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The Effects of Haptics on Rhythm Dance Game Performance and Enjoyment

Bridger Scott Hodges
Brigham Young University

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Bridger Scott Hodges

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Derek L. Hansen, Chair
Barry M. Lunt
Amanda L. Hughes

School of Technology

Brigham Young University

ABSTRACT

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Dance Game Performance
and Enjoyment

Bridger Scott Hodges
School of Technology, BYU
Master of Science

Haptics are an exciting, ever-expanding field, particularly in relation to video games. Though haptics found their way rather quickly into conventional games through devices like handheld controllers, music and rhythm titles have hardly seen such attention. Little research has been done to examine the effects of haptics on rhythm dance games from a quantitative and qualitative standpoint for the player.

StepMania is an open-source dance game which closely mimics the popular title Dance Dance Revolution. This research investigates the effects of haptics on a sample size of fifty individuals. Each completed three songs in the game with varying conditions: the game's visuals only, a haptic device only, or both the haptics and visuals together. The haptic device warned the participant of an incoming step by vibrating two beats in advance in the direction needing to be stepped in. Music was present for all conditions, as it is an implied essential component of the game.

Performance, self-reported enjoyment and self-reported difficulty were very similar between conditions involving visuals only and trials involving both the visuals and haptic device. Conditions involving the haptic device only (no visuals) saw a large drop in performance, a large increase in self-reported difficulty, and a very minor decrease in enjoyment. Despite the difference, participants reported enjoying the experience in free-response questions.

The results of the study illustrate the potential for haptics to enhance user experience in rhythm dance video games. Additionally, these results indicate the beginnings of an avenue through which such dance games could become more accessible to the blind, who have been unable to participate in such games up to this point.

Keywords: dance game, rhythm game, haptic, DDR, accessibility

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1 INTRODUCTION

Video games, particularly those which are rhythm-based, present a unique set of circumstances in the world of gaming. Not only do such games often require the abandonment of a handheld controller and the use of special dance mats or camera accessories, they also present a unique set of challenges and opportunities for users and haptic devices. “Haptics” simply describes the concept of touch, such as through vibration. Rhythm games are all based on the same basic principle: a user must precisely time an input relative to a song which plays in the background.

This presents a unique challenge for an everyday player, and a near impossible task for individuals who are blind or who have other sensory impairments. The ability to properly anticipate upcoming steps or notes in the game is paramount, and such gameplay may not come as intuitively to some players by just viewing a screen and listening to the music. Stepping and moving in time with the music may prove to be unnatural, and the familiarization period may be longer, especially for those who are not well-versed in gaming to begin with. Even those who are familiar with gaming may have a harder time becoming accustomed.

Some efforts have been made through research to bridge the ability gap in rhythm games, particularly for the disabled. One study was able to make a guitar-based rhythm game accessible to the blind (Yuan & Folmer, 2008), and another prototype aimed at making cell phone games possible for the deaf (Gillian, O'Modhrain, & Essl, 2009). In most cases, haptic feedback was used either in the form of specialized hardware or built-in vibration mechanisms. A common problem which each study needed to address was how to properly inform a player when to give a precisely-timed input. However, some studies that mentioned such attempts did not select methods which were musically valuable and intuitive (Yuan & Folmer, 2008).

Despite the studies and time spent on game accessibility, very little research has been done on the effects of haptics in general within the scope of rhythm video games. It is unknown whether haptic devices can enhance and improve player performance when used in tandem with the innately available cueing methods, namely the audio and video. It is also unknown whether such devices improve the overall gaming experience for a player in such a setting, increasing enjoyment, familiarity or confidence with the game.

The two primary purposes of this research are to:

1) Evaluate whether a head-mounted haptic device, synchronized in time with the game music, enhances the game score of rhythm game players in comparison to playing the game without our device, and
2) Evaluate whether the haptic device enhances users' subjective experiences while playing the rhythm game.

The secondary purpose of this research is to gain additional insight regarding how to properly cue players for precisely-timed input. An entire study could be devoted to this topic alone, but it is hoped that this study will be helpful in obtaining additional understanding in the use of haptics and signals for this purpose.

Chapter two of this thesis examines the relevant literature for this topic, discussing rhythm games in general and moving through resources on video games, disability, and haptics, then concludes with the novelties we pursue in this study. Chapter three moves on to the methodology of the study, examining our specific research methods and techniques. Chapter four presents and briefly discusses the results of the research, and chapter five concludes with a review of the findings and more discussion of their implications.

2 LITERATURE REVIEW

2.1 Rhythm Games

The term “rhythm game” is already highly self-descriptive: a video game involving rhythm. This does not mean, however, that the game merely involves music or rhythm as a secondary mechanic; the entire gameplay centers around music and a player’s immersion in it. Players engage with the music in increasingly intricate ways, either reacting to or creating the music through use of an input device.

Although multiple titles were released in the early ages of gaming which involved aspects of rhythm, the first game generally accepted as the one which defined and ignited the rhythm gaming category was *PaRappa the Rapper*, produced by Sony Computer Entertainment in 1996. The concept of the game revolved around pressing a series of buttons presented on the screen in time with the music, which would then cause the character on screen to rap the lyrics to the chosen song. Each individual button press was scored according to how accurately a player provided the inputs, and a performance meter reflected the overall song performance of the player. Too low of a performance during the song resulted in failure, and the stage had to be restarted. At the end of the stage, the player was presented with their overall score.

Despite large advancements in both gaming input and output technology, these general concepts of rhythm games have remained largely unchanged ever since *PaRappa*. Nearly every game involving song and rhythm requires a player to provide precisely-timed inputs based on auditory cues, such as the beat and rhythm of a song, and reinforced with visuals, such as arrows or indicators travelling across the screen toward a target. A very recent example of such a game is Beat Saber, a virtual reality game in which players must slice through blocks in time with the music. The blocks begin far out on the Z-axis (in 3D space) and travel toward the player with precise spacing calibrated to the beat and rhythm of the music.

One of the most successful, long-running music games of all time, and one with which this study occupies itself, is Dance Dance Revolution (DDR). DDR was released in 1998 by Bemani, the rhythm game division of Konami Entertainment. Keeping with the traditional "base rhythm game" mechanics, the game involves providing musically precise inputs which correspond to arrows travelling up the screen. What was particularly groundbreaking about the game upon its release, however, was that the player is required to stand on a metal dance pad and step in the direction shown on the screen in time with the music.

Not surprisingly, a vast majority of rhythm game-centric research revolves around these games' applicability either in the physical education or musical education spheres. Most of these studies examine the efficacy of such games in assisting players to become more healthy or musically adept. For example, a study from Staiano and Calvert recommends the adaptation of exercise games (such as DDR) in schools and health clubs (Staiano & Calvert, 2011). The researchers claim that such games can not only improve physical wellness such as weight, but also self-esteem, attention span, and social interaction skills. Similarly, another study suggested that these active video games produce quantitatively similar results when compared to traditional moderate-exercise counterparts (Peng, Lin, & Crouse, 2011). The same researchers conducted a systematic review of relevant literature under the same notion, and suggested that while all video games classified as "active" were able to produce low to moderate amounts of physical activity, very few were found to be effective in promoting true increases in physical health and wellness (Peng, Crouse, & Lin, 2013).

2.2 Video Games and Accessibility

Ever since their inception, video games have always silently begged the question of accessibility. The standard mechanics for games present a huge challenge for nearly every kind of disability. Users who lack fine motor skills may find it difficult to utilize the small buttons, gamepads, and joysticks present in such games. Others who are hard-of-hearing or deaf may find games which rely heavily on auditory clues frustrating, whereas the non-sighted may have huge difficulties interpreting what the game expects of them and whether they are performing at a satisfactory level. Studies over the years have increased general understanding of these accessibility problems, as well as possible avenues toward their solution.

