# Designing a First Person Shooter Game for Quadriplegics

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## ABSTRACT

Video games are often about being able to do things that are not possible in real life, about experiencing great adventures and visiting new places. Yet, as prolific as gaming is, it is inaccessible to a significant number of people with neuromuscular diseases who are unable to play games with traditional input methods like game controllers or keyboard and mouse combinations. While primarily used for entertainment in the early days, gaming now provides the possibility of countering social isolation and connecting with others through multiplayer games, online gaming communities and game streaming. In our work, we explore how facial expression recognition can be harnessed to provide quadriplegic individuals a way to play games independently and without complex mouth controller devices. We demonstrate our input interface with the design of a first person shooter game.

## CCS CONCEPTS

• **Human-centered computing** → **Accessibility**; **Accessibility systems and tools**;

## KEYWORDS

facial expression recognition, FPS, PC gaming, hands-free input, quadriplegia, accessibility

**ACM Reference Format:**
Atieh Taheri and Ziv Weissman. 2021. Designing a First Person Shooter Game for Quadriplegics. In *CHI Conference on Human Factors in Computing Systems Extended Abstracts (CHI '21 Extended Abstracts), May 8–13, 2021, Yokohama, Japan.* ACM, New York, NY, USA, 6 pages. https://doi.org/10.1145/3411763.3451850

## 1 INTRODUCTION

Over the last three decades, video gaming has undergone dramatic change, both technologically and culturally. More recently, interest in video games has risen dramatically as people have taken to games not only as an escape from the impositions of the COVID-19 pandemic but also as a way to work [1] and socialize [2]. US consumer spending on video gaming in the second quarter of this year increased 30% when compared to the second quarter of last year[3].

With growing interest in playing video games and with video games increasingly being used for purposes other than entertainment, such as education [6], rehabilitation [10, 15] or health [13, 34], game accessibility is increasingly critical, and even more so for players with disabilities who stand to benefit greatly from the opportunities video games offer. But, games are usually far more demanding than other entertainment media "in terms of motor and sensory skills needed for interaction control, due to special-purpose input devices, complicated interaction techniques, and the primary emphasis on visual control and attention" [9]. According to the CDC, 1 in 4 US adults have some type of disability[4] making it challenging to play commercial games without custom hardware or in-game accessibility options from game developers. For individuals with severe motor impairments, gaming input methods present a significant barrier. With limited hand muscle control, actions of grasping or holding a game controller, moving or clicking a mouse, and pushing or pulling a joystick pose insurmountable problems. Additional challenges include pressing multiple keys and moving the mouse simultaneously, a common two-handed interaction mechanism in many video games. While a number of input devices have been developed to allow motor impaired players to interact with games such as mechanical switches [24], mouth and tongue controllers and joysticks [14, 23, 27], brain-computer interfaces [26], and eye-gaze controllers [7, 28], most of them are typically constrained with regard to the input they can provide when compared with the types of input required in conventional games.

In this work, we present the design of a hand-free gaming input system for quadriplegic gamers and demonstrate its use through the design of a First Person Shooter (FPS). The input system recognizes facial muscle movements in a realtime video stream and maps facial expressions (FEs) to actions in an FPS game. The system includes speech recognition which serves as a secondary input modality. While there is a lot of prior work that attempts to determine player emotions from their facial expressions, to the best of our knowledge, ours is the first implemented system that uses facial expressions as gaming input for individuals with several motor impairments.

