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Dynamic Difficulty Adjustment in a Virtual Reality Affective Video Game

Relatore: Prof. Pier Luca LANZI

Correlatore: Prof. Andrew JOHNSON

Tesi di Laurea di:

Simone AMICO Matr. 877012

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Milano, October 2018

S. A.

to my family and my grandparents

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Abstract

One of the main problems that most developers have is how to address the right difficulty of a game in a dynamic way to satisfy all the players that have different skills and different attitudes toward the game. The most used method to achieve this goal is the performance-based dynamic difficulty adjustment (DDA), i.e. modifying the difficulty of the game according to the score of the player. Often, it is not enough to rely only on the score to adjust the game's difficulty. It is important to consider the emotional state of the person because each player is different and can enjoy playing the game in different ways. This is why affective-based DDA methods should be considered to adjust the difficulty of a game. Moreover, thanks to Virtual Reality, people can do physical exercises while playing the game and motivating them by implementing the best DDA method is even more important. In this thesis I first discuss the performance-based and affective-based methods implemented in other games and researches, and the background theory related to flow, arousal, and skin conductance. Then, a Virtual Reality game called ETNA (Entertaining Training Neuro Affective) has been developed in 3 variants, one implementing a performance-based only DDA, one implementing an affective-based DDA only, and one implementing a mixed perfo-affective DDA, with both of them active at the same time. Two version of the game were developed (ETNA v1 and ETNA v2) and two user studies were conducted. The results showed that affective gaming can be implemented in Virtual Reality to improve the overall gaming experience if the player is highly immersed inside the game and that the perfo-affective method was the best method (in ETNA v1). If the player was not immersed inside the game and got easily distracted, the affective based DDA variants did not obtain good results and the best was the performance based DDA (ETNA v2).

Keywords: Dynamic Difficulty Adjustment, Virtual Reality, Skin Conductance, Video Game

Sommario

Uno dei maggiori problemi che hanno quasi tutti gli sviluppatori di video games è il trovare un modo per modificare la difficoltà del gioco in maniera dinamica con il fine di soddisfare tutti i giocatori che hanno differenti abilità e differenti attitudini nei confronti del gioco. Il metodo più usato per raggiungere questo obiettivo è attraverso l'adattamento dinamico della difficoltà (DDA) basato sulle performance del giocatore. Spesso non basta affidarsi solo sulle performance per aggiustare la difficoltà del gioco. È importante considerare anche lo stato emotivo del giocatore perché ogni persona è diversa e può divertirsi giocando in modi diversi. Ecco perché bisognerebbe considerare l'uso di metodi basati sullo stato emotivo dell'individuo per modificare la difficoltà di un gioco. Inoltre, grazie alla realtà virtuale, i giocatori possono fare esercizio fisico mentre giocano e diventa ancora più importante il motivarli a giocare implementando il migliore algoritmo possibile. In questa tesi inizialmente sono discussi i metodi basati sulle performance e sullo stato emotivo implementati in altri giochi e ricerche e la teoria relativa al concetto di "flow", "arousal" e conduttanza della pelle. Successivamente, è stato sviluppato un gioco in realtà virtuale chiamato ETNA (Entertaining Training Neuro Affective) in 3 varianti: una che implementa un DDA solo basato sulle performance, uno solo basato sullo stato emotivo e uno basato su un mix dei primi due attivi in contemporanea. Sono state sviluppate due versioni del gioco (ETNA v1 e ETNA v2) e sono stati condotti due studi su persone. I risultati dimostrano che possono essere sviluppati "giochi affettivi" in realtà virtuale per migliorare l'esperienza di gioco generale del giocatore se egli è altamente immerso all'interno del video gioco. In questo caso il metodo migliore è risultato essere quello basato sul mix tra performance e stato emotivo (ETNA v1). Se il giocatore non è totalmente immerso all'interno del gioco e si distrae più facilmente, le varianti basate sullo stato emotivo non hanno ottenuto buoni risultati e il metodo migliore è risultato essere quello basato sulle performance (ETNA v2).

Parole chiave: Adattamento Dinamico della Difficoltà, Realtà Virtuale, Conduttanza della pelle, Video Game

Introduction

The video game industry is growing year after year and is the 4th largest entertainment market in the world behind gambling, reading, and TV and exceeds movies and music in popularity. In 2016 it generated globally around US\$101.1 billion and is expected to arrive to US\$128.5 billion by 2020 (McDonald, 2017, Wikipedia, 2018).

In the last 10 years, some big companies like Microsoft with Kinect and Nintendo with Wii have improved the interactivity between the player and the game by including gamer movement, opening a lot of new possible uses of video games. One of the most important improvements is the possibility of doing physical activity while playing the game, that was one of the greatest weakness of traditional gaming that requires the player stay in his seat without moving for hours.

Recently the interactivity between the player and the video game has improved even more thanks to virtual reality. With virtual reality the player can fully immerse himself into the virtual world while moving also across a predefined zone. Therefore, virtual reality can be used also to make physical activity and exercises less tedious both for casual and medical uses (Kim, 2016).

To exploit all the strengths of virtual reality and to be really entertaining, a video game should be neither too easy nor too hard and this is not a simple problem to solve in game design.

Problem Definition

As said before, one of the most challenging problem in game design is how to address the right difficulty in the game to entertain the player and let him feel always challenged and not bored (game too easy) or frustrated (game too difficult). There are two main methods that are used for changing the level of difficulty of a video game: through *difficulty selection* and with *dynamic difficulty adjustment* (DDA).

The most commercially used solution to solve this problem is the method of *difficulty selection*: the player can choose the level of difficulty while playing the game between some predefined values (e.g. easy, medium, hard). This one is the easiest to develop because the choice relies only on the player but it is less efficient because the level of difficulty does not adapt automatically to the player's skill level or physical state. A more efficient way to do it is with *dynamic difficulty adjustment*. This can be done mainly in two ways: performance-based and affective-based. Both of them introduce non-trivial game design issues. The performance-based method changes the game at run-time according to the player's capabilities, while the affective-based one changes it according to physiological parameters, such as skin conductance

(SC), heart rate (HR), facial recognition, etc.

For the affective-based method skin conductance will be used to evaluate the arousal of the player during the game and try to adjust it to reach the optimal arousal level. This optimal level is not fixed, changes from person to person, and also from task to task.

Objective

This thesis will be focused on implementing dynamic difficulty adjustment to change at run-time the difficulty of a virtual reality (VR) game in both ways: based on the performance of the player and based on the affective state of the player. For this thesis a VR game called ETNA (Entertaining Training Neuro Affective) was created in three variants: one implementing a performance-based only DDA, one implementing an affective-based DDA only, and one implementing a mixed perfo-affective DDA, with both of them active at the same time. The affective part was done using skin conductance values collected through an external commercial device, MindLAB Set¹. In my research, I only collected skin conductance in the affective-based DDA as it is one of the less intrusive physiological signals to measure. Its levels are related to the arousal of a person and rise with the increasing of the difficulty of given tasks (Frijda, 1986). Therefore, the objectives of the thesis are: a) creating an efficient affective-based DDA based on skin conductance and b) seeing which method gives the best results in a VR Game.

In order to achieve the objectives, two versions of ETNA were created and two user studies have been conducted.

Thesis Overview

Chapter 1 gives to the reader general background knowledge about psychophysiology, arousal, the concept of flow, and skin conductance, and how all of them are related to each other.

In *Chapter 2* related researches is discussed in the field of dynamic difficulty adjustment, in the use of skin conductance in games, and in the rationale of using virtual reality to achieve the optimal flow.

Chapter 3 explains in details the game developed for the thesis, called *ETNA* (*Entertaining Training Neuro Affective*), focusing on how performance-based and affective-based DDA have been implemented.

In *Chapter 4* I discuss how the user study for ETNA v1 has been conducted and the results that can be deduced from it, coupling the survey data with the in-game data.

In *Chapter 5* I discuss how the user study for ETNA v2 has been conducted and the results that can be deduced from the in-game data, comparing them with the results collected after the user study done for ETNA v1.

Finally, *Chapter 6* is a summary of the work and the results gathered from the user studies.

¹<http://www.psychotech.it/pages/en/mindlab-set.php>

Chapter 1

Background Knowledge

In this chapter I am going to talk about all the information needed to fully understand the thesis work. Starting from the psychological theories related to emotions through the application of them in the game design process to adjust game difficulty.

1.1 Psychophysiology

Psychophysiology is the branch of psychology which focuses on the biological processes that happen inside our body and how they are influenced from internal and external stimuli. Its primary aim is to explore how the mind and body interact ([Andreassi, 2013](#)). Some of the strongest concepts related to psychophysiology are the theories of emotions.

1.1.1 Emotions

Emotions play a crucial role in our lives, we use them mainly in three areas: intrapersonal (within each of us individually), interpersonal (between individuals in a group) and social-cultural (in the maintenance of social order within a society) ([Hwang and Matsumoto, 2016](#)).

There are several theories of emotion classification that range from a discrete approach to a dimensional one. The most used is the circumplex model of emotion developed by James Russell ([Russell, 1980](#)) that classifies emotions into two components: valence and arousal ([1.1](#)).

Valence (horizontal axis) is related to how positive an emotion is: positive emotions have high valence, like happiness, while negative emotions have low valence, such as sadness. Arousal (vertical axis) is related to the intensity of an emotion: low intensity corresponds to low arousal, like calmness, high intensity corresponds to high arousal, such as excitement. Different combinations of arousal and valence generate different emotions.

In the recent years a lot of research has been focused on how to recognize and evaluate changes in the emotional state through physiological changes of the human body. The changes can be external, such as facial expression, or internal, like heart rate (HR) or skin conductance (SC). These physiological manifestations of emotion

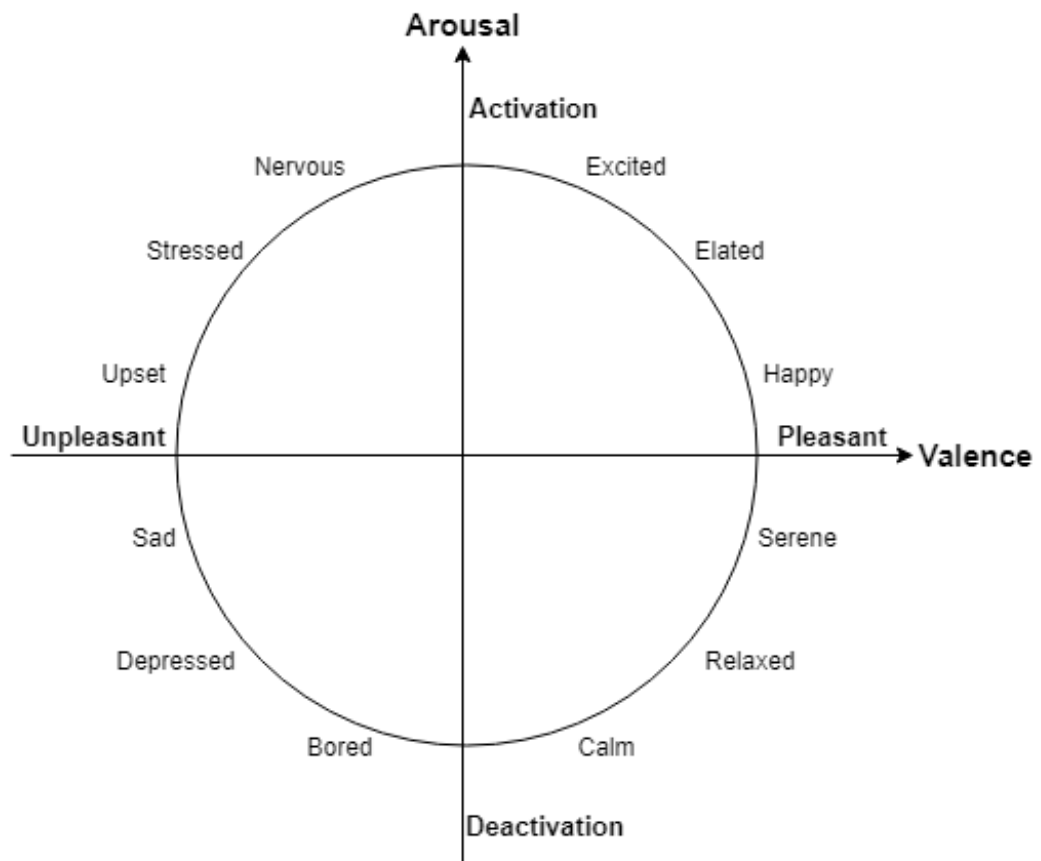


Figure 1.1: Circumplex model

are triggered by the autonomic nervous system, the component of the nervous system which governs the unconscious activities of the body (Kreibig, 2010). So to evaluate an emotion, it is possible to measure the physiological changes in the body. Some of them give information only about the arousal of a person, like HR and SC, while some others tell only about the valence, like the facial expression. One of the most used physiological parameters concerning arousal is the electrodermal activity (EDA), in the past called also Galvanic Skin Response (GSR). More precisely, the most used and widely studied EDA property is skin conductance (Braithwaite et al., 2013).

1.1.2 Skin Conductance

Skin conductance is a measure of how electrically conductive the skin is. It can be measured by passing a small electrical current through the skin and is directly related to the arousal of a person. It is probably the most useful indicator of arousal because people can't explicitly control their skin conductance levels and it is not affected by other body functions (like heart rate). Skin conductance is also a good indicator of cognitive activity (Shi et al., 2007) and is used also to recognize the player's emotion during interaction with video games (Mandryk and Atkins, 2007). Historically, research in the field of skin conductance began in 1849 when Dubois-Reymond in Germany noticed that human skin was electrically active. Around 30 years later, in 1878, in Switzerland, Hermann and Luchsinger found a correlation between sweat gland activity and electrical current in the skin (Boucsein, 2012). How does skin conductance work? The skin is the principal interface between ourselves as an organism and the environment. It is extremely important for actions related to our body like regulating the immune system (protective barrier), thermoregulation and is really important in the maintenance of the body's water balance. Temperature and water regulation are done thanks to the production of sweat that is regulated by the sweat glands. There are two types of sweat glands: the eccrine and the apocrine. The relevant one concerning skin conductance are the eccrine sweat glands. Their quantity varies across the body but the greatest number can be found on the palms, fingers, and on the sole of the feet. When those glands are triggered, they secrete moisture through skin's pores. Since the proportion of ions in the produced fluid changes, the skin conductance value changes accordingly. The most interesting fact is that even if the primary purpose of sweat emission is the regulation of body temperature, sweat is also triggered whenever we are emotionally aroused and responds more to those stimuli than to the thermal ones. That happens because sweat secretion is driven and balanced by our autonomic nervous system, specifically by the sympathetic nervous system (iMotions, 2016). The skin conductance signal is made up of two major components: tonic (related to the slower changes of the signal) and phasic (related to the faster changes). The most common measure of the tonic level is the skin conductance level (SCL) and it reflects changes in the arousal of subjects. The phasic refers to the skin conductance responses (SCRs) that can be event related (ER-SCRs, attributed to a specific eliciting stimuli) or non specific (NS-SCRs, that occur in the absence of an identifiable eliciting stimuli) (1.2) (Braithwaite et al., 2013).

If the research aim is to identify responses to a particular stimuli (like an image)

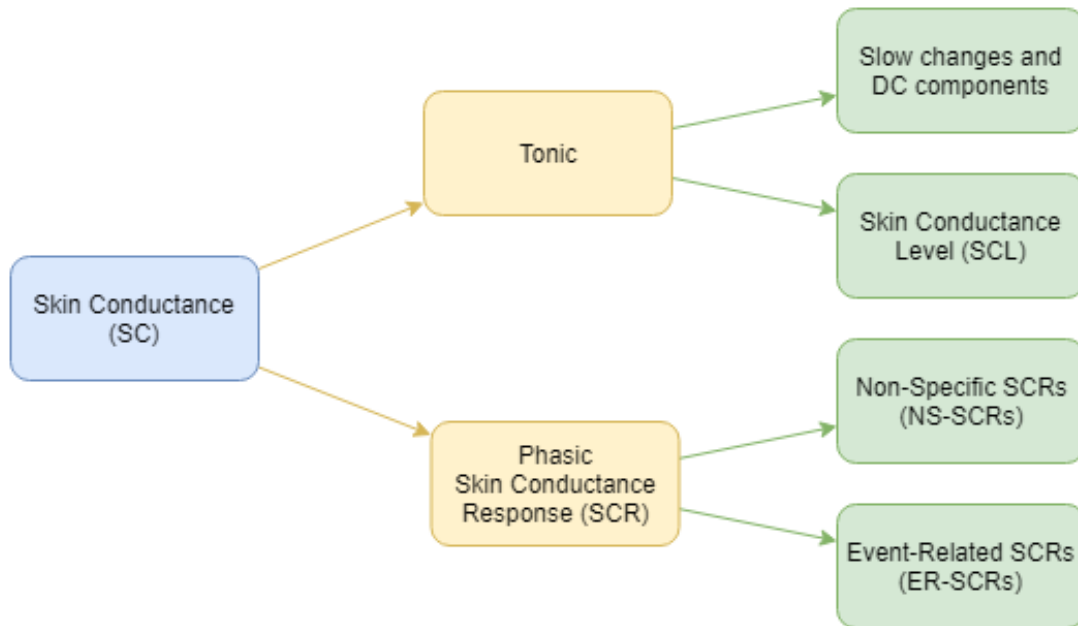


Figure 1.2: Skin Conductance components diagram

the component to measure is SCRs (precisely ER-SCRs). If the aim is to measure the physiological arousal over an extended period of time, the most appropriate component to measure is the SCL.

The reader can have a better comprehension of these two main components looking at 1.3. The black curve is the SCR, with the peaks in the white rectangles (fast changes) and the blue line is the SCL (slow changes).

Researches supporting the use of skin conductance to evaluate arousal while playing video games will be discussed in section 2.2.

1.2 Arousal Theory, Yerkes-Dodson Law, and Flow

The arousal theory of motivation affirms that the main reason people do any action is to keep an optimal level of physiological arousal and this optimal level differ between individuals (Psychestudy, 2017a). If our arousal is too low then we are going to be motivated to engage in behaviours that will increase arousal and if our arousal is too high then we will be motivated to engage in behaviours that will help to reduce our arousal level.

We can think also about how our level of arousal is associated with our performance on different tasks and this brings us to the Yerkes-Dodson Law (Psychestudy, 2017b). The idea of this law is that we have peak performance at a particular, optimal, level of arousal. Whether arousal is too low or too high both will result in impaired performance, following an inverted U-model (1.4).

All of this leads to the "flow", which is the sense of full and motivated concentration in a task, with a great level of fun, satisfaction and productivity. It was coined by the Hungarian psychologist Csikszentmihalyi that identified eight main components necessary to achieve flow (Chen, 2007):

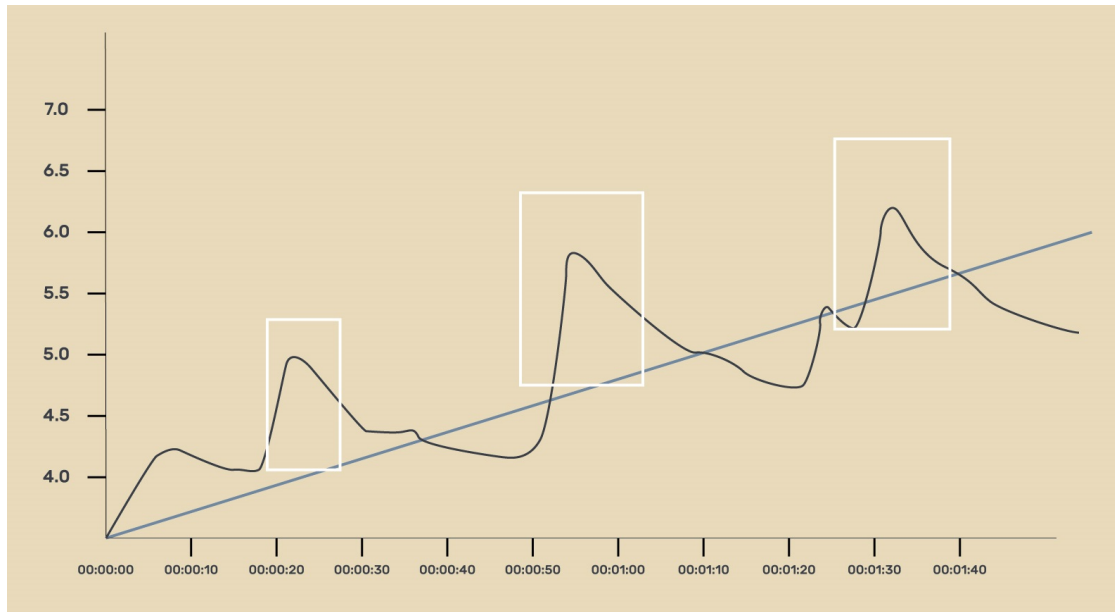


Figure 1.3: Skin Conductance plot example

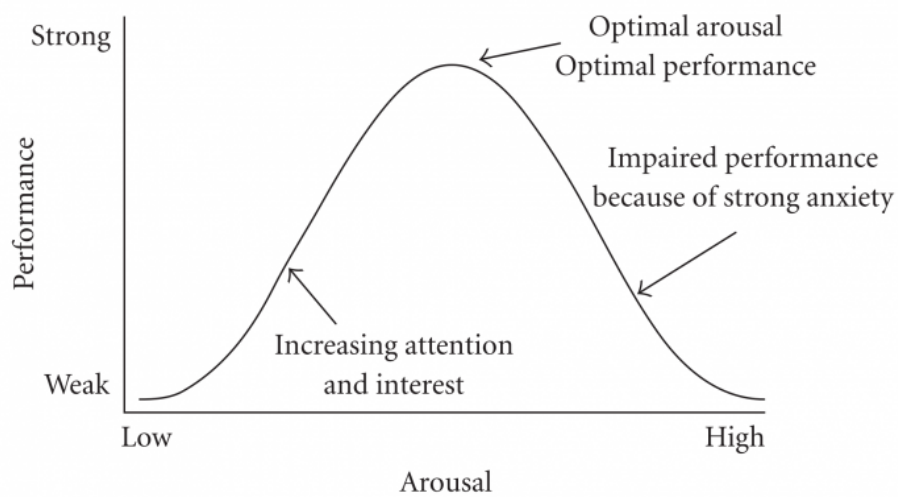


Figure 1.4: Yerkes-Dodson Law ([contributors, 2018](#))

- "A challenging activity requiring skill"
- "A merging of action and awareness"
- "Clear goals"
- "Direct and immediate feedback"
- "Concentration on the task at hand"
- "A sense of control"
- "A loss of self-consciousness"
- "An altered sense of time"

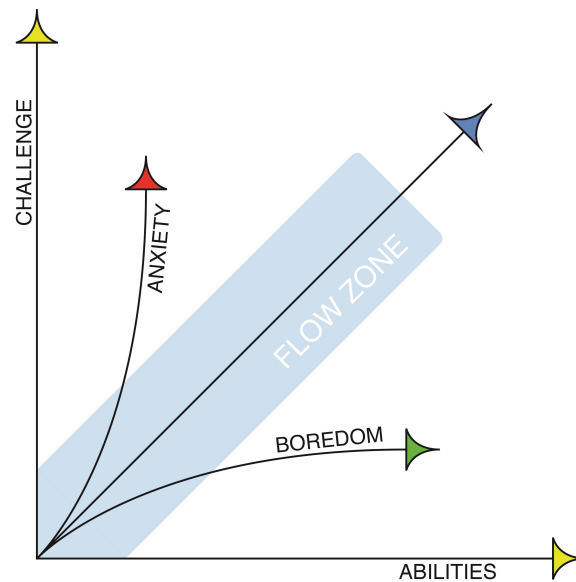


Figure 1.5: Flow zone factors

The concept of flow can be represented on a chart with the skill level of a person along one axis and the difficulty of a task along the other one (1.5). If the challenge is greater than the skills of a person, the task becomes too difficult and it causes frustration. If it is too low and does not engage the player, he loses interest and becomes bored. The optimal zone usually stays in the middle and is called "Flow Zone". The design of any interactive experience, like videogames, is centered on how to maintain people inside the "Flow Zone" while they are playing. The game must adapt its difficulty level to reflect the correct balance of challenge and ability and therefore maintain players in the "Flow Zone". But as the size of the audience increases, designing such a balance becomes a more difficult task because players can have different approaches to the game (1.6) (Chen, 2007). Hardcore players are the category of people who like to play games where the difficulty is a little bit higher than their skill level, while novices are the ones who like to be in control of

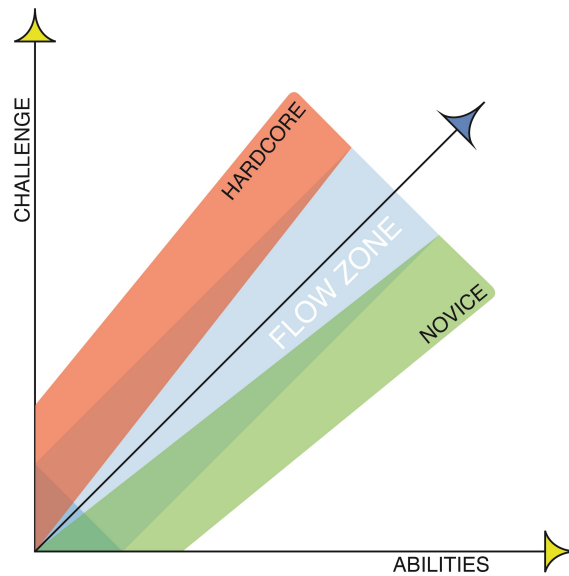


Figure 1.6: Different Flow Zones per player

the game and so they want to maintain their skill level a little bit higher than the difficulty of the game.

