Lead Rush: A First-Person Shooter for User Studies and Understanding Effects of Frame Time Spikes

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***Abstract*—User studies are a cornerstone of human-computer interaction research, including measures of user performance and quality of experience (QoE) – particularly important for games where frame rates and frame timings can impact performance. Unfortunately, commercial games have limited options for customization and do not log player performance data with sufficient detail for use in such studies. This paper introduces *Lead Rush*, a first-person shooter game designed for conducting user studies on the effects of frame timing and frame rate. Lead Rush is tuned to run at extremely high frame rates and includes hooks to induce frame time "spikes". Researchers can configure Lead Rush's gameplay, trigger frame time spikes during specific actions, and log player data per game round and per study session. This paper also introduces a dataset from a user study on the effects of frame time spikes on player performance gathered from Lead Rush, and includes gameplay logs with both performance data and QoE results. Some analysis of the dataset is presented to illustrate its use.**

I. Introduction

Computer games are a major form of entertainment worldwide, with first-person shooter (FPS) games attracting large online player bases [1, 4, 6, 8]. These games are also used in research to study player behavior, performance and perception for technical factors such as network latency and frame timing [3, 7, 13].

Research assessing players' gaming interactions is often conducted via *user study*, where participants typically play parts of games with controlled parameters while the system logs relevant user data. Most commercial titles are largely unsuitable for user studies, being too large and unwieldy for general use and typically not gathering data at sufficient granularity to help assess user performance and experience. With some effort, moddable FPS games like Counter-strike [12] can be used for some studies, and open-source FPS games like Red Eclipse [5] can be adapted for other studies. Still, even these do not provide enough configuration options or readily expose internal data to make them generally usable for user study-based research. As a result, many researchers turn to bespoke games designed and implemented for their specific study. More flexible versions of these tools are useful for many implementations of specific types of experiments [2, 9]. However, the bespoke-game approach requires games for each area of specific research interest.

This work introduces a custom user study-focused FPS game *Lead Rush*, specifically designed to operate at very high frame rates (e.g., 500 Hz) and with hooks to trigger frame time "spikes" during specific player actions: weapon reload, rapid mouse movement and targeting. Further features include gameplay configuration, including the number of rounds, round duration, and experimental settings, and logging of game and player data. In addition, this paper presents a dataset from a user study conducted with Lead Rush [11] where the research focus was on studying how frame time spikes triggered during FPS actions affected player performance and QoE. While the primary independent variables from the study design have been analyzed, the wealth of data provided by Lead Rush could yield additional insights and be used for comparative purposes by other studies.

The rest of this paper is organized as follows: Section II presents Lead Rush; Section III describes the dataset and shows some analysis; and Section IV summarizes our conclusions.

II. Lead Rush

This section describes the Lead Rush game, highlighting key implementation details, the log system and configuration options.

A. Game Description

Lead Rush is an FPS game developed using Unity 2023 and designed and implemented to run at consistent, ultra-high frame rates (1500+ Hz). The game features fluid procedural animations that scale with frame rate, tactile gunplay, and positional audio. Lead Rush supports a configurable experimental harness to facilitate user study experiments, including a logging system to collect game and player performance data. A gameplay video showing Lead Rush is available at: https://youtu.be/YOxMcQbLEcI

1) Core Gameplay Loop: Lead Rush includes many common core FPS gameplay paradigms. The player controls their avatar from a first-person perspective, aiming and shooting projectiles at an enemy using a reticle while avoiding being hit themselves. Enemies are computer-controlled and encountered one at a time. The player tries to destroy each enemy by shooting it 5 times, triggering the spawn of a new enemy.

2) Enemy Behavior: The enemy avatar is a pink floating orb that moves straight towards the player, going around any obstacles that it encounters. If the orb comes in contact with the player, it explodes, eliminating both the player avatar and the orb. The player's avatar is reset to the starting point on the

Fig. 1: Lead Rush in-game screenshot. The enemy is the pink orb, with a steam trail indicating location (only the circular orb is hittable). The yellow arc region at the top indicates that the enemy is in front of the player. The gray blocks are obstacles, and at the horizon is a low wall that prevents the player from leaving the circular arena.

map, and the orb respawns in a random location within a fixed-ranged distance from the player avatar. If the player manages to shoot and destroy the orb, another orb respawns after 100 milliseconds in a random, fixed-range distance location.

The enemy's respawn location is dynamic within a torus-shaped region centered on the player, with a minimum radius of 4 meters and a maximum radius of 6 meters. If the respawn point is blocked by an obstacle on the map, the orb or player position is shifted to the nearest unobstructed location.