One such study explores these issues faced by the disabled and lists technologies to bridge the gap (Bierre, et al., 2005). The researchers specifically mention six general categories of adaptations: Alternative Pointing Devices, On-Screen Keyboards, Speech Recognition, Screen Readers (text-to-speech), Screen Magnifiers, and Miscellaneous Hardware such as gloves and different types of mice. The study fails to explicitly mention haptics as an option, though this can likely be attributed to its age.

Another study makes a very interesting statement regarding the sources of problems for disabled individuals playing video games: "Accessibility problems may include the following: (1) not being able to receive feedback; (2) not being able to determine in-game responses; (3) not being able to provide input using conventional input devices" (Yuan, Folmer, & Harris, 2011). They go on to present a model for gameplay, which consists of receiving stimuli, determining a response, and providing an input. Any physical or mental impairment means a break in this chain of events, and a need for technologies to help complete the cycle. Both of these studies illustrate a need for more novel adaptations in video games so that games can continue to become more accessible to a wider array of disabled individuals.

Researchers have developed novel games designed specifically for those with disabilities. One study summarized work between 2005 and 2010, finding a rather sizeable array not only of games adaptable to the disabled, but also games and software made expressly for use by disabled individuals (Westin, Bierre, Gramenos, & Hinn, 2011). For example, one piece of software called Blindstation was developed which allows developers to separate the key components of games from their supporting code and logic. This allows games to be played while utilizing accessible devices such as Braille and tactile boards.

Another example of such a game, called UA-Chess, was created by a group of researchers from Greece (Grammenos, Savidis, & Stephanidis, 2005). The web-based chess adaptation was designed specifically to be universally accessible, meaning that the game was playable by a wide array of ability levels. To accomplish this, the developers incorporated auditory feedback for moves, created high-visibility displays, and allowed for speech input, which provided accessibility for hand-motor impaired individuals. The game could be played locally by two players and alternate "profiles" based on the player's preferences and disabilities each turn.

Returning to DDR, a group of researchers modified the game to be more accessible to players with visual impairments (Gasperetti, et al., 2010). These modifications were more simple measures, such as closer placement of the controller to the screen, increased screen contrast, reduced pace of music, or even calling out the arrows verbally for the player.

Some accessibility measures involve a concept called "sensory substitution", which involves coupling an artificial receptor to a human brain using a special device. This device then transmits information to the brain in place of a missing or dysfunctional sense organ. Such devices typically compensate for auditory or visual impairments and rely on the brain's ability to adapt (called "plasticity") to function (Bach-y-Rita & Kercel, 2003). One study utilized visual-to-audio sensory substitution in order to allow blind users to experience a graphical interface (Maidenbaum, Buchs, Abboud, Lavi-Rotbain, & Amedi, 2016). Their tests proved highly successful for users.

This concept was further examined in another study, where researchers investigated the effects of age on sensory substitution (Levy-Tzedek, Maidenbaum, Amedi, & Lackner, 2016). Participants were tasked with navigating a three-dimensional maze. Unsurprisingly, the study found that performance did indeed decrease with age. However, it is still important to note that the substitution enabled users to experience environments which were previously impossible.

Other research took a new approach on substitution, allowing players to use full-body gestures to interact with a gesture-based game (Morelli & Folmer, 2014). The study used a real-time video analyzer calibrated to recognize certain visual cues and deliver haptic feedback to the user. The study found no significant difference in performance between users who received visual cues versus haptic cues, which is promising from an accessibility standpoint. However, the solution is expensive and relies on the Kinect, a piece of hardware which has been discontinued. Examining solutions which can be easily re-adapted with new technology would be beneficial. Overall, there is much to still be examined with regards to senses other than the auditory and the visual.

2.3 Haptics and Games for Accessibility

The arrival of haptics into the video game market meant another revolution for the disabled. Such users had a new chance at experiencing the thrill of gaming for themselves. The word “haptics” simply describes the sense of touch, both related to contact through skin as well as information provided through limbs and tendons regarding their position in space (Kortum, 2008). Simple examples of this include small vibrations when tapping a touchscreen phone. Not only can haptics provide feedback after-the-fact, they can also provide the means to alert and prepare players for an incoming event.

There is an abundance of work examining haptics and their application to human-computer interaction. One such study examined the potential for a desktop user to feel the objects they manipulated on a screen (Hardwick, Rush, Furner, & Seton, 1996). Preliminary findings were successful in implementing a force display alongside gesture and 3D object manipulation. Along that same line but with an emphasis on accessibility, another study developed a system for allowing the visually disabled to feel objects in 3D space through the use of a dual-finger haptic interface alongside supporting auditory cues (Iglesias, et al., 2004). On a larger scale, an entire work dedicated to assistive technologies for the visually disabled and blind dedicates an entire chapter to haptics as a substitute for vision, noting that “low-tech” examples such as sight canes and braille have existed for decades (Hersh & Johnson, 2010).

Although the studies are sparse, a handful of researchers have taken the leap into the field of haptics for accessibility in games. One “poster child” example of such a combination comes from a study called Blind Hero (Yuan & Folmer, 2008). This particular study involved making a derivative of a game called Guitar Hero. Normally, a player is expected to hold a guitar-shaped controller which has six buttons along the neck as well as a rocking switch where the sound hole of the guitar would normally be. After selecting a song, individual “notes” travel down the screen toward the player. Depending on how far left or right the note is on the screen, a player holds down the corresponding “string” (button on the neck of the controller) and “strums” the guitar when the note reaches a bar at the bottom of the screen. Of course, all of this is synchronized to the song chosen.

In order to accommodate blind players, the researchers developed a glove armed with vibrating motors in each finger. The correct finger would vibrate shortly before the player needed to press the button and strum the guitar. Since the number of available buttons to press (6) exceeded the number of fingers available to leave resting on the buttons (4), the researchers opted to restrict the gameplay to only four buttons.

Not surprisingly, the researchers found that not only were blind individuals finally able to get on the scoreboard in the game, they were able to steadily improve with practice. What is more interesting is that in Blind Hero, blind individuals who had never played original Guitar Hero before performed significantly better than sighted individuals who also hadn’t. This fact may allude yet again to sensory substitution and the ability for the disabled to become more proficient in alternative sensory experiences. Additionally, it is worth noting in the study that all groups’ performance followed a similar trend of improvement, regardless of game or disability.

One limitation of the Blind Hero study lies in the choice of haptic feedback timing; as mentioned, the finger in the glove would vibrate barely before the button was to be pressed, at an interval determined to comfortably fit standard human reaction time. The trouble with this, however, is that standard human reaction time carries no value in the context of a rhythm game. A much more powerful approach could have been to vibrate a finger a beat or two in advance, or perhaps format songs into a “question-answer” format, where a short series of notes is played through the haptic device, and then the player parrots them back through the controller.

Several other games have been developed on varying platforms. The game Finger Dance, for example, was developed as a keyboard-based alternative to Dance Dance Revolution and relied on auditory cues which corresponded to four different keys needing to be pressed (Miller, Parecki, & Douglas, 2007). Another mobile game called Scratch-Off utilized the motor in a cell phone to help players reliably simulate the scratching of a vinyl record in time with music (Gillian, O'Modhrain, & Essl, 2009).

2.4 Haptics for Performance

There is a noticeable lack of research which specifically pertains to performance in video games. However, a handful of studies have surfaced over the years with a more general approach between haptics and simulations. Some of the most prominent articles pertain to the use of haptics in medical training, particularly laparoscopy.

The results and claims of these studies vary; a systematic review of literature pertaining to virtual reality-based surgical training assessed the results to determine the current status and value of feedback (Van der Meijden & Schijven, 2009). Ultimately, the study determined that no real conclusion could be reached; this was due to ambivalence and lack of unanimity regarding how to assess haptics when used in conjunction with surgical training.

However, a different study observed a noticeable improvement in skill when comparing a group of surgeons which had been trained using haptics before an exercise and a group which had not (Ström, et al., 2006). Its experiment used a pool of 38 surgical residents to conduct a randomized study involving haptic or non-haptic training. The training lasted two hours, and the participants then conducted two diathermy operations thereafter. The group which began with the haptic training was found to perform significantly better in all regards.