There are two main ways to solve this problem: with active flow adjustment or passive flow adjustment. The simplest is the active flow adjustment, through which are provided different in-game choices to the players, so that the game can adapt to the single player's game style (1.7).

In better approaches (passive flow adjustment), the game should adapt dynamically and automatically to each users' personal Flow Zone. All of this is achieved using DDA methods that generate a feedback loop between the player and the game to tailor the experience on him. Different approaches to achieve this are discussed in [section 3.1](#).

1.3 Affective Gaming

Why we play video games? There can be many different answers to this questions: because we want to have fun, to challenge ourselves, to get excited, and so on. All of those answer have a common thread: emotions. We want to play video games (or games in general) because they can induce in us some emotions. They can sometimes be good, like excitement, and sometimes bad, like frustration because the game is too difficult. But usually games do not respond to the players' emotion, they only respond to the user input from the game controller, there is no feedback, no loop. Researchers in the affective gaming field want to fill this gap adding an emotional intelligence in the video game ([Gilleade, Dix, et al., 2005](#), [Gilleade and Allanson, 2003](#)). In order to do that, first it is necessary to collect some physiological parameters of the person with some devices, then the game should be able to sense and understand the player's emotions to modify itself

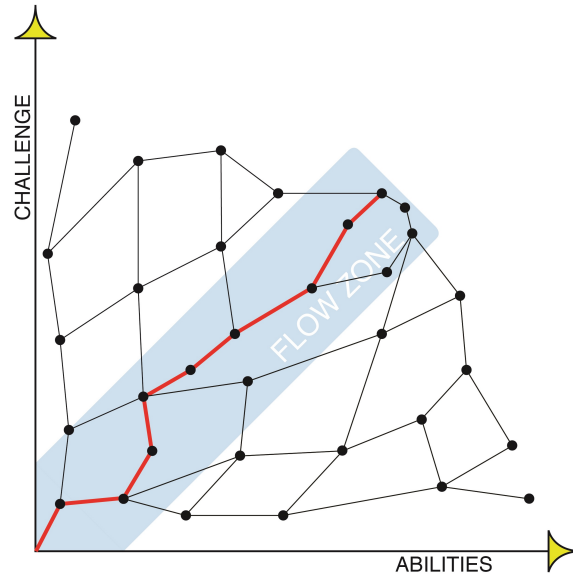


Figure 1.7: Players' Flow adaptation through in-game choices

according to them. Concerning the first part, there are many different physiological signals that can be considered, such as skin conductance, heart rate, respiration, face recognition, blood pressure, electromyogram, pupil tracking and so on. Some approaches have also focused on studying the correlation between the difficulty of a game and the intensity with which the player presses the buttons (Sykes and Brown, 2003). For the second part, there are three main ways a game can be influenced by affective parameters (and so it becomes an affective game):

- *Assist me*: measuring frustration of the player and combining it with information from the game context, it is possible to understand when a player is stuck somewhere and is not enjoying the game as they should (e.g. does not know where to go or how to kill a boss). When a situation like this is recognized, the game can provide clues to the player to help them and let them enjoy the experience more.
- *Emote me*: providing a full and effective emotional experience to the players, measuring their emotional state and modifying the game content to induce again the expected emotions.
- *Challenge me*: is essentially the application of the theory of flow with affective-based DDA, the major focus of this thesis. The player's engagement in a game is measured through his arousal level and this can be used to change in a dynamic way the difficulty of the game to let the player stay inside their personal optimal flow zone. This will be discussed more deeply in [section 3.1.3](#).

Not all the games are suited to be affective games. For example, genres like role-playing and strategy usually last for a longer time and are played slower, so it

is very difficult to notice relevant changes of physiological parameters throughout the gameplay.

One of the most important features in affective games is that physiological responses from the player should not be controlled. If the player can control and consciously manipulate his physiological parameters as a means of interaction, the game becomes a biofeedback game.

An example of a biofeedback game is *Relax-To-Win* (Bersak et al., 2001), a competitive racing game where two players control a dragon and their objective is to arrive first to the end of the level. SC is evaluated to see how much a player is relaxed. The more relaxed the player is, the faster his dragon moves. In this way the players use their biofeedback as an additional input to the game and have to control it in order to win the game.

However, biofeedback games are not the focus of this research.

Chapter 2

State of the Art

In this chapter I am first going to describe the current methods for adjusting the difficulty of games, also providing examples of commercially available games or made for research purposes that adopted those methods. Then I will talk about the research that supports my choice to use the skin conductance as a physiological parameter to evaluate during a game experience. In the last section, I will discuss similar research done in the field of virtual reality games and why it should be better than normal non-VR gaming.

2.1 Changing difficulty in games

The entertaining level of a video game is strongly based on the difficulty of it related to the skill of the player and to the attitude of the player toward the game. In order to be really entertaining, a video game should be neither too easy nor too hard for the player and this is not a simple problem to solve in game design. There are two main methods that are used for changing the level of difficulty of a video game: through *difficulty selection* and with *dynamic difficulty adjustment* (DDA).

2.1.1 Difficulty Selection

As said before, one of the most challenging problems in game design is how to address the right difficulty in the game to entertain the player and let him always feel challenged and not bored (game too easy) or frustrated (game too difficult). The player should be in his optimal flow zone, with the optimal arousal level. The most used solution to solve this problem is the method of *difficulty selection*. The player can choose the level of difficulty while playing the game between some predefined values (e.g. easy, medium, hard). This one is the easiest to develop because the choice relies only on the player but it is not so efficient because it does not adapt automatically to the player's skill level or physical state. An example of this approach can be found in almost all of the commercial games. In the soccer game *FIFA* you can change the difficulty of a match when it starts between 5 values and you cannot change it during the match. In the RPG *The Elder Scrolls V: Skyrim* you can change the difficulty of the game too (between 6 values), but at a certain point your skills and your character can become so strong

that you will be bored even playing with the strongest difficulty (2.1).

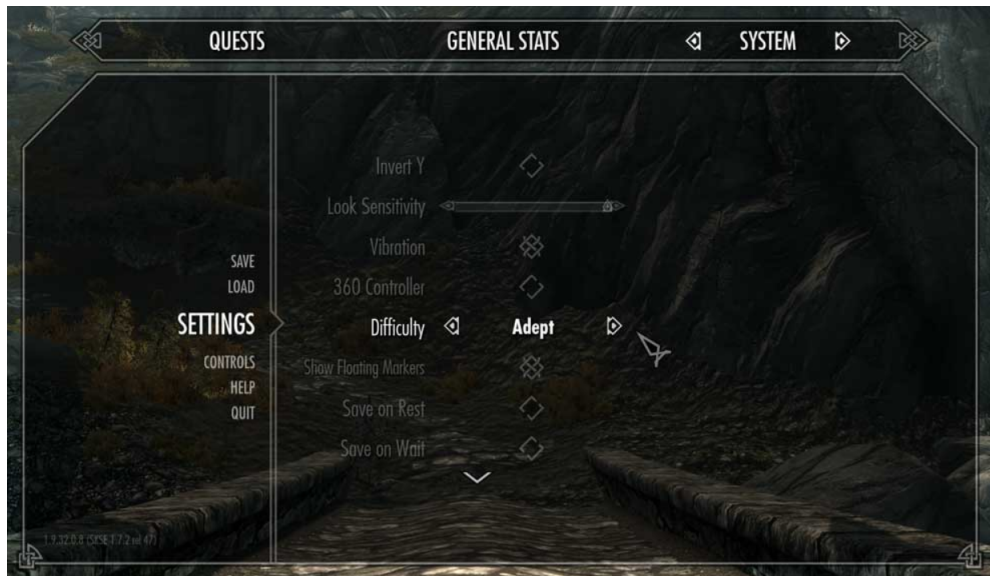


Figure 2.1: Skyrim’s settings menu

In *Grand Theft Auto* or *The Sims* you can use cheat codes to ease the game and increase the fun.

A more efficient way to achieve a better balance between challenge and player’s skills that leads to optimal flow is with dynamic difficulty adjustment. This can be done mainly in two ways: performance-based and affective-based. Both of them introduce non-trivial game design issues.

2.1.2 Performance-Based DDA

Performance-based DDA changes the game at run-time according to the player’s capabilities.

According to a study conducted by Bailey and Katchabaw (Bailey and Katchabaw, 2005), the most important thing to focus on when developing a performance-based DDA is to recognize what adjustments to make and when and how to make them. If this is not done with the proper attention, we can negatively affect the experience, such as interrupting the immersion of the player.

To answer at the first question (*what* to adjust), four gameplay elements should be considered:

- *Player character attributes*: some player parameters such as speed, strength, jump force, health regeneration and so on, can be decreased to increase the difficulty. The opposite to make the game easier. This solution works better with non-VR games because some components like speed, jump force can’t change in some VR games where the character movements are mapped onto the player ones.
- *Non-player character attributes*: all the characters controlled by the game’s artificial intelligence can change their behaviour and attributes to decrease

or increase the difficulty of the game. An example could be to have smarter non-player characters to increase the difficulty or less intelligent to decrease it.

- *Game world and level attributes*: the game world changes depend a lot on the type of game. For example in platform games the map can be modified to change the size of gaps, smaller to decrease difficulty and larger to increase it. Relating to level attributes we can change the spawn rate or the size of ammunition or health packs to modify the difficulty.
- *Puzzle and obstacle attributes*: while it is challenging to modify puzzles while completing them, a nice option is to adjust the difficulty of future puzzles based on how the player solves the previous puzzles of the same type.

To answer also to the second question (*when* and *how* to adjust difficulty), there are several aspects to consider. Game-related data, that depends by the type of game that we consider, like average health, hits received, percentage of enemies killed, etc. must be collected and analyzed during the gameplay. From these data the current skill level of the player should be evaluated and this should be reflected in the changes of some of the game parameters discussed before.

The concept of performance DDA is not something new. It has been used since 1981 in *Astrosmash*, a modified version of *Asteroids* where the player was assisted by reducing the game's difficulty when he had few lives. Another example of performance DDA can be found in the *Mario Kart* games (or in general in racing games) with the discussed *rubber banding* AI method ([GiantBomb, 2016](#)). This feature allows computer-controlled AI to go faster and to reach the player if he is too far away in the first position, but at the same time slows down the same computer-controlled AI when the player is in the last positions. In *Mario Kart*, this is done also thanks to the many objects that can be found during the race. If the player is in the last positions he gets the best items.

An important research related to DDA has been conducted in 2005, when it was shown by Robin Hunicke, that even a simple DDA system can improve player performances in the game ([Hunicke, 2005](#)). In the DDA system developed for his research, called *Hamlet*, if the player's probability of death were higher, more health kits were spawned to ease the game.

In 2006, Spronk used a more complex DDA technique called dynamic scripting to change non-player characters' behaviors according to the player's skills ([Spronk et al., 2006](#)). It uses an adaptive rulebase for the generation of the game AI at run-time to control enemies' behaviour. Each rule has a weight that changes according to their success rate in the game. The higher the weight, the higher the possibility that it will be selected.

The main problem of performance-based DDA is that it is usually not true that the player's score in the game reflects his emotional state. As discussed in section 1.2, players can have different approaches to the game and the optimal flow zone varies from player to player. Some enjoy having a perfect score and are frustrated even with only an error, some others are excited when they are challenged more than their possibilities even if their score is really bad. That's why, also according to

Pagulayan, Keeker, Wixon, Romero and Fuller, measuring a player's affective state is a more reliable indicator of how good the game experience is (Blythe, 2004).

2.1.3 Affective-Based DDA

Affective-based DDA uses the player's indicators of emotion, often physiological like electrocardiogram (ECG), skin conductance (SC) or electromyogram (EMG), to manipulate components related to the difficulty of a video game. There are several methods to use biofeedback for affective DDA, depending on which signals are used.

As discussed in section 1.3, there are three main heuristics for affective gaming: *assist me*, *emote me* and *challenge me* (Gilleade, Dix, et al., 2005). Affective-based DDA is an application of the *challenge me* heuristic. The game's difficulty is changed according to the physiological arousal level of a person, considering that low levels of arousal are related to boredom (Mikulas and Vodanovich, 1993).

A lot of research has been conducted in the field of affective-based DDA, using different approaches and physiological signals. The most basic concept to know to create an affective-based DDA is the affective loop (Tijs et al., 2008).

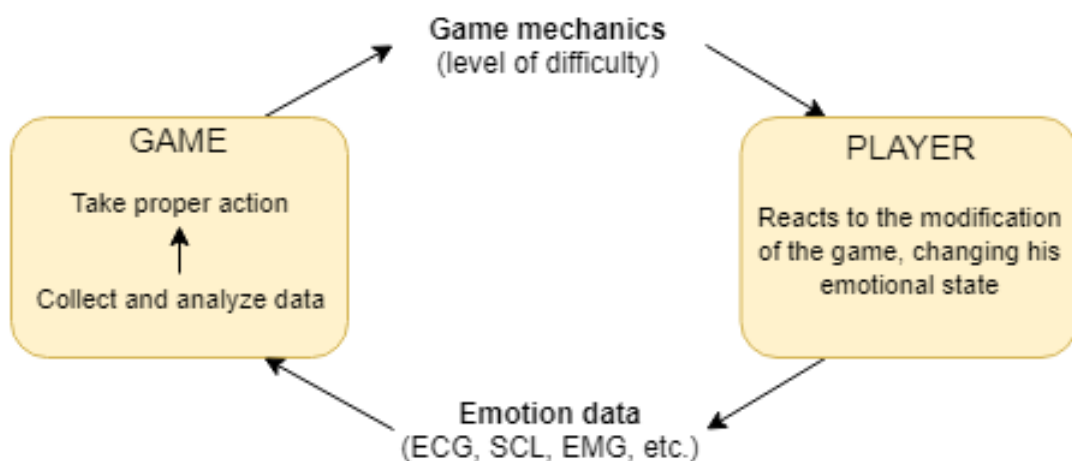


Figure 2.2: Affective loop

In the affective loop (2.2) the game collects and analyzes the player's emotional data, makes proper choices according to the values gathered and changes the difficulty level. The player reacts to those modifications and this leads to a change also in his emotional state that is collected through some sensors inside the game to restart the loop.

We can subdivide an affective-based DDA algorithm into three phases. First we should choose which physiological signals to collect and how to collect them. Then we have to evaluate the affective state from those parameters and in order to do that we can use a *model-based* approach or a *model-free* approach (Yannakakis and Paiva, 2014). In *model-based* approaches the developers base their studies on

famous theories of emotions, like the circumplex model shown in 1.1, and implement some logic, for example to notify the game that the player is bored if his SCL is low. *Model-free* approaches are less rigid, but more complex. They use machine learning techniques or statistical approaches to put together different physiological signals and predict the players' affective state. At the end we have to find which parameters of the game to change according to the affective state of the player.

Imre (Imre, 2016) designed a game, called *Electroderma*, based on affective-DDA using skin conductance. He used the SCL to change the difficulty level of the game, choosing between low, medium and high. In order to avoid baseline problems he used an algorithm called *data subset analysis* that looks at the difference between the two most recent collected values and changes the difficulty only if it is greater than a fixed threshold. Furthermore, he coupled the measure of skin conductance with the player's in-game health, creating a sort of mix between performance and affective DDA. In this way he can deduce also the valence of emotions felt by the player (e.g. when player health is low and SCL high, frustration is implied). More researches supporting use of SC in games are discussed in section 2.2.

In 2012 Parsons and Reinebold developed a serious adaptive virtual reality game (Parsons and Reinebold, 2012). They used HR, SC, respiration and pupillometry as physiological parameters to put into a support vector machine (SVM) to classify arousal levels and modify the difficulty of the game according to this. The game is a virtual war zone environment where the player is driving a car and has to maintain a certain distance from another vehicle in front of him. The speed of the other vehicle is modified according to the arousal level detected in order to maintain the optimal flow.

The first to do an experiment implementing an affective-based DDA and comparing it with a performance-based DDA were Liu, Agrawal, Sarkar and Chen in 2009 (Liu et al., 2009). They used a lot of physiological signals such as cardiovascular, electrodermal, electromyographic, and body temperature to evaluate the anxiety of the player. Their work is subdivided into two phases. In *Phase I* they realized an affective model (using a regression tree) for each participant to evaluate anxiety, while in *Phase II* they did a real-time prediction performance of the affective model. They designed two computer games: *Anagram* and *Pong*. The former (used only in *Phase I*) implemented some solvable anagrams to cause low level of anxiety and some other unsolvable or difficult anagrams to cause high levels of anxiety. In the latter they changed ball speed and size and some other parameters to cause low or high levels of anxiety. Two versions of *Pong* were created: one implementing a performance-based DDA and another one implementing an affective-based DDA. The results showed that:

- Most participants have improved performance during the affective-based DDA.
- The majority of the participants perceived that the affective-based DDA version was more challenging and satisfying than the performance-based one.
- The perceived anxiety-level was reduced during the affective-based DDA session.

2.2 Skin Conductance in Games: Pro and Cons

All the games developed in the research described above collected skin conductance in order to detect the arousal level of the player. There is a large amount of research that supports the use of skin conductance in games and its importance to evaluate the affective state of the player from it.

Mandryk et Al. did several studies related to this and found a statistically significant correlation between SC and subjective evaluation of fun while playing a video game (Mandryk, Inkpen, and Calvert, 2006). Moreover, SCL were higher when playing against a real person (a friend) instead of playing against an opponent controlled by the computer AI (Mandryk and Inkpen, 2004). Another study done by Mandryk (Mandryk and Atkins, 2007) found that high SCL values can be linked to different affective states, such as challenge, excitement or frustration, depending on the situation. That is a limitation of SC, because both the arousal and valence components are needed to precisely evaluate an emotion. A trivial way to solve this problem can be to couple the physiological data with the data collected from the game. A more complex way to do it is using EMG or face recognition to also evaluate the valence component.

Frijda with his studies affirms that SCL rises with the difficulty of some given tasks (Frijda, 1986). This statement was proved by Tijs et Al. with a modified version of *Pac-Man* (Tijs et al., 2008) with different difficulty levels, noticing that SCL differed significantly between the different difficulty sessions.

The most important conclusion that we can take from those studies is that SC can be used as an indicator of arousal. Low arousal values corresponds to low SCL values and high arousal values corresponds to high SCL values. In some situations SC data should be coupled with other data related to valence in order to evaluate the exact emotion. However, there are two cases in which an affective DDA can use only SC as physiological parameter:

- When the SC data is coupled with the game context (as done in *Electroderma* (Imre, 2016)).
- When the main objective is to maintain an optimal level of arousal and so letting the player stay in his flow zone (main focus of this thesis with *ETNA* game).

In both the situations, the biggest problem of using SC to evaluate arousal is the baseline problem. People usually have different SC baselines that depend on many factors, so it is not possible to use a prefixed baseline for everyone (Braithwaite et al., 2013). Moreover, a simple relaxing period before the game session is not enough because it does not guarantee emotional equilibrium (Wagner, 1988). A way to solve this problem can be to do an initial pre-session stimulating the player with precise stimuli that generate a controlled level of arousal. This can be done for example with some simple math calculus or with some multimedia files such as images and/or videos. In this way the optimal level of arousal relative to the player can be evaluated and used in the affective-based DDA algorithm.

2.3 Virtual Reality and Flow

As discussed before in section 1.2, flow is a state that humans aim to achieve because it is the root of much of their happiness. According to Steven Kotler (Kotler, 2014) it has been almost impossible to artificially stimulate flow states and the best technology that does it are video games. The limitation of video games is that they can take players into a lesser type of flow called *dopamine loop*, but cannot induce all the factors required for the flow state. That was true until some years ago, when Oculus started to develop the first modern virtual reality headset. Virtual Reality is the medium that can help people best to achieve flow, thanks to its high immersion. With virtual reality games interactivity between the player and the game has been taken to a higher level. The player is physically at the center of the action and not external like normal pc, console or mobile games. This leads to different benefits. The most obvious is the fact that it helps people become more physically active and improve mental and physical health (Blog, 2012). If we link this aspect with the fact that it is easier to achieve and maintain flow, gamers that usually do not like to move or do exercises, can use the so called *exergames* to do what they like most (play video games) and at the same time also do physical activity.

First commercial uses of virtual reality dates back to the early 1990s where people could start to experience virtual reality in arcade rooms thanks to products like *Virtuality* (Lewis Packwood, 2016). The main limitation of those kind of products is that people had to go to specific arcade rooms to play it, while now Oculus with the Rift brought this technology directly into the player's home.