The enemy continuously floats up and down vertically, oscillating between a height of 0.9 and 1.1 meters once per second. The enemy moves at a speed of 3.1 meters per second, while the player avatar moves at 3 meters per second so that the player avatar cannot outrun the enemy over time. The enemy uses a Unity Navmesh[1] to move towards the player avatar while avoiding obstacles.

3) Heads Up Display (HUD): Figure 1 shows a screenshot of the game with an enemy and some of the UI elements in the scene. The heads-up display (HUD) provides a visual indication of direction and proximity of the enemy through flashing yellow lights along the sides of the screen. For example, if the bar is on the left, it means the enemy is off-screen to the left of the player. The bars become larger and brighter and flashing as the enemy gets closer. In addition to regular sound effects for hits and destruction, there is also positional audio feedback for the enemy.

4) Weapon Dynamics: Lead Rush has various types of weapons typically found in commercial FPS games, and all are hit scanned (i.e., do not propagate projectiles). The weapon has procedural recoil, sway, camera shake and aim-down sight animations. The gun has a green laser pointer to assist the player with aiming. A yellow hit marker appears in the center of the screen after a successful hit, and a red marker is displayed when the player destroys an enemy. The weapon has unlimited reloads, with 31 shots available after each reload by default. The game automatically reloads when the weapon is empty, but the player can also press 'R' to perform an on-demand reload. The reload animation takes about 2 seconds to complete and blocks shooting, regardless of its source.

5) Scoring: By default, players earn 10 points per hit and 100 points per enemy destroyed but lose 100 points each time their player-avatar is destroyed by an enemy. Each missed shot deducts 1 point and scores can drop below zero. Game scoring can be modified using the game's global configuration settings.

[1]Navmesh: https://docs.unity3d.com/ScriptReference/AI.NavMesh.html

B. Frame Time Spike Implementation

Lead Rush is instrumented to allow for the introduction of controlled frame time spikes during key game events. A frame spike is implemented in the game by measuring the duration of each main loop (with nanosecond precision) and, if the frame completes sooner than the specified spike duration, the game runs a busy loop for the remaining duration.

Frame time spikes can be configured to trigger for several in-game events:

- *Reload*: when the player initiates a weapon reload, either automatically (when the magazine is empty) or manually (by pressing `R`).
- *Mouse Speed*: when the player's mouse movement exceeds a configurable threshold within a frame. To avoid excessive triggering, a configurable cool down period is enforced between spikes.
- *On Target*: when the player's aim moves close to an enemy. This is detected using an invisible collider around the enemy, with the collider's x-scale oscillating over time to introduce unpredictability. A configurable cool down is applied after each spike to limit frequency.

Spike durations (in milliseconds) and frame rate targets are configurable. The game also records the precise timing and occurrence of each spike, along with related game and player performance data, for later analysis.

C. Configuration

Before used in an experiment, Lead Rush loads configuration parameters from the `Data/Configs/` directory. Key parameters, including round duration, enemy stats, score values, session settings, and the experimental design for each round (e.g., frame rates and frame time spike durations) are set via `GlobalConfig.csv`, `SessionID.csv`, `RoundConfig.csv`, and `LatinMap.csv` configuration files. The session and round configuration files work together to randomize and balance experimental conditions for each session. For a complete list of configuration options and formats, see the Lead Rush git repository:

https://github.com/Tokey/Lead-Rush

D. Log System

Lead Rush logs player actions, gameplay performance, mouse and movement data, aiming, and QoE ratings each round. Detailed tick-level data on player input, position, and rotation is also captured, along with key enemy status and angles. Log values are buffered in memory and saved to disk at the end of each round after the player provides QoE input.

CPU	Intel Core i9-11900K
GPU	NVIDIA RTX 4070 Super FE
RAM	32 GB DDR4
Storage	Samsung 970 EVO SSD
Mouse	Logitech G502
Keyboard	Logitech G910
Display	Alienware AW2524H (500 Hz, 1920×1080)
Latency	<20 ms (at 500 Hz)

TABLE I: System used for studies.

E. Use in User Studies

Lead Rush was used to assess the impact of frame time spikes on player performance and QoE [11], detailed in the next section. Lead Rush was also used in a study assessing the impact of high frame rates on player performance and QoE [10]. Users playing Lead Rush saw performance improvements for frame rates from 7 Hz to 90 Hz but showed little benefit above 120 Hz, while users perceived visual smoothness (QoE) – albeit more gradually – even up to 500 Hz.

