Effects of Computer Mouse Lift-off Distance Settings in Mouse Lifting Action

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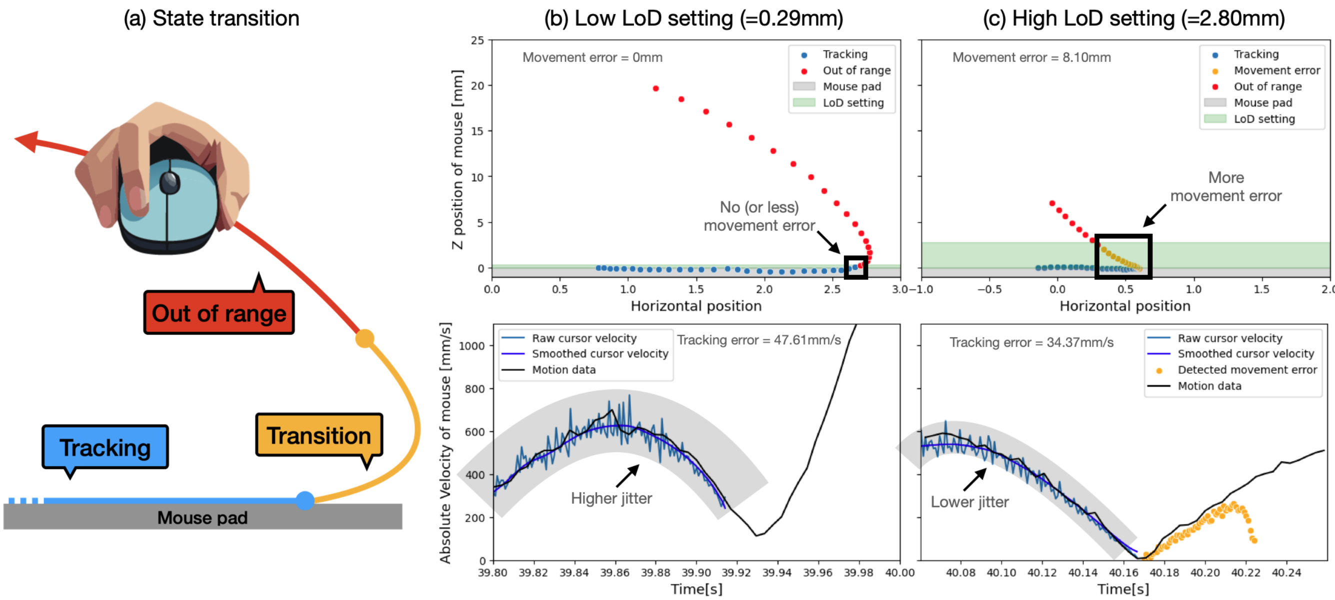

Figure 1: (a) State transition from tracking to out-of-range. (b) When the LoD setting is low, the unintended movement error was not detected (upper) while high jitter detected from raw cursor (lower). (c) When the LoD setting is high, the unintended movement error detected during state transition (upper). In contrast, the jitter get low compared to low LoD setting (lower).

ABSTRACT

This study investigates the effect of Lift-off Distance (LoD) on a computer mouse, which refers to the height at which a mouse sensor stops tracking. Although a low LoD is generally preferred to avoid unintended cursor movement in mouse lifting (=clutching), especially in first-person shooter games, it may increase tracking errors. We conducted a psychophysical experiment to measure the perceptible differences between different LoD settings, and we quantitatively measured unintended cursor movement and tracking errors at four levels of LoD while users performed mouse lifting. The results quantified the amount of the two types of errors, which revealed the trade-off between them in the varying levels of LoD. Our findings offer valuable information on optimal LoD settings, which could serve as a guide for choosing a proper mouse device for enthusiastic gamers.

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CHI EA '24, May 11–16, 2024, Honolulu, HI, USA

ACM ISBN 979-8-4007-0331-7/24/05
https://doi.org/10.1145/3613905.3650958

CCS CONCEPTS

• **Human-centered computing** → **Pointing devices**; **User studies**; **Laboratory experiments**; **Pointing**.