Another good reason of using virtual reality is that it solves a problem that all the other research done in the field of affective-based DDA have: the real world distractions. When evaluating some physiological parameters while playing a normal video game, the player is not isolated from the environment and so his physiological reaction can also be a consequence of something that happened around him and not inside the game. This leads to noise in the data. With virtual reality, instead, the player is totally immersed in the virtual environment and does not have external distractions that can influence the data. Moreover, with virtual reality the player can trigger both physical and cognitive arousal, not only cognitive as in non VR video games.

Virtual reality games are used a lot for rehabilitation purposes, especially for upper and lower limb, and neurorehabilitation. In this way, patients can do movement in a more enjoyable way that can also distract them and feel less pain. Furthermore, coupling a virtual reality game with a dynamic difficulty adjustment method, the game difficulty can adapt to the disabilities of the patient. In my research I will test the game on healthy people, but all the work can be also tested in the future on people that have to do rehabilitation.

Chapter 3

Game Development: ETNA

In this chapter I will talk about the development of the game I created for this thesis, *ETNA*. I have developed two versions of the game: one for HTC Vive and one for Oculus Rift.

3.1 Purpose

The name has two meanings. The first comes from the fact that the game is settled inside a volcano and so it is called Etna like the highest active volcano in Europe, located next to my home town, Catania. Then, it is also the acronym of *Entertaining Training Neuro Affective*, because the aim of this game is to create an entertaining training in virtual reality that exploits the affective-based DDA collecting physiological responses from the autonomic nervous system through skin conductance.

In this VR game all the concepts discussed in the previous chapters are applied. The objective is to take the user inside his Flow Zone and to maintain his arousal at the optimal level to maximize the performances and the enjoyment, and improve skills in a short time. In order to do that, performance-based DDA information about the player score during the game are collected and the level attributes to adjust the difficulty will be modified. For the affective-based DDA, solely the skin conductance will be used to maintain the optimal arousal level in the player. The game can also be played in a variant where both affective and performance DDA are active at the same time. The aim was to see which method will work the best. Before playing the affective-based DDA versions of the game, it should be played in three variants while collecting skin conductance in order to find the personal optimal SCL of the player. The three variants are ultra easy mode, ultra hard mode and performance-based DDA. To the best of my knowledge this is the first time a technique like this is used to find the optimal arousal level for a game with affective-based DDA.

3.2 Hardware and Software

All the hardware needed to play the game is commercially available. The hardware components used in the two versions of ETNA (ETNA v1 and ETNA v2)

are slightly different:

- *VR head mounted display*: ETNA v1 is developed for the HTC VIVE¹, while ETNA v2 is developed for the Oculus Rift². Both are commercially available Virtual Reality Head Mounted Display (HMD) used to display information to the user as well as for tracking purposes and are connected to a computer with a cable.
- *Audio strap (only in ETNA v1)*: In order to have a full audio immersion, the HTC VIVE deluxe audio strap³ should be used and attached to the HMD. In ETNA v2 the headphones are included in the headset, so is not necessary to use additional hardware.
- *VR controllers*: Similarly, the commercially available, consumer-grade HTC VIVE controllers are used for ETNA v1, while the Oculus Touch controllers are used for the ETNA v2.
- *Trackers (only in ETNA v1)*: The main difference between ETNA v1 and ETNA v2 is that HTC Vive has some official additional trackers that can be used to better track the player during the game: the HTC VIVE Tracker⁴. Two trackers are required to correctly track the feet of the player. In ETNA v2 there is no tracking of the player's feet during the game.
- *Skin Conductance device*: There are many commercially available devices to collect skin conductance, I am using MindLAB Set⁵ (3.1). It is composed of a hardware data acquisition unit (Psychodata Acquisition Unit) and two dry, stainless steel bipolar electrodes that will be positioned onto two fingers of one hand of the player with a strap.
- *VR ready computer*: A computer with a good graphics card is needed to exploit the power of virtual reality and have a fluid experience without lag. For ETNA v1 an Alienware Aurora with the Nvidia 1080ti was used, while for ETNA v2 a MSI GE62MVR 7RG Apache Pro with the Nvidia 1070 was used.

Both versions of the game have been developed with the Unity engine, precisely with the version 2017.3.0f3, the latest available at the time the study was performed.

3.3 Game design

ETNA is a VR room-scaled game. In this game the player has to move around a rocky platform positioned in the center of a volcano and has to hit the lava balls that will come out from 4 mini volcanoes positioned around the platform using two guns. While doing this, in order to not get penalties, the player also has to avoid

¹<https://www.vive.com/us/product/vive-virtual-reality-system/>

²<https://www.oculus.com/rift/>

³<https://www.vive.com/us/vive-deluxe-audio-strap/>

⁴<https://www.vive.com/us/vive-tracker/>

⁵<http://www.psychotech.it/pages/en/mindlab-set.php>



Figure 3.1: MindLAB Set

the lava balls. In ETNA v1 the player has to pay attention also to where he/she walks because there will be lava holes generated randomly in the platform when the game is started. In ETNA v2, since there is not feet tracking, the platform does not have any holes (3.3). In the real world the user will move around a fixed open area (max 20x20 feet) mapped into the virtual world.

The player has two guns (one per hand, mapped on the controllers) that will start with a 50% charge. Each shot costs 5% of charge and there will be some blue balls that will spawn randomly over the platform. The player can collect them by touching them with the gun in order to add the 25% of charge (3.2).

3D sounds are used to improve the feeling of immersion of the player. Therefore, hearing the sound of the spawn explosion, the player can feel from which direction the ball is coming. 3D audio is also used when a collectible to charge the gun spawns, so the player can know where to go instead of guessing. Furthermore, there is also a haptic feedback coupled with the sound of shooting when the gun has energy which is different than when there is no charge.

In both the dynamic difficulty adjustment methods, three level attributes will be modified: the spawn rate of the lava balls from the volcanoes, the number of volcanoes that will be active, and the speed of the lava balls.

At level 0 (the starting level for DDA methods) the speed multiplier is 1, the spawn rate is 3s and the number of volcanoes active is 2.

The code used to generate and control the scene (which includes the parameters used in ultra easy and ultra hard modes) can be found in Appendix A.

3.3.1 Performance-based DDA

In the *performance-based DDA*, the game is subdivided in sessions of 15 seconds. Each 15 seconds the number of lava balls spawned and the score of the player are counted. If the player hits a ball it counts as 1 point, if not 0 points, and for each

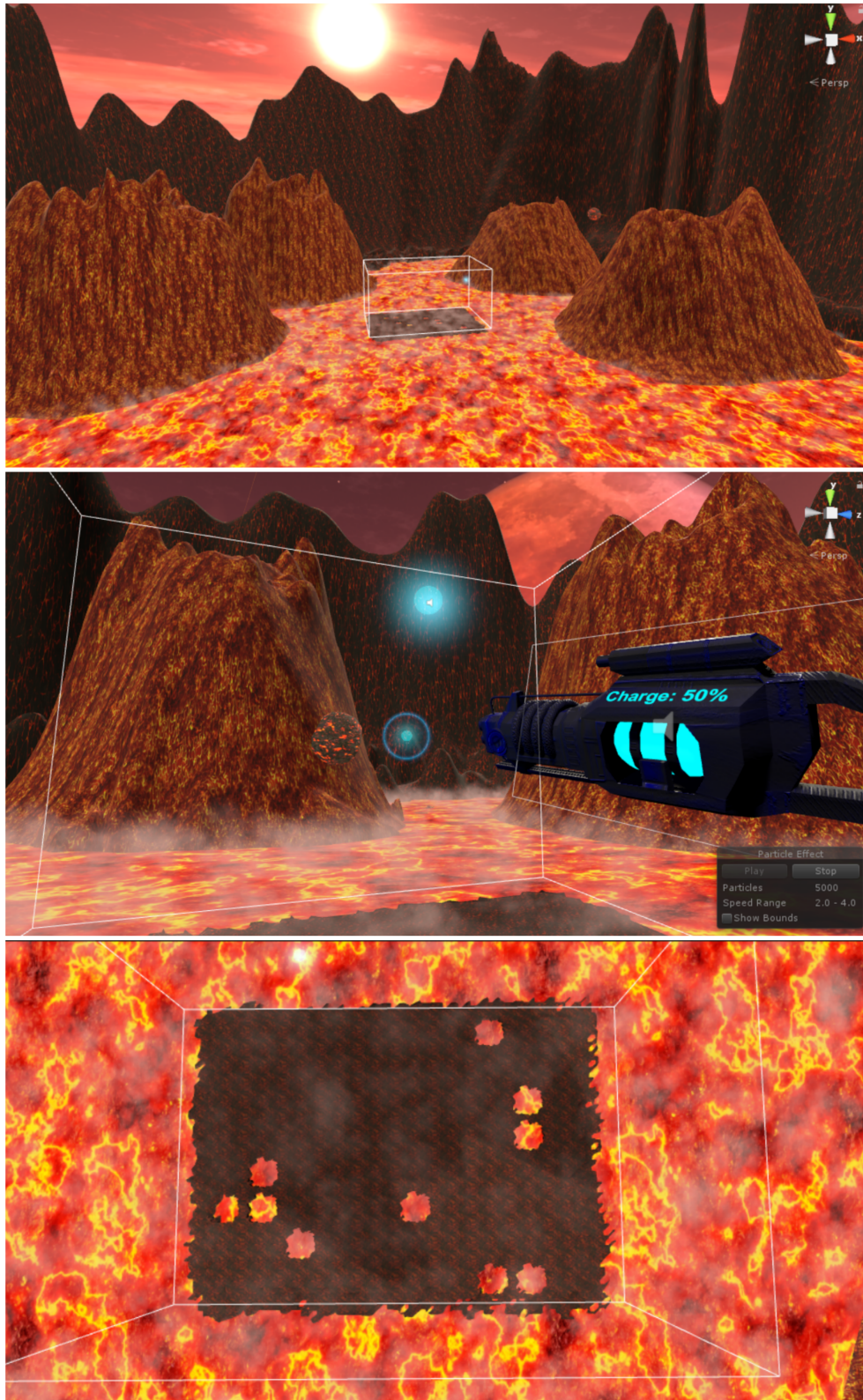


Figure 3.2: Screenshots from ETNA v1

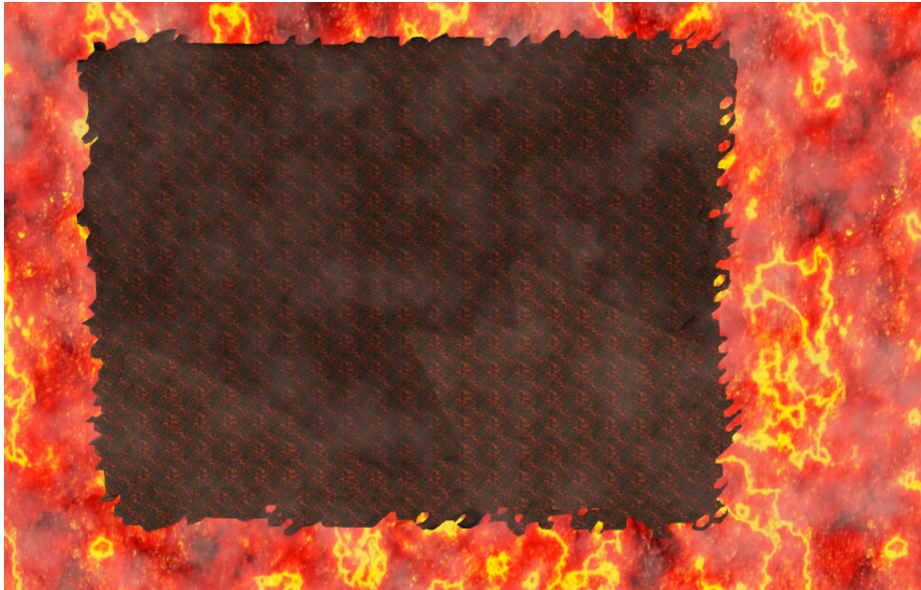


Figure 3.3: Screenshot from ETNA v2 with no holes in the platform

penalty it gets -1 point. When a session ends, the ratio (in percentage) is evaluated by dividing the score with the total number of balls spawned. The difficulty level will change according to this value:

- If it is higher than 90%, the difficulty is increased by two levels
- If it is between 70% and 90%, the difficulty is increased by one level
- If it is between 50% and 70%, the difficulty does not change
- If it is between 20% and 50%, the difficulty is decreased by one level
- If it is lower than 20%, the difficulty is decreased by two levels

There is not a fixed number of levels; the game starts from level 0 and can go up with positive values and down with negative values.

The code used for the *performance based-DDA* can be found in Appendix B.

3.3.2 Affective-based DDA

Also for the *affective-based DDA* the game is subdivided in sessions of 15 seconds. During the sessions the skin conductance is collected through the MindLAB Set and is read by the pc into the game through a serial USB connection. SCL is collected every game frame and after each session the average SCL is calculated and compared to the optimal baseline SCL. The optimal baseline SCL is evaluated from the analysis of the SCL collected in the three variants ultra easy mode, ultra hard mode and performance-based DDA. The assumption that I made was that during ultra easy mode the user was bored while during ultra hard mode he/she was frustrated. I chose qualitatively an intermediate level between the two averages, adjusting it also considering the performance-based DDA SCL data. The difficulty level will change according to the result of that comparison:

- If the average SCL is higher than the optimal SCL, the difficulty is decreased by one level
- If the average SCL is lower than the optimal SCL, the difficulty is increased by one level

3.3.3 Mixed Perfo-affective DDA

The game is subdivided in sessions of 15 seconds as the other two methods. In this variant the two methods are active at the same time, so every 15 seconds are used both the score and the SCL to change the difficulty of the game. Since both the performance DDA and affective DDA are active at the same time, the difficulty level can go up by 3 or down by 3 every 15 seconds (2 from performance DDA and 1 from affective DDA).

Chapter 4

Evaluation ETNA v1

In this chapter I am going to talk about how the user study for ETNA v1 has been conducted, discussing the results collected combining the surveys' data with the game data.

4.1 User Study

In the user study sessions the participants played the 5 variants of the game: ultra easy, ultra hard, performance DDA, affective DDA and mixed perfo-affective DDA. First, they played 2-3 minutes with the ultra easy mode, then other 2-3 minutes with the ultra hard mode, and at the end with the performance-based DDA version for 4-5 minutes. During those gaming sessions the skin conductance was recorded in order to find the optimal SCL to use in the two affective-based DDA. Before the performance-based DDA gaming session the participant saw a 360 degree relaxing video with relaxing audio in virtual reality with the HMD to help stabilize the arousal level. Each user study session was done individually.

4.1.1 Procedures

The total session lasted approximately 45 minutes and followed these procedures:

- **Introductory phase** (5 minutes) during which the participant was briefed on the experiment, equipped with the VR Head Mounted Display (HMD) HTC VIVE, VR Controllers, two HTC VIVE Trackers mounted on the feet, and the skin conductance sensors were attached to two fingers of one hand. The participant was also introduced to the basic operation tasks involved.
- **Training and Baseline phase** (around 15 minutes) during which the participant played the game in three different ways:
 - Super Easy mode: 2-3 minutes of play in easy mode while collecting SC.
 - Super Hard mode: 2-3 minutes of play in hard mode while collecting SC.
 - Performance DDA: 2-3 minutes watching a relaxing video + 4-5 minutes playing the game with performance-based DDA while collecting SC.

- **First evaluation phase** (5 minutes) during which the participant put away all the equipment and filled out a short survey about his/her game experience with performance-based DDA.
- **Affective DDA phase** (around 5 minutes) 4-5 minutes playing the game with affective-based DDA while collecting SC.
- **Second evaluation phase** (5 minutes) during which the participant put away all the equipment and filled out a short survey about his/her game experience with affective-based DDA.
- **Mixed Perfo-affective DDA phase** (around 5 minutes) 4-5 minutes playing the game with both performance-based and affective-based DDA while collecting SC.
- **Third evaluation phase** (5 minutes) during which the participant put away all the equipment and filled out a short survey about his/her game experience with mixed perfo-affective DDA.

4.2 Results

27 people took part to the user study. For 3 of them the SC data was not totally reliable because of problems with the sensor, so only 24 people's data have been considered.

From the survey's data I saw that almost all the people felt really immersed in the virtual environment, like they were separated from the real-world environment, thanks to virtual reality. They also liked to move and to do physical exercise while playing the game and they were satisfied at the end of the sessions. Moreover, 2 people said that the session they liked most was the one with Performance DDA, 11 said that the one they liked most was the one with Affective DDA and the other 11 said that was the mixed Perfo-Affective DDA. I alternated one user playing with Affective DDA as the last method and one playing the mixed Perfo-Affective DDA, but I noticed that almost everyone said that the one they liked most was the last one. Therefore, from the survey's analysis I cannot assert that people on average liked the game most with a certain method.

The most interesting results come from the in-game and skin conductance data I have collected while the users were playing the game. More precisely, here it is the raw data that I have collected from each participant: variation of skin conductance (4.1, 4.2), variation of the difficulty level (4.3, 4.4), variation of the score (4.5, 4.6)

4.3 Discussion

First of all, I have plotted some graphs of the data to see if there were some correlations between them. The first thing that can be noticed, looking at the SC values collected during the Ultra Easy and Ultra Hard mode (4.1), is that SC is influenced by the game difficulty. In 19 sessions out of 24, the average SCL during the Ultra Easy mode was lower than the one collected during the Ultra Hard mode.

Table 4.1: SCL VALUES OF USERS DURING THE 3 DDA METHODS (1)

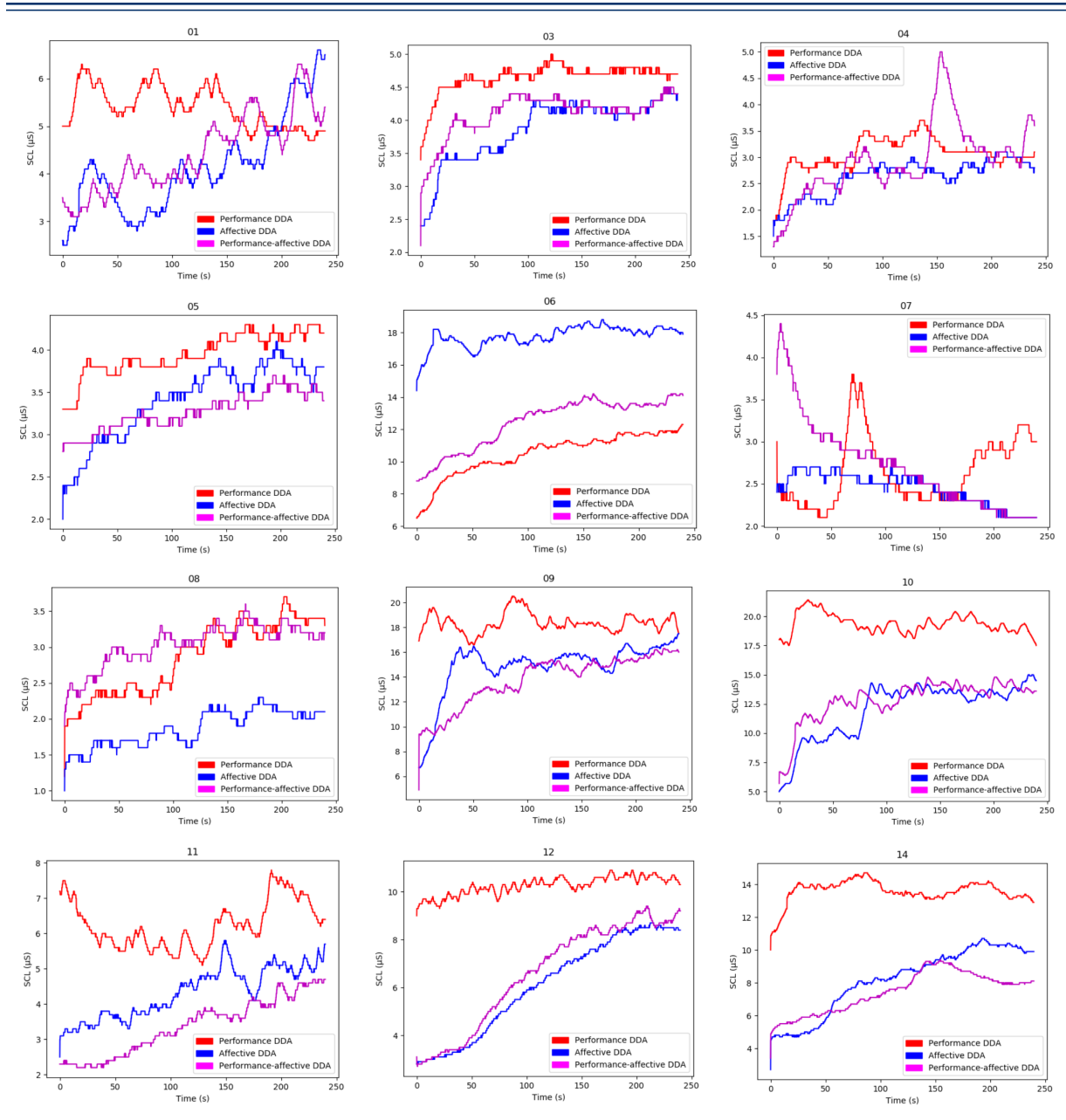


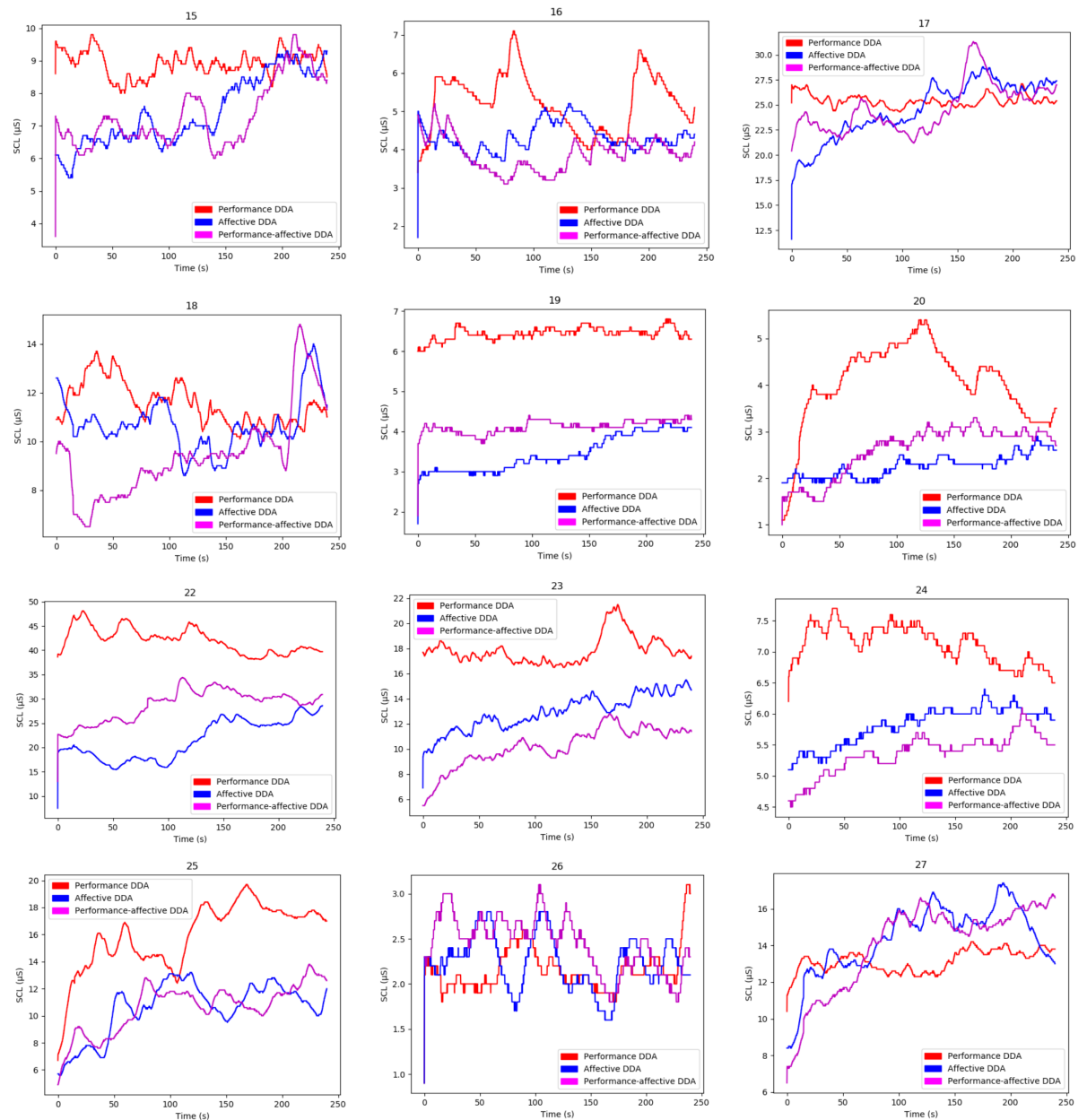
Table 4.2: SCL VALUES OF USERS DURING THE 3 DDA METHODS (2)

