# Digitally Augmenting Sports: An Opportunity for Exploring and Understanding Novel Balancing Techniques

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## ABSTRACT
Using game balancing techniques can provide the right level of challenge and hence enhance player engagement for sport players with different skill levels. Digital technology can support and enhance balancing techniques in sports, for example, by adjusting players' level of intensity based on their heart rate. However, there is limited knowledge on how to design such balancing and its impact on the user experience. To address this we created two novel balancing techniques enabled by digitally augmenting a table tennis table. We adjusted the more skilled player's performance by inducing two different styles of play and studied the effects on game balancing and player engagement. We showed that by altering the more skilled player's performance we can balance the game through: (i) encouraging game mistakes, and (ii) changing the style of play to one that is easier for the opponent to counteract. We outline the advantages and disadvantages of each approach, extending our understanding of game balancing design. We also show that digitally augmenting sports offers opportunities for novel balancing techniques while facilitating engaging experiences, guiding those interested in HCI and sports.

### Author Keywords
Games; physical games; sports; game balancing; handicapping; game adjustment; player engagement; player performance; exertion games

### ACM Classification Keywords
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## INTRODUCTION
Many sports involve competition between players, which can facilitate engaging experiences when the players' skills are well-matched. However, if one player is significantly more skilled than the other, the players might feel that they are either under- or over-challenged, which can decrease their engagement [11] [12]. Game balancing can help address this problem by adjusting the game (e.g. by giving the less skilled player additional points) in order to provide the right amount of challenge for the players and thus enhance player engagement [7] [10] [18].

There exist different forms of game balancing techniques. In digital games, game balancing often consists of altering digital game elements in order to hinder the more skilled player or help the less skilled player. For example, many racing games increase the speed of the less skilled player's vehicle or reduce the speed of the more skilled one in order to balance the game [10].

Techniques for game balancing in sports differ to those used in digital games because there are fewer opportunities to adjust the game elements such as the speed of a car in a racing game. In sports there are often "ladders", which aim to match players with similar skill levels, a score adjustments that can give a "head start" to the less skilled player [4], or there is the handicap in golf [23]. Interestingly, we note that sports are embracing digital technology in order to create novel balancing experiences. For example, Mueller et al. [18] showed how digital technology can be used to allow joggers with different fitness levels to jog together. This shows that digital technology can also be used as a resource for balancing in sports.

Another way of balancing players' skill level is by limiting the more skilled player's performance. This can be achieved, for example, by asking the more skilled player to play using his or her weaker hand in table tennis [4]. By player's performance, we mean the player's behaviour or actions towards the execution of a task [3]. An example of a player's performance in table tennis would be the style of play he or she adopts such as a defensive or an aggressive play.

Although there are several techniques for achieving game balance, in this paper we will focus on those that alter the player's performance (i.e. altering the player's actions during the game) because this technique can be more suitable for balancing "non-parallel" games such as tennis, soccer or table tennis than, for example, the typical score adjustment. The rationale is that in such games each player influences his or her opponent to achieve the game goals [17], and each player has to counter the opponent's play. In contrast, in parallel games such as bowling, each player can score independently from the other. Game balancing in non-parallel games should be able to moderate the influence of one player over the other, for example, by preventing those player's actions that his or her opponent find difficult to counter. Altering the player's performance might be able to moderate this influence better than a score adjustment.

Prior research has examined game balancing [7] [10] [14] [18] [22], but in each of these works the emphasis was mainly on parallel games where each player can act independently from the other. In addition, this prior work did not focus on understanding the effects of different ways of altering the player's performance (e.g. different restriction on the player's actions) on game balancing and player engagement. This understanding could be important for the design of balancing.

To contribute to prior understandings of game balancing, we have digitally augmented the traditional table tennis game in order to explore the use of digital technology in sports, create novel ways of altering the more skilled player's performance and study the effects on game balancing and player engagement.

We limited the more skilled player's performance by inducing two different styles of play. In one, the game encouraged the more skilled player to play defensively and to perform strokes that were easy for the opponent to counter. In the other, the game encouraged the player to perform strokes that were aggressive, yet easier for the opponent to predict and therefore counteract. These styles of defensive and aggressive play are common in sports. For example, some table tennis players will play more defensively in order to have more control over the game point and to encourage long rallies, while others play more aggressively in order win points faster. In this research we explore how these two ways of altering the player's performance can be used for game balancing and the impact of each approach on player engagement.

To alter the player's performance we were inspired by the work of Ishii et al. [15] where the authors augmented a table tennis table with visual digital information. For this research we created a new form of game where we adjusted the playing surface area of the traditional table tennis table using digital image projection technology to display the boundaries of the playing area on a physical table.

Our study aimed to investigate how do game adjustment that modify player's performance impact on (i) game balancing, and (ii) player engagement. And we found:

- Altering the more skilled player's style of play in a way that helps the less skilled player to counteract such as the defensive play in table tennis can:
  - Effectively be used for balancing the game's score and leveling the players' skills.
  - Facilitate longer game rallies and more points for the less skilled player.
- Altering the more skilled player's style of play to be aggressive can:
  - Effectively be used to balance the game's score by encouraging more game mistakes (though it might shorten game rallies).
- The style of play, i.e. the amount of actions players were allowed to perform, was important for the more skilled player's engagement.

Using these findings we were able to identify two approaches that can be used for designing a balanced game by altering the more skilled player's performance. That is achieved through:

- Encouraging game mistakes by restricting the more skilled player's performance.
- Changing the more skilled player's style of play such that it is easier for the opponent to counteract.

In this research, we outline the advantages and disadvantages of these two approaches such that these insights can inform the design of game balancing.

## LITERATURE REVIEW

In this section we review prior work under two main relevant themes: (i) game balancing and (ii) the relationship between a player's performance and player engagement.