KEYWORDS

Mouse, Pointing, Lift-off Distance, LoD, Gaming, User Performance, Mouse lifting, Clutching

ACM Reference Format:
Munjeong Kim, Joongseok Kim, and Sunjun Kim. 2024. Effects of Computer Mouse Lift-off Distance Settings in Mouse Lifting Action. In *Extended Abstracts of the CHI Conference on Human Factors in Computing Systems (CHI EA '24), May 11–16, 2024, Honolulu, HI, USA.* ACM, New York, NY, USA, 7 pages. https://doi.org/10.1145/3613905.3650958

1 INTRODUCTION

The computer mouse is crucial in the domain of competitive computer gaming, where players constantly seek improvements in their performance. The search for an ideal mouse involves various design aspects, such as weight [7, 8, 24, 25, 38, 42], shape [16, 17, 20, 21], hand position [9, 14], and technical specifications such as sensor sensitivity [3, 5, 6, 39], polling rate [11, 15, 32, 41], and sensor position [22]. In particular, competitive players are interested in optimizing these features to improve their gaming performance.

In this study, we focus on a key aspect of gaming mice known as Lift-Off Distance (LoD), which is the height at which a mouse sensor stops tracking. This feature is especially important for first-person shooter (FPS) players who tend to set Control-Display (CD) gain low (=low sensitivity and dpi) for more accurate aiming [31], which causes unavoidable *lifting* or *clutching* [3] – which involves picking up the mouse device from the surface and moving it to a more comfortable area within the motor space. Ideal lifting refers to physically relocating the device without disrupting the position of the cursor on the display [5]. For this, the mouse sensor has to stop tracking as soon as the mouse is lifted from the surface. Therefore, a low LoD is desirable in this regard, and gamers seek the lowest possible LoD to prevent adverse mouse movements [13, 35].

However, a low LoD is not always better; it comes with the cost of tracking error, because a computer mouse does not move on a perfectly smooth and even surface. The high and low LoD are in the trade-off relationship [43], therefore, optimal mouse LoD settings that are suitable for the tracking surface is also an important user setting. Although several automated surface calibration tools [10, 27, 33] try to optimize mouse LoD for users, quantitative measurement regarding the effect of LoD changes on tracking performance is less reported in the public from academia and industry.

To the best of our knowledge, no scientific experiments have been conducted to measure the impact of varying levels of LoD on user perception and pointing errors, in addition to the lack of a proper LoD measurement methodology. Consequently, most of the sources cited here are from outside academia, primarily from online forums and articles, which might be non-archival in the future.

In gaming communities, users often use *CD*s or *DVD*s as a unit of an LoD measurement, which is 1.2 mm per disc [12, 23, 34]. When someone mentions that the LoD of their mouse is between 1 DVD and 2 DVDs, they are implying that the mouse can move the cursor when it is placed on top of a single DVD's thickness (usually through the center hole of the disc) but will not work when two DVDs are stacked.

Gamers prefer to keep the level of lift-off distance (LoD) low, typically less than 3 mm, to prevent unintentional cursor movement when lifting the mouse [35]. However, some argue that the impact of LoD on gameplay is minimal. For example, Rocket Jump Ninja, a prominent figure in FPS gaming communities, has claimed that LoD does not cause much cursor movement when lifting due to the low sensitivity [30] that FPS players usually set.

In conclusion, while the gaming community has shown interest in the impact of LoD on user experience and performance, there is a lack of scientific research on this topic. The available information is based primarily on anecdotal evidence from online forums and articles, which may not be reliable. To address this knowledge gap, well-designed experiments are necessary. This paper would provide valuable insights into the optimal LoD range for gaming and other pointing tasks, contributing to the development of more effective mouse device design.

2 LIFT-OFF DISTANCE (LOD) SENSING METHODS AND MEASUREMENT

Modern computer mice utilize optical displacement sensor modules consisting of a light source, a two-dimensional array image sensor, and optics. The lateral displacement of the module can be sensed by computing the cross-correlation of two consecutive images captured from the sensor. However, the mouse sensor lacks the ability to measure vertical distance from the surface directly.

One direct way to control mouse LoD is to employ a separate distance sensor, such as in the SteelSeries RIVAL 600 and EVGA X17 models. This dedicated distance sensor provides a precise LoD control with good accuracy. Nevertheless, this requires an additional sensor, which incurs additional costs, leading to only a small number of mouse models opting for this approach.