Table 4.3: DIFFICULTY LEVELS DURING THE 3 DDA METHODS (1)

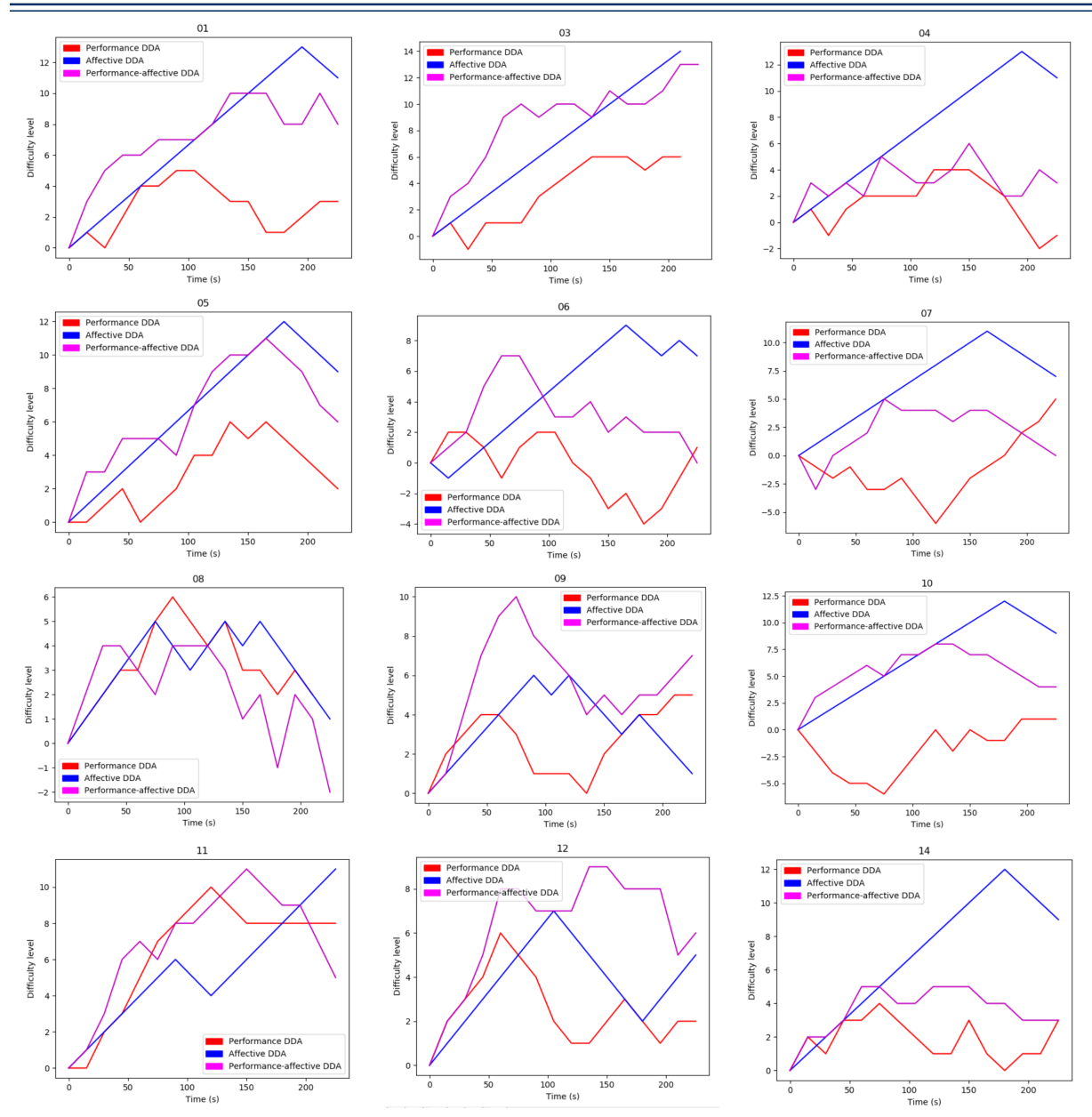


Table 4.4: DIFFICULTY LEVELS DURING THE 3 DDA METHODS (2)

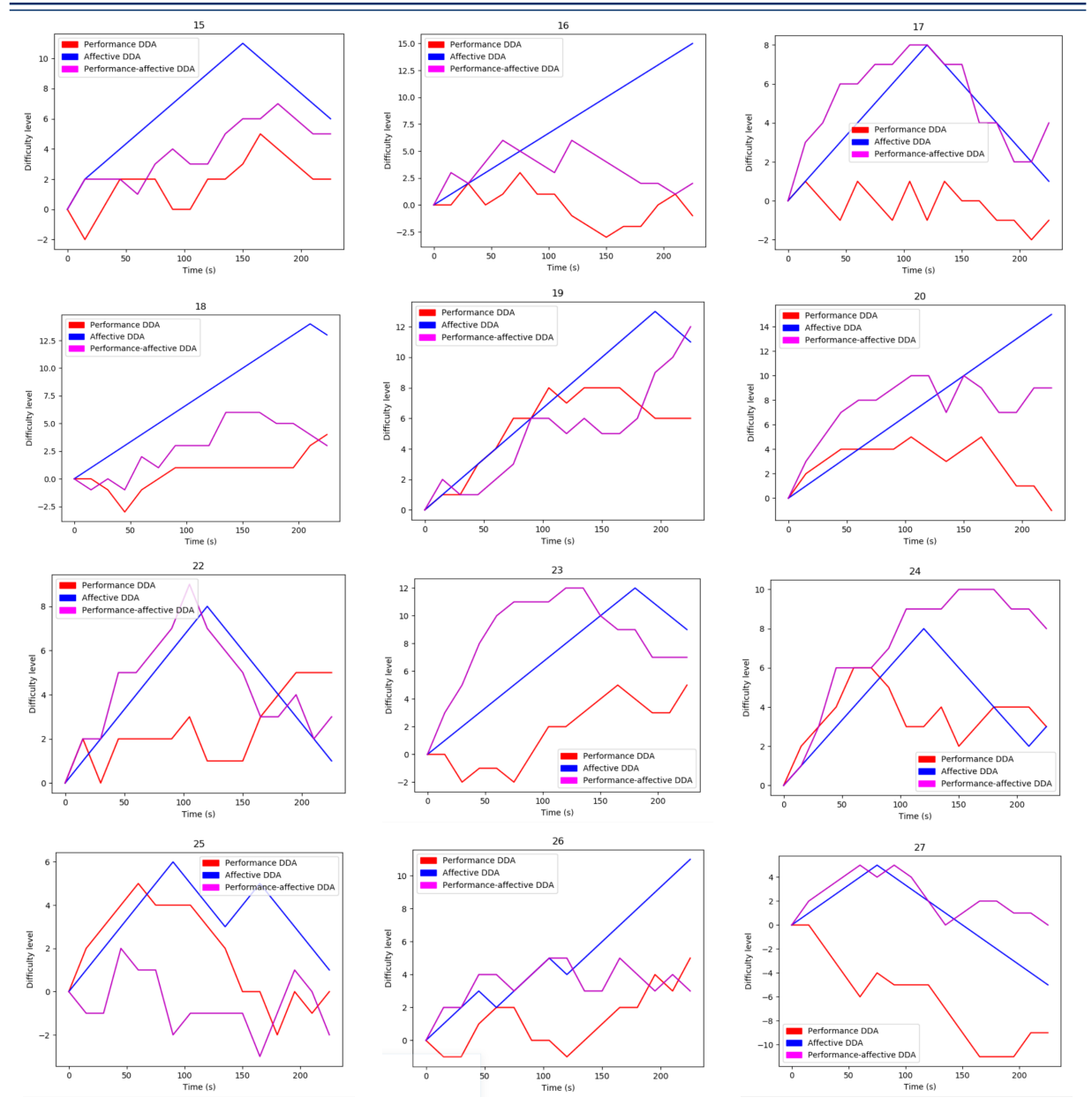


Table 4.5: SCORE EVERY 15 SEC DURING THE 3 DDA METHODS (1)

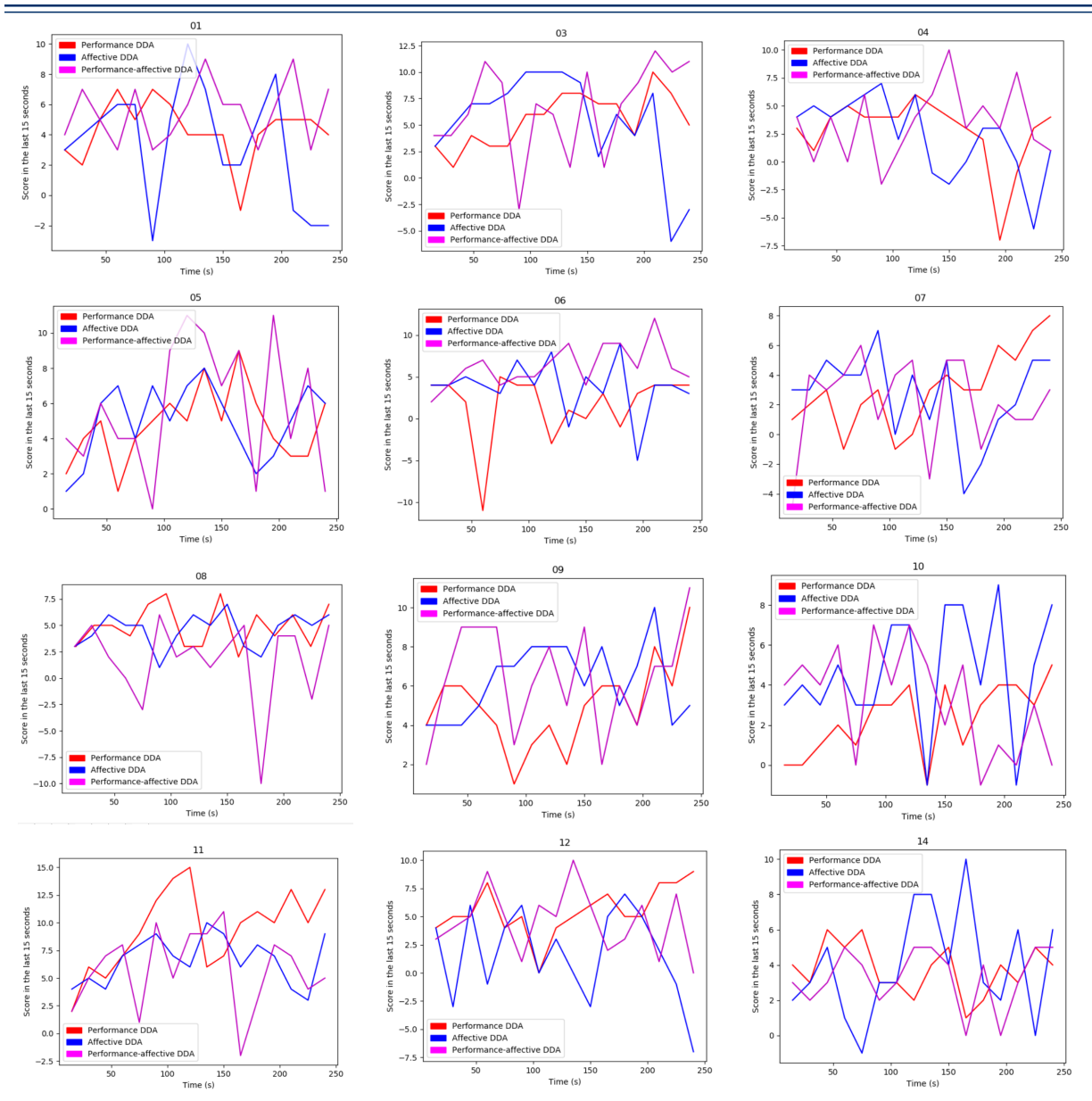
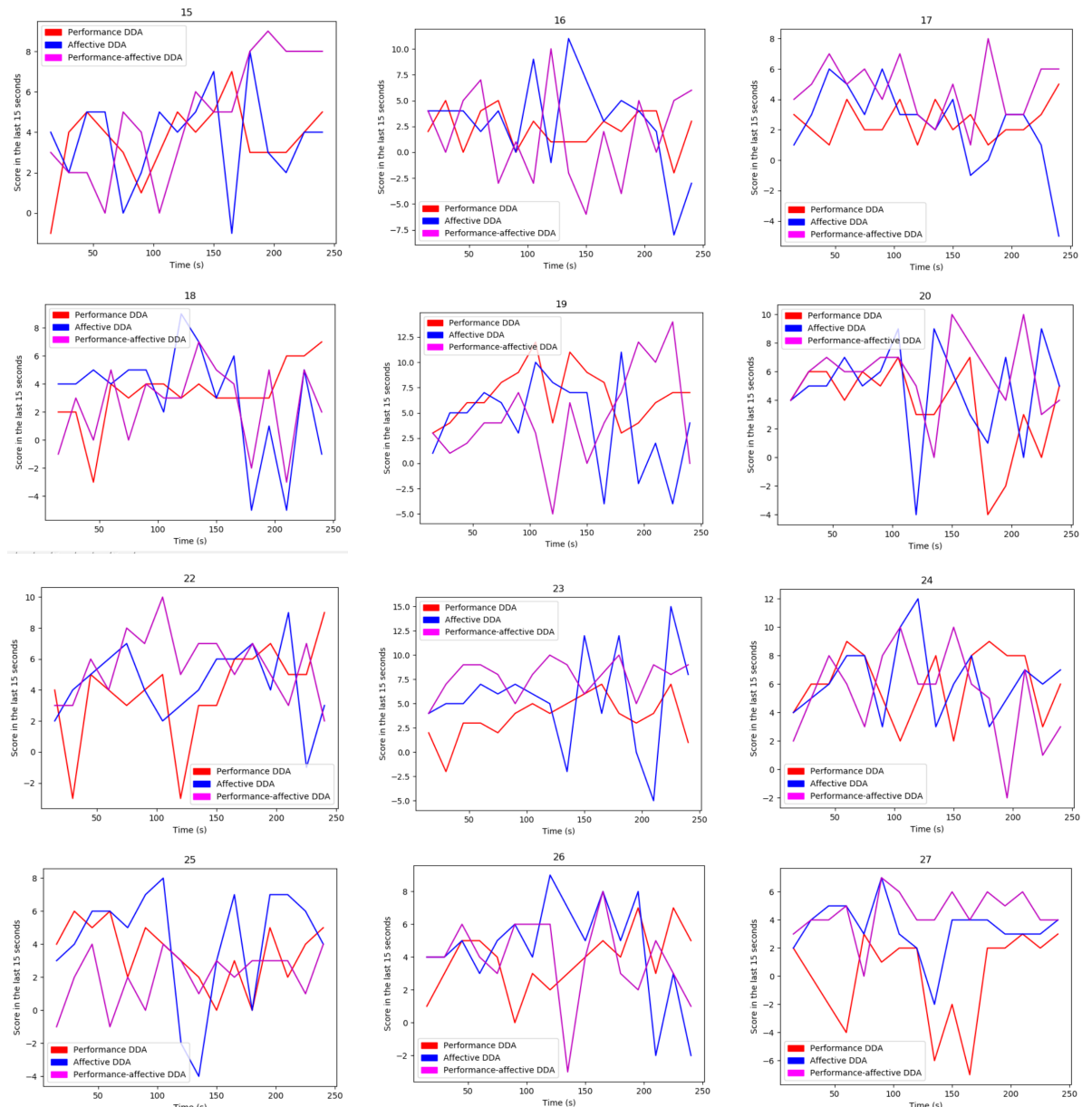


Table 4.6: SCORE EVERY 15 SEC DURING THE 3 DDA METHODS (2)



The most important thing to notice is that each user has its own baseline SC level. The importance of this consideration can be demonstrated by doing an anova test on the SC data.

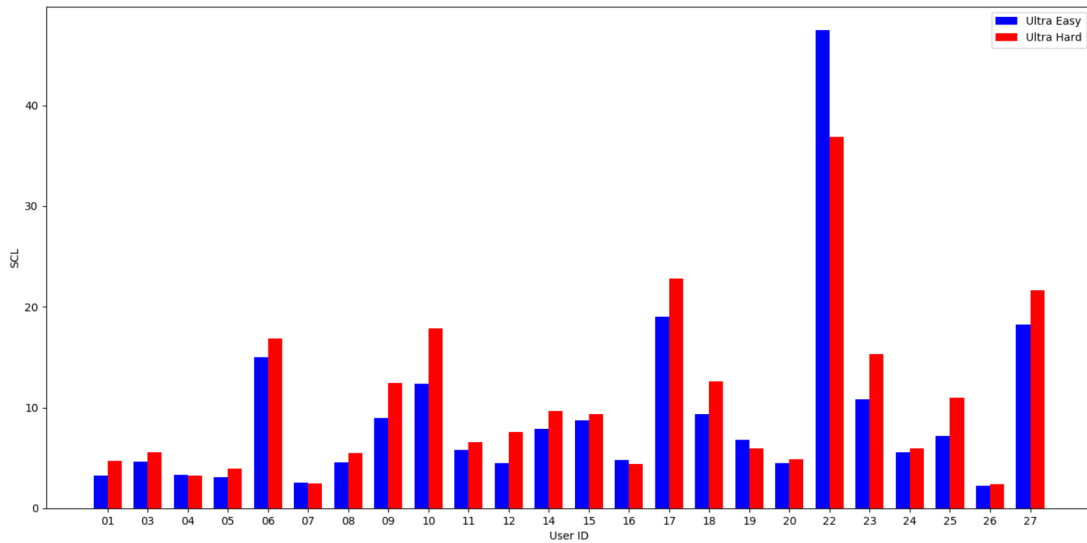


Figure 4.1: Comparison of Easy and Hard avg SCL across all the data

Conducting an anova test on the raw data without considering the different baselines, the p results show that the correlation is not statistically significant (4.7).

Conducting an anova test setting the easy value to 100 and then computing the other new values to be the percentage compared to the easy value, p results show that the correlation is now statistically significant (4.8).

Comparing the SCL results evaluated from the 3 DDA methods (each value is the percentage compared to the easy value of the same person, set to 100), it can be noticed that the highest SCL was collected during the performance DDA in all but 5 cases (4.2). Therefore, adjusting the difficulty of the game according to the SC has helped to control and reduce the average SCL during the session.

In 14 cases the method with the highest average difficulty level was the Affective DDA, in only 1 case the highest was Performance DDA, and for the remaining 9 people the highest was the mixed Perfo-Affective DDA (4.3). To understand better this data, it can be coupled with the scores' results. 6 people did their best score during the Performance DDA, 6 during the Affective DDA and 12 during the Perfo-Affective DDA (4.4).

I have conducted some anova tests to see how significant are the results related to the scores and to the difficulty levels (4.9).

The p results of the 4 anova tests related to scores show that the correlation is not statistically significant, while the 4 related to the difficulty levels show that the correlation is statistically significant for all except the one related to the correlation between affective and perfoaffective.