## 2 RELATED WORK

There has been a lot of research in the past twenty years aimed at developing assistive technology (AT) devices to increase independence for individuals with motor impairments of various origins (e.g., locked-in-syndrome, amyotrophic lateral sclerosis, spinal muscular atrophy, quadriplegia, muscular dystrophy, cerebral palsy, etc.) [25]. We present a subset of that work here that is specifically

[1]https://www.nytimes.com/2020/07/31/business/video-game-meetings.html
[2]https://www.nytimes.com/2020/04/21/technology/personaltech/coronavirus-video-game-production.html
[3]https://www.npd.com/wps/portal/npd/us/news/press-releases/2020/the-npd-group-us-consumer-spend-on-video-game-products-continues-to-break-records/
[4]https://www.cdc.gov/media/releases/2018/p0816-disability.html


*CHI '21 Extended Abstracts, May 8–13, 2021, Yokohama, Japan*

ACM ISBN 978-1-4503-8095-9/21/05.
https://doi.org/10.1145/3411763.3451850

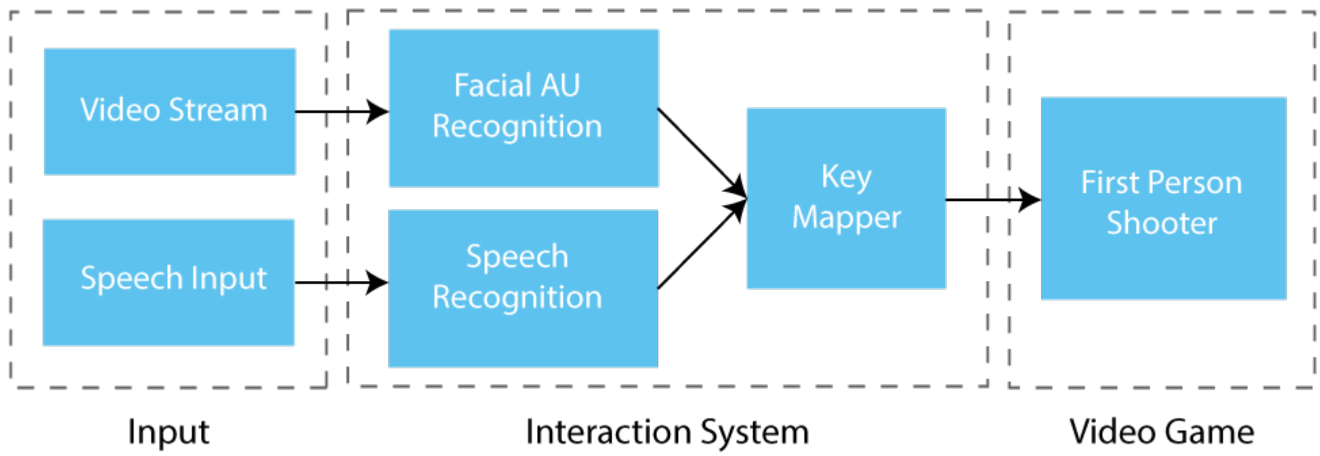


**Figure 1: The system pipeline showing input of video and speech data that is processed and converted to keyboard bindings for controlling action in the FPS game.**

related to interaction with video games, both for a broader audience of users with disabilities and for those with neuromuscular diseases.

### 2.1 Accessibility in Consumer Video Games

Increasingly, consumer games are starting to include accessibility options. For example, The Last of Us: Part II released in June 2020 offers around 60 accessibility options like directional subtitles and awareness indicators for deaf players or auto-target and auto-pickup for those with motor disabilities [5]. Sony has included a number of accessibility functions in the PS4 system[6], including text-to-speech, button remapping, and larger font for players with visual and auditory impairments.

In addition to adding accessibility options in commercial games, many special purpose desktop [19, 36] and virtual reality games [35] and input methods [38] have also been developed for those with visual disabilities. Players of a recently released game, Animal Crossing: New Horizons are using the game's customization options to make the game more accessible [7]. A leading example of an accessible game controller is Microsoft's Xbox Adaptive game controller that allows people with physical disabilities who retain hand/finger movement and control, to be able to interact and play games [18]. By connecting the adaptive controller to external buttons, joysticks, switches and mounts, gamers with a broad range of disabilities can customize their setup. The device can be used to play Xbox One and Windows 10 PC games and supports Xbox Wireless Controller features such as button remapping [2].

The solutions here, although accessible, are not usable by severely disabled people as they rely on hand-based controls. While both hardware and software solutions can increase game accessibility, we believe software solutions can be more affordable and customizable. In this work we explore the design of a software-based hands-free input system.