In a non-medical environment, a group of researchers performed an experiment designed to identify benefits (if any) of haptics in completing a hands-on assembly task (Adams, Klowden, & Hannaford, 2001). The study involved three groups, all tasked with assembling a LEGO model: the first group received advance training using virtual reality and haptics, the second received virtual reality only, and the third received no virtual reality training at all. Analyzation of the completion times for each group showed a statistically significant difference in those who received haptic feedback and those who did not. However, the researchers admit that their sample size was small, so these findings cannot be fully confirmed in their significance until the study is repeated with a larger subject pool.

2.5 Haptics and Dance-Based Rhythm Games

In the midst of surrounding research, it has been difficult to uncover any studies surrounding haptics and true dance-based rhythm games. Pursuing this sector of research allows us to examine further improvements and developments in accessibility, particularly for the blind. This study presents a prototype for a solution which, if perfected, could provide the viable means for a non-sighted individual to have the ability to participate in a dancing rhythm game.

Secondarily, this research allows us to discover any implications haptics may have for user performance and accuracy in rhythm games when used in tandem with visual cues. Investigating this subject will allow us to come closer to determining whether a haptic device can increase the score of video game players, whether they have disabilities or not. Findings here could lead to implications for the gaming industry, specifically the development of new control methods and mechanics. Further, an increase in human performance could also have consequences for the skill ceiling in competitive gaming scenes.

3 METHODOLOGY

3.1 Introduction

This chapter describes the methodology used to evaluate the haptic StepMania experience. StepMania is the open-source version of Dance Dance Revolution used in this study. The gameplay mechanics between the two are identical. After describing the technology and equipment used to set up the haptic StepMania experience, the experiment that was used to address the research questions is described.

3.2 Haptic DDR Experience

3.2.1 Equipment

In order to play Dance Dance Revolution, a gamepad is needed that detects steps. We used "Afterburner" dance mats created by RedOctane, a now-defunct electronic entertainment company, which are compatible with StepMania and Dance Dance Revolution. Although they were created in the mid-2000's, they were highly-rated and respected for their low latency and high durability, especially due to their metal construction. These dance pads were tested during the initial testing phase as well as each morning before trials. The principal investigator, a skilled player at the game, was able to successfully obtain high scores on songs much more difficult than those which would be presented to participants.

In order to be read properly as input, the pad comes with a control box which provides connections to either a PlayStation 2 or Xbox gaming console. Since neither of these was used in this study, it was necessary to purchase a conversion box from Amazon which would accept a PlayStation connection and convert it into plain USB for use with a PC. The specific model chosen was the MayFlash 3-in-1 conversion box, available at the time of writing for $19.99.

The game itself, StepMania, is open-source and easy to find, as development of the software is still ongoing to this day. It was downloaded and installed on a Windows 7 i5 PC with 8GB of RAM, which was more than sufficient to carry out the task of running the game alongside any other back-end tasks needed for communication with the back-end systems for control of the motors. Despite newer versions of the game being available, StepMania 3.9 was chosen for use in this experiment, due to the researchers' familiarity with the version. Additionally, version 3.9 allowed for instant compatibility with Windows 7 without any further issues or installations.

The MayFlash 3-in-1 conversion box was then attached to the PC, and the dance pad was connected to the conversion box over the PlayStation 2 connector. The PC was then connected via HDMI to a large TV screen for use by the user during gameplay, and a second monitor was also attached via VGA for use by the researcher on a second screen. The complete setup is shown in Figure 3-1.

Figure 3-1 Room and Equipment Used for Study

3.2.2 Basic Gameplay

The basic game is simple in concept; users stand on top of the dance pad and watch the screen. At the top, four directional arrows flash to the beat of the music and correspond to the four directional arrows on the dance pad. When the song starts, other arrows travel up the screen toward the four arrows fixed at the top (see Figure 3-2). At the moment a traveling arrow meets the fixed arrow, the user steps in the corresponding direction. Generally, all songs' arrows will have musical value corresponding to the beat or rhythm of the music. It was ensured that all arrows were musically predictable in all songs used in this study, meaning they were mapped to nothing more complex than 8th notes as to not rhythmically overcomplicate a song.

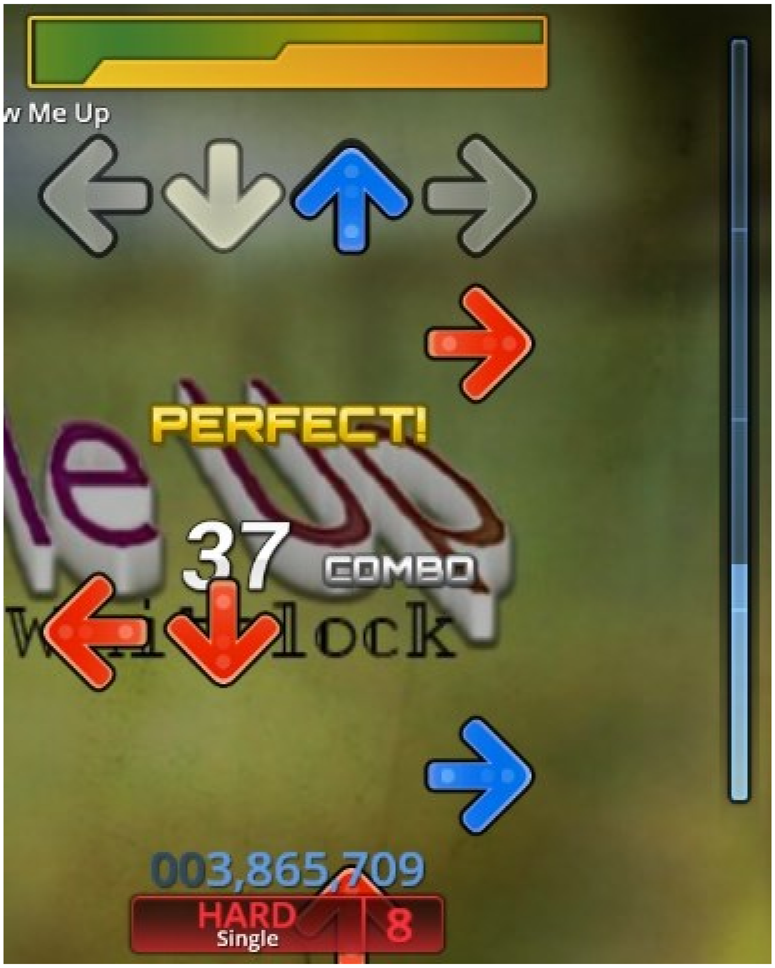

Figure 3-2 Sample Gameplay Screen

Once a user steps on an arrow, they are immediately presented with a timing score pertaining to that particular step. From best to worst, the possible timings are “Marvelous”, “Perfect”, “Great”, “Good”, “Boo”, and “Miss”. Receiving any of the first three scores for a step increases the overall song score, which is kept in the bottom-left of the screen. Receiving a

“Boo” or “Miss” too many times in a row will typically cause the song to stop and the user to receive a failure, but this rule was disabled for the purposes of this study.

At the end of a song, the user is taken to a summary screen which gives the player an overall letter grade for their performance. The possible scores in StepMania (from best to worst) are AAAA, AAA, AA, A, B, C, D, and E. The first three scores are only attained by seasoned veterans of dance games, and a player unfamiliar with StepMania will still have a difficult time obtaining an “A” or a “B”. The score screen also displays a summary of all step scores: the total number of “Marvelous”, “Perfect”, and so on, as well as the cumulative (overall) score for the song (see Figure 3-3).