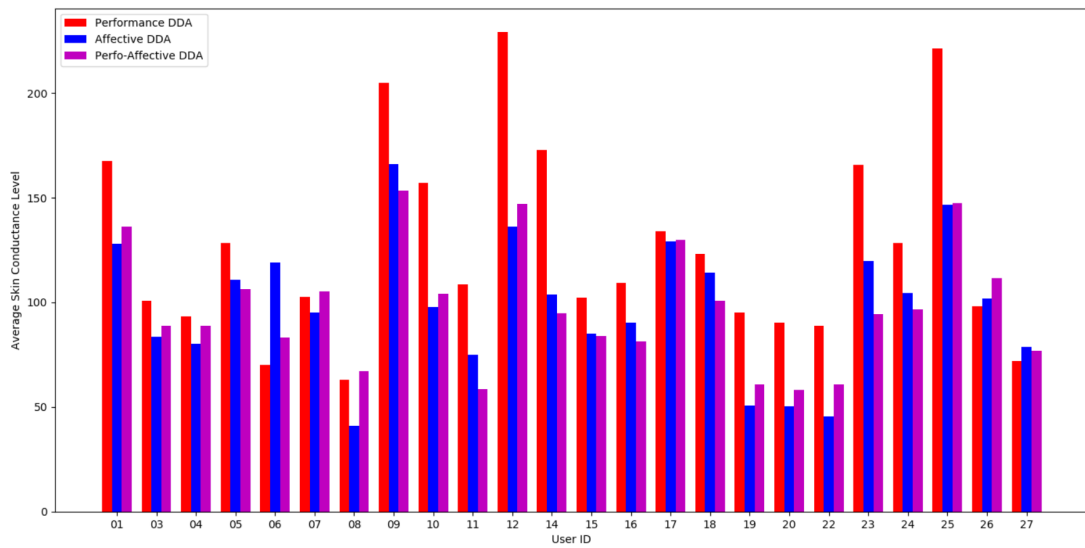
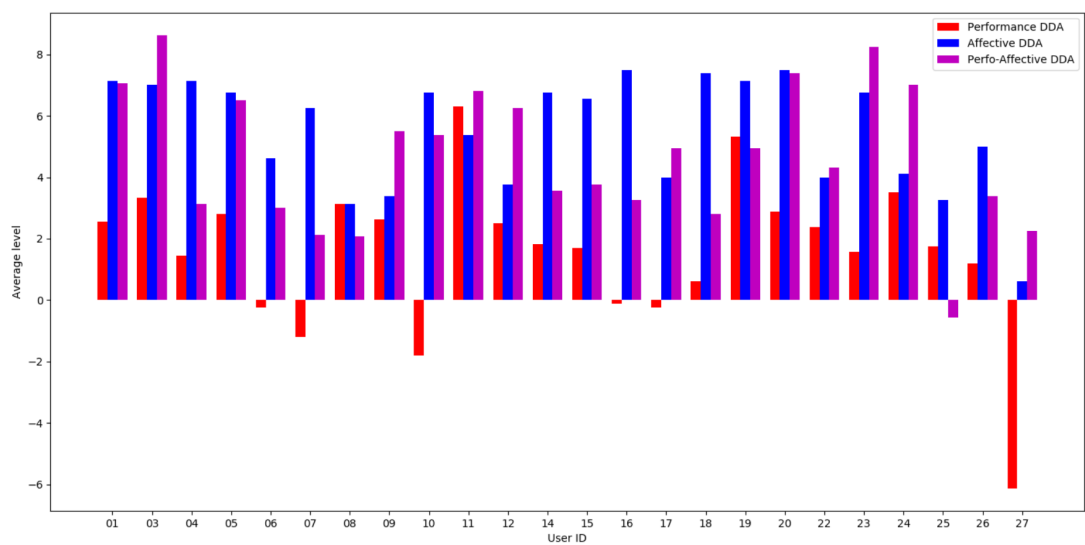
Better ways to evaluate the score can be considered in future studies to see if the p results are improved. There are some nice conclusions that can be drawn out from these results: on average, Performance DDA was too easy, Affective DDA too

Table 4.7: ANOVA TEST ON RAW SCL

Hard + Easy SCL	$p = 0.637$
Performance + Affective + Perfoaffective SCL	$p = 0.426$
ALL SCL	$p = 0.749$

Table 4.8: ANOVA TEST ON SCL CONSIDERING BASELINE

Hard + Easy SCL	$p < 0.001$
Performance + Affective + Perfoaffective SCL	$p = 0.011$
ALL SCL	$p = 0.001$

**Figure 4.2:** Comparison of avg SCL collected during the 3 DDA methods**Figure 4.3:** Comparison of avg difficulty collected during the 3 DDA methods

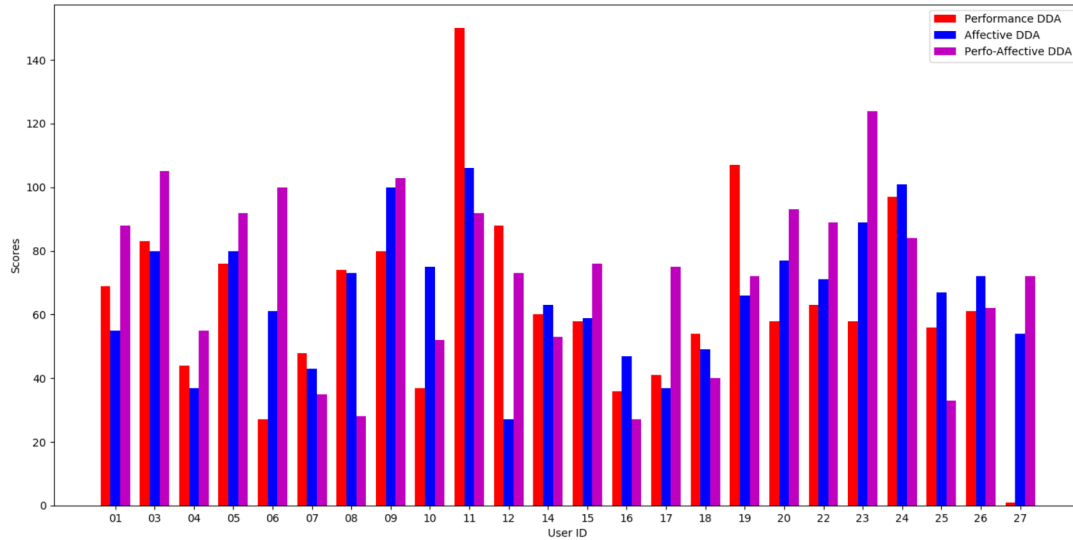


Figure 4.4: Comparison of people's scores collected during the 3 DDA methods

Table 4.9: ANOVA TEST ON SCORES AND DIFFICULTY LEVELS

Performance + Affective scores	$p = 0.723$
Performance + Perfoaffective scores	$p = 0.318$
Affective + Perfoaffective scores	$p = 0.424$
Performance + Affective + Perfoaffective scores	$p = 0.538$
Performance + Affective difficulty levels	$p < 0.001$
Performance + Perfoaffective difficulty levels	$p < 0.001$
Affective + Perfoaffective difficulty levels	$p = 0.169$
Performance + Affective + Perfoaffective difficulty levels	$p < 0.001$

difficult, but the mix of them led to the best result. This is confirmed looking at the scores, because 50% of people did their best result exactly during the mixed Perfo-Affecting DDA. Therefore, I can conclude saying that the best method was the mixed Perfo-Affective DDA.

To see if VR experience has influenced the test, I tried also to cluster the data into two main groups: people who had past experience in VR and people who did not. The p value results from the anova tests can be found in [4.10](#).

Both these results show that the correlation is less statistically significant than the non-clustered ones. Therefore, we can conclude saying that there is no significant difference between the result collected from people who had past VR experience and people who did not.

Table 4.10: ANOVA TEST ON VR AND NOT VR EXPERIENCED PLAYERS

Legend: P = Performance A = Affective PA = Perfoaffective	Prior VR Experience	No Prior VR Experience
Hard + Easy SCL	p = 0.004	p = 0.011
P + A + PA SCL	p = 0.132	p = 0.090
ALL SCL	p = 0.084	p = 0.047
P + A scores	p = 0.206	p = 0.734
P + PA scores	p = 0.343	p = 0.652
A + PA scores	p = 0.922	p = 0.238
P + A + PA scores	p = 0.504	p = 0.676
P + A difficulty levels	p < 0.001	p < 0.001
P + PA difficulty levels	p = 0.008	p = 0.002
A + PA difficulty levels	p = 0.394	p = 0.276
P + A + PA difficulty levels	p < 0.001	p < 0.001

Chapter 5

Evaluation ETNA v2

In this chapter I am going to talk about how the user study for ETNA v2 has been conducted, discussing the results collected the game data only. Since I realized that I could not find any relevant information from the survey analysis in ETNA v1, I chose to do not collect any type of survey for ETNA v2.

The main reason I did a second version of ETNA is that during the first user study some people told me that they felt the game too hard with the holes in the platform and would have preferred to play without them.

5.1 User Study

As in ETNA v1, in the user study sessions the participants played the 5 variants of the game: ultra easy, ultra hard, performance DDA, affective DDA and mixed perfo-affective DDA. First, they played 2-3 minutes with the ultra easy mode, then other 2-3 minutes with the ultra hard mode, and at the end with the performance-based DDA version for 4-5 minutes. During those gaming sessions the skin conductance was recorded in order to find the optimal SCL to use in the two affective-based DDA. Before the performance-based DDA gaming session the participant saw a 360 degree relaxing video with relaxing audio in virtual reality with the HMD to help stabilize the arousal level. Each user study session was done individually.

5.1.1 Procedures

The total session lasted approximately 30 minutes and followed these procedures:

- **Introductory phase** (5 minutes) during which the participant was briefed on the experiment, equipped with the VR Head Mounted Display (HMD) Oculus Rift, VR Controllers, and the skin conductance sensor was attached to two fingers of one hand. The participant was also introduced to the basic operation tasks involved.
- **Training and Baseline phase** (around 15 minutes) during which the participant played the game in three different ways:
 - Super Easy mode: 2-3 minutes of play in easy mode while collecting SC.

- Super Hard mode: 2-3 minutes of play in hard mode while collecting SC.
- Performance DDA: 2-3 minutes watching a relaxing video + 4-5 minutes playing the game with performance-based DDA while collecting SC.
- **Affective DDA phase** (around 5 minutes) 4-5 minutes playing the game with affective-based DDA while collecting SC.
- **Mixed Perfo-affective DDA phase** (around 5 minutes) 4-5 minutes playing the game with both performance-based and affective-based DDA while collecting SC.

5.2 Results

28 people took part to the user study. For 4 of them the SC data was not totally reliable because of problems with the sensor, so only 24 people's data have been considered.

Here it is the raw data that I have collected from each participant: variation of skin conductance (5.1, 5.2), variation of the difficulty level (5.3, 5.4), variation of the score (5.5, 5.6)

5.3 Discussion

First of all, I have plotted some graphs of the data to see if there were some correlations between them. Also in this case, the first thing that can be noticed, looking at the SC values collected during the Ultra Easy and Ultra Hard mode (5.1), is that SC is influenced by the game difficulty. In 22 sessions out of 24, the average SCL during the Ultra Easy mode was lower than the one collected during the Ultra Hard mode. We can notice that each user has its own baseline SC level too. The importance of this consideration can be demonstrated by doing an anova test on the SC data.

Like in the ETNA v1, conducting an anova test on the raw data without considering the different baselines, the p results show that the correlation is not statistically significant (5.7).

Conducting an anova test setting the easy value to 100 and then computing the other new values to be the percentage compared to the easy value, p results show that the correlation is now statistically significant for the Easy/Hard SCL, while it is worse if we consider only the 3 DDA variants. (5.8).

Comparing the SCL results evaluated from the 3 DDA methods (each value is the percentage compared to the easy value of the same person, set to 100), it can be noticed that the highest SCL was collected during the performance DDA in all but 5 cases (5.2). Therefore, adjusting the difficulty of the game according to the SC has helped to control and reduce the average SCL during the session.

In 10 cases the method with the highest average difficulty level was the Affective DDA, in 9 cases the highest was Performance DDA (plus one tie with the Perfo-Affective DDA), and for the remaining 4 people the highest was the mixed Perfo-Affective DDA (5.3). We can also notice that many times the average difficulty

Table 5.1: SCL VALUES OF USERS DURING THE 3 DDA METHODS (1)

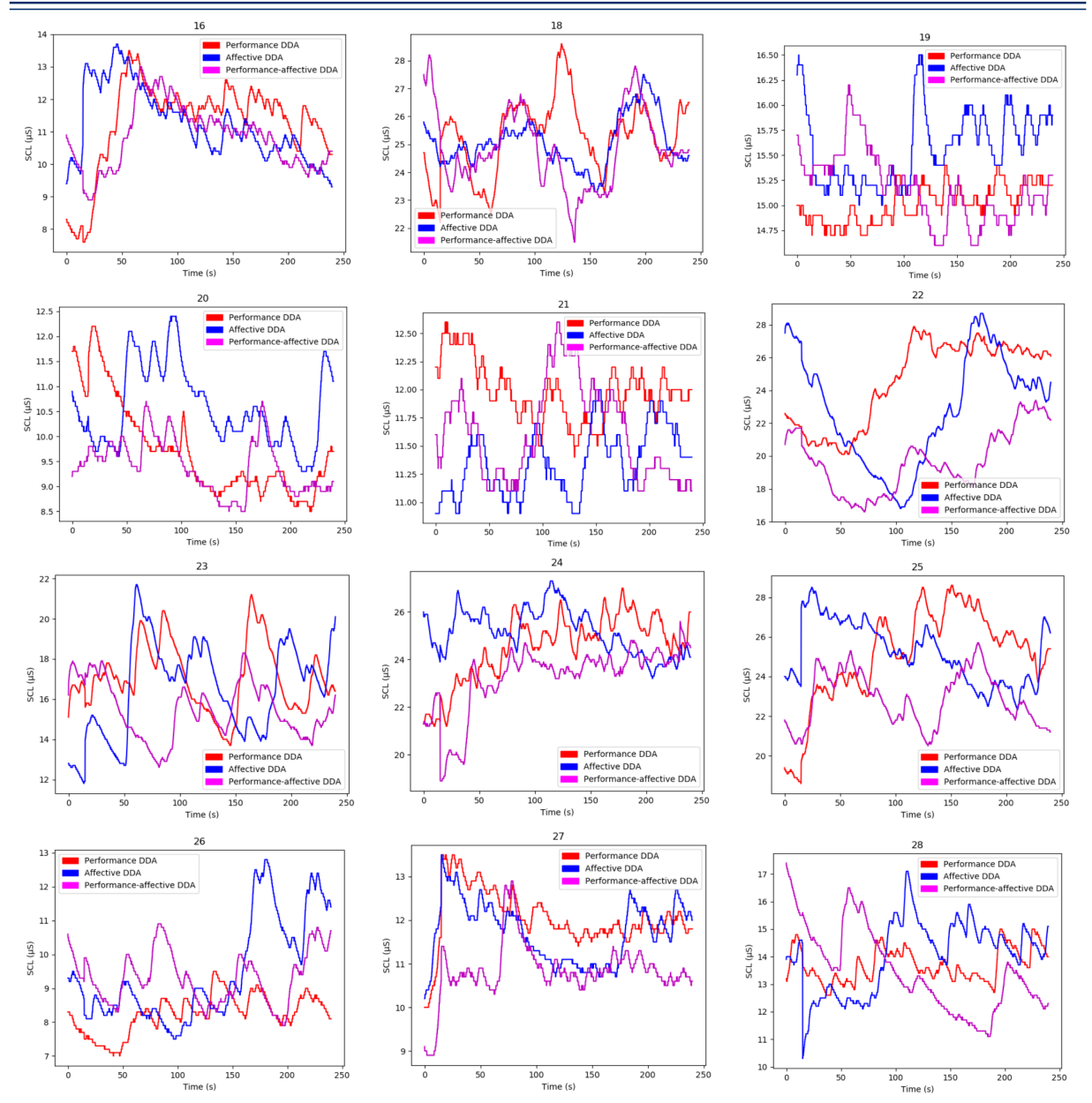
Table 5.2: SCL VALUES OF USERS DURING THE 3 DDA METHODS (2)

Table 5.3: DIFFICULTY LEVELS DURING THE 3 DDA METHODS (1)

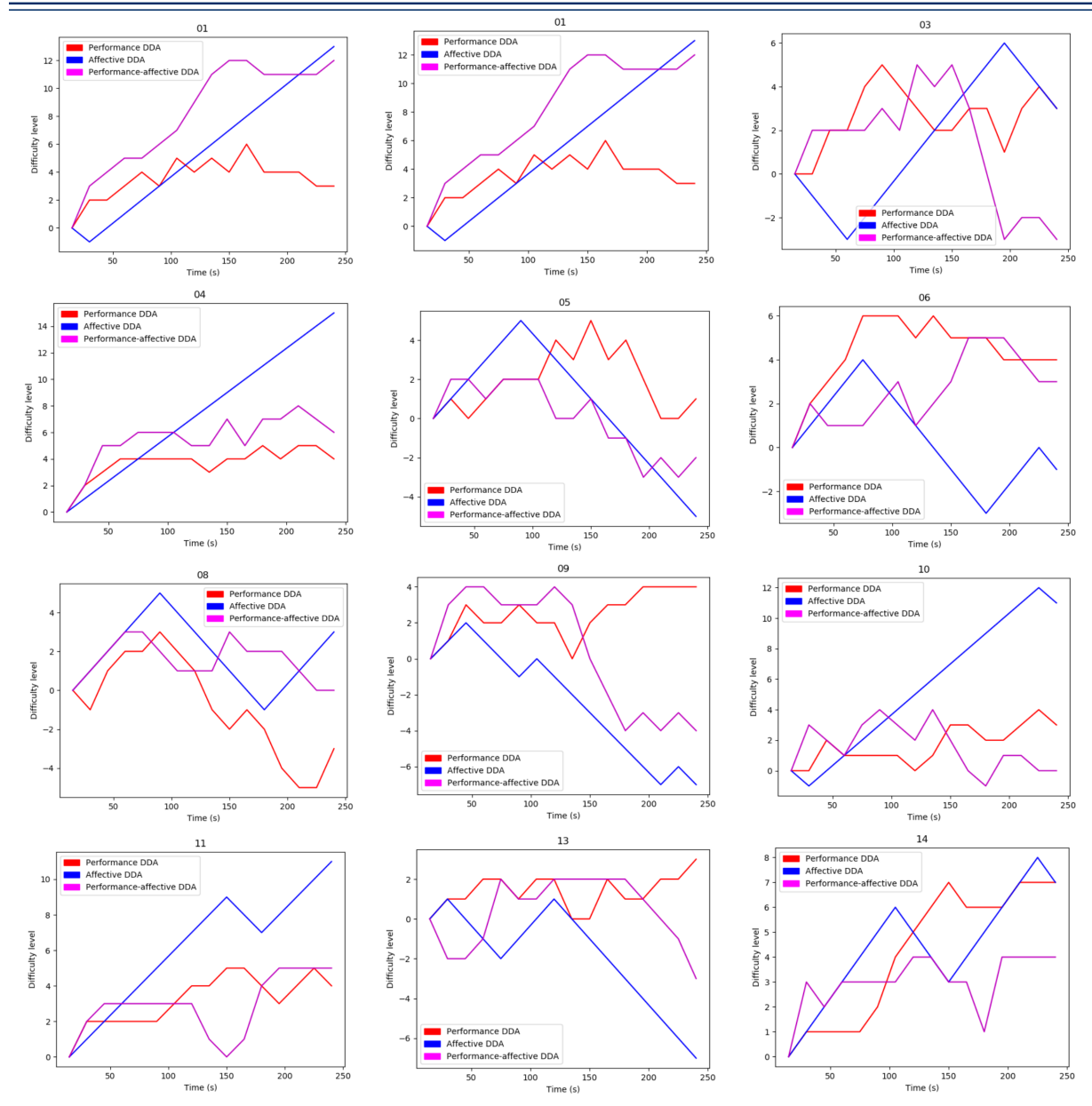


Table 5.4: DIFFICULTY LEVELS DURING THE 3 DDA METHODS (2)

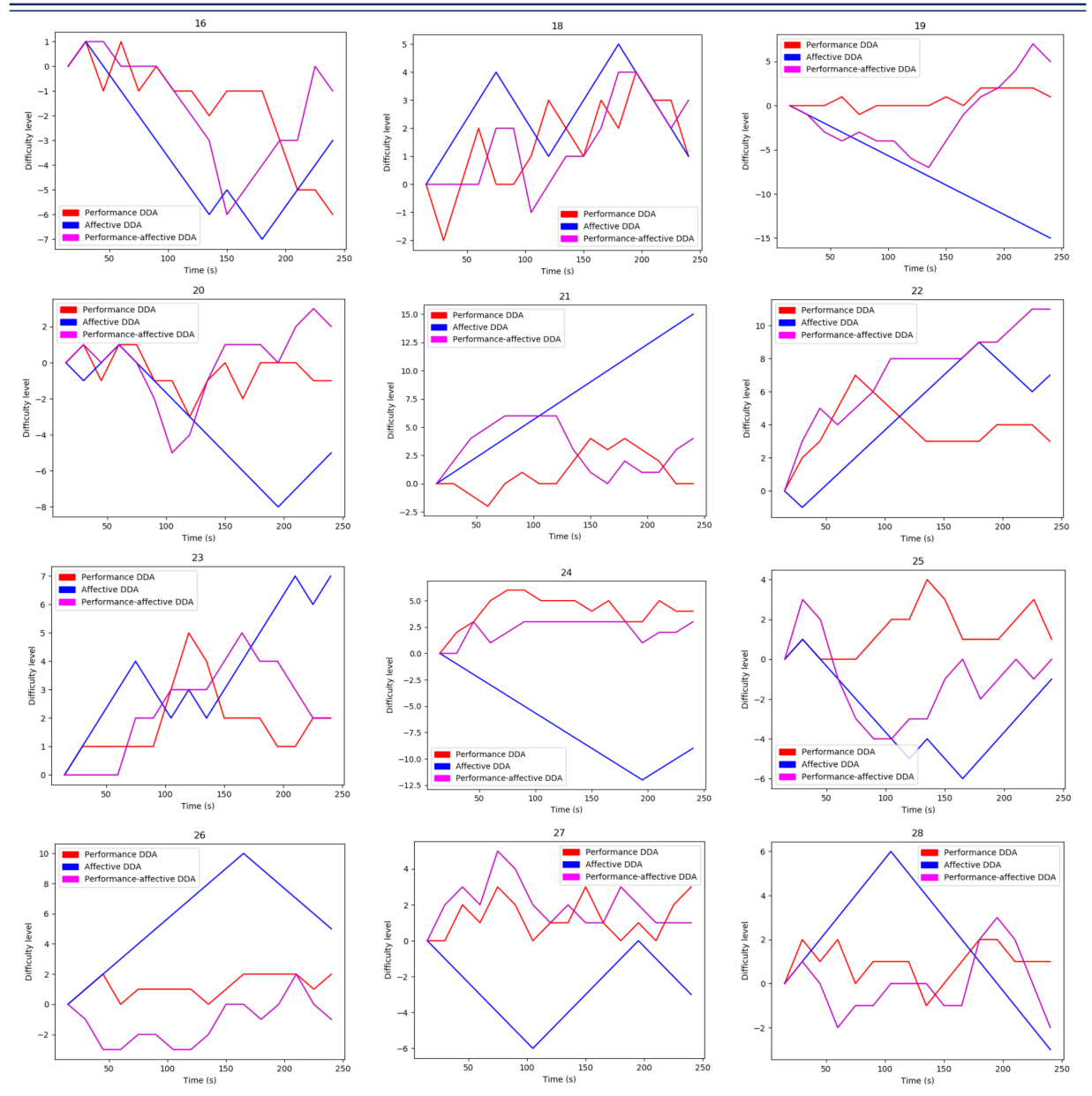


Table 5.5: SCORE EVERY 15 SEC DURING THE 3 DDA METHODS (1)