### 2.2 Game Input Methods for Quadriplegia

For individuals with severe motor impairments, there are limited options for playing video games without assistance. Most options are based on acquiring signal from parts of the body such as the tongue, brain, or muscles that the individual likely has voluntary control over. Tongue Machine Interfaces (TMIs) include tongue-operated switch arrays [29] or permanent magnet tongue piercings that are detected by magnetic field sensors [12, 14] to enable interaction with a computer. Leung et al. [16] presented a theoretical framework for using a multi-camera system for facial gesture recognition for children with severe spastic quadriplegic cerebral palsy. Müller et. al. [20] designed an in-car 2D game for children that uses the Affectiva SDK [8] to recognize three facial expressions for running, jumping and crouching. Brain-computer interfaces (BCI) have not become popular among users despite being researched since the early 1970s [17, 33] due to limitations of bandwidth and susceptibility to noise and interference [11]. Buttons or switches are the most commonly used game input method as they can be operated with any part of the body that is able to produce voluntary movement, enabling actions like sip and puff, pull, push and squeeze [37]. There are a few consumer products that allow motor impaired users to play video games. One Switch [31] is a non-profit dedicated to arcade style games that can be played with one switch. The QuadStick [27] is a mouth operated device available in three versions that allow interacting with a computer or playing video games. Depending on the version, it includes sip/puff pressure sensors, a lip position sensor, and a joystick with customizable input

[5] https://www.playstation.com/en-us/games/the-last-of-us-part-ii-ps4/accessibility/
[6] https://support.playstation.com/s/article/PS4-Accessibility-Settings?language=en_US
[7] https://kotaku.com/how-animal-crossing-new-horizons-players-use-the-game-1844843087
[8] https://developer.affectiva.com/

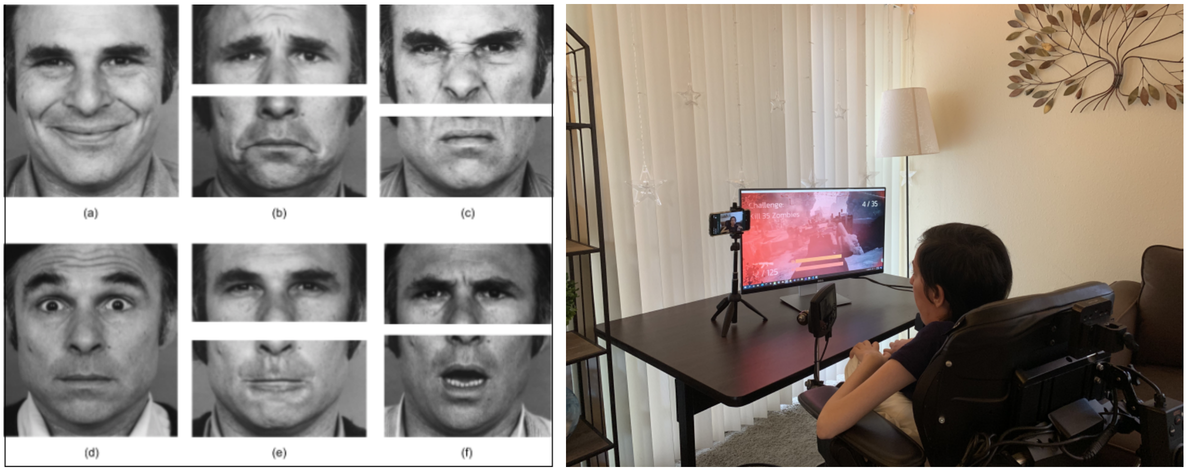


**Figure 2: Left: Six AU combinations used for playing the games [21]. Top row a) Happiness, b) Sadness and c) Disgust. Bottom row: d) Wide eyes, e) Lip and lid tightener and f) Jaw drop. Right: Atieh playtesting the FPS game at home, using her phone as the webcam.**

and output mapping. Quadstick has enabled players with severe disabilities play videos games and engage in social interaction through streaming on Twitch [9].