As an indirect control of LoD, a common approach is the SQUAL-based method, which is widely used in standard gaming-grade mouse sensors. The SQUAL method relies on the optical sensor's limited depth of field, typically restricted to a range of 2-3 mm. The optics possesses a stationary focal point, and as the tracking surface moves away from the ideal distance, the captured images become blurry, making it difficult to detect surface features. SQUAL measures the prominence of surface features, with higher values corresponding to crisp and in-focus images, and lower values indicating defocused images. Sensors stop tracking when SQUAL falls below a certain threshold, and LoD can be controlled by adjusting the SQUAL threshold value. Higher LoD corresponds to lower SQUAL thresholds and vice versa.

For our experiments, we required a mouse that had precise LoD control. While there are numerous commercial mice that advertise adjustable LoD, the specific measurements of their LoD have not been made publicly available. As a result, we constructed a precision measurement jig for an accurate LoD assessment (see Figure 2).

For choosing an apparatus, we measured four LoD adjustable mice: two SQUAL-based LoD sensing mice (RAZER DeathAdder V2 and RAZER Viper 8KHz) and two distance sensor-based LoD sensing mice (SteelSeries RIVAL 600 and EVGA X17). Among the devices tested, EVGA X17 exhibited superior performance in the range of 10 LoD levels from $0.4mm$ to $3.0mm$ (see Figure 3).

3 USER TEST

To understand how different LoD settings affect pointing performance, a psychphysical LoD perception experiment and quantitative error measurements were couducted. For the apparatus, a desktop computer (Intel Core i9 9900, 32 GB RAM, NVIDIA GeForce RTX 2060 SUPER) with a gaming-grade monitor (ASUS ROG SWIFT PG259QN, 24.5 inch, 1920×1080px, 360Hz refresh rate) and large mouse pad (Steelseries Qck HEAVY, $450mm \times 400mm \times 6mm$) was used with the EVGA X17 mouse.

To find out the performance of the LoD sensor while playing FPS games, we recruited participants who play games for at least four hours a week using a computer mouse, right-handed and between

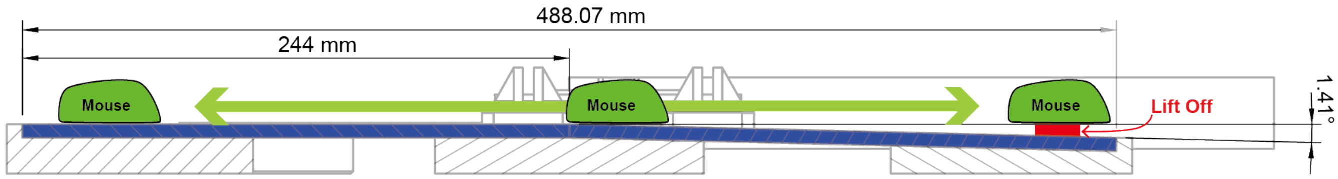


Figure 2: Design of mouse LoD measurement jig. A mouse is fixed to a rail that is moving horizontally. As the mouse moves to the right, the base (blue) is slanted downward to increase the distance between the mouse and the surface. By recording the mouse position where the cursor stops and moves again while moving to the left and right, the precise height of the mouse could be calculated.