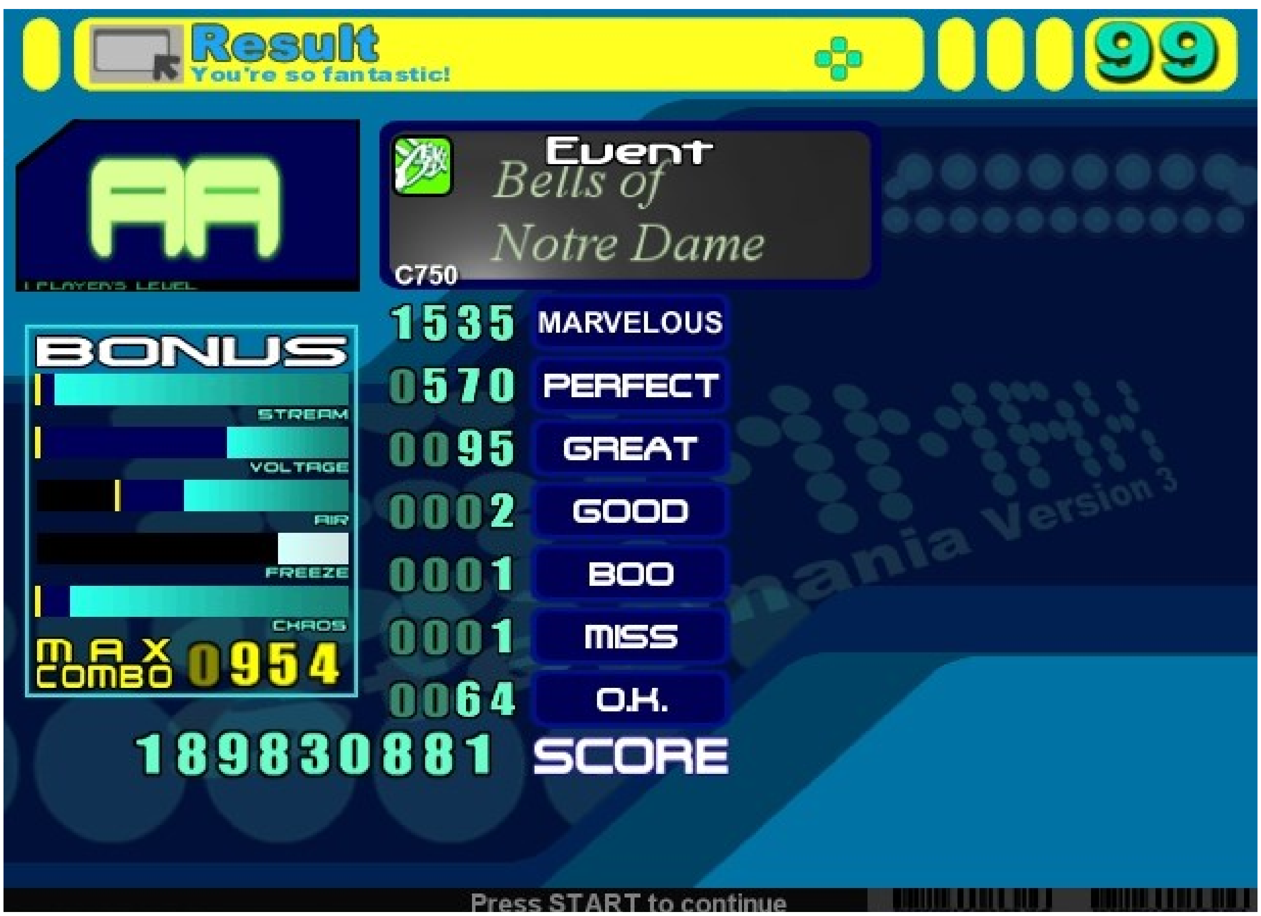

Figure 3-3 Sample Game Score Screen

3.2.3 Haptic Functionality

A Raspberry Pi 3B served as the major backend driver for the haptic motors. The Pi was imaged with Raspbian Stretch, which natively comes with Python 3 and the package pigpio, which was all that was needed on the Pi itself. The Pi was connected to a breadboard via a Sparkfun Pi Wedge, where cables connected predetermined GPIO pins to four different Polulu H-Bridges for use with the four separate motors. The motors themselves were small 3V cell phone-grade vibration motors and were powered (with H-Bridges) via a variable-voltage-or-current benchtop power supply. Each motor had a 12-foot-long cable lead coming from the output of its H-Bridge. The motors then needed to be mounted inside the visor so they would correspond with the directional arrows on the screen. To accomplish this, the motors were mounted on the inside edge of the visor in each of the four cardinal directions and secured using adhesive which came pre-attached to each motor. The wires were bunched together using zip ties and sewn into the fabric fold of the visor to further secure and hide them.

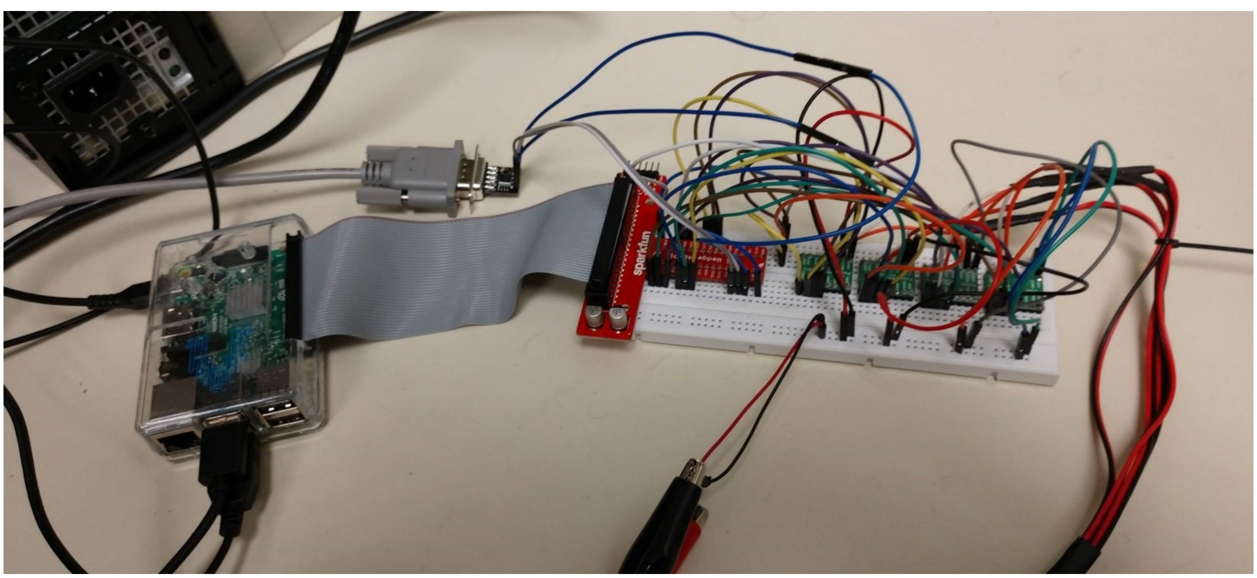

Figure 3-4 Back-End System for Haptic Device

Figure 3-5 Haptic Device Used

The complement to the Raspberry Pi was installed on the same PC which ran StepMania. The program used was "SMPlayer", a freeware application developed by an online user under the name SomethingUnreal. The application allows a user to read in a StepMania dance file and send signals over serial, which contain information on arrow presses and musical beats. For the serial connection itself, a generic serial-to-TTL converter was used, which allowed for a serial cable to be connected from the PC to the converter, and wires were used to bridge the connection from the converter to the Tx and Rx UART pins via the breadboard.

Figure 3-6 View of Left Motor Inside Haptic Device

The SMPlayer software itself allows a user to play, stop and set the song to the beginning of the music or the steps via keyboard shortcuts. When a song is playing, it sends serial signals corresponding to the beat of the music as well as the dance steps the song requires. This data was then picked up by a Python script on the Pi which was listening for serial data, parsed into command strings, added to an array, and executed. The array contained four commands, one for each step direction, with simple high/low voltage used to vibrate the correct motor in time with the music.

