# Toward Injury-Aware Game Design

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**Abstract.** As video games and esports continue to grow in popularity, gaming injuries are also on the rise. In recent years, medical professionals have placed greater emphasis on preventing and treating gaming injuries and proposed specific gaming health guidelines. However, the game industry and game research community have not done enough to address the hazards of gaming injuries or raise awareness about such hazards to players, parents, and game designers. In this paper, we propose a framework of injury-aware game design that addresses the two main causes of gaming injuries: prolonged gaming and repetitive microtrauma. We have identified a set of injury-aware game design techniques to help raise awareness of gaming-related hazards, promote healthy gaming behavior, and optimize gameplay to prevent injuries. We believe an effective way to deliver gaming-related health information to game players is through games themselves. To demonstrate this framework, we have developed an injury-aware game and conducted a user study with players and game designers. The results from the proof-of-concept game and user study show that both players and designers have a positive reception to the idea of implementing more inclusive measures into games, with nearly all participants of the user study being interested in the idea of hand exercise recommendations.

**Keywords:** Game design · Gaming injuries · Injury prevention

## 1 Introduction

A large portion of the population has been playing video games regularly, and many people play games for long periods. According to a recent report from the Entertainment Software Association (ESA) [11], there are nearly 227 million game players across all ages in the US. Specifically, 67% of American adults and 76% of American youth are game players. Seventy-seven percent (77%) of game players play more than three hours per week, and 51% of them play over seven hours per week. Fifty-five percent (55%) of the players have played more during


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the pandemic. In addition, esports has been growing rapidly in recent years, and esports players play video games intensively for even longer periods, ranging from 5.5 to 10 h daily [8,10]. Top esports competitors play 12 to 14 h a day, at least six days a week [18].

Excessive video game play often leads to gaming injuries [10,16]. A study of esports players by DiFrancisco-Donoghue et al. [8] found that the most frequent complaint was eye fatigue (56%), followed by neck and back pain (42%), wrist pain (36%) and hand pain (32%). Among the players surveyed, only 2% had sought medical attention. PC gamers have a higher incidence of hand and wrist-overuse injuries such as tendinitis and carpal tunnel syndrome [6].

Many medical professionals have studied gaming injuries and published their work in medical journals or health-related media platforms. The medical community has placed greater emphasis on the identification, management, and prevention of gaming-related health hazards. A comprehensive framework and detailed guidelines to address gaming injuries have been published in the field of sports medicine [10]. However, such information does not normally reach game players since they do not regularly read medical journals.

On the other hand, the game industry and academic game research community have not done enough to address gaming injuries. For example, neither the 2021 Essential Facts about the Video Game Industry by ESA [11] and the GDC 2021 State of the Game Industry Report [12] mentions gaming injuries or health issues. The popular game engines do not include any mechanism to monitor and report excessive gameplay or hand and wrist overuse. Healthcare-related game research generally focuses on studying the potential benefits of video games for treating health issues [1,9], such as promoting exercises or helping rehabilitation. Our work is different from this type of research in that we focus on the injuries or health issues caused by gaming.

We argue that game designers and developers can do much more to address gaming injuries by introducing injury-aware mechanisms into game design and game engines. We believe the best way to deliver gaming-related health information to game players is through games themselves. In this paper, we propose a framework for injury-aware game design. This framework includes three basic injury-aware design mechanisms: feedback to game designers, feedback to game players, and injury-aware game AI. At the center of this framework is a real-time player activity monitor component that can be added to existing game engines to collect player activity data. This relatively simple and non-intrusive activity monitor can provide feedback to game designers during game design or after the game is released. Game designers can use such feedback to modify the game mechanics and level designs to alleviate the mental and physical stress of players. Game designers can also create injury-aware game AI that takes real-time feedback from the activity monitor and dynamically adjust gameplay to reduce stress to hands and wrists. In addition, a summary report of player activities can be presented to game players and/or their guardians to keep them informed of potential health risks. Finally, personalized medical advice on exercises and injury prevention can be presented to game players and their guardians. This proposed framework is a type of calm technology [4] that stays largely in the background.

As a proof of concept, we have developed an injury-aware game to demonstrate some of the features in our proposed framework. This game includes a player activity monitor that records the players' key presses and locations in the game world. Detailed finger usage data is presented to game designers to help redesign the game to reduce hand overuse. A summary report is presented to game players to raise awareness of the potential hazards of gaming injuries.