### Game Balancing

Prior work on game balancing has focused on providing the right level of challenge for players to allow people with different skills or abilities to play together [7] [10] [14] [23]. In games that require physical activity, prior work has also looked at balancing the physical challenge instead of varying skills and abilities of each player in order to allow people with different fitness levels to exercise together [18] [22]. The ability of game balancing to allow joggers with different fitness levels jog together, or to provide assistance to a weaker player for playing a game against a stronger player and thus facilitate a closer competition between players, has been shown to help enhance player engagement [7] [18]. Similarly, the competitive position of a player against his or her opponent, such as the difference between the players' scores, can influence players' moods and self-esteem [24]. Prior work showed that player engagement can decrease when the game becomes more predictable [21], and that competitors are optimally motivated when they feel they have about 50% probability of success [5]. This aligns with Flow Theory [12] that describes the players' optimal experience when they experience the right level of challenge. Although game balancing is important for player engagement, only a limited number of studies have aimed to compare game adjustments with each other, which can be important for game balancing design.

Understanding the suitability and benefits of various game adjustments is important as it can lead to different levels of engagement [4] [7] [10] [14]. For example, Bateman et al. [7] studied different target assistance techniques in a Wii-shooting game, finding that the assistance type affected the game score and the player's enjoyment. Cechanowicz et al. [10] found that balancing techniques that facilitate lead reversals, for example in a racing game, can help enhance player engagement more than other techniques that do not facilitate leader changes. In another study, Gerling et al. [14] examined different game adjustments, such as score multipliers, the precision of the input movements, and the number of movements each player had to perform. They found that (i) explicit game balancing can reduce players' self-esteem in comparison to implicit balancing; (ii) score balancing can be suitable for closing extreme performance gaps between players; and (iii) the adjustment of the precision of the input movements can be suitable for reducing small differences in players' performance and for asymmetric physical input, such as when a player plays using a wheelchair. While these studies provide insights on the suitability of some game adjustments compared to others, it is worth noting that the focus of their studies were on parallel games such as bowling where each player can score or act independently from each other. In games like table tennis, where a player's performance (e.g. player's strokes) affect the other player's performance, game balancing might need to be approached differently in order to moderate the influence that each player has on the other player. In addition, these prior works have applied game adjustments in a virtual world where it can be easier to assist the less skilled players by, for example, enhancing the player's accuracy in a shooting game [7] or enhancing the speed of the player's vehicle in a racing game [10]. However, this type of assistance might be difficult to achieve in the physical world.

Other work examined different game adjustments for balancing a traditional table tennis game [4]. The authors aimed to balance the game by either giving a score advantage to the less skilled player or by asking the more skilled player to play with the non-dominant hand, but they did not find an increased level of engagement in comparison to the no-adjustment condition. A drawback of such adjustments is that it is difficult to know the impact of these adjustments on the player's performance beforehand. For example, it can be difficult to know whether (and how) a score adjustment or asking to play with the non-dominant hand would influence the player's performance (e.g. change to defensive play and type of strokes). As the resulting player's performance is unpredictable with these adjustments, from this work [4], it is difficult (i) to conclude which are the effects of altering the player's performance on game balancing and player engagement, and (ii) to evaluate whether these adjustments can be suitable to moderate the influence of a player on the other's performance, which can be particularly important for non-parallel games (see Section "Introduction").

To summarise, there is a gap in the research when it comes to understanding the effects of altering the player's performance on game balancing and player engagement. However, prior work indicates that a relationship between player's performance and player engagement does exist and is worth exploring.

### Player's performance and player engagement

Altering the player's performance could affect the gameplay. Gameplay are the challenges the players have to overcome and the actions that enable these players to overcome them [1, p. 251]. Prior work indicates that the actions of the players during the game are important for player engagement [21, p.315] [9] [1, p.251]. For example, a study shows that video game controllers that facilitate different body movements affect player engagement differently [9]. This shows that altering the player's performance can impact player engagement, and if it is used for game balancing, it is relevant to study the interrelationship between player's performance adjustment, game balancing and player engagement.

### Research Gap and Research Questions

To answer the research gap about the effects of altering the player's performance on game balancing and player engagement we ask the following research questions:

- RQ: How do game adjustments that modify player's performance impact on game balancing?
- RQ: How do game adjustments that modify player's performance impact on player engagement?

## METHODOLOGY

### The game

The method used to explore these research questions involved building a digitally augmented table tennis table (see Figure 1). We chose table tennis as an example of sport to augment because table tennis is a two-player, non-parallel physical game. This allowed us to study the impact of game adjustments when one player plays against another. The digital augmentation of the table tennis table allowed us to project images onto the table surface to:

- Show the boundaries of different table adjustments.
- Show the location of where the ball hit the table and whether it is outside of the projected boundaries.
- Show the participants' scores after each point.

Using this digital augmentation we implemented the different game adjustments for balancing the game.

### Game Adjustment Designs

The game adjustment designs we used aimed to induce different player performances. In particular, we looked for game adjustments that encouraged different styles of play. To encourage different styles of play in table tennis we altered the players stroke. The parameters that define the stroke in table tennis are the hit-ball position, the ball spin and the ball velocity [6]. We chose to alter the ball-hit location, which can be influenced more easily by adjusting the playing surface area.

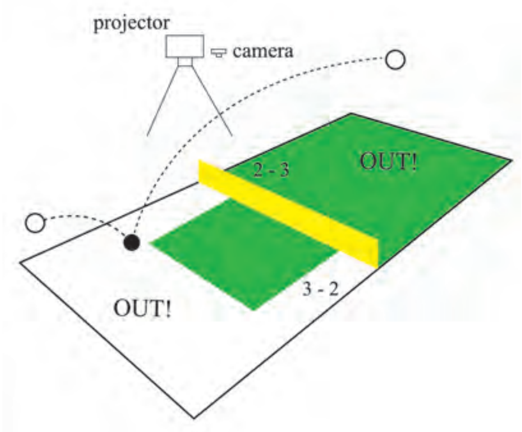


**Figure 1. Digitally enhanced table tennis game. A video projector mounted on the ceiling projects images onto the table surface, and a camera on the ceiling and four piezoelectric sensors under each side of the table detect the hit position of the ball on the table**

*Table Adjustment Design*

By adjusting the playing surface area for the more skilled player we were able to induce him or her a different styles of play. When the more skilled player hit outside of the projected area the player lost a point. The less skilled player, on the other hand, was allowed to play over the full table all the time without any penalty.

