strongly disagree) to 5 (strongly agree). Participants "clearly noticed the difference between the two delay conditions" in both tasks, but they better perceived latency in the elementary task ($M = 4.83, SD = 0.39$) compared to the composite task ($M = 4.5, SD = 0.52$), $t(11) = 2.35, p = .039$. This is consistent with the results from Annett et al. on latency perception [2]: with a greater cognitive load, latency is less perceived. Participants felt that "the delay strongly impacted their performances" on the elementary task ($M = 4.5, SD = 0.80$) and on the composite task ($M = 4, SD = 1.0$), but the difference is not significant ($t(11) = 1.11, p = 0.29$). The subjective questionnaire is consistent with the quantitative results: even if latency is less perceivable in the composite task than in the elementary task, there is no clear agreement on a weaker effect on performance in the composite task.

This study, revealing the unexpected strong effect of latency on demanding tasks, opens the way to further fundamental research that should question the detrimental mechanisms of latency. In particular, we need to understand how latency can keep the same influence on users' performances when its perception by users is reduced. This will require further investigations, such as a fine analysis of finger trajectories with feedback (delayed or not) and no feedback at all.

In term of touch system design, our experiment emphasizes the crucial importance of low latency even in an every day use context. It reveals that the negative influence of latency on users' performances, previously exposed on elementary tasks, might generalize to a broader range of tasks, in particular tasks that resemble the every day use of touch surfaces. Hence, efforts to improve touch detection in hardware [16] or software [5] should be pursued, as any improvement should have immediate benefits for the users. More user studies are also required to understand the interaction between the latency of the system and the properties of the task. This could open new alternative for task-specific design.

CONCLUSION

In this paper, we compared the effect of a touch-system's latency on an elementary dragging task and a bimanual composite task more similar to the everyday use of touch devices. We expected that the more demanding composite task would reduce participants' ability to perceive latency and thus limit latency's influence on participants' performances. We observed, however, that the latency's negative influence on performance, shown in many previous studies, was similar in the more demanding composite task. Regarding the everyday use of touch surfaces, we contemplated the idea that a smaller effect of latency on composite tasks could account for the success of touch devices despite their high levels of latency. Rather, our study indicates that the reason of the success may lie elsewhere. This study opens the way to further reasearch questionning the detrimental mechanisms of latency and its interaction with task properties. In addition, it reinforces the expectation of a clearly noticeable benefit of latency reduction in commercial touch devices.

ACKNOWLEDGMENTS

This work has been partially supported by the LabEx PERSYVAL-Lab (ANR-11-LABX-0025-01).

REFERENCES

1. Anderson, G., Doherty, R., and Ganapathy, S. User perception of touch screen latency. In *International Conference of Design, User Experience, and Usability*, Springer (2011), 195–202.
2. Annett, M., Ng, A., Dietz, P., Bischof, W. F., and Gupta, A. How low should we go?: Understanding the perception of latency while inking. In *Proceedings of Graphics Interface (GI)* (2014).
3. Blanch, R., and Ortega, M. Benchmarking pointing techniques with distractors: adding a density factor to fitts' pointing paradigm. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM (2011), 1629–1638.
4. Cattan, E., Rochet-Capellan, A., and Bérard, F. A predictive approach for an end-to-end touch-latency measurement. In *Proceedings of the 2015 International Conference on Interactive Tabletops & Surfaces*, ACM (2015), 215–218.
5. Cattan, E., Rochet-Capellan, A., Perrier, P., and Bérard, F. Reducing latency with a continuous prediction: Effects on users' performance in direct-touch target acquisitions. In *Proceedings of the 2015 International Conference on Interactive Tabletops & Surfaces*, ACM (2015), 205–214.
6. Fitts, P. M. The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology 47*, 6 (1954), 381–391.
7. Friston, S., Karlstrom, P., and Steed, A. The effects of low latency on pointing and steering tasks.

8. Guiard, Y. Asymmetric division of labor in human skilled bimanual action: The kinematic chain as a model. *Journal of motor behavior 19*, 4 (1987), 486–517.
9. Ivkovic, Z., Stavness, I., Gutwin, C., and Sutcliffe, S. Quantifying and mitigating the negative effects of local latencies on aiming in 3d shooter games. In *Proceedings of ACM CHI* (2015).
10. Jota, R., Ng, A. N., Dietz, P., and Wigdor, D. How fast is fast enough? a study of the effects of latency in direct-touch pointing tasks. In *ACM CHI*, ACM (2013).
11. Kabbash, P., Buxton, W., and Sellen, A. Two-handed input in a compound task. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM (1994), 417–423.
12. Kabbash, P., MacKenzie, I. S., and Buxton, W. Human performance using computer input devices in the preferred and non-preferred hands. In *Proceedings of the INTERACT'93 and CHI'93 Conference on Human Factors in Computing Systems*, ACM (1993), 474–481.
13. MacKenzie, I. S., and Ware, C. Lag as a determinant of human performance in interactive systems. In *Proceedings of ACM CHI* (1993), 488–493.
14. Meehan, M., Razzaque, S., Whitton, M. C., and Brooks Jr, F. P. Effect of latency on presence in stressful virtual environments. In *Virtual Reality, 2003. Proceedings. IEEE*, IEEE (2003), 141–148.
15. Ng, A., Annett, M., Dietz, P., Gupta, A., and Bischof, W. F. In the blink of an eye: Investigating latency perception during stylus interaction. In *ACM CHI*, ACM (2014), 1103–1112.
16. Ng, A., Lepinski, J., Wigdor, D., Sanders, S., and Dietz, P. Designing for low-latency direct-touch input. In *Proceedings of ACM UIST*, ACM (2012), 453–464.
17. Pavlovych, A., and Gutwin, C. Assessing target acquisition and tracking performance for complex moving targets in the presence of latency and jitter. In *Proceedings of the 2012 Graphics Interace Conference*, Canadian Information Processing Society (2012), 109–116.