We also conducted a user study to seek feedback from players and game designers about the proposed injury-aware game design mechanism. The majority of participants (70%) had previously played the game and 60% identified as game designers or developers. Those who had played the injury-aware version leaned toward the control switching mechanic being either neutral or somewhat enjoyable. The tool's feedback for recommending hand exercises after a session was a resounding yes for a feature. However, guardians were split on if it would be beneficial for recommending how a game should be used. 83.3% of game developers also found the idea for the real-time aspect of the tool to be beneficial for reshaping level design, with the same amount noting that they would use both the temporal (the keylogger) and spatial (zoning) aspects.

We believe that injury-aware game design should be part of the normal game design process. The game design community and ultimately the game players will benefit from a comprehensive and thorough study of how games can be designed to prevent gaming injuries and keep players properly informed of such risks. Our proposed framework is a step in that direction.

The rest of the paper is organized as follows. In Sect. 2, we discuss related work from the medical community and game research. In Sect. 3, we briefly discuss gaming injuries and health issues. In Sect. 4, we describe the injury-aware game design framework. In Sects. 5 and 5.4, we discuss our proof-of-concept injury-aware game and a preliminary user study. Section 6 is our conclusion and future work.

## 2 Related Work

Gaming related health issues have been the subjects of some previous medical research [3,5,7,8,10,13–15,17,19–26]. For example, Emara et al. [10] classified esports related hazards into the following categories: musculoskeletal hazards, sedentary activity hazards, central neurological and psychological hazards, and infectious hazards. McGee and Ho [20] pointed out that there was still a dearth of esports-specific medical research but argued that esports competitors are subject to the kinds of repetitive loads that increase the risk for tendinopathy.

In addition, Emara et al. [10] proposed a three-point medical care framework for sports medicine providers, trainers, and coaches to care for the esports athletes. The three-point framework includes awareness and management of common musculoskeletal and health hazards, opportunities for health promotion, and recommendations for performance optimization. There is no corresponding framework for game designers and developers to tackle gaming injuries from a game design perspective. Our work is an attempt to address this gap.

Most of the research on gaming-related health hazards was conducted in the field of medicine. Relatively little work was done in the game design and development research community to address health issues caused by gaming. We reviewed the papers published in the major game design and development conferences and journals for the last three years and found no paper related to gaming injuries or gaming-related health issues. The publication venues we reviewed include Foundations of Digital Games (FDG), IEEE Conference on Games, ACM CHI PLAY, IEEE Transactions on Games, Entertainment Computing, and Games for Health Journal. For example, IEEE Transactions on Games had a special issue on Serious Games for Health [9], but the papers were about using games for rehabilitation, healthcare education, childhood obesity treatment, etc. Similarly, the papers published in Games for Health Journal [1] were primarily about studying the potential benefits of games for healthcare. Our work is different from this type of research in that we focus on the injuries or health issues caused by gaming.

## 3 Gaming Injuries

There are two leading causes for gaming-related musculoskeletal hazards [10]: prolonged aberrant posturing and repetitive microtrauma. Prolonged aberrant posturing can lead to neck and back pain. Repetitive microtrauma can lead to musculoskeletal illness. Game players, particularly esports players, often use rapid and repetitive hand motions in gameplay. High-intensity games may reach up to 500 to 600 moves per minute, sometimes for long periods of time. As a result, over 30% of esports players reported hand and wrist pain [8,10]. Emara et al. [10] identified 18 specific types of esports related musculoskeletal and medical hazards, including overuse shoulder tendon pathology, overuse elbow tendon pathology, cubital tunnel syndrome, overuse wrist tendon pathology, carpal tunnel syndrome, cervical pain, thoracic pain, lumbar pain, gluteal pain, ischial pain, hamstring tightness, etc.

Prolonged gaming can also cause other health hazards such as visual strain, dry eyes, headache, sleep deprivation, excess weight gain, and psychological and behavior issues [10,22,25]. For example, Pujol et al. [22] found that children who played 9 h or more of video games per week were often associated with conduct problems, peer conflicts, and reduced prosocial abilities.