In one table adjustment we aimed to encourage the more skilled player to perform long strokes and undertake an aggressive style of play, yet easier for the less skilled player to predict and counteract. We aimed to achieve this by reducing the playing surface to one corner of the table. We will refer to this table adjustment as **corner adjustment** (see Figure 2 A).

In the other table adjustment we aimed to influence the more skilled player to play more defensively and to perform strokes that were easy for the less skilled player to counteract. We did this by reducing the playing surface to an area close to the centre of the net (see Figure 2 B). We will refer to this adjustment as the **centre adjustment**.

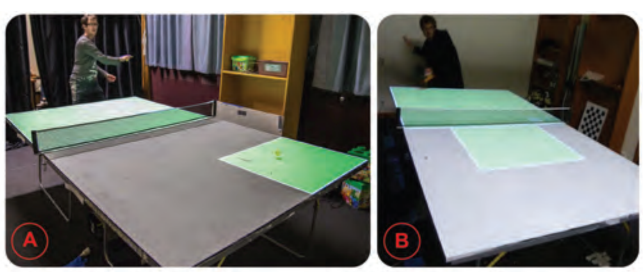


**Figure 2. Table adjustments designs: (A) visually highlighted playing surface area located at one of the corners (corner adjustment), and (B) visually highlighted playing surface area located at the centre of the net (centre adjustment)**

In the centre adjustment (Figure 2, right) the playing surface area was 30% of the size of the original table tennis table, which we found was enough to induce a defensive style of play and the use of strokes that were relatively easy for the other player to counteract. We acknowledge that this playing surface area size might not be useful to provide the right level of challenge for all players. However, we note that this study did not aim to provide the right level of challenge for players, but to study the effects of altering the player's performance (in this case by altering the style of play through adjusting the hit-ball position).

To determine the size of the playing surface area in the corner condition that facilitates a similar level of difficulty as the centre adjustment, we conducted a pre-experimental study. Six participants (3 pairs) were asked to play an 11-point game in the centre adjustment with 30% of the size of the regular table tennis table, and different table sizes of the corner adjustment: 30%, 15% and 7.5% of the size of the regular table tennis table. We decided the table size of the corner adjustment should be the same size or smaller than the table size of the centre adjustment because we noticed that some zones of the table in the centre adjustment were almost unused because of its proximity to the table tennis net. In this pre-experimental study we also chose to place the target location area on the right corner (see Figure 2 A) because we believed the less skilled players would find it easier to return the ball using forehand rather than backhand (given most of the players would be right handed). In this study we asked participants to rate their perception of difficulty [1-"Very easy", 5-"Very hard"] in placing the ball on the table in each of the four conditions. The study showed that the playing surface area size of the corner condition would have to be 20% of the size of the regular table tennis table to match the difficulty level of the centre adjustment.

## Apparatus

We used a video projector to implement the table adjustments. To locate the position of the ball when it hits the table, we used piezoelectric sensors placed underneath the table to detect hits, and a PlayStation 3 camera (120 Hz), which we mounted on the ceiling facing down to locate the position of the ball when the piezoelectric sensors detected the hit (Figure 1).

The software we developed allowed us to control the information projected and record data related to the study (see Figure 3). With this software we could save the score of each player after each point, start/stop each game point, display the score on the physical table after each game point, inform the players when the ball hit outside the virtual boundaries, and to save all the information related to the game into a database. The recorded information included the players' scores, the average of strokes per point and per player, and the average ball velocity per player.

## Design of the Study

The study was a 2x2 split-plot design [16, p. 54] with two independent variables: (i) table adjustment and (ii) the player's skill level. We defined the table adjustment as a within factor with two levels. The order of conditions was counterbalanced to avoid any order effect. We also did not include the non-adjustment condition since the aim of the study was to investigate whether or not two different adjustments would affect game balancing and player engagement differently. For

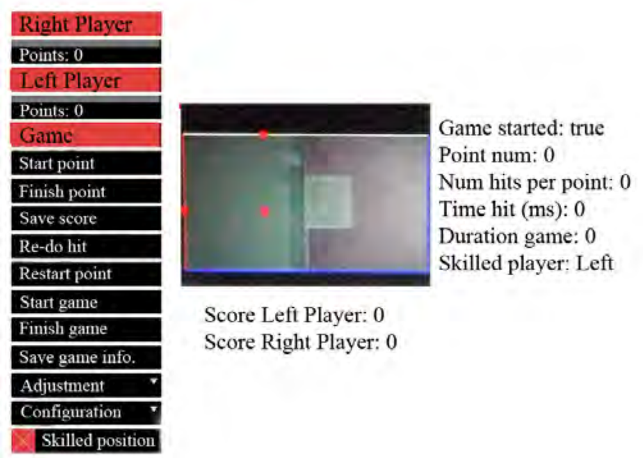


**Figure 3. Software developed where we controlled the information projected and recorded data related to the study**

the second independent variable, we defined the players' skill status as a between factor with two levels. We matched participants with different skill levels, so that in every match one participant was assigned as "the more skilled player", and the other as "the less skilled player".

### Participants

We selected a sample from the population aged 18+ years old. We recruited participants through public advertisement and asked people interested to fill out an on-line pre-experiment questionnaire, where we assessed their self-reported table tennis skill level. We selected only those people who had played table tennis before.