III. Frame Time Analysis Dataset

This section introduces a dataset gathered with Lead Rush both for illustrative purposes and to make this data available for analysis by other researchers. To evaluate the effects of event-based frame time spikes on player experience and performance, we used Lead Rush in a controlled lab user study [11]. Thirty-eight (38) participants played 20 rounds each, with frame time spikes (0–675 ms) triggered during reloading, fast mouse movement, or targeting. Each of the participant sessions lasted approximately 30 minutes and included demographic and reaction time tests, two practice rounds, and 18 main experiment rounds, all played on a high-end gaming PC (specs reported in Table I).

For each participant, data was collected and organized in individual session folders. Each folder contains three gameplay log files (player, round, and enemy data in CSV formats), and a text file recording reaction time test results. The complete dataset, including all session folders, is available online for reference and analysis at:

https://tinyurl.com/FTLeadRush

To illustrate possible uses of the dataset, we show analysis of the impact of frame spike duration for two types of dependent variables: *player performance* and *player QoE*.

Player Performance: Figure 2 depicts the number of enemies a player destroyed per round (on the y-axis) versus the spike magnitude/duration (on the x-axis). Each data point is the mean value for all users, shown with a 95% confidence interval. Only spikes during targeting caused a visible drop in target eliminations. Spikes during reload and mouse movement did not impact performance much, as indicated by the relatively flat data trends. In contrast, spikes during targeting caused a degradation in performance correlating with spike size. However, even for targeting, small 75 ms spikes did not degrade performance much.

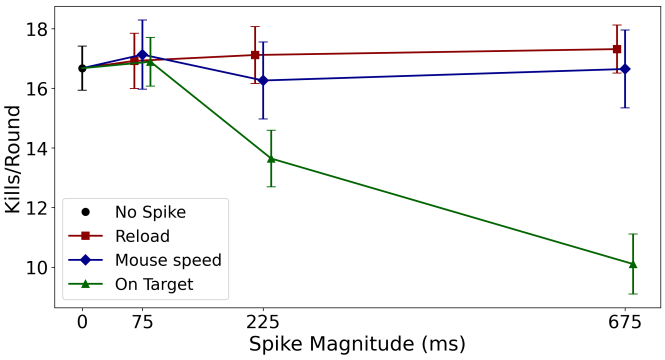

Fig. 2: Eliminations vs. frame time spikes during actions.

This highlights that when a spike occurs matters as much as or more than spike duration for performance.

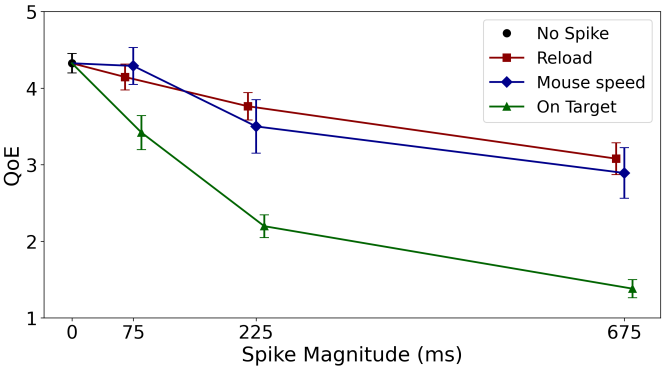

Fig. 3: QoE vs. frame time spikes during actions.

Player QoE: Figure 3 shows similar analysis as performance, but with the y-axis depicting QoE based on a 5-point scale (1-low to 5-high). Spikes during targeting once again show a drop, but *also* spikes during reload and mouse movement degraded visual smoothness. There was no clear flat region – QoE declined as spike magnitude increased, with spikes during targeting having the strongest effect. This shows that both spike timing and spike size impact perceived QoE.

IV. Conclusion

Lead Rush is a customize-able FPS game designed for users studies on the effects of frame timing and frame rates on players. It supports configurable experimental conditions and a test harness for running experiments and logging data. Studies using Lead Rush show: 1) frame rates greather than 90 Hz minimally benefit player performance but continue to improve player perception of smoothness up to 500 Hz [10]; and 2) the (relative) timing of frame time spikes, not just their duration, affects player performance and experience [11].

Future work can use Lead Rush for frame rate, frame time spike or even general user studies that need FPS gameplay with logging. Future work can also analyze the released public frame time spike dataset for additional insights or comparative purposes.

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