## 4 Injury-Aware Game Design

Injury-aware game design is about crafting an enjoyable gameplay experience and informing game players and designers about the hazards of gaming, promoting healthy gaming activity, and optimizing gameplay to prevent injury. We designed our framework based on the gamer's health framework by Emara et al. [10]. However, we approach the same problem from a game design perspective, and our focus is on delivering gaming-related health information via games themselves. While the frame by Emara et al. was designed to inform sports medicine providers, trainers, and coaches, our frame is designed to inform players and game designers.

Our framework addresses the two main causes of gaming-related hazards from three perspectives: hazard awareness, health promotion, and performance optimization. Based on this general idea, we have identified the main tasks for injury-aware game design (Table 1).

**Table 1.** Major tasks for injury-aware game design

| | Prolonged gaming | Repetitive microtrauma |
|---|---|---|
| Hazard awareness | Monitor and display gaming time; display warnings | Monitor and display gameplay activity; display warnings |
| Health promotion | Display personalized health recommendations | Create and display personalized information about injury prevention |
| Performance optimization | Design and develop injury-aware game mechanics to prevent prolonged gaming | Design and develop injury-aware game mechanics to prevent repetitive microtrauma |

To support these tasks, an injury-aware game needs to have one or more of the following components. A player activity monitor needs to be embedded in the game to collect player activity data, such as the length of each gaming session, the frequency of keystrokes and mouse clicks, etc. Such information can be used in three different scenarios. First, the data can be presented to game designers to help them redesign their games to reduce the risk of gaming injuries. Second, game designers and developers can develop injury-aware game AI to dynamically change gameplay based on real-time player activity data to reduce the risk of repetitive microtrauma or prolonged gaming. Third, the data can be presented to game players to raise awareness of gaming injuries and promote healthy gaming activities. Game UI should include health hazard warnings and medical recommendations.

Figure 1 shows the basic components of injury-aware game design. An injury-aware game can be based on any combinations of these components.

### 4.1 Player Activity Monitor

The player activity monitor will collect data about keystrokes, mouse clicks, and game controller inputs at regular intervals. This information can be used to calculate the per-minute frequency of player actions. Since different keys, mouse buttons, and game controller buttons are mapped to specific figures, the detailed user input information can be mapped to specific finger activities. This can be

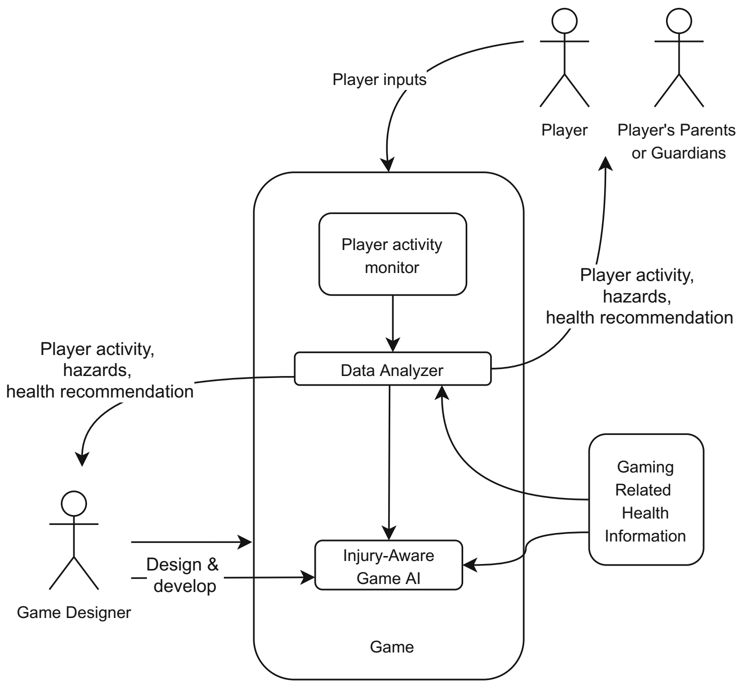


**Fig. 1.** Basic components of injury-aware game design

used to monitor the risk of musculoskeletal hazards associated with repetitive microtrauma. The player activity monitor can also record the length of a player's gameplay sessions, which can be used to estimate the risk of prolonged gaming.

Embedding a player activity monitor in a game is not difficult. Game engines such as Unity and Unreal have event systems for checking keyboard, mouse, and other input events. Many games may already have built-in user input loggers for user profiling and performance optimization. The data can be easily converted to gaming health-related analysis. Game engine developers can add more functions to their APIs to make it easier to monitor player input activities.