We recruited 30 participants: 8 females and 22 males with an average age of $M$=23.6 years and $SD$=3.83. The self-reported skill levels of the participants were: novice (1 participant), beginner (13), competent (6), proficient (9) and expert (1). We used this information to pair the participants for the study. The objective was to create pairs where the participants in each pair had a difference in self-assessed skill as large as possible. The pairs were as follows: novice vs. proficient (1), beginner vs. proficient (8 pairs), competent vs. expert (1) and beginner vs. competent (5).

To establish whether any pair of participants were mismatched, we tested whether the final score difference of each pair of participants in the two table adjustments differed greatly from the other pairs of participants. We applied the Z-value test to the score difference distribution in both table adjustments separately in order to look at those Z values greater than or equal to 3, to detect outliers [2]. From the test results we did not find any outliers, hence we concluded there was a satisfactory difference between participants' skills in all pairs, and we did not need to discard any pair.

### Experimental Environment

We setup an environment with two physical spaces separated with a curtain: a playing area, and a control area (see Figure 4). The playing area was where participants played the table tennis game, and the control area was where participants filled in the questionnaires and were interviewed. In the control area, the lead researcher also operated the software developed, took notes of observations from the gameplay, and noted comments from the participants. Although the lead researcher did not have direct contact with the participants while they were playing, the lead researcher could follow the game through the visual information from the camera mounted on the ceiling, which captured the whole table and ball movements (see Figure 3).

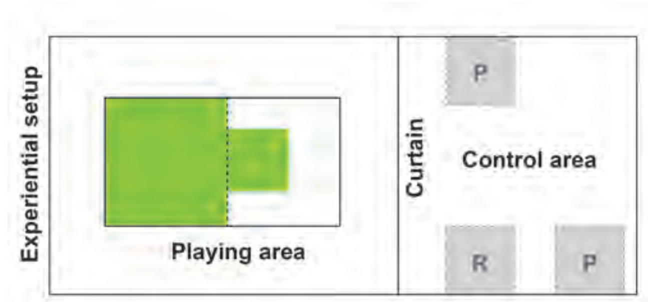


**Figure 4. Playing and control areas. On the left the playing area is shown and on the right the control area. R is the lead researcher desk. P are the participants' desks**

### Procedure

Participants were instructed to play for 6 minutes without any adjustment, as warm up. They then played with the two different table adjustments (2 minutes per condition). Players were requested to play competitively at all times. After they finished the warm up, the participants played two games of 21 points with each table adjustment. We opted for a 21-point game instead of the standard 11-point game to allow sufficient time for the participants to experience each table adjustment. After each game, the participants completed a questionnaire that assessed their engagement. Finally, the participants were interviewed in pairs using a semi-structured interview. We decided to interview participants in pairs to encourage discussion between them about their experience during the experiment.

### Data Collection and Analysis Methods

We collected information about the participants' performance, which included the style of play of the players and variety and type of strokes as well as the ball velocity. This information helped us to validate our game adjustment designs.

For the ball velocity we approximated the speed by measuring the elapsed time between consecutive ball-hits on each side of the table and the distance between these two hit locations. We used paired t-tests to compare ball velocity between the two table adjustments.

We also used qualitative measures to further assess the participant's performance. Semi-structured interviews were conducted by the lead researcher to understand the variety and types of strokes participants performed and the participant's style of play. During each experimental test, the lead researcher took note of the observations regarding participant's style of play. The observations were conducted using the camera installed on the ceiling, and notes were used in the semi-structured interviews for discussion.

We collected information about game balancing, including the score difference, win/lose ratio and the average number of hits per point. The score difference was evaluated using a paired t-test. The win/lose ratio was evaluated using the Fisher's exact test to evaluate whether there was a relationship between the table adjustment and the number of matches won by the more skilled participants. Since in a non-parallel game one player's performance can influence the other player's performance, we decided to evaluate whether game adjustments helped to moderate this influence. For this we also measured and compared the average number of hits per point in each of the table adjustments. We used the Wilcoxon test since the data did not meet the assumptions of the t-test.

To further evaluate game balancing we used qualitative data from the semi-structured interviews conducted by the lead researcher for assessing whether participants perceived that one table adjustment leveled the participants' skills more than the other table adjustment. We expected that the results of the average number of hits per point will be aligned with the participant's reports on which table adjustment leveled the participants' skills better.

To collect feedback on the experience of participants we used the engagement scale questionnaire (five-point scale where the higher the value the more the engagement) from the O'Brien model of engagement [20]. We considered this engagement scale suitable for this study because it is not tied to a particular videogame context and the survey scale was verified statistically, in terms of both reliability and validity [20]. We excluded the items regarding the aesthetic factor because this factor was not relevant to the traditional table tennis game. We adapted the wording of the engagement scale to our context (e.g. changing the statement *"The time I spent shopping just slipped away"* to *"The time I spent playing the game just slipped away"*). We found that Cronbach's-$\alpha$ for the engagement scale had high reliability, $\alpha$= 0.8.

For analysing the engagement scores we used a repeated measures ANOVA with the table adjustment as a within-subjects factor and the player's skill status as a between-subjects factor. For all the tests the significance level was set at $\alpha$=0.05.

For the measured variables where we used t-tests and ANOVA (i.e. ball velocity, score difference and engagement scores), we checked that their distributions were not significantly different from the normal distribution (Shapiro test $p > .05$), and that the variance between the groups we compared were not significantly different (Levene test $p > .05$).

In the semi-structured interviews the lead researcher discussed with the participants about the impact of game adjustment on player's performance and game balancing. He also asked which table adjustment participants preferred most, and the reasons for their preference in order to better understand the engagement scores.

The data from the semi-structured interviews was transcribed by the lead researcher, and we used a quasi-statistics method for the analysis, which consists on counting the number of times something is mentioned to measure the frequency of a phenomenon [8]. This qualitative analysis provided a better understanding of how different game adjustments influenced the players' performance, player engagement, game balancing, and the reasons for preferring one game adjustment over the other.