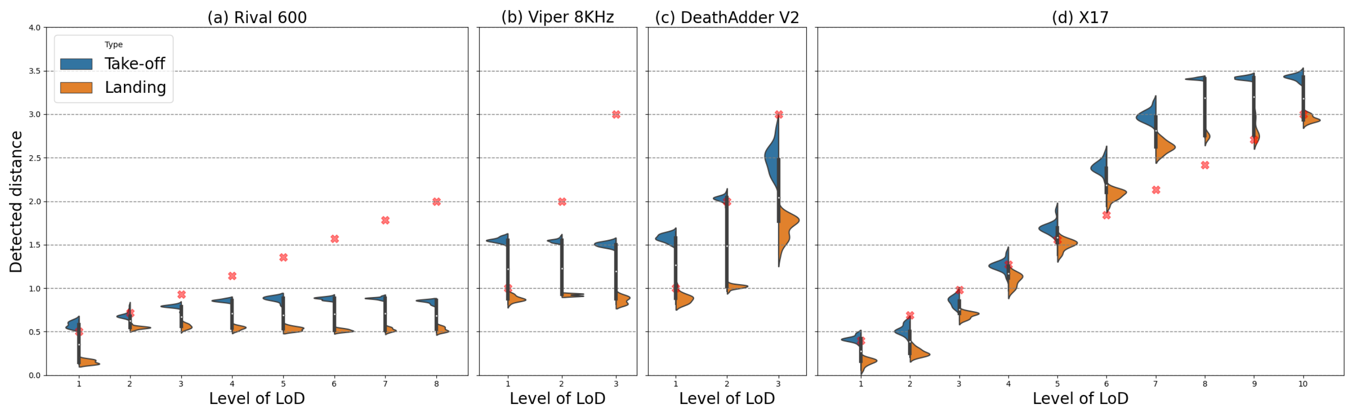


Figure 3: Result of measured LoD during Take-off (=moving right) and Landing (=moving left) using the LoD measuring jig. From the left, (a) RIVAL 600, (b) Viper 8KHz, (c) DeathAdder V3, and (d) X17. The red ×-markers are the claimed LoDs of the device, and the actual LoD points were measured ten times each.

the ages of 19 and 50. From a local university, 27 participants were recruited. Three participants with the shortest time playing the FPS game per week based on the demographic survey were excluded (for counterbalancing), and the remaining 24 participants joined the experiment. They were asked to read and sign a consent form prior to the experiment. The participants performed both experiments and it lasted approximately 60 minutes. They were compensated 15,000 KRW (≈ 11 USD) each for their participation. The University's Internal Review Board (IRB) approved the entire procedure of this study.

LoD level was set as an independent variable: LoD levels of 1, 3, 5, and 7 (0.29, 0.77, 1.60, and 2.80mm in measured LoD, respectively) as shown in Figure 3d. These levels could provide a wide range of LoD while keeping the number of tested conditions manageable. We label them LoD1, LoD3, LoD5, LoD7 in the rest of the paper.

3.1 LoD perception test

In the first experiment, a psychophysical test was conducted to determine the ability of humans to discriminate between different LoD levels. ISO 4120:2021 triangle test method [19] was adopted.

During the triangle test, one trial presented three stimuli, called the *triad*: two stimuli had the same LoD and one stimulus was different from the others. For each stimulus, one of the four levels of LoD was set, then participants were given 45 seconds to freely interact within the 'Countryside' map of AIMLABS[1], which simulates an FPS game environment that allows one to move around, aim and shoot random targets without a specific task assigned. Time constraints were established to restrict the use of additional tactics to distinguish the mouse beyond the intuitive recognition of LoD [2, 28]. Participants examined all three stimuli sequentially in random order and were asked which one had a different LoD from the others they thought of. They were forced to choose one, even though the stimuli were indistinguishable.

During trials, interaction between the participants and the experimenter is strictly minimized. The experimenter only set the LoD triads (blindly from the partcipants) without talking. Each participant tested six triads[2] made from four levels of the LoD. The presentation order of the six triads was counterbalanced across the participants using a balanced Latin square design [40]. Within a triad, the stimuli order[3] was randomly assigned. Therefore, 6 (triads) × 24 (participants) = 144 triangle test results were collected.

[1] A online training platform to enhance player's core FPS aiming skills.
[2] When constructing triads using 4 level of LoD, the six possible pairs exist (1&3, 1&5, 1&7, 3&5, 3&7, 5&7).
[3] When constructing a triad with two stimuli LoD1 and LoD3, there are six possible sequences (113, 131, 311, 133, 313, 331).

Table 1: The results of LoD perception test ($N = 24$)**.**

Compared setting level Difference of LoD (mm)	LoD1&LoD3 0.48	LoD3&LoD5 0.83	LoD5&LoD7 1.20	LoD1&LoD5 1.31	LoD3&LoD7 2.03	LoD1&LoD7 2.51
Correct responses (N)	11	10	6	18	16	16
α-risk	= 0.2	-	-	= 0.001	= 0.001	= 0.001

3.2 Target click (TC) task

In the second experiment, the trade-off between unintended cursor movement (Section 3.2.1) and tracking error (Section 3.2.2) was explored. For the TC task, participants played AIMLABS 'SPIDERSHOT 180 (ULTIMATE)' in different LoD settings with low sensitivity (0.69°/mm, which is a low value but still in the optimal sensitivity range [3]) to encourage mouse lifting. Within a TC task, two targets appeared in a random position within the current field of view (FoV), and the following two targets appeared in a random position 180° behind and were repeated for one minute. This task forced participants to rotate their FoV 180° per two targets, to maximize the number of observable lifting actions.