### 4.2 Data Analyzer

A data analyzer can be embedded in a game to apply statistical analysis to the player input data from the player activity monitor. The analyzer can generate personalized health warnings or recommendations based on the guidelines from the medical professionals.

For example, Emara et al. [10] provided detailed health guidelines and specific exercises for gamers, such as "begin with 3 to 5 min of warm-up stretch with 5 min of stretching every 2 h" and "limit continuous gaming sessions to a maximum of 1.5 to 2.0 h at a time". These guidelines and recommendations can be stored in a searchable database (Fig. 1), and user input data is used to select the most relevant health information for a player.

### 4.3 Feedback to Game Designers

The data analyzer can present information to game designers via a special UI during game testing. The data presented to game designers should be low-level, detailed data so that game designers can use them to design or redesign games. Three types of data can be presented to game designers: spatial, temporal, or integrated spatial-temporal data.

Spatial data shows player input activities by regions of the game world. This information may help game designers redesign the level to reduce players' hand workload for certain regions. The temporal information may include the intensity of player input activities over time so that game designers may redesign the game to reduce the intensity of repetitive hand activities. Spatial-temporal data combines both spatial and temporal data to provide a more detailed picture. Data visualization techniques such as heatmaps can be used to display spatial-temporal data.

As discussed earlier, the analyzer can use player input data (e.g., actions per minute and length of gaming session) to select relevant health information, such as musculoskeletal hazard, and present it to game designers so that game designers are aware of the potential health risks to players during game design. Between retooling a game or level to not over-rely on any given finger or to better distribute interactions across a level, some genres and mechanics are inherently more stressful than others. The feedback will allow designers to review the data to decide on the best course of action to remedy the intrinsic strains of these genres or mechanics.

### 4.4 Feedback to Game Players

Injury-aware games may provide feedback to game players and, in the case of young children, their guardians. The information presented to game players is less detailed than the information presented to game designers. Three types of data are presented to game players: aggregated player activity, warnings about potential hazards, and health recommendations. Again, the analyzer will use player input activities (e.g., hand actions frequency) to select the relevant health hazard information (e.g., potential hand and wrist pain) and recommendations (e.g., 5 min of stretching every 2 h).

This information can be displayed in the regular game UI during or after each gaming session. Warnings messages may be displayed if the gaming activities are deemed excessive based on the health guidelines. In some cases, the warnings may be delivered by a non-player character (NPC) in the game. The purpose of this information display is to make a player aware of the potential health hazards based on the player's personal and immediate gameplay data. The players will feel the information is more relevant because it is delivered in-game, in real-time, and based on their own personal gameplay data. This is a type of calm technology [4] that stays largely at a user's peripheral attention.

For younger children, the information may be delivered separately as a report to the parents or guardians to keep them informed. The typical parental control software can report the total amount of time of gaming but without much detail. An injury-aware game can provide parents with more specific information about hand activity, warnings on health hazards, and health recommendations.

### 4.5 Injury-Aware Game AI

A more advanced form of intervention is to develop game AI that can dynamically adjust the gameplay to reduce the risk of hand and wrist injury or prolonged gaming. The injury-aware game AI takes inputs from the player activity monitor and health information database. A player's activity statistics are constantly compared with the normal ranges based on the health guidelines. If a player's gaming activity goes outside the normal range, the game AI can automatically adjust the gameplay. For example, the game AI can adjust the difficulty level, reduce the frequency of enemy attacks, provide more breaks, end the game quickly, or even lock the game for a period of time.

Building injury-aware game AI is technically feasible. Adaptive gameplay, dynamic difficulty adjustment, and procedural content generation in games have been studied for many years. Many games already have a built-in dynamic difficulty adjustment mechanism. The main difference for injury-aware game AI is to incorporate gaming health guidelines into the algorithms.