## RESULTS

To answer the research questions, we first analysed the player's performances. Afterwards we focused on how these different performances influenced game balancing and player engagement.

### Players' performance

The results of the participant's performance include the participant's style of play, ball velocity, the variety and types of participant's strokes.

**Player's style of play:** Our observations of the participants playing indicated that the style of play of the more skilled participants in the corner condition was different from the centre condition. In the centre condition, the participants seemed to be more passive, as if they were waiting for the opponent's mistake, instead of trying to win the point. This seemed to be the opposite in the corner condition. This was confirmed by participants' comments during the interview. One participant said "in the centre is like keeping the rally going down rather than actually trying to win the point (...) it is just tap it over". Another participant said "I liked the first condition [corner] because it allowed me to be more aggressive".

We found that the results of the ball velocity were aligned with the player's style of play:

**Ball velocity:** The paired t-test showed the ball moved (measured in m/s) significantly slower in the centre adjustment (*M*=2.00, *SD*=0.35) than the corner adjustment (*M*=2.61, *SD*=0.45), $t(29) = 8.06, p < .01$.

With the change of style of play, the variety and type of strokes changed as well:

**Variety and types of strokes:** Reports from participants revealed that each table adjustment afforded a different amount and type of strokes. Sixty per cent (9/15) of the more skilled participants reported the types of strokes to be different in the two table adjustment conditions, and 20% (3/15) of the more skilled participants reported they could practice a greater variety of strokes in the corner adjustment. Examples of reports regarding the play in the corner condition include: "I can do my big forehand", "I can play long strokes", "I can play like a real game, perform normal strokes" and "I can smash". In contrast, the reported types of strokes available in the centre condition were different: "In the centre it is just tap over the net", "I could not do my big forehand", "I could not do the shots I usually do in table tennis".

These findings indicated that the more skilled participants played with the style of play we expected in each of the table adjustments.

## Game Balancing

**RQ: How do game adjustments that modify player's performance impact on game balancing?**

The results show that the table adjustments impacted the game balancing differently. While the corner adjustment provided a closer game (in terms of the score) and facilitated more wins to the more skilled players, the centre adjustment facilitated more wins to the less skilled players, a greater number of hits per point, and is where players perceived their skills were more balanced.

**Score difference**: The score difference of the participants is summarized in Figure 5. The score difference (in absolute value) was significantly greater in the centre adjustment (*M*=8.9, *SD*=4.6) than in the corner adjustment (*M*=5.7, *SD*=2.7), $t(14) = 2.49, p = .026$.

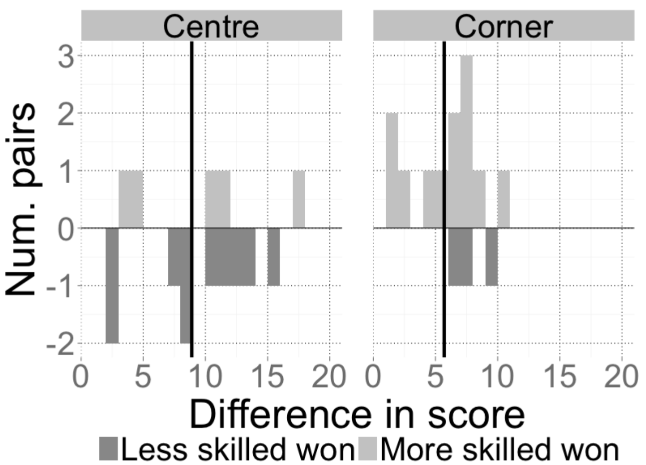


**Figure 5. Players' difference in score of the centre and corner adjustments. The vertical black line shows the average of the difference in score**

**Win-lose ratio**: The more skilled participants won 33.3% of the matches (5/15) in the centre adjustment, and 80% of the matches (12/15) in the corner adjustment. The Fisher's exact test indicated that the table adjustment had a significant influence on the number of matches won by the more skilled participants ($p = .025$).

**Leveling the player's skills**: Sixty per cent of the participants reported that the centre adjustment leveled the player's skills more, while 26.7% reported the corner adjustment helped in leveling the skills more, and 13.3% reported no difference between the two table adjustments.

**Average hits per point**: The Wilcoxon test showed significant differences regarding the average number of hits per point (per participant) between the centre adjustment (*M*=2.03, *SD*=0.61) and the corner adjustment (*M*=1.35, *SD*=0.32), $W = 460, p < .01$.

To summarise:

- When the more skilled participants played defensively they:
  - Encouraged more wins for the less skilled participants.
  - Leveled the participant's skills with a higher number of hits per point.
- When the more skilled participants played more aggressively:
  - They won more often.
  - There was a closer game score.

## Engagement Scores

**RQ: How do game adjustments that modify player's performance impact on player engagement?**

Player engagement did not significantly differ between the two table adjustments, $F(1,28) = 2.56, p = 0.12, \eta_G^2 = 0.02$, mainly because the table adjustments impacted differently on the engagement of the more skilled and the less skilled participants. The more skilled participants reported higher average engagement scores in the corner adjustment (*M*=3.90 , *SD*=0.33) than in the centre adjustment (*M*=3.61, *SD*=0.51), see Figure 6. However, the less skilled participants reported lower average engagement scores in the corner adjustment (*M*=3.66, *SD*=0.38) than in the centre adjustment (*M*=3.72, *SD*=0.42). The different effect of the centre and corner adjustments for the more skilled and less skilled participants was significant ($F(1,28) = 5.75, p = .023, \eta_G^2 = 0.04$). We performed a contrast analysis to explain this interaction effect, showing significant differences between the centre and the corner adjustments for the more skilled players ($t(28) = -2.83, p < .01$), but no significant differences for the less skilled ones ($t(28) = 0.56, p = .58$).