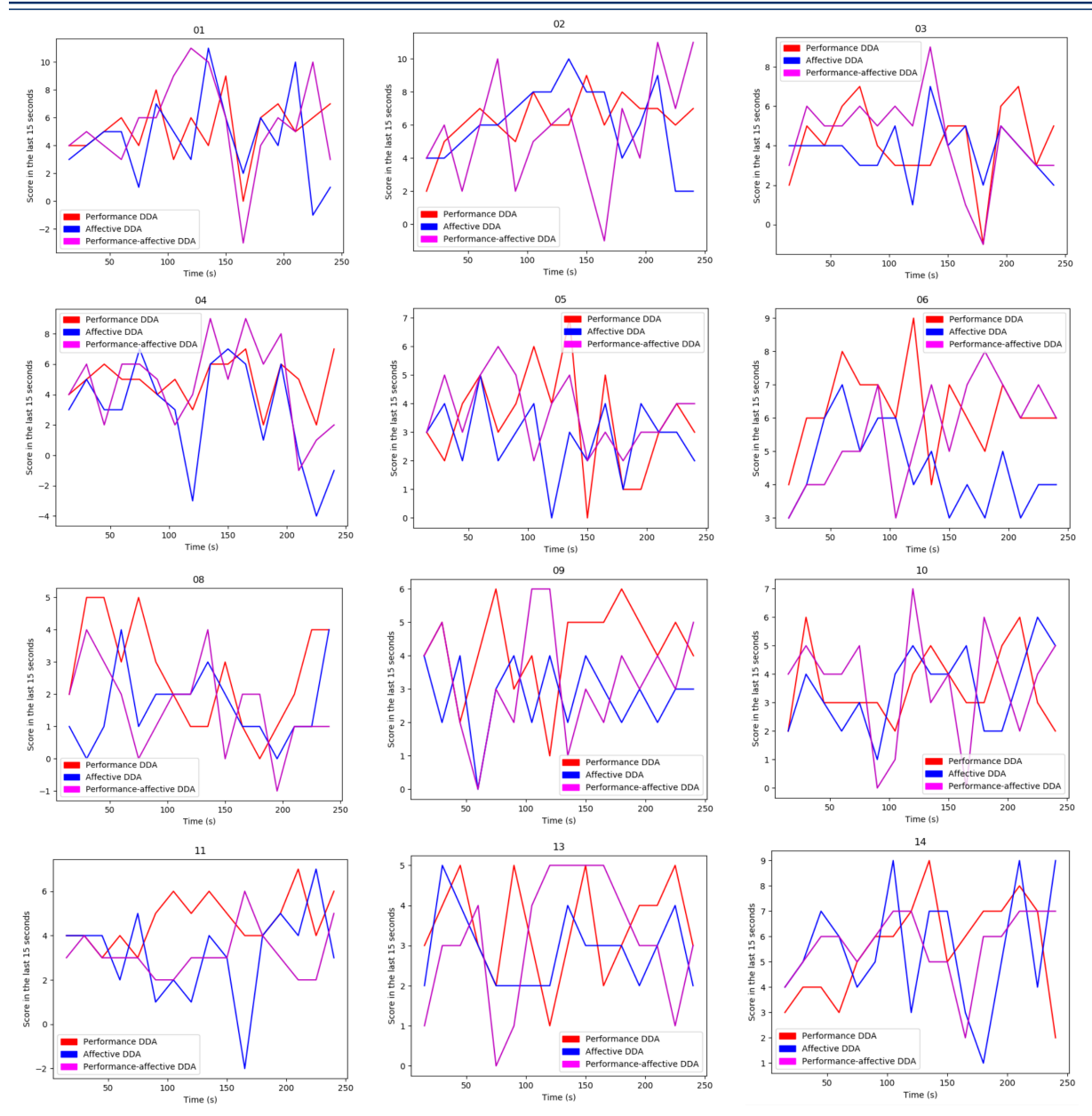
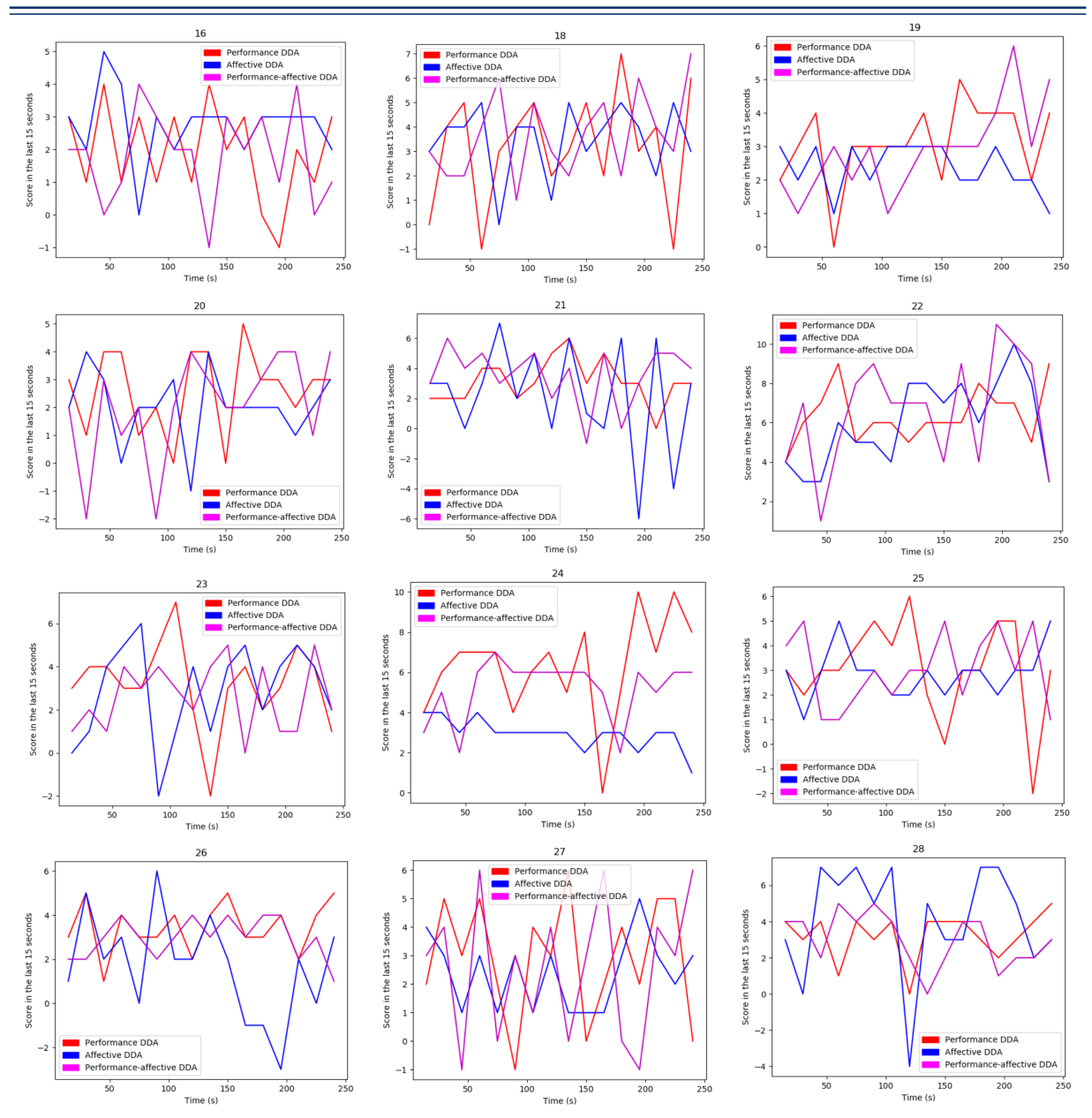


Table 5.6: SCORE EVERY 15 SEC DURING THE 3 DDA METHODS (2)**Table 5.7:** ANOVA TEST ON RAW SCL

Hard + Easy SCL	$p = 0.108$
Performance + Affective + Perfoffective SCL	$p = 0.982$
ALL SCL	$p = 0.593$

Table 5.8: ANOVA TEST ON SCL CONSIDERING BASELINE

Hard + Easy SCL	$p < 0.001$
Performance + Affective + Perfoffective SCL	$p = 0.988$
ALL SCL	$p = 0.009$

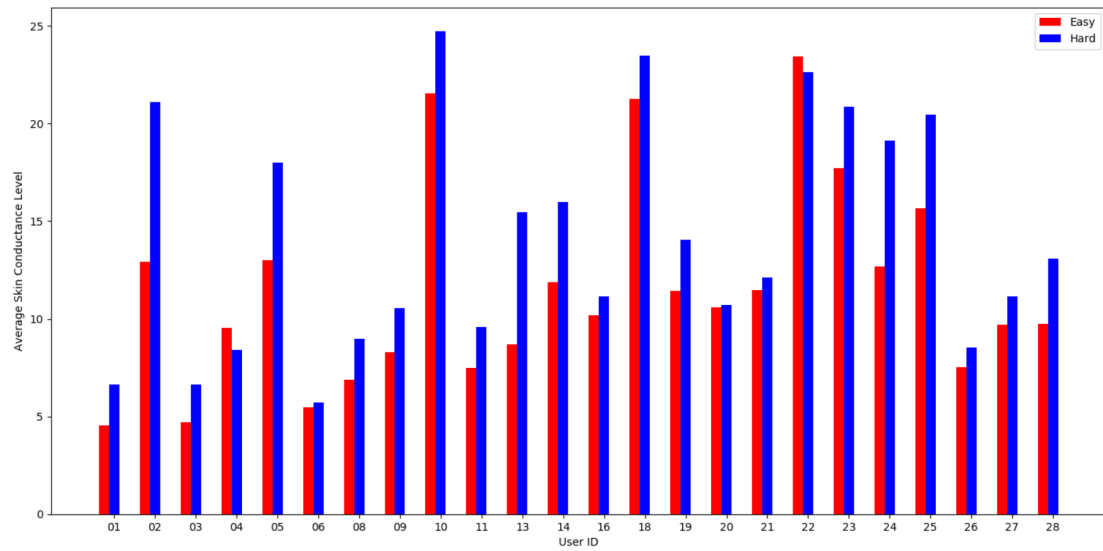


Figure 5.1: Comparison of Easy and Hard avg SCL across all the data

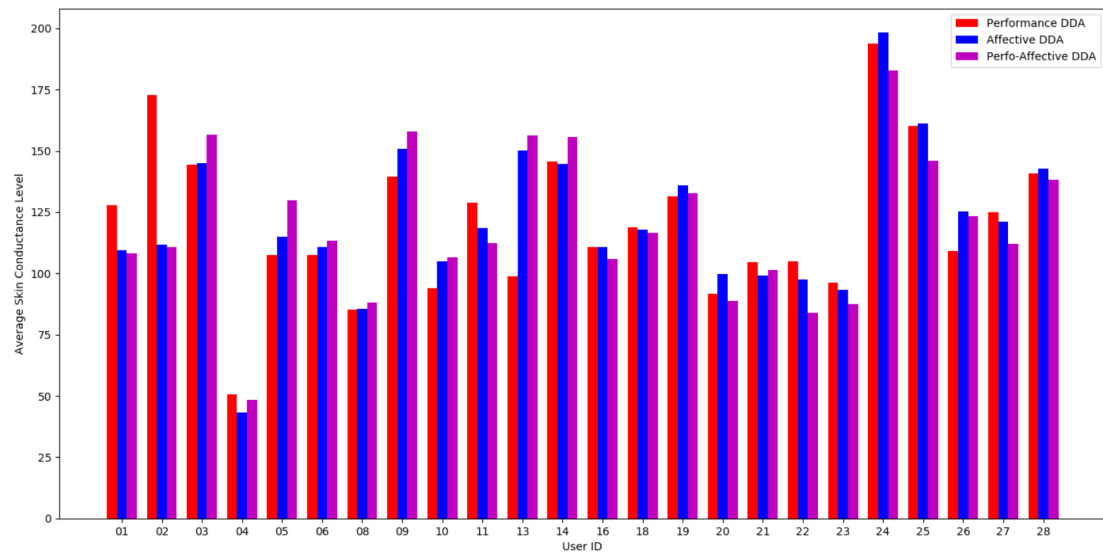


Figure 5.2: Comparison of avg SCL collected during the 3 DDA methods

level during the Affective DDA was really low, reaching high negative values, so the affective DDA algorithm did not work well this time, probably because the player was less immersed, so the SCL was more variable. A confirm can be seen looking at the scores' results: 14 people did their best score during the Performance DDA, 2 during the Affective DDA and 8 during the Perfo-Affective DDA (5.4).

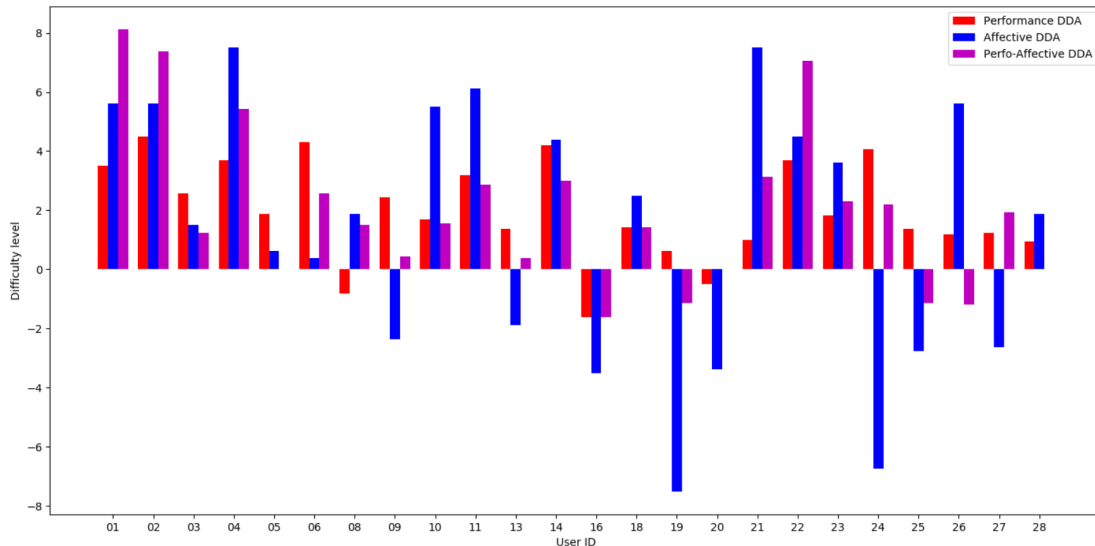


Figure 5.3: Comparison of avg difficulty collected during the 3 DDA methods

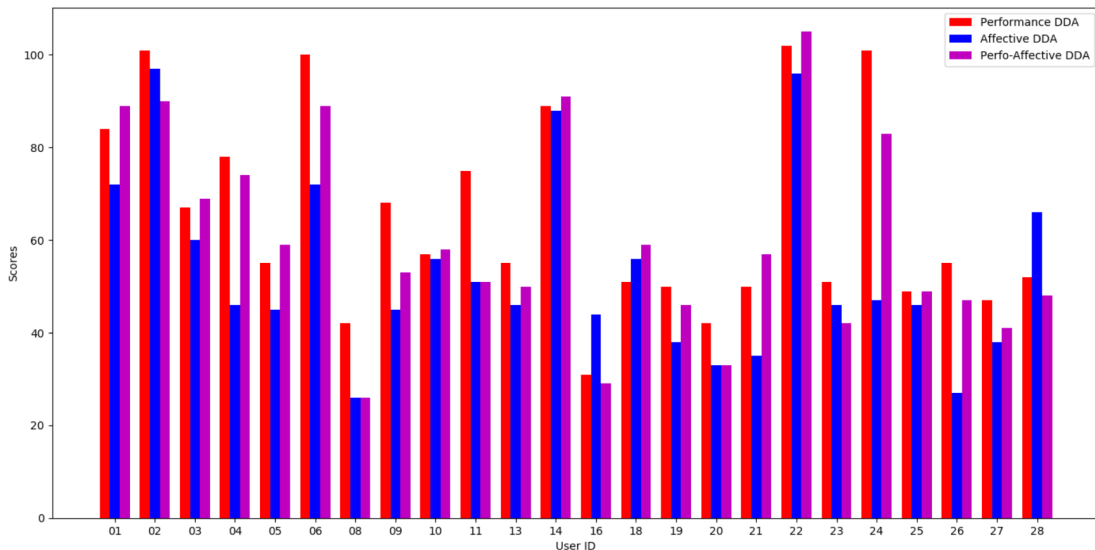


Figure 5.4: Comparison of people's scores collected during the 3 DDA methods

I have conducted some anova tests to see how significant are the results related to the scores and to the difficulty levels (5.9).

The p results of the 4 anova tests related to scores show that the correlation is not statistically significant (except for the performance + affective scores), while the 4 related to the difficulty levels show that the correlation is not statistically

significant for all.

In this second version of the game the results related to the affective variants were not good and on average did not lead to the best result.

5.4 Comparison between ETNA v1 and ETNA v2 results

Comparing the results of the anova test conducted on the two versions of the game, we can notice that the results related to the score are more significant in the second version, while the others are more significant in the first version (5.10).

As I said before, the main reason I did a second version of ETNA was that during the first version some people complained about the fact that having the holes in the ground was too hard because they were stepping too many times in the holes. Probably the score's results are more significant in the second version because they represent the real score of the player without considering the accidental penalties caused by the holes, that in many cases added noise to the results.

At the same time, the results related to SCL and difficulty levels could be worse in ETNA v2 because without having the controls of their feet the players felt less immersed in the game, more static and less focused. They got distracted easier and consequently their SCL varied in not significant ways.

Table 5.9: ANOVA TEST ON SCORES AND DIFFICULTY LEVELS

Performance + Affective scores	p = 0.059
Performance + Perfoaffective scores	p = 0.448
Affective + Perfoaffective scores	p = 0.265
Performance + Affective + Perfoaffective scores	p = 0.169
Performance + Affective difficulty levels	p = 0.553
Performance + Perfoaffective difficulty levels	p = 0.987
Affective + Perfoaffective difficulty levels	p = 0.596
Performance + Affective + Perfoaffective difficulty levels	p = 0.769

Table 5.10: COMPARISON BETWEEN ETNA V1 AND ETNA V2

Legend: P = Performance A = Affective PA = Perfoaffective	ETNA v1	ETNA v2
Hard + Easy SCL	p < 0.001	p < 0.001
P + A + PA SCL	p = 0.011	p = 0.988
ALL SCL	p = 0.001	p = 0.009
P + A scores	p = 0.723	p = 0.059
P + PA scores	p = 0.318	p = 0.448
A + PA scores	p = 0.424	p = 0.265
P + A + PA scores	p = 0.538	p = 0.169
P + A difficulty levels	p < 0.001	p = 0.553
P + PA difficulty levels	p < 0.001	p = 0.987
A + PA difficulty levels	p = 0.169	p = 0.596
P + A + PA difficulty levels	p < 0.001	p = 0.769

Chapter 6

Conclusion

The goals that this thesis sought to achieve were: a) creating an efficient affective-based DDA based on skin conductance and b) seeing which method gives the best results in a VR Game. In order to achieve these goals, a VR game called ETNA (Entertaining Training Neuro Affective) has been developed in 3 variants: performance DDA, affective DDA and perfo-affective DDA. Two user studies have been conducted and the results showed that the best method to adjust the difficulty of the game was the mixed perfo-affective DDA when the player was fully immerse into the virtual world (ETNA v1), while the two affective DDA did not work very good in the second version. This leads to the conclusion that coupling an affective DDA to a basic performance DDA algorithm, in some specific cases (player fully immersed inside the game), the game experience can be improved. Moreover, the technique of evaluating qualitatively the optimal SCL from previous sessions of the same user to create the affective DDA has worked well in ETNA v1, even if it can be perfected to improve the affective algorithm in future works. To improve the effectiveness of the affective and perfo-affective DDA more features of skin conductance, such as SCR, should be evaluated instead that the only SCL. This thesis has demonstrated that affective gaming can be implemented in Virtual Reality to improve the overall gaming experience and to help people making physical exercises. A game like ETNA can be also used by people who need to do rehabilitation since the game will adapt its difficulty to their disabilities and will help them to have fun while doing rehabilitation.

Appendix A

ETNA main code

```
1 void Start () {
2
3     x = 360f;
4     y = 3f;
5     z = 500f;
6
7     incX = 8.38f;
8     incZ = 7.88f;
9
10    sclValues = new List<float>();
11    allValues = new List<string>();
12    sessionValues = new List<string>();
13
14    // 10 is the number of holes
15    GeneratePlatform(10);
16
17    tColl = -3;
18    tBall = -3;
19    tSession = -3;
20    gamePaused = false;
21    gameActive = false;
22
23    if (easyMode){
24        isPerformanceDDA = false;
25        hardMode = false;
26        normalMode = false;
27
28        spawnRate = 5.3f;
29        speedMult = 1;
30        difficultyLevel = -10;
31    }
32
33    if (hardMode){
34        isPerformanceDDA = false;
35        easyMode = false;
36        normalMode = false;
37
38        spawnRate = 0.6f;
39        speedMult = 4f;
40        difficultyLevel = 10;
41    }
```

```

42
43     if (!collectAffective)
44         serialController.gameObject.SetActive(false);
45
46     gamePaused = true;
47     Time.timeScale = 0;
48
49     abilityLab = false;
50 }
51
52
53 void FixedUpdate () {
54     if (Input.GetKeyDown(KeyCode.Space))
55         gamePaused = !gamePaused;
56
57     tBall += Time.deltaTime;
58     tColl += Time.deltaTime;
59     tSession += Time.deltaTime;
60
61     if (tSession >= 0)
62         gameActive = true;
63
64     if (tBall >= spawnRate) {
65         tBall = 0;
66
67         int minIndex = 0;
68
69         if (spawnRate < 2)
70             minIndex = 0;
71
72         if (spawnRate >= 2 && spawnRate < 2.8)
73             minIndex = 1;
74
75         if (spawnRate >= 2.8 && spawnRate < 3.8)
76             minIndex = 2;
77
78         if (spawnRate >= 3.8)
79             minIndex = 3;
80
81         int index = UnityEngine.Random.Range(minIndex, 4);
82         Vector3 targetPos = platformsF[UnityEngine.Random.
83             Range(0, platformsF.Count - 1)].transform.
84             position + new Vector3(-incX / 2, 0, -incZ / 2);
85         volcanos[index].target.transform.position =
86             targetPos;
87         volcanos[index].SpawnBall(speedMult);
88         totalBalls++;
89     }
90
91     if(tColl >= collRate && activeColl == null) {
92         tColl = 0;
93         Vector3 collPos;
94         if (isWheelChairMode)
95             collPos = new Vector3(UnityEngine.Random.Range
96                 (310,330), 25, UnityEngine.Random.Range(500,
97                 520));

```

```
93
94     else
95         collPos = platformsF[UnityEngine.Random.Range
          (0, platformsF.Count - 1)].transform.
          position + new Vector3(-incX / 2, 35, -incZ
          / 2);
96
97         activeColl = Instantiate(collectible, collPos,
          Quaternion.identity);
98
99     }
100
101     if (collectAffective) {
102         ReadSerial();
103         if (scl != 0) {
104             sclValues.Add(scl);
105         }
106     }
107
108     if (tSession >= sessionTime) {
109         tSession = 0;
110         float ratio = actualScore / totalBalls * 100;
111         string sessionResult= "\n" + "Session " + nSession
          + ":\n" +
112             "Difficulty Level: " +
          difficultyLevel + "\n"+
113             "Total balls: " + totalBalls +
          "\n" +
114             "Spawn Rate: " + spawnRate + "
          \n" +
115             "Speed Mult:" + speedMult + "
          \n" +
116             "Penalties: " + penaltyCount
          + "\n" +
117             "Score: " + actualScore + "\n
          " +
118             "Balls hitteD: " + (
          penaltyCount+actualScore)+
          "\n" +
119             "Ratio: " + ratio;
120
121         sessionValues.Add(sessionResult);
122         Debug.Log(sessionResult);
123         PrintOutput(sessionResult);
124
125         if(collectAffective)
126             AffectiveDDA(sclValues);
127
128         if (isPerformanceDDA)
129             PerformanceDDA(ratio);
130         //IncrementalDifficulty();
131
132         sclValues = new List<float>();
133         nSession++;
134         totalBalls = 0;
135         actualScore = 0;
```

```
136         penaltyCount = 0;
137         //actualScore + penaltyCount = ballHitted
138     }
139
140 }
141
142 private void GeneratePlatform(int holes){
143     platformsF = new List<GameObject>();
144     platformsH = new List<GameObject>();
145     GameObject pF;
146     GameObject pH;
147
148     for (int i = 0; i < 10; i++) {
149         for (int j = 0; j < 8; j++) {
150             pF = Instantiate(platformFull, new Vector3(x, y
151                 , z), Quaternion.identity);
152             platformsF.Add(pF);
153             z += incZ;
154         }
155         z = 500f;
156         x -= incX;
157     }
158
159     for (int i = 0; i < holes; i++) {
160         pF = platformsF[UnityEngine.Random.Range(0,
161             platformsF.Count-1)];
162         platformsF.Remove(pF);
163
164         pH = Instantiate(platformHole, pF.transform.
165             position, Quaternion.identity);
166         platformsH.Add(pH);
167         Destroy(pF);
168     }
169 }
```