Participants completed the TC task 12 times: four LoD levels × three sessions per each LoD level. The order of the LoD level was counterbalanced across the participants using a balanced Latin square design [40]. During the TC task, we collected raw displacement tracking reports from the mouse (Win32 RAWINPUT[4]) and physical movement of the mouse using a motion capture system (OptiTrack Prime^X 13W, 1.3MP, ±0.30mm 3D accuracy, 240 FPS).

3.2.1 Unintentional Movement Error. When the LoD is set high, an unintentional cursor displacement may occur at the beginning of take-off and at the end of landing actions. Because we designed the task to rotate the FoV horizontally in a significant amount (180° turn), any movements in the opposite direction to the previous tracked movement during lifting are likely to be unintentional; hence, we defined it as an unintentional movement error. For example, a user moved the mouse all the way to the edge of the mouse pad, lifted it, and relocated the mouse back to the center position. During this sequence, any reversal cursor movement against the primary direction of the motion while lifting should be minimized.

When a lifting action occurs, there will be two clusters of tracking logs: before and after the lifting. We then measured the amount of reversal movement on the edge against the major direction vector of the primary movement of the logs before lifting (= take-off) and after lifting (= landing). The primary direction of a movement cluster was measured as follows. We calculate the mouse velocity while tracking, detect the local peak velocities, and calculate the major movement vector from the 11 data points around the peak.

3.2.2 Tracking Error. We expect that the instability of cursor movement (=jitter) will increase when the LoD is set lower. We define jitter as a fluctuation in cursor velocity; in other words, we measured the difference between smoothed and raw cursor velocities. We first grouped cursor movement data according to their speed, dividing them into bins of 50mm/s. For each bin, we calculated the standard deviation of the difference between the smoothed (moving average applied three times, window size = 10 units.)[5] and the raw cursor velocity. The cursor speed distribution shows a long-tail distribution all the way up to 2339mm/s; however, the 95 percentile of the value lies within 416mm/s. Therefore, we used only seven bins up to 400mm/s for further analysis.

4 RESULTS

4.1 Demographic survey

There were 2 women and 22 men (between 19 and 28 years old, 22.04 ± 2.74) who play the FPS game for 4.38 hours a week on average. Only 2 out of 24 participants knew about the LoD sensor among mouse sensor performance metrics, and only one responded that they tuned the LoD setting.

4.2 LoD perception test

ISO 4120:2021 [19] triangle test defines a perceptible difference between samples if the number of correct answers is equal to or greater than a certain number determined from the total number of trials. From 24 triads, 13, 15, and 16 (equal or more) correct answers are required to conclude that there is a detectable difference between stimuli with α-risk levels of 0.05, 0.01, and 0.001 respectively.

Table 1 shows the number of correct answers in each triad consisting of two LoD levels, and their corresponding α-risk level in the triangle test. The triads are ordered by the difference in measured LoD between the levels. Participants could not distinguish two LoD settings with differences of up to 1.20mm, and all triads with a LoD difference greater than 1.31mm were distinguishable.

4.3 Target click task

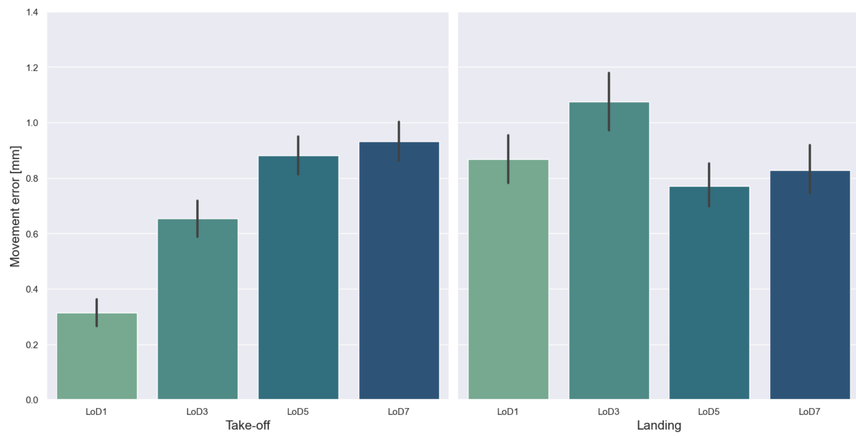
From TC task, we measured the amount of unintentional movement errors and tracking error and performed two-way Repeated-Measure Analysis of Variance (RM-ANOVA) as statistical analysis (JASP v0.17.3). *LoD levels* and *Session* were set as the within-subject variables, and the Greenhouse-Geisser correction was applied whenever the data violated the sphericity assumption. As a post hoc test, pairwise *t-test* with Bonferroni corrections was performed.