All these systems and devices have their unique affordances and limitations. Many have steep learning curves like the Quadstick [27] or are constrained in the type of input they provide (e.g., switches) when compared with the types of input required in conventional games. Our software-based design enables complex inputs in a non-invasive and inexpensive manner and it does not require the user to wear any devices. To the best of our knowledge, facial expression recognition has not yet been investigated in the context of game interaction for quadriplegic individuals.

## 3 INPUT INTERFACE DESIGN

Assistive Technologies (AT) are are usually designed for the individual, showing the greatest amount of success when developed with and tested by the potential end user [30]. In this work we take the AT approach to collaboratively design and create an FPS game and a facial input interface with one quadriplegic graduate student, Atieh. Due to SMA, Atieh is no longer able to use their hands to grasp and push mouse buttons or use the keyboard and mouse simultaneously. The fundamental idea behind the design was to make the most out of the voluntary muscle control that Atieh has over their facial muscles. To create an easy to use low cost facial muscle detection system we chose to use a camera-based system vs an EEG-based system as shown in prior work [30].

In the 1970s, Ekman and Friesen [4] categorized into *Facial Action Units (FAUs)* which form the *Facial Action Coding System (FACS)*. To detect AUs for input in our gameplay interface we use the OpenFace 2.0 toolkit [3], hereon referred to as OpenFace. Our interaction interface has four main parts: 1) facial action unit (AU) recognition, 2) speech to text conversion, 3) AU and text to keyboard mapping, and 4) FPS design and gameplay. Figure 1 shows the system pipeline.

Input from the webcam and the microphone is sent through the interaction interface to the keyboard mapper, which converts them into keyboard inputs for the game. We used Unreal Engine (UE) version 4.25.1 for building the FPS game. Game logic was created using UE’s Blueprint system.

In our pipeline, AU detection takes two forms: 1) AU presence or absence - a binary value depicting whether a particular AU is present in the captured frame or not, and 2) AU intensity - a real value between 0.0 and 5.0 depicting the intensity of the detected AUs in a captured frame. OpenFace provides access to 18 AUs of which we discarded AUs 14, 17, 20 because of similarity to other AUs and removed AU45, which detects blinking. We extract AUs from the input video stream in realtime and translate that data through our keyboard mapper into game input (Table 1). The AU combinations used for the FPS game are based on facial expressions that Atieh could comfortably make and that were reliably detected by OpenFace. The numbers in Table 1 show the AU intensity threshold values for the AU combinations that were used for playing the FPS game. We built a customization interface on top of OpenFace to enable users to change both the sensitivity of the detected AUs and the mapping of AUs to game actions. We used a Python speech recognition library [32] to communicate with Google Cloud Speech API [8] for converting spoken commands to text. Text keywords like “Walk” or “Yes” are converted into keyboard input using Pynput [22]. Because speech is processed in the cloud, speech interaction can be slow due to network latency and is thus not the primary form of interaction in the FPS game which requires faster input. It is included as a modality for interactions that are not time dependent such as menu selection, pause/restart etc.

Facial expressions and speech-to-text keywords are mapped to keyboard input through the keyboard mapper. To prevent continuous mapping an AU needs to be detected in at least five consecutive frames before it is mapped to the keyboard. This frame number was arrived at through playtesting and helps improved detection reliability and reduces frustration of detection in each frame. The frame