Appendix B

Performance-based DDA code

Here is the code used to generate the performance-based DDA.

```
1 // ActiveVolc: 4 , 4 , 4 , 4 , 4 , 4 , 4 , 3 ,
   3 , 2 , 2 , 2 , 2 , 1 , 1 , 1 , 1 , 1 ,
   1 , 1 , 1 ..
2 // Difficulty: +10 , +9 , +8 , +7 , +6 , +5 , +4 , +3 ,
   +2 , +1 , 0 , -1 , -2 , -3 , -4 , -5 , -6 , -7 ,
   -8 , -9 , -10 ..
3 // SpeedMult : 2.5 , 2.4 , 2.3 , 2.2 , 2.1 , 2.0 , 1.8 , 1.6 ,
   1.4 , 1.2 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 ,
   1 , 1 , 1 ..
4 // SpawnRate : 1 , 1.1 , 1.2 , 1.3 , 1.4 , 1.5 , 1.8 , 2.1 ,
   2.4 , 2.7 , 3 , 3.3 , 3.6 , 3.9 , 4.2 , 4.5 , 4.8 , 5.1 ,
   5.2 , 5.3 , 5.4 ..
5
6 private void PerformanceDDA(float ratio){
7     if (ratio < 20) {
8         //decrease a lot difficulty
9         difficultyLevel = difficultyLevel - 2;
10        if (spawnRate > 1.5 && spawnRate < 5) {
11            spawnRate += 0.6f;
12            if (spawnRate <= 3)
13                speedMult -= 0.4f;
14        }
15
16        else {
17            spawnRate += 0.2f;
18            if (spawnRate <= 3)
19                speedMult -= 0.2f;
20        }
21    }
22
23
24    if (ratio >= 20 && ratio < 50) {
25        //decrease difficulty
26        difficultyLevel--;
27        if (spawnRate > 1.5 && spawnRate < 5) {
28            spawnRate += 0.3f;
29            if(spawnRate <= 3)
30                speedMult -= 0.2f;
31    }
```

```
32
33     else {
34         spawnRate += 0.1f;
35         if(spawnRate <= 3)
36             speedMult -= 0.1f;
37     }
38 }
39
40 if (ratio >= 70 && ratio < 90) {
41     //increase difficulty
42     difficultyLevel++;
43     if (spawnRate > 1.5 && spawnRate < 5) {
44         spawnRate -= 0.3f;
45         if (spawnRate <= 3)
46             speedMult += 0.2f;
47     }
48
49     else {
50         spawnRate -= 0.1f;
51         if (spawnRate <= 3)
52             speedMult += 0.1f;
53     }
54 }
55
56 if (ratio >= 90) {
57     //increase a lot difficulty
58     difficultyLevel = difficultyLevel + 2;
59     if (spawnRate > 1.5 && spawnRate < 5) {
60         spawnRate -= 0.6f;
61         if (spawnRate <= 3)
62             speedMult += 0.4f;
63     }
64
65     else {
66         spawnRate -= 0.2f;
67         if (spawnRate <= 3)
68             speedMult += 0.2f;
69     }
70 }
71 }
```

Appendix C

Affective-based DDA code

Here is the code used to generate the affective-based DDA.

```
1 // ActiveVolc: 4 , 4 , 4 , 4 , 4 , 4 , 4 , 3 ,
   3 , 2 , 2 , 2 , 2 , 1 , 1 , 1 , 1 , 1 ,
   1 , 1 , 1 ..
2 // Difficulty: +10 , +9 , +8 , +7 , +6 , +5 , +4 , +3 ,
   +2 , +1 , 0 , -1 , -2 , -3 , -4 , -5 , -6 , -7 ,
   -8 , -9 , -10 ..
3 // SpeedMult : 2.5 , 2.4 , 2.3 , 2.2 , 2.1 , 2.0 , 1.8 , 1.6 ,
   1.4 , 1.2 , 1 , 1 , 1 , 1 , 1 , 1 , 1 , 1 ,
   1 , 1 , 1 ..
4 // SpawnRate : 1 , 1.1 , 1.2 , 1.3 , 1.4 , 1.5 , 1.8 , 2.1 ,
   2.4 , 2.7 , 3 , 3.3 , 3.6 , 3.9 , 4.2 , 4.5 , 4.8 , 5.1 ,
   5.2 , 5.3 , 5.4 ..
5
6 private void AffectiveDDA(List<float> currentValues){
7     float avg = currentValues.Average();
8
9     if (isAffectiveDDA){
10        float diff = avg - optimalSCL;
11        if (diff > 0 && diff > diffSCL){
12
13            //decrease difficulty
14            difficultyLevel--;
15            if (spawnRate > 1.5 && spawnRate < 5){
16                spawnRate += 0.3f;
17                if (spawnRate <= 3)
18                    speedMult -= 0.2f;
19            }
20
21            else{
22                spawnRate += 0.1f;
23                if (spawnRate <= 3)
24                    speedMult -= 0.1f;
25            }
26        }
27
28        if (diff < 0 && -diff > diffSCL){
29
30            //increase difficulty
31            difficultyLevel++;
```

```
32         if (spawnRate > 1.5 && spawnRate < 5){
33             spawnRate -= 0.3f;
34             if (spawnRate <= 3)
35                 speedMult += 0.2f;
36         }
37
38         else{
39             spawnRate -= 0.1f;
40             if (spawnRate <= 3)
41                 speedMult += 0.1f;
42         }
43     }
44 }
45 }
```

Appendix D

All users data ETNA v1

Here is all the user's data related to SCL, difficulty levels and scores collected during the ETNA v1 user study.

Each session represents an interval of 15 seconds.

```
1
2 *****
3
4 01st
5
6 EASY:
7 Diff: -10.0
8 Score: 19.0
9 Ratio: 74.07407222222223
10 AverageSCL: 3.2446168888888893
11
12 HARD +++:
13 Diff: 10.0
14 Score: 14.0
15 Ratio: 6.8
16 AverageSCL: 4.717566100000001
17
18 PERFORMA:
19 Diff: 2.5625
20 Score: 69.0
21 Ratio: 62.44543875
22 AverageSCL: 5.4416848125
23
24 PERFOAFF:
25 Diff: 7.0625
26 Score: 88.0
27 Ratio: 50.78125
28 AverageSCL: 4.421326
29
30 AFFECTIV:
31 Diff: 7.125
32 Score: 55.0
33 Ratio: 38.446990000000001
34 AverageSCL: 4.158381125000001
35
36 *****
```

```
37
38 03rd
39
40 EASY:
41 Diff: -10.0
42 Score: 18.0
43 Ratio: 77.77777555555555
44 AverageSCL: 4.621956777777778
45
46 HARD +++:
47 Diff: 10.0
48 Score: 37.0
49 Ratio: 17.2
50 AverageSCL: 5.5453484
51
52 PERFORMA:
53 Diff: 3.3333333333333335
54 Score: 83.0
55 Ratio: 66.68294666666667
56 AverageSCL: 4.6573336
57
58 AFFECTIV:
59 Diff: 7.0
60 Score: 80.0
61 Ratio: 58.049165333333334
62 AverageSCL: 3.8708253999999997
63
64 PERFOAFF:
65 Diff: 8.625
66 Score: 105.0
67 Ratio: 52.913225624999995
68 AverageSCL: 4.107522124999999
69
70 *****
71
72 04th
73
74 EASY:
75 Diff: -10.0
76 Score: -9.0
77 Ratio: 30.555553333333325
78 AverageSCL: 3.292088083333332
79
80 HARD +++:
81 Diff: 10.0
82 Score: -146.0
83 Ratio: 0.0
84 AverageSCL: 3.2304461428571427
85
86 PERFORMA:
87 Diff: 1.4375
88 Score: 44.0
89 Ratio: 55.75644875
90 AverageSCL: 3.0741035000000005
91
92 PERFOAFF:
```

```
93 Diff: 3.125
94 Score: 55.0
95 Ratio: 39.672202375
96 AverageSCL: 2.9286372500000004
97
98 AFFECTIV:
99 Diff: 7.125
100 Score: 37.0
101 Ratio: 34.380379687499996
102 AverageSCL: 2.6370069375
103
104 *****
105
106 05th
107
108 EASY:
109 Diff: -10.0
110 Score: 41.0
111 Ratio: 91.66666500000001
112 AverageSCL: 3.080245625
113
114 HARD +++:
115 Diff: 10.0
116 Score: 18.0
117 Ratio: 8.0
118 AverageSCL: 3.896804692307693
119
120 PERFORMA:
121 Diff: 2.8125
122 Score: 76.0
123 Ratio: 61.497428125000006
124 AverageSCL: 3.9572193749999993
125
126 AFFECTIV:
127 Diff: 6.75
128 Score: 80.0
129 Ratio: 42.8909493125
130 AverageSCL: 3.4134943125
131
132 PERFOAFF:
133 Diff: 6.5
134 Score: 92.0
135 Ratio: 48.77298425
136 AverageSCL: 3.2738053125000004
137
138 *****
139
140 06th
141
142 EASY:
143 Diff: -10.0
144 Score: 21.0
145 Ratio: 80.55555416666667
146 AverageSCL: 14.956953333333333
147
148 HARD +++:
```

```
149 Diff: 10.0
150 Score: -32.0
151 Ratio: 2.0
152 AverageSCL: 16.85386
153
154 PERFORMA:
155 Diff: -0.25
156 Score: 27.0
157 Ratio: 54.017856875
158 AverageSCL: 10.494023
159
160 PERFOAFF:
161 Diff: 3.0
162 Score: 100.0
163 Ratio: 58.2365
164 AverageSCL: 12.428166437500002
165
166 AFFECTIV:
167 Diff: 4.625
168 Score: 61.0
169 Ratio: 51.059123124999999
170 AverageSCL: 17.796138125
171
172 *****
173
174 07th
175
176 EASY:
177 Diff: -10.0
178 Score: -9.0
179 Ratio: 30.30302909090909
180 AverageSCL: 2.575149909090909
181
182 HARD +++:
183 Diff: 10.0
184 Score: -65.0
185 Ratio: 0.36363636363636365
186 AverageSCL: 2.426510636363637
187
188 PERFORMA:
189 Diff: -1.1875
190 Score: 48.0
191 Ratio: 62.693451875
192 AverageSCL: 2.6399126249999996
193
194 AFFECTIV:
195 Diff: 6.25
196 Score: 43.0
197 Ratio: 33.3752334375
198 AverageSCL: 2.4508132500000004
199
200 PERFOAFF:
201 Diff: 2.125
202 Score: 35.0
203 Ratio: 35.9185605625
204 AverageSCL: 2.7058194374999998
```



```
205
206 *****
207
208 08th
209
210 EASY:
211 Diff: -10.0
212 Score: 6.0
213 Ratio: 49.999997999999999
214 AverageSCL: 4.5352066
215
216 HARD +++:
217 Diff: 10.0
218 Score: -36.0
219 Ratio: 1.3333333333333333
220 AverageSCL: 5.497226666666667
221
222 PERFORMA:
223 Diff: 3.1333333333333333
224 Score: 74.0
225 Ratio: 59.690236666666667
226 AverageSCL: 2.8572435333333333
227
228 PERFOAFF:
229 Diff: 2.0625
230 Score: 28.0
231 Ratio: 47.234623125000006
232 AverageSCL: 3.042407875
233
234 AFFECTIV:
235 Diff: 3.125
236 Score: 73.0
237 Ratio: 64.692460625
238 AverageSCL: 1.8684764999999999
239
240 *****
241
242 09th
243
244 EASY:
245 Diff: -10.0
246 Score: 12.0
247 Ratio: 73.80952285714285
248 AverageSCL: 8.984128714285715
249
250 HARD +++:
251 Diff: 10.0
252 Score: 10.0
253 Ratio: 8.444444444444445
254 AverageSCL: 12.454622666666666
255
256 PERFORMA:
257 Diff: 2.625
258 Score: 80.0
259 Ratio: 70.60267875
260 AverageSCL: 18.394555000000004
```

```
261
262 AFFECTIV :
263 Diff: 3.375
264 Score: 100.0
265 Ratio: 66.09557
266 AverageSCL: 14.90274525
267
268 PERFOAFF :
269 Diff: 5.5
270 Score: 103.0
271 Ratio: 61.51743937499999
272 AverageSCL: 13.791010125
273
274 *****
275
276 10th
277
278 EASY :
279 Diff: -10.0
280 Score: -20.0
281 Ratio: 18.74999875
282 AverageSCL: 12.343309875000001
283
284 HARD +++:
285 Diff: 10.0
286 Score: -10.0
287 Ratio: 0.0
288 AverageSCL: 17.862399999999997
289
290 PERFORMA :
291 Diff: -1.8125
292 Score: 37.0
293 Ratio: 57.0833325
294 AverageSCL: 19.388109375
295
296 PERFOAFF :
297 Diff: 5.375
298 Score: 52.0
299 Ratio: 36.3829393125
300 AverageSCL: 12.85443925
301
302 AFFECTIV :
303 Diff: 6.75
304 Score: 75.0
305 Ratio: 40.525453750000004
306 AverageSCL: 12.0592043125
307
308 *****
309
310 11th
311
312 EASY :
313 Diff: -10.0
314 Score: 24.0
315 Ratio: 98.14814666666666
316 AverageSCL: 5.786382555555556
```

```
317
318 HARD +++:
319 Diff: 10.0
320 Score: 40.0
321 Ratio: 17.77777777777778
322 AverageSCL: 6.539998222222222
323
324 PERFORMA:
325 Diff: 6.3125
326 Score: 150.0
327 Ratio: 66.33920625
328 AverageSCL: 6.27787975
329
330 AFFECTIV:
331 Diff: 5.375
332 Score: 106.0
333 Ratio: 65.01755125000001
334 AverageSCL: 4.330754937499999
335
336 PERFOAFF:
337 Diff: 6.8125
338 Score: 92.0
339 Ratio: 48.133844187499996
340 AverageSCL: 3.3789643125000004
341
342 *****
343
344 12th
345
346 EASY:
347 Diff: -10.0
348 Score: 2.0
349 Ratio: 40.90909
350 AverageSCL: 4.480228272727272
351
352 HARD +++:
353 Diff: 10.0
354 Score: -25.0
355 Ratio: 1.8181818181818181
356 AverageSCL: 7.531992636363636
357
358 PERFORMA:
359 Diff: 2.5
360 Score: 88.0
361 Ratio: 61.114491249999986
362 AverageSCL: 10.261961937499999
363
364 AFFECTIV:
365 Diff: 3.75
366 Score: 27.0
367 Ratio: 33.189466249999995
368 AverageSCL: 6.102795312499999
369
370 PERFOAFF:
371 Diff: 6.25
372 Score: 73.0
```

```
373 Ratio: 41.651737125
374 AverageSCL: 6.594013375
375
376 *****
377
378 14th
379
380 EASY:
381 Diff: -10.0
382 Score: 23.0
383 Ratio: 70.83332916666667
384 AverageSCL: 7.865066333333334
385
386 HARD +++:
387 Diff: 10.0
388 Score: -26.0
389 Ratio: 0.8888888888888888
390 AverageSCL: 9.663176444444446
391
392 PERFORMA:
393 Diff: 1.8125
394 Score: 60.0
395 Ratio: 63.995535000000004
396 AverageSCL: 13.600907499999998
397
398 AFFECTIV:
399 Diff: 6.75
400 Score: 63.0
401 Ratio: 32.799725
402 AverageSCL: 8.158074
403
404 PERFOAFF:
405 Diff: 3.5625
406 Score: 53.0
407 Ratio: 36.477273749999995
408 AverageSCL: 7.4403454375
409
410 *****
411
412 15th
413
414 EASY:
415 Diff: -10.0
416 Score: -4.0
417 Ratio: 21.212119090909088
418 AverageSCL: 8.713875272727273
419
420 HARD +++:
421 Diff: 10.0
422 Score: 3.0
423 Ratio: 5.5
424 AverageSCL: 9.319439625
425
426 PERFORMA:
427 Diff: 1.6875
428 Score: 58.0
```

```
429 Ratio: 60.647320625
430 AverageSCL: 8.921968125
431
432 AFFECTIV:
433 Diff: 6.5625
434 Score: 59.0
435 Ratio: 33.732758125000004
436 AverageSCL: 7.411290875000001
437
438 PERFOAFF:
439 Diff: 3.75
440 Score: 76.0
441 Ratio: 51.643668125
442 AverageSCL: 7.318957625
443
444 *****
445
446 16th
447
448 EASY:
449 Diff: -10.0
450 Score: 11.0
451 Ratio: 74.99999749999999
452 AverageSCL: 4.792373625
453
454 HARD +++:
455 Diff: 10.0
456 Score: -22.0
457 Ratio: 6.0
458 AverageSCL: 4.428638416666666
459
460 PERFORMA:
461 Diff: -0.125
462 Score: 36.0
463 Ratio: 52.291666875000004
464 AverageSCL: 5.244742
465
466 PERFOAFF:
467 Diff: 3.25
468 Score: 27.0
469 Ratio: 33.7977124375
470 AverageSCL: 3.8891936874999997
471
472 AFFECTIV:
473 Diff: 7.5
474 Score: 47.0
475 Ratio: 34.646222312499994
476 AverageSCL: 4.318695249999999
477
478 *****
479
480 17th
481
482 EASY:
483 Diff: -10.0
484 Score: 30.0
```

```
485 Ratio: 70.83333125
486 AverageSCL: 18.997960624999997
487
488 HARD +++:
489 Diff: 10.0
490 Score: -6.0
491 Ratio: 10.0
492 AverageSCL: 22.816919000000002
493
494 PERFORMA:
495 Diff: -0.25
496 Score: 41.0
497 Ratio: 56.04166625
498 AverageSCL: 25.43121875
499
500 AFFECTIV:
501 Diff: 4.0
502 Score: 37.0
503 Ratio: 30.801958125
504 AverageSCL: 24.551558125000007
505
506 PERFOAFF:
507 Diff: 4.9375
508 Score: 75.0
509 Ratio: 53.5206101875
510 AverageSCL: 24.674443124999996
511
512 *****
513
514 18th
515
516 EASY:
517 Diff: -10.0
518 Score: 7.0
519 Ratio: 48.333329999999999
520 AverageSCL: 9.367521800000002
521
522 HARD +++:
523 Diff: 10.0
524 Score: -31.0
525 Ratio: 2.6666666666666665
526 AverageSCL: 12.612244444444444
527
528 PERFORMA:
529 Diff: 0.625
530 Score: 54.0
531 Ratio: 64.471725625
532 AverageSCL: 11.544668125
533
534 PERFOAFF:
535 Diff: 2.8125
536 Score: 40.0
537 Ratio: 39.537909375
538 AverageSCL: 9.430382624999998
539
540 AFFECTIV:
```

```
541 Diff: 7.375
542 Score: 49.0
543 Ratio: 38.181059375
544 AverageSCL: 10.678235562500001
545
546 *****
547
548 19th
549
550 EASY:
551 Diff: -10.0
552 Score: 17.0
553 Ratio: 81.24999749999999
554 AverageSCL: 6.775216999999999
555
556 HARD +++:
557 Diff: 10.0
558 Score: -9.0
559 Ratio: 3.2
560 AverageSCL: 4.76897362
561
562 PERFORMA:
563 Diff: 5.3125
564 Score: 107.0
565 Ratio: 64.12087874999999
566 AverageSCL: 6.447391500000001
567
568 AFFECTIV:
569 Diff: 7.125
570 Score: 66.0
571 Ratio: 43.0354123125
572 AverageSCL: 3.4477473749999996
573
574 PERFOAFF:
575 Diff: 4.9375
576 Score: 72.0
577 Ratio: 47.342566874999996
578 AverageSCL: 4.126069125000002
579
580 *****
581
582 20th
583
584 EASY:
585 Diff: -10.0
586 Score: 15.0
587 Ratio: 72.916665
588 AverageSCL: 4.48561425
589
590 HARD +++:
591 Diff: 10.0
592 Score: -73.0
593 Ratio: 0.0
594 AverageSCL: 4.898941428571428
595
596 PERFORMA:
```

```
597 Diff: 2.875
598 Score: 58.0
599 Ratio: 56.897321250000005
600 AverageSCL: 4.0554909375
601
602 PERFOAFF:
603 Diff: 7.375
604 Score: 93.0
605 Ratio: 52.897519375
606 AverageSCL: 2.6068317500000004
607
608 AFFECTIV:
609 Diff: 7.5
610 Score: 77.0
611 Ratio: 45.3091890625
612 AverageSCL: 2.2618386874999996
613
614 *****
615
616 22th
617
618 EASY:
619 Diff: -10.0
620 Score: 10.0
621 Ratio: 56.249998749999996
622 AverageSCL: 47.445164999999996
623
624 HARD +++:
625 Diff: 10.0
626 Score: -52.0
627 Ratio: 0.0
628 AverageSCL: 36.850591428571434
629
630 PERFORMA:
631 Diff: 2.375
632 Score: 63.0
633 Ratio: 64.828868125
634 AverageSCL: 42.130076249999995
635
636 PERFOAFF:
637 Diff: 4.3125
638 Score: 89.0
639 Ratio: 53.85871249999999
640 AverageSCL: 28.757704374999996
641
642 AFFECTIV:
643 Diff: 4.0
644 Score: 71.0
645 Ratio: 49.252465625000006
646 AverageSCL: 21.604125624999998
647
648 *****
649
650 23th
651
652 EASY:
```



```
653 Diff: -10.0
654 Score: 26.0
655 Ratio: 81.9444425
656 AverageSCL: 10.801864416666668
657
658 HARD +++:
659 Diff: 10.0
660 Score: -27.0
661 Ratio: 13.777777777777779
662 AverageSCL: 15.296357777777779
663
664 PERFORMA:
665 Diff: 1.5625
666 Score: 58.0
667 Ratio: 61.38392875
668 AverageSCL: 17.877682500000002
669
670 AFFECTIV:
671 Diff: 6.75
672 Score: 89.0
673 Ratio: 53.934871875000006
674 AverageSCL: 12.945127499999998
675
676 PERFOAFF:
677 Diff: 8.25
678 Score: 124.0
679 Ratio: 63.278078125
680 AverageSCL: 10.214263125
681
682 *****
683
684 24th
685
686 EASY:
687 Diff: -10.0
688 Score: 22.0
689 Ratio: 102.0833325
690 AverageSCL: 5.5621132499999995
691
692 HARD +++:
693 Diff: 10.0
694 Score: 1.0
695 Ratio: 4.0
696 AverageSCL: 5.958020375
697
698 PERFORMA:
699 Diff: 3.5
700 Score: 97.0
701 Ratio: 62.587464999999995
702 AverageSCL: 7.13176825
703
704 PERFOAFF:
705 Diff: 7.0
706 Score: 84.0
707 Ratio: 44.4020725
708 AverageSCL: 5.3673660625
```

```
709
710 AFFECTIV :
711 Diff: 4.125
712 Score: 101.0
713 Ratio: 68.596403125
714 AverageSCL: 5.818749125
715
716 *****
717
718 25th
719
720 EASY :
721 Diff: -10.0
722 Score: 11.0
723 Ratio: 64.583329999999999
724 AverageSCL: 7.217354875
725
726 HARD +++:
727 Diff: 10.0
728 Score: -20.0
729 Ratio: 1.3333333333333333
730 AverageSCL: 10.975192222222223
731
732 PERFORMA :
733 Diff: 1.75
734 Score: 56.0
735 Ratio: 58.048115625
736 AverageSCL: 15.96043375
737
738 AFFECTIV :
739 Diff: 3.25
740 Score: 67.0
741 Ratio: 50.69165125
742 AverageSCL: 10.57454675
743
744 PERFOAFF :
745 Diff: -0.5625
746 Score: 33.0
747 Ratio: 50.625
748 AverageSCL: 10.625759249999998
749
750 *****
751
752 26th
753
754 EASY :
755 Diff: -10.0
756 Score: 14.0
757 Ratio: 58.333332500000004
758 AverageSCL: 2.1998760833333333
759
760 HARD +++:
761 Diff: 10.0
762 Score: -29.0
763 Ratio: 0.8888888888888888
764 AverageSCL: 2.3601498888888894
```

```
765
766 PERFORMA :
767 Diff: 1.1875
768 Score: 61.0
769 Ratio: 66.56250187500001
770 AverageSCL: 2.1584301249999998
771
772 PERFOAFF :
773 Diff: 3.375
774 Score: 62.0
775 Ratio: 56.753471250000004
776 AverageSCL: 2.4524120000000003
777
778 AFFECTIV :
779 Diff: 5.0
780 Score: 72.0
781 Ratio: 56.0441475
782 AverageSCL: 2.2378245
783
784 *****
785
786 27th
787
788 EASY :
789 Diff: -10.0
790 Score: 2.0
791 Ratio: 23.333330999999998
792 AverageSCL: 18.248347
793
794 HARD +++:
795 Diff: 10.0
796 Score: -19.0
797 Ratio: 3.0
798 AverageSCL: 21.645149999999997
799
800 PERFORMA :
801 Diff: -6.125
802 Score: 1.0
803 Ratio: 47.39583124999999
804 AverageSCL: 13.158278124999999
805
806 AFFECTIV :
807 Diff: 0.625
808 Score: 54.0
809 Ratio: 65.066961875
810 AverageSCL: 14.3878550625
811
812 PERFOAFF :
813 Diff: 2.25
814 Score: 72.0
815 Ratio: 59.19304687500001
816 AverageSCL: 14.043934750000002
```


Appendix E

All users data ETNA v2

Here is all the user's data related to SCL, difficulty levels and scores collected during the ETNA v2 user study.