4.3.1 Unintentional Movement error. We measured the unintentional movement error (see Section 3.2.1 and Figure 4a) in the take-off and landing sequence separately.

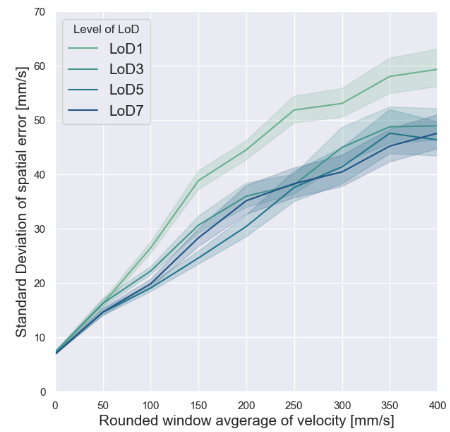
A significant main effect of LoD levels was found in unintentional movement error at take-off ($F_{2.35,51.77} = 13.995, p < .001, \eta_p^2 = 0.389$). The post hoc test showed that the amount of error was significantly lower in LoD1 (0.314mm ± 1.493mm) condition compared to LoD3 (0.653mm ± 2.068mm, $p = 0.018$), LoD5 (0.881mm ±

[4]RAWINPUT data contains the raw usb HID reports from the mouse device before the Windows transfer function (i.e., mouse related settings on the control panel) applied.

[5]Compared to moving average with larger window size, the repeated application of the moving average was more effective in producing a smoother result and applying center-weighted smoothing



(a) Unintentional movement error (=reversal movement while lifting) during mouse take-off (left) and landing (right) by LoD levels. The error bars are 95% confidence intervals.



(b) Tracking error (=instability of cursor movement) by LoD levels. The error bands are 95% confidence interval.

Figure 4: The results of target click task. The significant main effect of LoD on movement error was observed in the take-off sequences, and LoD1 exhibited more tracking error than others.

2.173mm, $p < .001$), or LoD7 (0.933mm ± 2.245mm, $p < .001$) (Figure 4a). No significant main effect of Session ($F_{1.79,39.33} = 2.665, p = 0.088, \eta_p^2 = 0.108$) and LoD × Session interaction ($F_{3.41,75.00} = 2.017, p = 0.111, \eta_p^2 = 0.084$) was identified in unintentional movement error at take-off.

For landing, no significant main effect of LoD ($F_{2.72,59.92} = 1.828, p = 0.157, \eta_p^2 = 0.077$), Session ($F_{1.75,38.41} = 0.615, p = 0.524, \eta_p^2 = 0.027$), or interaction effect ($F_{4.11,90.35} = 0.230, p = 0.924, \eta_p^2 = 0.010$) was found.

4.3.2 Tracking error. We measured the tracking error (=jitter) while the mouse was moving on the surface of the mouse pad (see Section 3.2.2 and Figure 4b).

A significant main effect of LoD levels was found in the tracking error ($F_{2.14,47.02} = 30.751, p < .001, \eta_p^2 = 0.583$). Post hoc analysis showed that the tracking error was significantly higher when the participants used LoD1 (40.430mm/s ± 8.079mm/s) compared to LoD3 (32.963mm/s ± 5.444mm/s, $p < .001$), LoD5 (30.088mm/s ± 4.411mm/s, $p < .001$),and LoD7 (31.033mm/s ± 5.243mm/s, $p < .001$). No significant effect of Session ($F_{1.52,33.40} = 2.088, p = 0.150, \eta_p^2 = 0.087$) and interaction effect between LoD × Session ($F_{3.62,79.71} = 1.012, p = 0.402, \eta_p^2 = 0.044$) was found.