## 5 An Example of Injury-Aware Game Design

As a proof of concept, we have developed an injury-aware game to demonstrate the mechanisms discussed earlier. This game is based on Katamari Damacy, where players roll a ball around a level to pick up items. The game consists of one level in a city setting, split into nine zones, where players roll a ball around to pick up items, according to the unlocked categories (shown by the highlighting of the item). The win condition is having a size above 2.5 m, which, on average, took players about 9 min to complete. The game is played with a keyboard and mouse. This game includes a player activity monitor, a data analyzer, feedback to game designers, and feedback to game players. We did not develop an injury-aware game AI for this proof of concept. For this study, we will be focusing on raising awareness of the Carpal Tunnel Syndrome (CTS) by tracking and analyzing keystrokes.

Our game has two versions. The first version (Fig. 2) allows for the use of both WASD and the arrow keys, with no break between them (the control group). In the second version (Fig. 3), we set the use of WASD and the arrow keys to a timer, allowing for a break on the player's hand for that given duration (the experimental group). Pauses and breaks in a game are either set in motion by players or an event happening in-game. These serve as natural checkpoints for players to catch up and reflect on what's going on in the game. For injury-aware gameplay to work while still being enjoyable, it needs to balance the subtlety of breaks without interrupting the game flow too much.


**Fig. 2.** The control group version.


**Fig. 3.** The experiential group version, with a radial in the top right to indicate which controls to use.

### 5.1 Player Activity Monitor

Our player activity monitor features two components: a temporal aspect in the form of a keylogger and a spatial aspect in the form of area or zone IDs. The temporal aspect is a keylogger, with the designers inputting the keys they want to track, and the tool records the counts over a user-inputted period of time. The keylogger records both WASD and arrow keys at every instance in time, no matter the version. The counts will be averaged over a period of time, in the case of this game, over a period of 10 s. Because our game had only one level that took around 9 min on average to reach the win condition, we decided to set a short time span to continually export our data. As it stands, it only takes keycodes but could also be modified to handle mouse movements or controller stick movements. Built using Unity's OnGUI event system, the temporal aspect can easily be ported into any given Unity project with no dependencies or built to be its own executable.

The spatial aspect is game-specific but is meant to track the player's location. In the proof-of-concept game, the level was split into nine areas, with each item being tagged with a zone ID. Zones are a way to track the player's location at any moment of time. Each item has an assigned category and zone number. The spatial component added a zone profiling tool, which allows us to view how many objects were picked up in any given zone. If a player picked up an item, it would be added to the respective zone's overall count, showing where the player was within the last 10 s. The spatial component, the zoning tool, can be used in a variety of contexts and manners. For an open-world game, the zones could be split by the LOD chunks on a given terrain, with each object to be tracked based on a zone ID. Another example would be a rhythm game. Most beatmaps are already sectioned off into parts, so each note in said part would be tagged with a zone ID.

The two aspects work in conjunction to give an idea of how the players are using their fingers over a period of time, in relation to how objects are distributed throughout a level. All of the data is exported in real-time to Google Sheets, with a new table created for each new session. The table name records the version and a timestamp of when they started playing. Therefore, we can track the length of each gaming session.

### 5.2 Feedback to Game Designers

Game designers will be able to view the raw data in the Google Sheets, port the data into a data visualizer, and view both the hand usage via the keylogger, as well as the player's movement and interactions throughout a level via the zoning component.

The heatmaps (Figs. 4 and 5) display the density of finger usage to standard keyboard finger configurations. Standard left-hand configurations for the WASD keys have a setup of the left middle finger assigned to both W and S, the left ring finger assigned to A, and the left index assigned to D. Standard right-hand configurations for the arrow keys have a setup of the right middle finger assigned to both the up and down arrows, left ring finger assigned to the right arrow, and the right index assigned to the left arrow.

Once a session ends, or a designer feels as though enough data has been gathered, they can use their visualizer of choice to view the overall impact of the player's finger usage and location.

We used Plotly [2] to create heatmaps of the unaggregated key presses over a period of time. A secondary heatmap of unaggregated object interactions in relation to player location can be created out of the zoning component's data. Designers can view these heatmaps to show both the density of finger usage as well as if there's any correlation of object interaction or inaction between the two heatmaps. Levels in any given game could potentially be redesigned accordingly if certain fingers are overused.