Each session represents an interval of 15 seconds.

```
1
2 *****
3
4 01st
5
6 EASY:
7 Diff: -10.0
8 Score: 41.0
9 Ratio: 92.70833125000001
10 AverageSCL: 4.54872625
11
12 HARD +++:
13 Diff: 10.0
14 Score: -2.0
15 Ratio: 4.6250001874999995
16 AverageSCL: 6.633833937500001
17
18 PERFORMA:
19 Diff: 3.5
20 Score: 84.0
21 Ratio: 65.094470625
22 AverageSCL: 5.824352875
23
24 AFFECTIV:
25 Diff: 5.625
26 Score: 72.0
27 Ratio: 49.86917456250001
28 AverageSCL: 4.980103375
29
30 PERFOAFF:
31 Diff: 8.125
32 Score: 89.0
33 Ratio: 48.76529125
34 AverageSCL: 4.9211429375
35
36 *****
```

```
37
38 02nd
39
40 EASY:
41 Diff: -10.0
42 Score: 36.0
43 Ratio: 83.33333125
44 AverageSCL: 12.923003750000001
45
46 HARD +++:
47 Diff: 10.0
48 Score: 13.0
49 Ratio: 7.9270838125
50 AverageSCL: 21.089544999999998
51
52 PERFORMA:
53 Diff: 4.5
54 Score: 101.0
55 Ratio: 64.91206687500001
56 AverageSCL: 22.336486875
57
58 PERFOAFF:
59 Diff: 7.375
60 Score: 90.0
61 Ratio: 51.096178125
62 AverageSCL: 14.305308125
63
64 AFFECTIV:
65 Diff: 5.625
66 Score: 97.0
67 Ratio: 66.53541875
68 AverageSCL: 14.44931875
69
70 *****
71
72 03rd
73
74 EASY:
75 Diff: -10.0
76 Score: 38.0
77 Ratio: 86.45833187500001
78 AverageSCL: 4.726239125
79
80 HARD +++:
81 Diff: 10.0
82 Score: -17.0
83 Ratio: 5.6041664375
84 AverageSCL: 6.631939250000001
85
86 PERFORMA:
87 Diff: 2.5625
88 Score: 67.0
89 Ratio: 60.5877975
90 AverageSCL: 6.8179268749999995
91
92 AFFECTIV:
```

```
93 Diff: 1.5
94 Score: 60.0
95 Ratio: 62.29629812500001
96 AverageSCL: 6.8558690625
97
98 PERFOAFF:
99 Diff: 1.25
100 Score: 69.0
101 Ratio: 67.07589375
102 AverageSCL: 7.4025943125
103
104 *****
105
106 04th
107
108 EASY:
109 Diff: -10.0
110 Score: 42.0
111 Ratio: 95.83333125000001
112 AverageSCL: 9.556224375
113
114 HARD +++:
115 Diff: 10.0
116 Score: 6.0
117 Ratio: 6.1979164375
118 AverageSCL: 8.39732675
119
120 PERFORMA:
121 Diff: 3.6875
122 Score: 78.0
123 Ratio: 63.598710624999995
124 AverageSCL: 4.8563341875
125
126 PERFOAFF:
127 Diff: 5.4375
128 Score: 74.0
129 Ratio: 45.104375437499996
130 AverageSCL: 4.612572625
131
132 AFFECTIV:
133 Diff: 7.5
134 Score: 46.0
135 Ratio: 33.901512187499996
136 AverageSCL: 4.120149312500001
137
138 *****
139
140 05th
141
142 EASY:
143 Diff: -10.0
144 Score: 43.0
145 Ratio: 96.87499875
146 AverageSCL: 12.995978124999997
147
148 HARD +++:
```

```
149 Diff: 10.0
150 Score: -24.0
151 Ratio: 5.1458334999999999
152 AverageSCL: 18.012163125
153
154 PERFORMA:
155 Diff: 1.875
156 Score: 55.0
157 Ratio: 57.710813125
158 AverageSCL: 13.969095
159
160 AFFECTIV:
161 Diff: 0.625
162 Score: 45.0
163 Ratio: 52.968748749999996
164 AverageSCL: 14.94440125
165
166 PERFOAFF:
167 Diff: 0.0
168 Score: 59.0
169 Ratio: 75.029760000000001
170 AverageSCL: 16.854106249999994
171
172 *****
173
174 06th
175
176 EASY:
177 Diff: -10.0
178 Score: 42.0
179 Ratio: 95.83333125
180 AverageSCL: 5.4693455625
181
182 HARD +++:
183 Diff: 10.0
184 Score: 44.0
185 Ratio: 12.96875
186 AverageSCL: 5.706364375000001
187
188 PERFORMA:
189 Diff: 4.3125
190 Score: 100.0
191 Ratio: 65.023726875
192 AverageSCL: 5.873387625
193
194 PERFOAFF:
195 Diff: 2.5625
196 Score: 89.0
197 Ratio: 74.571609375000001
198 AverageSCL: 6.193324125
199
200 AFFECTIV:
201 Diff: 0.375
202 Score: 72.0
203 Ratio: 84.940475625
204 AverageSCL: 6.056893312499999
```



```
205
206 *****
207
208 08th
209
210 EASY:
211 Diff: -10.0
212 Score: 37.0
213 Ratio: 82.29166375000001
214 AverageSCL: 6.893748375
215
216 HARD +++:
217 Diff: 10.0
218 Score: -33.0
219 Ratio: 0.5
220 AverageSCL: 8.9640695
221
222 PERFORMA:
223 Diff: -0.8125
224 Score: 42.0
225 Ratio: 57.470236250000006
226 AverageSCL: 5.8659701250000005
227
228 PERFOAFF:
229 Diff: 1.5
230 Score: 26.0
231 Ratio: 30.312499374999998
232 AverageSCL: 6.074744749999999
233
234 AFFECTIV:
235 Diff: 1.875
236 Score: 26.0
237 Ratio: 24.337798125000003
238 AverageSCL: 5.899809812499999
239
240 *****
241
242 09th
243
244 EASY:
245 Diff: -10.0
246 Score: 37.0
247 Ratio: 81.249998125
248 AverageSCL: 8.3122781875
249
250 HARD +++:
251 Diff: 10.0
252 Score: -22.0
253 Ratio: 2.5312500625
254 AverageSCL: 10.540689812499998
255
256 PERFORMA:
257 Diff: 2.4375
258 Score: 68.0
259 Ratio: 64.7966275
260 AverageSCL: 11.58796375
```

```
261
262 AFFECTIV :
263 Diff: -2.375
264 Score: 45.0
265 Ratio: 71.66666562500001
266 AverageSCL: 12.529274375000002
267
268 PERFOAFF :
269 Diff: 0.4375
270 Score: 53.0
271 Ratio: 54.0564125
272 AverageSCL: 13.13913125
273
274 *****
275
276 10th
277
278 EASY :
279 Diff: -10.0
280 Score: 31.0
281 Ratio: 69.79166562500001
282 AverageSCL: 21.539608750000003
283
284 HARD +++:
285 Diff: 10.0
286 Score: 16.0
287 Ratio: 8.21875
288 AverageSCL: 24.716068124999996
289
290 PERFORMA :
291 Diff: 1.6875
292 Score: 57.0
293 Ratio: 60.625
294 AverageSCL: 20.23958375
295
296 PERFOAFF :
297 Diff: 1.5625
298 Score: 58.0
299 Ratio: 47.023566875
300 AverageSCL: 22.975815624999996
301
302 AFFECTIV :
303 Diff: 5.5
304 Score: 56.0
305 Ratio: 35.801385
306 AverageSCL: 22.614857499999996
307
308 *****
309
310 11th
311
312 EASY :
313 Diff: -10.0
314 Score: 43.0
315 Ratio: 97.91666500000001
316 AverageSCL: 7.492800187499999
```

```
317
318 HARD +++:
319 Diff: 10.0
320 Score: -56.0
321 Ratio: 1.0208333125
322 AverageSCL: 9.5749594375
323
324 PERFORMA:
325 Diff: 3.1875
326 Score: 75.0
327 Ratio: 64.176586875
328 AverageSCL: 9.663371812500001
329
330 AFFECTIV:
331 Diff: 6.125
332 Score: 51.0
333 Ratio: 33.6894085625
334 AverageSCL: 8.890543625
335
336 PERFOAFF:
337 Diff: 2.875
338 Score: 51.0
339 Ratio: 46.584821250000005
340 AverageSCL: 8.4277328125
341
342 *****
343
344 13th
345
346 EASY:
347 Diff: -10.0
348 Score: 36.0
349 Ratio: 80.208329375
350 AverageSCL: 8.686631562499999
351
352 HARD +++:
353 Diff: 10.0
354 Score: 22.0
355 Ratio: 9.416666812499999
356 AverageSCL: 15.459985624999998
357
358 PERFORMA:
359 Diff: 1.375
360 Score: 55.0
361 Ratio: 60.312500625000006
362 AverageSCL: 8.576117125000001
363
364 AFFECTIV:
365 Diff: -1.875
366 Score: 46.0
367 Ratio: 69.16666437500001
368 AverageSCL: 13.054568187500001
369
370 PERFOAFF:
371 Diff: 0.375
372 Score: 50.0
```

```
373 Ratio: 59.360119375000004
374 AverageSCL: 13.574957499999998
375
376 *****
377
378 14th
379
380 EASY:
381 Diff: -10.0
382 Score: 41.0
383 Ratio: 92.70833125000001
384 AverageSCL: 11.874889999999999
385
386 HARD +++:
387 Diff: 10.0
388 Score: 4.0
389 Ratio: 5.395833125
390 AverageSCL: 15.973364999999998
391
392 PERFORMA:
393 Diff: 4.1875
394 Score: 89.0
395 Ratio: 66.2973475
396 AverageSCL: 17.3120175
397
398 PERFOAFF:
399 Diff: 3.0
400 Score: 91.0
401 Ratio: 79.588294375
402 AverageSCL: 18.483765
403
404 AFFECTIV:
405 Diff: 4.375
406 Score: 88.0
407 Ratio: 56.671084812500006
408 AverageSCL: 17.186013750000004
409
410 *****
411
412 16th
413
414 EASY:
415 Diff: -10.0
416 Score: -5.0
417 Ratio: 18.74999875
418 AverageSCL: 10.185050250000002
419
420 HARD +++:
421 Diff: 10.0
422 Score: -116.0
423 Ratio: 0.0
424 AverageSCL: 11.142809312499999
425
426 PERFORMA:
427 Diff: -1.625
428 Score: 31.0
```

```
429 Ratio: 47.083333125
430 AverageSCL: 11.289366000000001
431
432 AFFECTIV:
433 Diff: -3.5
434 Score: 44.0
435 Ratio: 78.12499937499999
436 AverageSCL: 11.2863883125
437
438 PERFOAFF:
439 Diff: -1.625
440 Score: 29.0
441 Ratio: 49.583330625
442 AverageSCL: 10.798065999999999
443
444 *****
445
446 18th
447
448 EASY:
449 Diff: -10.0
450 Score: 31.0
451 Ratio: 70.83333125
452 AverageSCL: 21.248299375000002
453
454 HARD +++:
455 Diff: 10.0
456 Score: -32.0
457 Ratio: 2.28125
458 AverageSCL: 23.474558125
459
460 PERFORMA:
461 Diff: 1.4375
462 Score: 51.0
463 Ratio: 59.66517875
464 AverageSCL: 25.278531875000002
465
466 AFFECTIV:
467 Diff: 2.5
468 Score: 56.0
469 Ratio: 53.36557499999999
470 AverageSCL: 25.055594375
471
472 PERFOAFF:
473 Diff: 1.4375
474 Score: 59.0
475 Ratio: 62.782738125
476 AverageSCL: 24.767137500000004
477
478 *****
479
480 19th
481
482 EASY:
483 Diff: -10.0
484 Score: 36.0
```

```
485 Ratio: 80.20833125
486 AverageSCL: 11.429176124999998
487
488 HARD +++:
489 Diff: 10.0
490 Score: 5.0
491 Ratio: 5.083333187500001
492 AverageSCL: 14.069556874999998
493
494 PERFORMA:
495 Diff: 0.625
496 Score: 50.0
497 Ratio: 60.133927500000006
498 AverageSCL: 15.014673124999998
499
500 PERFOAFF:
501 Diff: -1.125
502 Score: 46.0
503 Ratio: 66.339285
504 AverageSCL: 15.17381875
505
506 AFFECTIV:
507 Diff: -7.5
508 Score: 38.0
509 Ratio: 79.06249875
510 AverageSCL: 15.553181875
511
512 *****
513
514 20th
515
516 EASY:
517 Diff: -10.0
518 Score: 42.0
519 Ratio: 93.74999875
520 AverageSCL: 10.59080675
521
522 HARD +++:
523 Diff: 10.0
524 Score: -46.0
525 Ratio: 2.3020831250000002
526 AverageSCL: 10.715908749999999
527
528 PERFORMA:
529 Diff: -0.5
530 Score: 42.0
531 Ratio: 59.89583125
532 AverageSCL: 9.726083000000001
533
534 AFFECTIV:
535 Diff: -3.375
536 Score: 33.0
537 Ratio: 57.604164374999996
538 AverageSCL: 10.567127187499999
539
540 PERFOAFF:
```

```
541 Diff: 0.0
542 Score: 33.0
543 Ratio: 46.860118125
544 AverageSCL: 9.414961125
545
546 *****
547
548 21st
549
550 EASY:
551 Diff: -10.0
552 Score: 28.0
553 Ratio: 61.458329375
554 AverageSCL: 11.466283125
555
556 HARD +++:
557 Diff: 10.0
558 Score: -58.0
559 Ratio: 1.5
560 AverageSCL: 12.11314875
561
562 PERFORMA:
563 Diff: 1.0
564 Score: 50.0
565 Ratio: 56.778273125
566 AverageSCL: 11.979223749999997
567
568 PERFOAFF:
569 Diff: 3.125
570 Score: 57.0
571 Ratio: 43.325320625
572 AverageSCL: 11.629515
573
574 AFFECTIV:
575 Diff: 7.5
576 Score: 35.0
577 Ratio: 25.816257062500004
578 AverageSCL: 11.35977875
579
580 *****
581
582 22nd
583
584 EASY:
585 Diff: -10.0
586 Score: 41.0
587 Ratio: 92.70833187500001
588 AverageSCL: 23.427810625
589
590 HARD +++:
591 Diff: 10.0
592 Score: 5.0
593 Ratio: 4.916666875
594 AverageSCL: 22.6257125
595
596 PERFORMA:
```

```
597 Diff: 3.6875
598 Score: 102.0
599 Ratio: 61.7891175
600 AverageSCL: 24.564773750000008
601
602 AFFECTIV:
603 Diff: 4.5
604 Score: 96.0
605 Ratio: 64.195350625
606 AverageSCL: 22.832570624999995
607
608 PERFOAFF:
609 Diff: 7.0625
610 Score: 105.0
611 Ratio: 51.733028124999999
612 AverageSCL: 19.659218125
613
614 *****
615
616 23rd
617
618 EASY:
619 Diff: -10.0
620 Score: 41.0
621 Ratio: 92.70833187500001
622 AverageSCL: 17.7082024375
623
624 HARD +++:
625 Diff: 10.0
626 Score: -27.0
627 Ratio: 2.0104166875000002
628 AverageSCL: 20.857224375000005
629
630 PERFORMA:
631 Diff: 1.8125
632 Score: 51.0
633 Ratio: 54.925595
634 AverageSCL: 17.034953749999996
635
636 PERFOAFF:
637 Diff: 2.3125
638 Score: 42.0
639 Ratio: 36.279310624999994
640 AverageSCL: 15.483325624999999
641
642 AFFECTIV:
643 Diff: 3.625
644 Score: 46.0
645 Ratio: 35.04120875
646 AverageSCL: 16.50640375
647
648 *****
649
650 24th
651
652 EASY:
```



```
653 Diff: -10.0
654 Score: 43.0
655 Ratio: 97.91666500000001
656 AverageSCL: 12.685089562499998
657
658 HARD +++:
659 Diff: 10.0
660 Score: 19.0
661 Ratio: 7.8541664375
662 AverageSCL: 19.112254375
663
664 PERFORMA:
665 Diff: 4.0625
666 Score: 101.0
667 Ratio: 61.928965
668 AverageSCL: 24.59046875
669
670 PERFOAFF:
671 Diff: 2.1875
672 Score: 83.0
673 Ratio: 82.72321812499999
674 AverageSCL: 23.183438125
675
676 AFFECTIV:
677 Diff: -6.75
678 Score: 47.0
679 Ratio: 92.499999375
680 AverageSCL: 25.145235624999998
681
682 *****
683
684 25th
685
686 EASY:
687 Diff: -10.0
688 Score: 35.0
689 Ratio: 79.16666375000001
690 AverageSCL: 15.6695299375
691
692 HARD +++:
693 Diff: 10.0
694 Score: -39.0
695 Ratio: 1.7708333125
696 AverageSCL: 20.442520625
697
698 PERFORMA:
699 Diff: 1.375
700 Score: 49.0
701 Ratio: 56.875000625
702 AverageSCL: 25.086996250000002
703
704 AFFECTIV:
705 Diff: -2.75
706 Score: 46.0
707 Ratio: 74.062499375
708 AverageSCL: 25.228676250000003
```

```
709
710 PERFOAFF :
711 Diff: -1.125
712 Score: 49.0
713 Ratio: 68.177083125
714 AverageSCL: 22.883364375000003
715
716 *****
717
718 26th
719
720 EASY :
721 Diff: -10.0
722 Score: 29.0
723 Ratio: 65.624998124999999
724 AverageSCL: 7.539181125
725
726 HARD +++:
727 Diff: 10.0
728 Score: -32.0
729 Ratio: 1.5208333125
730 AverageSCL: 8.5340883125
731
732 PERFORMA :
733 Diff: 1.1875
734 Score: 55.0
735 Ratio: 61.05654812500001
736 AverageSCL: 8.238206062500002
737
738 PERFOAFF :
739 Diff: -1.1875
740 Score: 47.0
741 Ratio: 67.098214375
742 AverageSCL: 9.307325375000001
743
744 AFFECTIV :
745 Diff: 5.625
746 Score: 27.0
747 Ratio: 21.73975875
748 AverageSCL: 9.442586500000003
749
750 *****
751
752 27th
753
754 EASY :
755 Diff: -10.0
756 Score: 24.0
757 Ratio: 60.41666375
758 AverageSCL: 9.708259187500001
759
760 HARD +++:
761 Diff: 10.0
762 Score: -90.0
763 Ratio: 0.0
764 AverageSCL: 11.170568000000001
```

```
765
766 PERFORMA :
767 Diff: 1.25
768 Score: 47.0
769 Ratio: 55.90773812500001
770 AverageSCL: 12.132649375
771
772 AFFECTIV :
773 Diff: -2.625
774 Score: 38.0
775 Ratio: 58.54166625
776 AverageSCL: 11.759418125000002
777
778 PERFOAFF :
779 Diff: 1.9375
780 Score: 41.0
781 Ratio: 36.35123625
782 AverageSCL: 10.875385937499999
783
784 *****
785
786 28th
787
788 EASY :
789 Diff: -10.0
790 Score: 28.0
791 Ratio: 62.499998125
792 AverageSCL: 9.7397208125
793
794 HARD +++:
795 Diff: 10.0
796 Score: -62.0
797 Ratio: 1.5
798 AverageSCL: 13.093311874999998
799
800 PERFORMA :
801 Diff: 0.9375
802 Score: 52.0
803 Ratio: 61.815475
804 AverageSCL: 13.707030625
805
806 PERFOAFF :
807 Diff: 0.0
808 Score: 48.0
809 Ratio: 63.526785000000004
810 AverageSCL: 13.454833125
811
812 AFFECTIV :
813 Diff: 1.875
814 Score: 66.0
815 Ratio: 62.187501874999995
816 AverageSCL: 13.900096875000001
```


Acronyms

DDA	Dynamic Difficulty Adjustment
EDA	Electrodermal Activity
ER-SCRs	Event-Related Skin Conductance Responses
EVL	Electronic Visualization Laboratory
GSR	Galvanic Skin Response
HMD	Head Mounted Display
HR	Heart Rate
NS-SCRs	Non-Specific Skin Conductance Responses
SC	Skin Conductance
SCL	Skin Conductance Level
SCRs	Skin Conductance Responses
SVM	Support Vector Machine
UIC	University of Illinois at Chicago
VR	Virtual Reality

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