4.4 Post-experimental survey

In response to the question about their preference for the ideal LoD level, 14 participants favored a lower LoD for better performance, and 8 participants indicated a preference for a higher LoD. The remaining 2 out of the total of 24 respondents mentioned that the optimal LoD setting could differ depending on the circumstances.

The preference for a low LoD was motivated by: "The cursor would shake less when moving my FoV quickly." "It would bounce less in the opposite (movement) direction when LoD was low." and "Unintended cursor movement would decrease."

The preference for a high LoD was motivated by: "When I play FPS games, my body becomes tense, in which case the mouse unintentionally raises off from the pad, and low LoD makes the cursor stutter."

The preference for adjustable LoD was motivated by: "Depending on the games or the users, I think there will be a LoD that suits each individual." and "I think a low LoD was good for lifting and a high LoD for tracking."

5 DISCUSSION

5.1 User perception on LoD changes

Overall, participants could not perceive a difference in LoD until the difference in LoD exceeds 1.20 mm. However, an interesting discovery was found in the comparison of LoD1&LoD3 and LoD5&LoD7 conditions. Even though LoD difference in LoD1&LoD3 condition (0.48 mm) was much smaller than the LoD difference in LoD5&LoD7 condition (1.20 mm), the number of correct responses was significantly higher in the LoD1&LoD3 condition. We suspect that comparing LoD1 (measured LoD = 0.29 mm, virtually zero LoD) against others is easier than comparing two midlevel LoDs, which suggests that the perceptible difference in LoD difference is nonlinear depends on the distance from the mouse pad. This could be further investigated in future work.

5.2 Trade-off between unintentional movement Error and Tracking Error

We find that there is a clear trade-off between the two types of error within the range of LoD1 (=0.29 mm) and LoD5 (=1.60 mm). Among these ranges, the increased LoD results in better tracking stability but more movement error. The optimal level of LoD might depend on the characteristics of the task, which should be further investigated.

The possible amount of unintentional movement was approximately up to 1 mm ($\approx 0.9^\circ - 1.8^\circ$ of the change in FoV in appropriate sensitivity settings [3]). In pixels, the unintentional error corresponds to ≈19–38 pixels on a full HD screen (1920×1080 px, assuming a narrow FoV of 90° [1]). For the tracking error, the spatial jitter in LoD1 was significantly more prominent (Figure 4b) than higher LoD settings. The increased amount of jitter could result in more erratic and jumpy cursor movement during high-speed motion. For future work, an investigation of how that amount of unintentional movement error and jitter affects the performance of professional gamers would be interesting.

5.3 Transition between states in input devices

The unintended movement error occurred because the transition threshold between the state, for example, between tracked or out of range (see Figure 1), is set differently from the user's intention depending on the LoD sensor setting [4]. This phenomenon is seen not only in mice. Users of the stylus pen experience annoying *hooks* at the end of the stroke due to the delayed transition from the dragging state to the tracking state [18, 29]. Furthermore, the flick gesture [26] with fast finger movement on the touch surface makes the transition from the tracking state to the out-of-range state [37], and the end velocity of the flick gesture, which determines the inertia of scrolling, might be affected by the unintentional movement error [36]. Hence, in future investigations, further research will be conducted on the impact of unintentional errors resulting from state transitions in different GUI elements.

6 CONCLUSION

This paper is the first study to quantify the performance of mice with different Lift-off Distance (LoD) settings. Unintentional cursor movement and tracking errors were quantitatively defined and measured, and a psychophysical experiment was conducted to investigate the human perception threshold of LoD settings. The findings show a trade-off between unintentional movement error and tracking error within the LoD range of 0.29 mm to 1.60 mm. Increasing LoD within this range improves tracking stability, but increases movement error. The optimal level of LoD may depend on task characteristics, requiring further investigation. The results increase our understanding of the impact of LoD settings on FPS gaming performance.

In further research, quantifying and understanding how state transitions in various input devices affect performance could help optimizing input device designs and settings and would enhance user experience across applications, including gaming.

ACKNOWLEDGMENTS

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT) (RS-2023-00211872 and RS-2023-00223062).

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