[9]https://www.washingtonpost.com/video-games/2019/10/14/its-my-escape-how-video-games-help-people-cope-with-disabilities/

| Facial AU Combination with Threshold Values | Muscle Movements Involved | Facial Expression | Keyboard Key | Game Action |
|---|---|---|---|---|
| $AU6 > 2.0 \bigotimes AU12 > 2.0$ | Cheek Raiser + Lip Corner Puller | Happiness | 1 | Start/Stop Walking Forward |
| $AU1 \bigotimes AU4 \bigotimes AU15$ | Inner Brow Raiser + Brow Lowerer + Lip Corner Depressor | Sadness | 2 | Aim and Shoot |
| $AU9 > 1.4 \bigotimes AU10 > 2.0$ | Nose Wrinkler + Upper Lip Raiser | Disgust | 3 | Start/Stop Turning Left |
| $AU1 > 1.0 \bigotimes AU2 > 0.5 \bigotimes AU5 > 1.5$ | Inner Brow Raiser + Outer Brow Raiser + Upper Lid Raiser | Wide Eyes | 4 | Start/Stop Turning Right |
| $AU7 > 1.4 \bigotimes AU23 > 1.0$ | Lid Tightener + Lip Tightener | Lid & Lip Tightener | 5 | Start/Stop Walking Backward |
| $AU4 \bigotimes AU25 \bigotimes AU26$ | Brow Lowerer + Lips Part + Jaw Drop | Jaw Drop | 6 | Jump |

**Table 1: Facial AU combinations with their intensity thresholds in column one (no value means AU presence/absence binary data was used). If each AU intensity in an expression is greater than the specified threshold value, the corresponding key press in that row is triggered. The next two columns present the muscle movements corresponding to each AU and their equivalent facial expressions. The last two columns specify the facial expression to keyboard key and FPS game action mappings.**

threshold prevents the system from responding to non-input expressions or unplanned facial muscle movements. We also attempted to match facial expressions to game actions based on Atieh's associations. For example, smiling is mapped to moving forward and frowning is mapped to aiming and shooting.

## 4 FIRST PERSON SHOOTER DESIGN AND GAMEPLAY

To demonstrate our hands-free input system, we designed a single-player 3D FPS game. The mapping of keyboard keys to game actions is shown in Table 1. The mapping was created with ease of use, memorability, frequency of use, muscle fatigue, and robustness of detection in mind after discussion and playtesting with Atieh. In the FPS game, the player needs to kill 20 zombies before they kill you. The game gets progressively challenging as more zombies spawn over time. While we did not add an ammo limit, it is important for the player to be mindful about their ammo usage because of a conservative reload system and limited ammo pickups on the map. Our goal was to create a game that closely matches a consumer FPS game in order to give Atieh a realistic FPS experience. After the first playtest, Atieh emailed:

> "All these years that I have had lost my ability to use my hands to grab game controllers or even since when I realized that using a keyboard and a mouse have become impossible I desperately looking for finding a way to regain those things that one day were my only way of having some entertainment in my life and the more I pursued the more I became disappointed and eventually gave up. But trying out this tool gave me hope that I still can go into the game world once again."

To build the game, we started out by modifying a third person shooter game template available through the Epic Games launcher [10]. The game map was built using a free asset called Infinity Blade: Ice Lands [5]. Speech recognition latency was too high for an FPS game. We therefore incorporated voice control only for enabling the character to manually reload their weapon instead of auto reload, for pausing gameplay, and for navigating the menus. The zombies, the game character and related animations were downloaded from Mixamo [1], an online service that provides free to download 3D character models and animations. In Unreal Engine, the animation blendspace was pieced together with the animation logic for FPS controls that included jumping, shooting, scoping, reloading, walking, etc. Similarly, the animation control for the zombies was created. A raycast system was used for shooting the zombies, adding sound effects and displaying a light flash from the tip of the gun. For the zombie horde logic, a pathfinding algorithm was used to make them move towards the player, only if the player was within range of the zombie. A horde system was created to spawn new zombies based on where the player's heading and taking into account the total number of zombies on the map at any moment. The zombies spawned at locations marked by trigger boxes placed along pathways to prevent spawning at random locations on the map. This also created an effect of their being more zombies than there were, which not only helped performance but also made the game feel higher action.