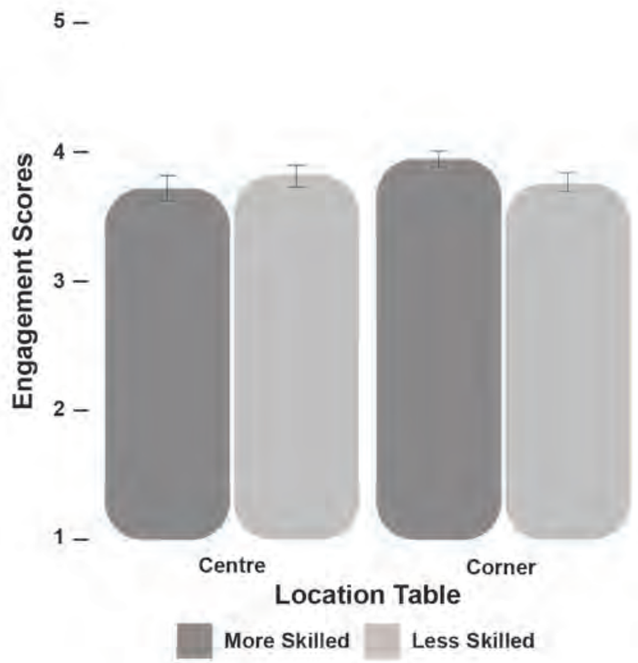


**Figure 6. Mean and error bars of engagement scores of the more skilled participants and less skilled participants in the centre and corner adjustments**

The results of the engagement scores were in line with the participant's reports about their preferred table adjustment.

Seventy-three per cent (11/15) of the more skilled participants preferred the corner adjustment, while 20% (3/15) preferred the centre adjustment. In contrast, 47% (7/15) preferred the corner adjustment, while 40% (6/15) of the less skilled participants preferred the centre adjustment.

To understand player engagement better, we analysed the participant's reports. The reports showed that player engagement was mainly affected by how the game adjustments affected the player's performance such as the player's style of play and the type and variety of strokes (see Section "Players' performance"). For example, the 80% of more skilled participants reported that they were more engaged in the corner adjustments because it allowed a greater variety of strokes, e.g. saying "definitely I liked more the corner adjustment because it allowed me to play a variety of shots rather than tap over the net". These participants also reported that the corner adjustment encouraged the performance of more engaging type of strokes, e.g. saying "the type of shots is preferable in the corner", "I like the corner adjustment because I could hit the ball harder", "I prefer playing long shots", "I like to play more in the corner, play as a normal condition", "I prefer the corner adjustment because I can practice my shots better, practice something I use in table tennis". Finally, the more skilled participants also reported the downsides of the corner adjustment. One of the participants reported that this adjustment allowed him to play aggressively, which increased the number of interruptions and shortened the game points: "I found when the table was on the corner I could smash and I was better . . . the game was less equal and less interesting because when we played and I smashed, I win and the play stopped".

The less skilled participant's engagement was similar between both table adjustments. The three most reported reasons for preferring one table adjustment over the other were the perception of challenge (47% of the participants), the player's performance (40% of the participants) and the sense of control (20% of the participants). These reasons were sometimes used to justify the preference for the corner adjustment, and other times to justify the preference for the centre adjustment. For example, four participants preferred the centre adjustment because it made returning the ball easier (e.g. saying "I like the centre adjustment, it was easier to hit"). However, another three participants preferred the corner adjustment because it provided a greater challenge and allowed them to test their skills. Finally, three participants preferred the centre adjustment because it facilitated a greater sense of control. These results show the great diversity in the type of players and their preferences.

To summarise:

- When the game encouraged the more skilled participants to play more defensively, they felt less engaged than when they played aggressively.
- The less skilled participants did not report significant differences in the level of engagement between the two conditions.

## DISCUSSION

In this section we will discuss the results and provide guidance about how this work can be useful for the design of game balancing in other games.

### The Results Obtained

The two ways of altering the player's performance balanced the game because of:

- The game mistakes: We penalised the more skilled players (by losing the point) when they hit the ball outside of the allowed playing surface area. This contributed to balancing the score and the win/lose ratio.
- The style of play: We encouraged a different style of play for the more skilled players, and one of the styles helped less skilled players to return the ball more easy (defensive style of play from the centre adjustment).

#### *Why did game adjustments that encourage different player's performance impact game balancing differently?*

Although both game adjustments encouraged game mistakes, the style of play of the centre adjustment made it easier for the less skilled players to counteract the play of the more skilled participants, leading to a higher average number of hits per point and the perception that the player's skills were more balanced. This also explains why the less skilled participants tended to win more in the centre adjustment than in the corner adjustment (see Figure 5).

#### *Why did game adjustments that encourage different player's performance impact player engagement differently?*

For the more skilled participants, the engagement scores were higher in the corner adjustment than in the centre adjustment. This is mainly because of the impact of the table adjustments on player's performance: style of play, variety of shots and the type of shots (see Section "Engagement Scores"). This indicates that the way players are challenged and constrained is critical for player engagement. This aligns with a prior study by Bianchi-Berthouze [9], which shows that video game controllers that encourage different body movements influence player engagement differently.

#### *Lessons Learned*

The results show that in non-parallel games, where a player can affect the opponent's performance, altering the player's performance can be a useful technique for game balancing. We also show that we can balance the game through altering the player's performance through two key ways, each one having advantages and disadvantages:

- **Encouraging game mistakes by restricting the more skilled player's performance**: The game mistakes encouraged by the game adjustments can depend on the challenge imposed on the players in playing with these game adjustments and the player's familiarity with the adjustment.
  - Advantages: This way of balancing does not rely on the style of play for balancing and thus can support different types of gameplay, for example both aggressive and defensive play.