Since SMPlayer and StepMania have no way of directly interfacing with each other for the purpose of synchronization, it became necessary to develop a way to ensure that SMPlayer was firing the motors in time with the gameplay of StepMania. This was accomplished by using a simple Python script housed on the PC, which listened to specific keyboard presses. When a researcher pressed the “enter” key, for example (which starts a StepMania song), the script set SMPlayer to the start of the music, waited a precise number of seconds, and then began the song in time with the music. The time delay between pressing “enter” and having the music start in StepMania is consistent within each session, which made this method reliable. The caveat to this method was making sure to avoid pressing the “enter” key at any time aside from the start of a song. This happened only once, and it was apparent there was a problem, so the song was restarted.

Proper cueing of musical inputs was extremely important and was a major source of consideration during this study. Rather than choose an arbitrary time correlating to human reaction or song tempo (as was done in Blind Hero), the musically valuable measure of beats was chosen. Such a unit of measurement is easy for human players to pick up and naturally integrates into rhythm games. Initially, a time advance of one beat was chosen to be sufficient warning for a user to feel the haptic feedback and step in the direction correlating to the vibrating motor. During initial testing, however, it was found that one beat was still insufficient time for proper reaction. Therefore, the delay was precisely set so that the haptic vibrations would occur two beats before the step was to take place. Greater units of musical time were not considered, because they could become so long that a user may get confused or forget which step needs to come next, especially amidst denser passages of steps.

3.3 Recruitment

A convenience sample of participants was recruited during the end of Winter and beginning of Spring semester 2018. Recruitment included emails to family and friends, student class announcements, and recruitment of people in the building which houses classes primarily for Engineering and Technology students. When approached either electronically or physically, the individual was asked whether they would have interest in participating in a study which involves Dance Dance Revolution and vibration feedback. Of course, a complete explanation was offered to every interested individual before they could participate. They signed a consent form that was approved by the Institutional Review Board.

The reasoning for this selection and process is worth noting. As was mentioned in the introduction, this study has potential implications for the world of accessibility, particularly blind individuals. However, it was determined that efforts would be best spent if this work focused on developing a viable, reliable prototype with promising preliminary work before introducing it primarily as an accessibility instrument.

3.4 Experimental Design

A within-subject experimental design was used, wherein each person participated in all 3 conditions. All conditions included audio, since dance games are inherently tied to music. The three conditions included: haptic only, visual only, and haptic plus visual. Each condition was randomly ordered. Additionally, 3 songs of a similar difficulty level were chosen. The song order was also randomized. This assured that differences between conditions were not a result of using the same song multiple times (i.e. learning) or due to differences in the songs themselves (if the same song were tied to the same condition each time it wouldn't be clear which was causing the difference).

3.5 Experimental Procedure

Each participant started out a 15-minute lab session by completing an initial training that included both visuals and haptics. Users wore the haptic device (visor) on their head while playing through a song in StepMania with the visuals present. The purpose of this training session was to allow participants to become familiar with not only the basic mechanics of the game, but also the feel and timing of the haptic feedback (e.g., haptic cues occur 2 beats before the arrows cross the line). Music was always present. All songs in the study were set to the "Beginner" difficulty, which is the easiest difficulty available in the game.

The training song was the same for all participants and reflected the general difficulty of the songs that followed the trial. After this song was completed (approx. 1.5 minutes), the actual trials began, and data collection started. The order in which users experienced each variant was randomized, but was either haptics only, video only, or video plus haptics. After each trial, the user completed a short series of questions pertaining to the recently-completed trial conditions via a web-based survey run on the Qualtrics system. In the case of visuals only, these questions asked how difficult the song was to complete, as well as how enjoyable it was to complete the song. Questions following a haptics-based trial included the visuals-only questions and also asked regarding the helpfulness and enjoyability of the haptic device. The period of time between songs also provided participants with a short break before the beginning of the next trial and allowed the equipment to be reset and reconfigured as necessary.

At the end of all trials, the participant was then presented with a final portion of the survey which asked them questions regarding their personal perceptions of the overall experience. They were asked questions regarding their most-preferred condition, their personal experience, distraction level, and perceived helpfulness or problems with using haptics, as well as the same for the game-provided visuals. Additionally, participants were asked for basic demographic information such as sex and age, as well as their previous experience with any sort of haptic device, experience with dance games, and experience with dancing in general. All of this was stored in Qualtrics for ease of further analysis. This survey can be viewed in the Appendix.

3.6 Analysis

The quantitative analysis focused on how well participants were able to accurately complete the steps provided by the song. Stepmania provides an aggregate score based on the different levels of accuracy associated with each step. This performance score was used as an objective measure of accuracy, which was a key dependent variable. Survey data about perceived difficulty, enjoyability, previous dance experience, and haptics-induced distraction was also collected and analyzed to answer the research questions.

A mixed model analysis of covariance blocking on subject was used. Covariates included age, owning a haptic device, gender, dancing experience, and experience with dance games. Variable selection was performed on the covariates and tested over the course of multiple models. Those variables which were found to be significant were retained in the final models. As a result, different models may have different covariates included.

Order of conditions, song, and the conditions themselves were also considered. Differences between the songs were not significant and were therefore not included in the final models. Differences in the order of conditions were also not significant, so they were also not included in the final models, unless stated otherwise.

The survey included several open-ended questions, such as “What did you like most about the haptic feedback?”, “Do you have any additional feedback about the experience?” and “Explain why you ranked them the way you did.”, which followed a question asking participants to rank each experience according to preference. These questions helped us to better understand perceptions about the experience with haptics. A thematic analysis was performed. After reading through all of the comments, non-mutually-exclusive themes were identified. All data with those themes were identified on a second pass through the comments. Quotes used throughout the results section are anonymized and used to complement understanding of the numerical data, which was the primary focus of this work. Additionally, the principal investigator’s personal observations are added to the analysis when appropriate, since he was able to listen and observe all of the participant sessions.

4 RESULTS

4.1 Participant Information

A total of 50 participants completed the within-subject experiment, including the surveys. A few participants did not answer some of the survey questions; however, all non-free-response questions had at least 47 respondents. In total, 36 males (72%) and 14 females participated in the study. 37 (74%) of individuals did not own a haptic device such as a smart watch. Boxplots illustrating the age of participants, their experience with dance games, and general dance experience are found in Figures 4.1-4.3.