After playtesting, Atieh found the game too challenging to play with facial input because of the fast pacing. To make the game fun and playable without making it too easy, we reduced the zombie movement speed by half and their count to 15 in addition to adding an auto-aim feature using the **sadness** expression (Table 1). To make the auto-aim feature, we replaced the raycast shooting feature since the player needed to aim and shoot simultaneously. Our solution was to turn the player by a calculated amount every frame

[10] https://www.unrealengine.com/en-US/

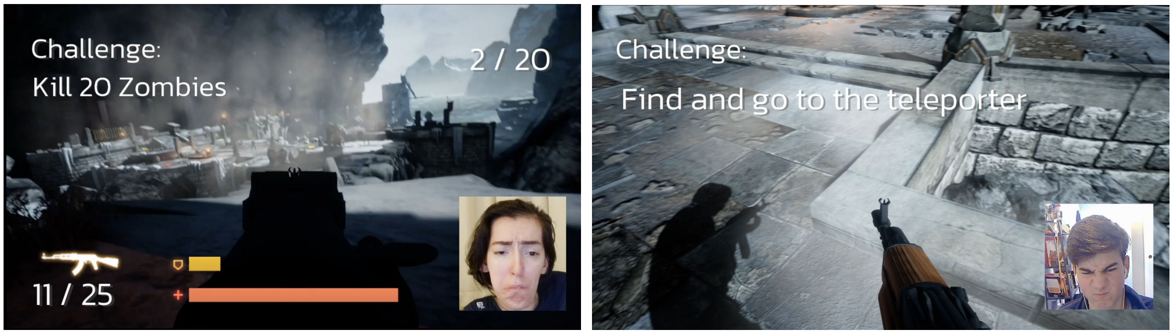


**Figure 3: Left: Player shooting zombies in the FPS game using the *sadness* facial expression shown in inset. Right: Player turning using the *disgust* facial expression shown in inset.**

such that the scoped gun would be pointed at the nearest zombie within a certain range. The effect of shooting a zombie was created by running the hit feature each time the character shot instead of when a raycast hit the zombie. This also helped improve the game's performance slightly. After the changes, Atieh emailed to say:

> "You know what was the most fun part about this system? In one of my playtesting it, one of my friends sat next to me and started telling jokes to make me laugh and so to do unwanted actions in the game and to make me lose the game. It was really really fun that for the whole game I was attempting to ignore him and play my game, although I was not successful all the time."

A challenging aspect of using facial expressions for input was player turning (left or right) which involves camera rotation, character model rotation and the turning animation to happen simultaneously. On a conventional game, the camera is usually controlled by the mouse and the turning is accomplished by holding down a keyboard key, which the player has full control over. We needed to accomplish the same effect in our game in a way that the player felt like they were in control of the turning with a facial expression. Our solution was to use a facial expression as a toggle to start and stop the turning. The turning speed and amount of turning were estimated and then iteratively play-tested and improved for comfort and control. Logic to determine if the expression toggle would continue turning the character in the same direction or reverse turning, was incorporated. To make the game more engaging without adding extra facial controls, pickups were placed around the map that would automatically get added to the player's inventory when they were in its proximity. We included health pickups and ammunition pickups. For added interest, we created a pickup that enabled a one-shot mode for a brief period of time, which weakens the zombies killing them with a single shot as opposed to seven shots otherwise. For creating tension and atmosphere, we added some action background music.

After a full playthrough of the game, Atieh emailed this:

> "[I]t is smooth and it did not frustrate me playing whereat of the time any assistive tool that are released for people with disability, would somehow need the person an exhausting effort. If you notice, for example when the character shoots the zombies, it is only a matter of lowering your lips and eyebrows which is very simple. For me, it is a fun experience...I just wish it was a multi-level game."

## ACKNOWLEDGMENTS

We would like to thank Mengyu Chen for his help with the video.

## 5 CONCLUSION

In this work, we explore the design of a hands-free game input system designed in collaboration with a quadriplegic player. We demonstrate the system through the design of a first person shooter game. We believe our facial expression recognition based system can be easily customized for players of different abilities, as long as that individual has voluntary control over their facial muscles. With a growing number of game developers and companies including accessibility options into the games, we are hopeful that facial expression recognition based input would also become a standard option, opening up the world of gaming to Atieh and others like her.

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