  - Disadvantages: This way of balancing is not designed to moderate the influence of the more skilled player's performance on the less skilled player's performance. Without this moderation, the less skilled player might experience difficulties in countering the "attacks" of the opponent player.

- **Changing the more skilled player into a style of play that is easier for the opponent to counteract:** By altering the player's performance, the style of play of the more skilled player can be altered in a way that facilitates a gameplay that is easy to counteract for the less skilled player, such as in the centre adjustment of this study.
  - Advantages: It can moderate the influence of the more skilled player's performance over his or her opponent's performance and therefore it can level the players' skills and also promote longer game rallies (see Section "Game Balancing").
  - Disadvantages: The more skilled player's actions, such as the strokes performed, might not be as engaging to perform as those actions that are difficult to counteract for the opponent (see Section "Engagement Scores").

### Generalizing the Results

Although we explored game balancing in table tennis, the understanding of the different ways we can balance the game through altering the player's performance can be applied to other games where the player's performance can also be altered such as soccer, basketball, tennis or squash. For example, in these games we could also alter the game in a way so that it encourages game mistakes (e.g. missing shots in basketball) or modify the players' style of play in a way that the opponent(s) find it easier to counteract. This understanding can be particularly useful for balancing non-parallel games where adjusting the player's performance might be used to moderate the influence of one player on another. For example, when players have great skill differences, game designers should consider altering the style of play to facilitate a game play that is easier to counter for the less skilled players.

For altering the player's style of play or encouraging game mistakes to players in other sports such as tennis, badminton and squash, we could apply similar game adjustments as the ones we used in this present study (i.e. altering the court or playing surface area), because of the importance of the ball-hit location to the player's score and style of play in these games. However, we acknowledge that the design of game adjustments might be more different in other games such as basketball or soccer. For example, in squash, a game designer can use the different court zones [25] to design game adjustments for game balancing, as follows:

- Alter the squash court dimensions to encourage game mistakes.

- Alter the more skilled player's style of play, such as encouraging strokes that go to the back of the court and that are difficult to counteract [25], or those that go to centre of the court and that are easier to counteract.

In squash, digital technology can be used as in this research to alter the court. Using digital technology can provide the advantage of altering the squash court and the style of play dynamically depending on the players' difference in score after each point. This can be useful to accommodate pairs with different amount of gaps in skill level.

In other types of non-parallel games, where the use of the field or court is different from table tennis or squash, the approach to alter the style of play or encourage game mistakes can be more different. However, in these games digital technology can take a role for balancing the game because of its capabilities to modify the different game elements such as the playing surface in table tennis shown in this study.

### Limitations of the Results

We assessed the participants' skill level using a pre-questionnaire. This allowed pairing the participants prior to the main study. Although this method of assessing the participants' skills was sufficient for the purpose of this study, we acknowledge that we might have obtained a more accurate assessment of the participants' skills by observing them playing before the main experiment, or by using player rankings from a tournament or club if those were available. Also, although we used a statistical test to assess mismatched participants, we note that the test has limitations in detecting mismatched participants when the distribution has a high standard deviation. In our study, we concluded that all pairs of participants were well matched observing that at least the corner condition had reasonably small variance, yet not having any outliers.

Another limitation is the sample size. Although the sample size was large enough to evaluate the differences between conditions, it was not large enough to enable further investigation of other aspects of game balancing. For example, whether there were differences between pairs with different amount of gaps in skill level.

Finally, we acknowledge that there can be other factors that can influence player engagement such as the personality of the players and their motivations [13] [19], as well as the type of activity [13]. Although these factors can be relevant to understanding player engagement and game balancing, studying such factors was out of the scope of this research and we leave such an investigation for future work.

## CONCLUSIONS

We conducted a study to investigate how adjusting the player's performance with different styles of play using digital technology could affect game balancing and player engagement in table tennis.

Our findings identified two approaches of balancing through altering the player's performance: (i) through encouraging game mistakes, and (ii) changing the more skilled players into a style of play that is easier for the opponent to counteract. The study results allowed us to outline the advantages and disadvantages of each of these approaches, which can inform the design of game balancing in other games.

The advantages and disadvantages of these two approaches of balancing indicate a trade-off between them. One approach can be more suitable for leveling the skills and helping the less skilled player in countering the more skilled player's play. In contrast, the other approach can be more suitable to encourage a style of play that is more engaging for the more skilled players. A dynamic adjustment could maximise the advantages of each technique while minimising their downsides. For example, in table tennis we could progressively reduce the playing surface area from full table size to the 'centre adjustment' of this present study based on difference in players' scores. This would progressively (i) encourage more game mistakes from the player who is leading and (ii) modulate his or her style of play to one that is easier for the opponent to counter. This approach would enable different types of gameplay and restrict the player's style of play when the score difference is high. As a future research direction, we propose investigating such dynamic adjustments that not only can keep the players' scores closer, but can also take care of this trade-off and enhance player engagement for both players.

The contribution of this work benefits game designers and the sporting community by providing a better understanding of how game adjustments can support game balancing and influence player engagement. It also contributes to HCI by providing novel balancing experiences using digital technology. This work extends prior work that explores the benefits of using digital technology in sports, and shows a promising future in the area of HCI and sports that focuses on the player's experience.

Further research into dynamic adjustments that adapt to users using digital technology in sports can benefit from the contributions of this research: the game adjustment designs shown and their effects on the player's experience. Ultimately, we hope that our work, and future systems inspired by our work, can help in encouraging more people to engage in physical activity and profit from its benefits.