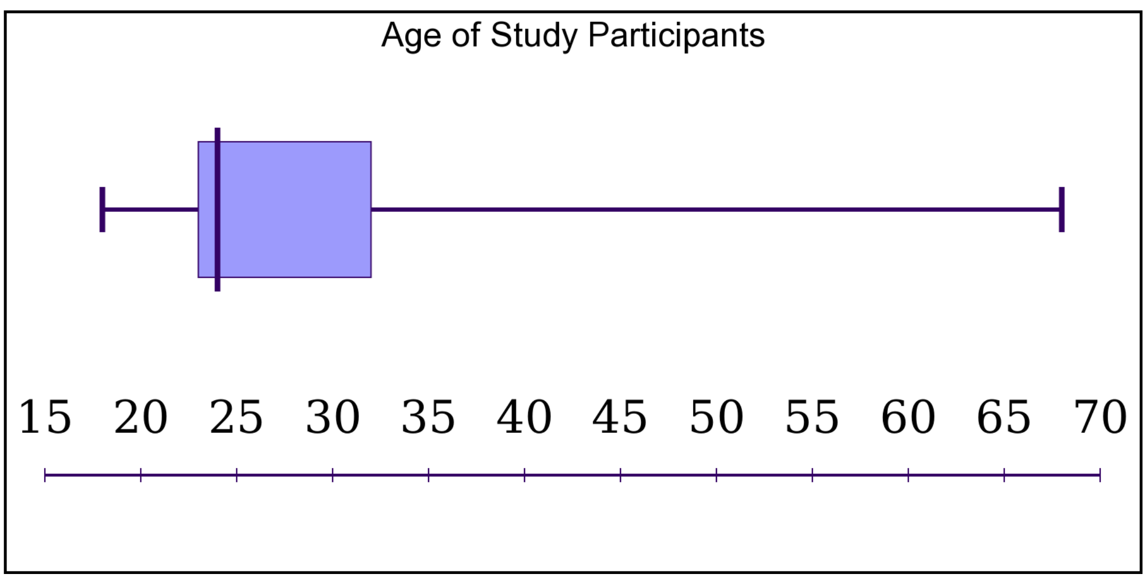

Figure 4-1 Age Distribution of Participants

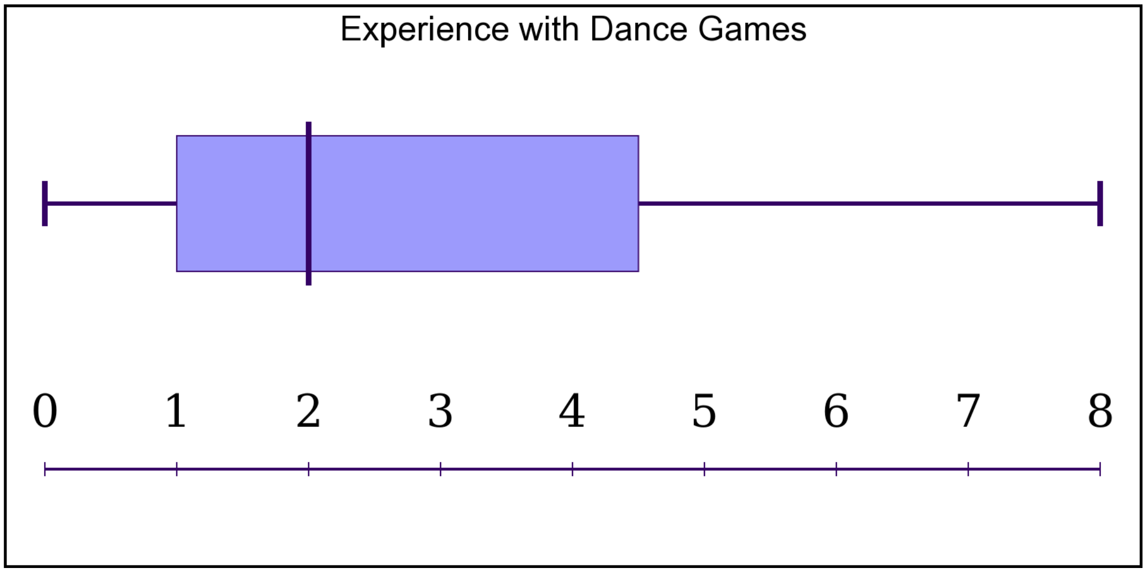

Figure 4-2 Participants' Self-Reported Level of Experience with Dance Games

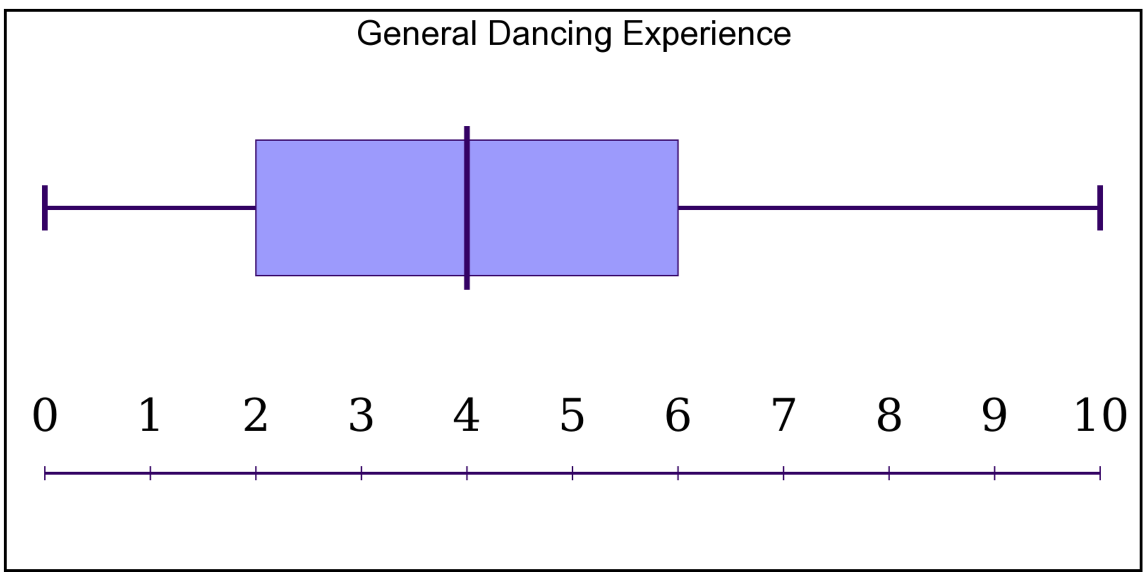

Figure 4-3 Participants' Self-Reported Level of Experience with Dancing

4.2 Perceived Difficulty

Participants indicated how difficult they perceived each condition to be after each trial. They answered the question "How difficult was it to complete the song successfully?" on a

Likert scale of 0 (Not at all difficult) to 10 (Extremely difficult). The final model included dance game experience (F=17.68; P<0.0001) and condition (F=41.67; P<0.0001). Gender was included as a covariate. Variables such as age, dancing experience, and experience with haptic wearables were tested for significance and not included. Table 4-1 shows the estimate and standard error for each condition. As is evident, the haptic condition was almost double the perceived difficulty of the other conditions. Table 4-2 shows that the differences were statistically significant.

Table 4-1 Perceived Difficulty: Estimates

	Condition	**Average**	**Standard Error**
Condition	Haptic	7.05	0.32
Condition	Visual	3.63	0.32
Condition	Both	3.53	0.32

Game experience was weakly negatively related (-0.28) to perceived difficulty, suggesting that those who had played dance games in the past perceived the game as less difficult.

Unsurprisingly, the haptic only condition (haptic) was found to be most difficult, approximately double the other conditions, whereas the visual only (visual) and visuals + haptic (both) conditions were not statistically different from one another. This ~3.5-point increase in difficulty shown in Table 4-1 illustrates a jump from an inferred “mildly difficult” (~3.5 on the Likert scale) to “difficult” (~7 on the scale).

Table 4-2 Perceived Difficulty: Differences of Least Squares Means

	Condition	**Condition**	**Difference**	**T Value**	**Adj P**
Condition	Haptic	Visual	3.4184	7.76	***<.0001***
Condition	Haptic	Both	0.4407	7.99	***<.0001***
Condition	Visual	Both	0.4454	0.23	0.9701

This does, however, indicate that the addition of haptics to the visuals was not found to make the overall game experience more difficult. This bodes well for the possibility of haptics being used to enhance gameplay.

4.3 Enjoyability

Participants responded to the question "How enjoyable was playing the game?" after each trial. This was measured on a Likert scale from 0 (Not at all enjoyable) to 10 (Extremely enjoyable). The final model included a participant's previous experience with dancing ($F = 4.15$; $P<0.0445$) as well as the condition (haptic, visual) experienced ($F=4.58$; $P<0.0128$). Gender was also included as a covariate. Table 4-3 provides the estimate as well as the standard error. As can be seen, the haptic-only experience was rated the lowest in enjoyability, nearly a whole point behind the most enjoyable condition (both). Table 4-4 demonstrates the statistical significance of the variables.

Table 4-3 Enjoyability: Estimates

	Condition	Average	Standard Error
Condition	Haptic	5.84	0.29
Condition	Visual	6.40	0.29
Condition	Both	6.76	0.29

Previous dancing experience was weakly positively related (0.26) to reported enjoyability, suggesting that those who have some background in dance may deem the game to be more fun to play. A significant difference was found between conditions 1 and 3 (haptics only vs. both), but other comparisons were not found to be statistically significant.