### 5.3 Feedback to Game Players

Game players and their guardians do not need to see the raw, unaggregated data. Instead, a condensed summary based on the data is presented to them. In this game, players and their guardians will receive a bar chart (Fig. 6) based on

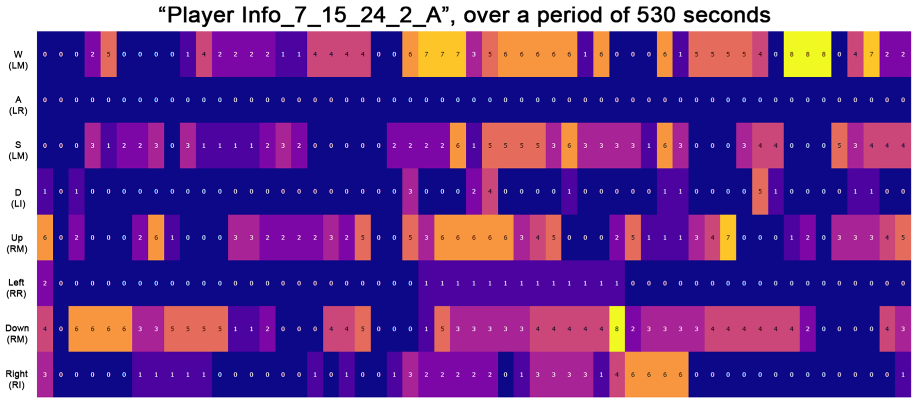


**Fig. 4.** The heatmap shows the key and finger usage over a period of 530 s for version A of the game. The horizontal axis is time. The vertical axis shows different keys and their finger mappings. For example, "W (LM)" means the W key is mapped to the left middle figure (LM), and "Right (RI)" means the right arrow key is mapped to the right index finger (RI). Here M, R, I mean middle, ring, and index finger, respectively.

the summed counts of each input, also marked with their corresponding finger configuration on their respective inputs. On these aggregated counts, a recommended hand exercise will be provided. These recommendations, if followed up by the players, can also aid in preventative measures against developing any gaming-related injuries.

### 5.4 Injury-Aware Game AI

In our proof-of-concept, we did not develop injury-aware game AI. In our game, the AI would not serve much purpose other than to potentially force a break if the player's inputs go outside the "healthy" range.

For example, in a rhythm game, a counter for the number of retries can run in the background, and after a certain threshold is reached, offer to automatically lower the difficulty of the current beatmap. For example, input-based fighting games have repetitive strains due to how much a player will be responding to an enemy's moves. In this case, a counter tagged by the moves that damage the player can be implemented. Based on the moves that hold the highest count, indicating which moves the player is struggling with the most, the probability of said moves being used by the computer can be reduced in subsequent replays of the current round or session.

### 5.5 User Study

Between the two studies, we gathered 29 people, 19 who played the game prior and consented to have their game session recorded, and ten who participated

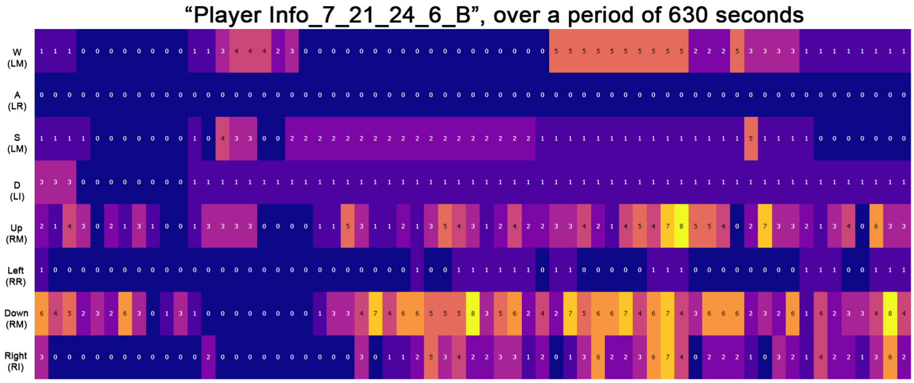


**Fig. 5.** The heatmap shows the key and finger usage over a period of 630 s for version B of the game. The horizontal axis is time. The vertical axis shows different keys and their finger mappings.

solely in the user study questionnaire. Participants were sent links to both studies in various Discord groups the researchers were a part of. In our preliminary user study, we gathered data both from participants who previously played the game, as well as a general populace – 60% of participants identified as game designers or developers. The questions were split into three sections: those relating to the proof-of-concept game, the relevancy of the tool's feedback to a player, and the relevancy of the tool to game designers.