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## REFERENCES

1. Ernest Adams. 2010. *Fundamentals of game design*. New Riders, Berkeley, Calif.
2. Charu C. Aggarwal. 2013. *Outlier analysis*. Springer, New York, NY.
3. Richard B. Alderman. 1974. *Psychological behavior in sport*. Saunders, Philadelphia.
4. David Altimira, Florian Mueller, Gun Lee, Jenny Clarke, and Mark Billinghurst. 2014. Towards Understanding Balancing in Exertion Games. In *Proceedings of the 11th Conference on Advances in Computer Entertainment Technology (ACE '14)*. ACM, New York, NY, USA, Article 10, 8 pages. DOI: http://dx.doi.org/10.1145/2663806.2663838
5. John W. Atkinson. 1957. Motivational determinants of risk-taking behavior. *Psychological Review* 64, 6, Pt.1 (1957), 359 – 372. http://ezproxy.canterbury.ac.nz/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=pdh&AN=1959-03029-001&site=ehost-live
6. A Baca. 2008. Feedback systems. *Computers in Sport* (2008), 43–67.
7. Scott Bateman, Regan L. Mandryk, Tadeusz Stach, and Carl Gutwin. 2011. Target assistance for subtly balancing competitive play. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11)*. ACM, New York, NY, USA, 2355–2364. DOI: http://dx.doi.org/10.1145/1978942.1979287
8. Howard S. Becker. 1958. Problems of Inference and Proof in Participant Observation. *American Sociological Review* 23, 6 (1958), 652–660.
9. Nadia Bianchi-Berthouze. 2013. Understanding the Role of Body Movement in Player Engagement. *Human Computer Interaction* 28, 1 (2013), 40–75. DOI: http://dx.doi.org/10.1080/07370024.2012.688468
10. Jared E. Cechanowicz, Carl Gutwin, Scott Bateman, Regan Mandryk, and Ian Stavness. 2014. Improving Player Balancing in Racing Games. In *Proceedings of the First ACM SIGCHI Annual Symposium on Computer-human Interaction in Play (CHI PLAY '14)*. ACM, New York, NY, USA, 47–56. DOI: http://dx.doi.org/10.1145/2658537.2658701
11. Jenova Chen. 2007. Flow in Games (and Everything else). *Commun. ACM* 50, 4 (2007), 31–34. DOI: http://dx.doi.org/10.1145/1232743.1232769
12. Mihaly Csikszentmihalyi. 1990. *Flow: the psychology of optimal experience*. Harper & Row, New York.
13. Stefan Engeser and Falko Rheinberg. 2008. Flow, performance and moderators of challenge-skill balance. *Motivation and Emotion* 32, 3 (2008), 158–172. DOI: http://dx.doi.org/10.1007/s11031-008-9102-4
14. Kathrin Maria Gerling, Matthew Miller, Regan L. Mandryk, Max Valentin Birk, and Jan David Smeddinck. 2014. Effects of Balancing for Physical Abilities on Player Performance, Experience and Self-esteem in Exergames. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '14)*. ACM, New York, NY, USA, 2201–2210. DOI: http://dx.doi.org/10.1145/2556288.2556963
15. Hiroshi Ishii, Craig Wisneski, Julian Orbanes, Ben Chun, and Joe Paradiso. 1999. PingPongPlus: design of an athletic-tangible interface for computer-supported cooperative play. In *Proceedings of the SIGCHI conference on Human Factors in Computing Systems (CHI '99)*. ACM, New York, NY, USA, 394–401. DOI: http://dx.doi.org/10.1145/302979.303115
16. Jonathan Lazar, Jinjuan Feng, and Harry Hochheiser. 2010. *Research methods in human-computer interaction*. Wiley, Chichester, West Sussex, U.K.

17. Florian Mueller, Martin R. Gibbs, and Frank Vetere. 2008. Taxonomy of exertion games. In *Proceedings of the 20th Australasian Conference on Computer-Human Interaction: Designing for Habitus and Habitat (OZCHI '08)*. ACM, New York, NY, USA, 263–266. DOI: http://dx.doi.org/10.1145/1517744.1517772

18. Florian Mueller, Frank Vetere, Martin Gibbs, Darren Edge, Stefan Agamanolis, Jennifer Sheridan, and Jeffrey Heer. 2012. Balancing exertion experiences. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12)*. ACM, New York, NY, USA, 1853–1862. DOI: http://dx.doi.org/10.1145/2207676.2208322

19. Curtiss Murphy, Dustin Chertoff, Michael Guerrero, and Kerry Moffitt. 2015. Design Better Games: Flow, Motivation, and Fun. In *Design and Development of Training Games: Practical Guidelines from a Multidisciplinary Perspective*, Talib Hussain and Susan Coleman (Eds.). Cambridge University Press, Chapter 6, 146–178.

20. Heather L. O'Brien and Elaine G. Toms. 2010. The development and evaluation of a survey to measure user engagement. *J. Am. Soc. Inf. Sci. Technol.* 61, 1 (2010), 50–69. DOI:http://dx.doi.org/10.1002/asi.v61:1

21. Katie Salen and Eric Zimmerman. 2003. *Rules of play: game design fundamentals*. MIT Press, Cambridge, Mass.

22. Tadeusz Stach, T. C. Nicholas Graham, Jeffrey Yim, and Ryan E. Rhodes. 2009. Heart rate control of exercise video games. In *Proceedings of Graphics Interface 2009 (GI '09)*. Canadian Information Processing Society, Toronto, Ont., Canada, 125–132.

23. Tim B Swartz. 2009. A new handicapping system for golf. *Journal of Quantitative Analysis in Sports* 5, 2 (2009).

24. Peter Vorderer, Tilo Hartmann, and Christoph Klimmt. 2003. Explaining the enjoyment of playing video games: the role of competition. In *Proceedings of the second international conference on Entertainment computing (ICEC '03)*. Carnegie Mellon University, Pittsburgh, PA, USA, 1–9. http://dl.acm.org/citation.cfm?id=958720.958735

25. Goran Vučković, Brane Dežman, Stanislav Kovačič, and Janez Perš. 2009. Quantitative analysis of playing efficiency in squash. *Science and racket sports IV* (2009), 220–226.