Table 4-4 Enjoyability: Differences of Least Squares Means

	Condition	Condition	Difference	T Value	Adj P
Condition	Haptic	Visual	-0.5608	-1.83	0.1667
Condition	Haptic	Both	-0.9225	-3.00	***0.0095***
Condition	Visual	Both	-0.3617	-1.19	0.4643

The fact that there was no significant difference between the haptic only and the visual only condition is interesting; it could suggest that haptic-only gameplay is as enjoyable to visual-only gameplay, though a larger sample size may find significantly different results. Still, the difference of less than a point on the 10-point scale is much smaller than the approximately 3.5-point increase in perceived difficulty. The novelty of the haptic experience may help explain the differences.

4.4 Haptic Helpfulness

Participants responded to the question “How helpful do you feel the haptic device was in helping you complete the song?” on a Likert scale from 0 (Not at all helpful) to 10 (Extremely helpful). Naturally, this question was omitted following a trial involving visuals only. The order of the condition (i.e. whether they experienced the haptics on the first or last trial) was found to be significant, so it was kept in the final model ($F=3.39$; $P<0.0422$). Condition itself was also included ($F=6.27$; $P<0.0158$), with gender as a covariate. Table 4-5 shows the estimate as well as the standard error. As is evident, a condition involving haptics was rated slightly higher if it occurred in the final (last trial) for a participant, and the haptic-only condition merited a higher helpfulness score. Table 4-6 provides the statistical significance of order and condition.

Table 4-5 Haptic Helpfulness: Estimates

	Condition	**Order**	**Average**	**Standard Error**
Order		1	4.55	0.43
Order		2	4.80	0.41
Order		3	5.97	0.42
Condition	Haptic		5.68	0.34
Condition	Both		4.53	0.35

Table 4-6 Haptic Helpfulness: Differences of Least Squares Means

	Condition	**Order**	**Condition**	**Order**	**Difference**	**T-Value**	**Adj P**
Order		1		2	-0.2507	-0.44	0.9012
Order		1		3	-1.4174	-2.41	0.0514
Order		2		3	-1.1667	-2.06	0.1084
Condition	Haptic		Both		1.1528	2.50	***0.0158***

It is unsurprising that participants experiencing condition 1 (haptics only) found haptics to be helpful, seeing that anything less would result in a player standing in front of a blank screen with no cues. What is worth noting, however, is that there appears to be a learning effect taking place. When haptics were used on the first or the second trial, there was no significant difference; this was also true between the second and third. Between the first and third, however, a just-barely-statistically-insignificant difference is seen. Due to its proximity to a P-Value of .05, it was chosen to be kept, especially since it suggested the possibility that the measure of helpfulness may be due in part to the participant becoming accustomed to the device and gameplay.

4.5 Performance

Performance was quantified using raw game score, rather than participant perception, and the natural log of each score was taken prior to further statistical analysis. When examining performance, age ($F=32.59$; $P<0.0001$), previous experience with haptic wearables ($F=4.64$; $P<0.0364$), and the condition itself ($F=53.98$; $P<0.0001$) were found to be significant and were included in the final model. Previous experience with wearable haptics was included as a covariate. Table 4-7 displays the estimate and standard error for each condition and demonstrates that participant score was notably lower on haptics-only trials. Table 4-8 shows the statistical significance between conditions.

Table 4-7 Performance: Estimates

	Condition	**Average**	**Standard Error**
Condition	Haptic	12.04	0.29
Condition	Visual	15.59	0.29
Condition	Both	15.44	0.29

For further illustration regarding the score estimates, the median in-game score for haptic-only was 371,280, whereas the medians for visual-only and both were respectively 5,880,835 and 5,656,151. Age was found to be weakly negatively related to performance (-0.23), and previous dance game experience was found to be weakly positively related (0.19). A notable difference in performance was seen between the haptic-only condition and the others, but no statistically significant difference was found between trials which were visual-only or haptics plus visuals.

Table 4-8 Performance: Differences of Least Squares Means

	Condition	**Condition**	**Difference**	**T Value**	**Adj P**
Condition	Haptic	Visual	-3.5494	-9.18	***<.0001***
Condition	Haptic	Both	-3.4030	-8.80	***<.0001***
Condition	Visual	Both	0.1463	0.38	0.9241

For even further illustration, figure 4-4 below displays the distribution of scores across all haptic-only conditions for all participants. As can be seen, most scored in the lower ranges, with a few very extreme outliers performing well.

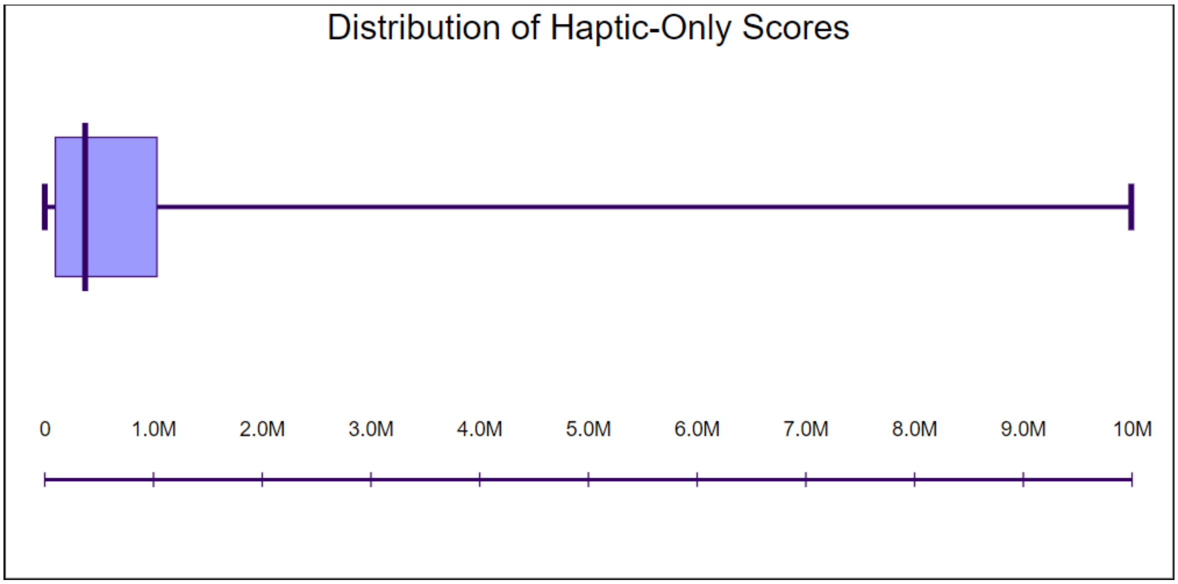

Figure 4-4 Distribution of Haptic-Only Scores for All Participants

It is unsurprising that participants performed the worst on haptic-only trials. However, this also demonstrates that haptics plus visuals did not appear to impede perceived performance in the game; on the contrary, there appeared to be a slight increase in perceived performance when comparing haptics + visuals to visuals alone.

4.6 Preference of Condition Comparison

Participants were asked the question "Sort the following ways to play the dance game in order from your most preferred (on top) to your least preferred (on bottom)." Figure 4-4 displays the distribution of each condition by its ranking.