About 70% of participants played the game previously versus the 30% who did not. Almost all participants stated that they relied on the WASD keys over the arrow keys throughout the game. For those that played the experimental group version, on a scale of 1 to 5 (1 being the lowest in enjoyability and 5 being the highest), participants ranked their enjoyment of the control switching mechanic between 2 and 4, with more of a lean towards the mechanic being neutral (25%), or potentially positive territory (50%). Conversely, all of the participants who played the control group version stated that a control switching mechanic would inhibit their enjoyment of the game. 62.5% of participants listed themselves as completionists, which for this game would mean remaining in a particular area to pick up as many items as they can.

The latter two sections were generalized to gauge the interest of the tool to an audience outside of this proof-of-concept, appealing to both players and designers.

All participants indicated that they would be interested in receiving hand exercise recommendations based on their key presses. While not too many participants identified as guardians or caretakers, it was an even split as to whether or not the tool's feedback would be beneficial in recommending how or when a game or games should be used.

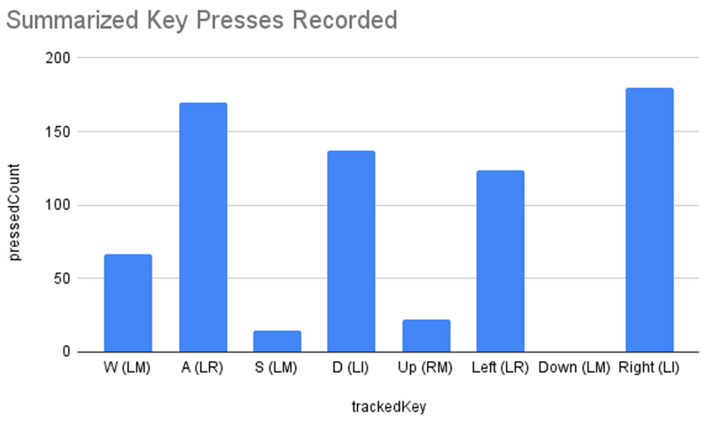


**Fig. 6.** This bar chart shows a summary of the key and finger usage for a gaming session. For example, "W (LM)" means the W key is mapped to the left middle figure (LM), and "Right (RI)" means the right arrow key is mapped to the right index finger (RI). Game players can see which fingers are used more frequently.

The last section focused solely on the players who identified as designers, which made up 60% of the participants, asking if the unadulterated data of the tool would be of use to them.

Eighty-three percent (83.3%) found real-time, raw data, based on players' key presses, in relation to the player's location to be beneficial in level design, whereas 16.7% did not see the need for it. The same split occurred for the next question of if they would consider using both the temporal (the keylogger) and spatial (the zones) components of this tool in any given project, with the 83.3% answering "both" and the 16.7% answering "neither."

Overall, players who experienced the injury-aware version of the game seemed not to mind or even somewhat enjoy the subtle breaks the game gave to their finger usage. While those who had not played the injury-aware version stated that the control switching mechanic would inhibit their enjoyability, all participants were interested in the idea of receiving hand exercise recommendations after play, with the majority of designers finding both aspects of the tool beneficial for any given project.

## 6 Conclusion and Future Work

Gaming injuries have become an important health issue as a large portion of the population plays video games regularly, and esports is growing rapidly. In recent years, the medical community has provided a specific framework and guidelines for treating and preventing gaming-related health hazards. We believe an effective way of delivering gaming-related health information to game players is to incorporate such information in game design and development via calm technology [4]. In this paper, we present a framework for injury-aware game design and identify key components for injury-aware games. As a proof of concept, we developed an injury-aware game and conducted a user study. The results showed that participants, both players and designers, would be open to exploring the avenue of injury-aware gaming, with the most positive reception of the feedback being recommendations for hand exercises. The majority of user study participants who played the injury-aware version of the game did not find their enjoyability hindered by the control switching mechanic. The majority of designers also felt both the temporal and spatial components of the tool to be beneficial to level design.

This work is the first step toward a comprehensive study of injury-aware game design. Many research questions remain to be studied. For example, there are different ways to deliver health warnings and recommendations. Their effectiveness needs to be studied and tested. Injury-aware game AI is a complicated subject, and different techniques need to be studied. Extensive user studies are needed to test the effectiveness of injury-aware game AI.

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