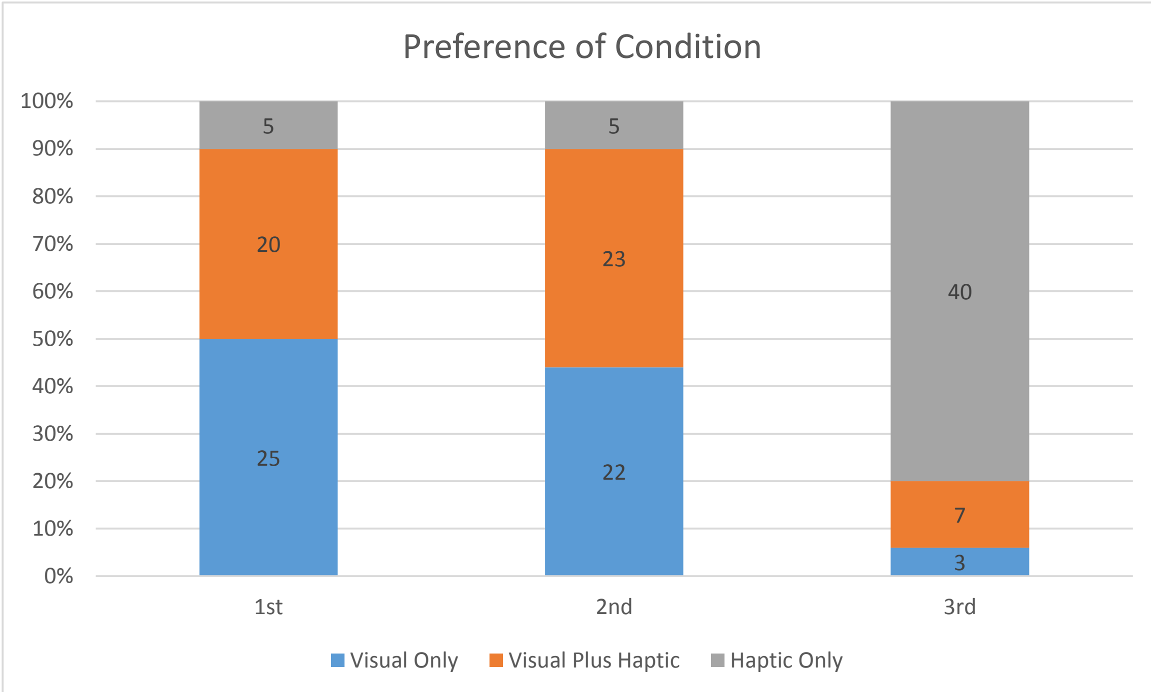

Figure 4-5 Preference of Condition

As is quite clear, the overwhelming majority of participants ranked the haptic-only experience last, while the visual-only condition narrowly took first place as the top first choice. There are many possible explanations for this, including familiarity and difficulty interpreting haptic feedback, which will be discussed shortly. Interestingly, the five individuals who indicated haptic-only as the most preferred position reported lower familiarity (median AND average score of 3) with dance games and dancing in general.

4.7 Qualitative Observations

The preference sorting question was followed up with “Explain why you ranked them the way you did”. A prevalent theme throughout the responses indicated that the haptic-only experience was rated lowest due to familiarity: “I am more used to the visual only”, “Most accustomed to visual display", "The visual was the easiest to see right when I needed to press the arrow", and so on. 12/50 participants indicated something to this effect.

Another common theme pertained to how difficult the haptic device feedback was to discern. Many users had trouble not only identifying the haptic feedback from the device, but also being able to process it alongside other cues as applicable: "Trying to have two ways of getting input at once is difficult", "I didn't notice the haptic device until… that was the only thing to rely on", "Haptic was distracting", "The left buzz felt like a front buzz". 14 of the 50 responses mentioned this sort of difficulty.

This isn't to say that there weren't many who still enjoyed the presence of haptics. Most comments in this regard indicated the perceived effectiveness of two conditions working together: "It helped to have two senses confirming the goal", "The more input the more you can just become one with the task", "Haptic and visual together help me perform better", "it gave the game an entirely new dimension". 13 of the 50 participants reported this effect.

Of those few individuals who indicated haptic-only as their most-preferred condition, two indicated the reasoning behind the rank was due to confusion while trying to interpret multiple signals at once: "Trying to have two ways of getting input at once is difficult", "Taking multiple inputs at once made it very difficult to play and recognize what was going on". Three others indicated satisfaction with the fun or novelty of the haptic-only experience: "I did terribly, but it made it fun to try to interpret the different signals", "Having the change from visual to haptic feedback was a pretty cool experience", "I loved the new style of gameplay I experienced with the haptic device. It was fun but not too incredibly difficult".

4.8 Additional Comments and Observations

Participants responded to the open-ended question “What did you like most about the haptic feedback?”. Responses varied greatly, but a rather consistent theme throughout the responses pertained to being prepared to make a step or affirming a player’s synchronization with the game: “Adds reinforcement”, “The advance warning it gave”, “Helped a lot with timing”, “Two beats ahead is a good number”, “It helped me become used to the right timing for my steps”. In total, 20/50 participants indicated such a sentiment. Seven other participants indicated a sense of novelty as the best thing about the haptics, such as: “It was a fun challenge”, “I could see it as being a fun party game”, and “It added to the experience of the game”.

As a complement to the previous question, participants also indicated what they would do to improve the haptic experience. Without question, the most prevalent theme (seen in 38/49 responses) had to do with the distinguishability of the haptic feedback, particularly its strength. “Make the vibrations stronger”, “The motors were hard to distinguish”, “Slightly more force”, “More pronounced directions”. A few of these individuals specifically commented on the difficulty of distinguishing between two directions at once, whereas others gave more unique suggestions such as making the device wireless or using a different article of clothing such as a belt.

The last question simply asked for any additional feedback, and the majority of responses (17 of the 35 who elected to respond) indicated enjoyment with the study or excitement about its further development and implications: “I’m not the best at rhythm games, but I must say I was surprised at how much this device improved my performance”, “This was fun”, “I think it could be a great addition to rhythm games”. Two individuals indicated inconsistencies with the dance pad’s ability to register steps, meaning that the device was failing to properly detect when a player stepped on an arrow. This concern is disputed from the principal investigator (an experienced player) testing the equipment during initial experimental development as well as daily before trials began. He was consistently able to achieve very high scores on songs of much higher difficulty than what participants were presented with.

5 CONCLUSION

5.1 Summary of Findings

The two primary purposes of our research were to:

1) Evaluate whether a head-mounted haptic device, synchronized in time with the game music, enhanced the game score of rhythm game players in comparison to playing the game without our device, and
2) Evaluate whether the haptic device enhanced users' subjective experiences while playing the rhythm game.

The secondary purpose of this research was to gain additional insight regarding how to properly cue players for precisely-timed input.

It was found that our device statistically neither improved nor worsened participants' game scores when it was used in tandem with the game-provided visuals. In trials consisting only of haptics and no visuals, player scores dropped dramatically, due to a mix of unfamiliarity with the system as well as a need for more discernible haptic feedback than that which was provided from the haptic visor. The distribution of these haptic-only scores was rather low, with a few outliers performing rather well. A statistically significant difference was not found between participants' self-reported enjoyability scores on trials involving visuals only or haptics plus visuals. However, the difference in enjoyability between haptic-only trials and haptic-plus-visual trials was significant, with haptic-only being reported as less enjoyable.

Participants perceived and reported haptic-only trials to be the most difficult and ranked this condition as least preferred, with visuals-only as most preferred. They also reported on how helpful they felt the haptic device was in helping them complete the song, and a statistically significant difference was found between when a haptic condition was experienced first instead of last, suggesting a possible learning or familiarity effect.

Correlations between conditions were also measured, though all of them were weak. Experience with rhythm games was negatively related to perceived difficulty, dance experience positively related to reported enjoyability, age negatively to performance, and dance game experience to performance.

In free-response questions regarding the study as a whole, most participants indicated enjoyment with the experience, complimenting the device's ability to help prepare them to make a dance step or reaffirm that they were in time with the music. One participant specifically mentioned that a two-beat warning before each step felt natural. Other open-ended questions were mixed; the most common complaints pertained to how perceivable the haptic feedback was.

5.2 Discussion of Findings

Haptics are new to many people. This study showed that they were of interest to many in a rhythm game context, though coupled with visual displays was preferred by most people. The novelty was largely viewed positively, and participants were able to perform reasonably well for a first-time experience.

The perceived difficulty and accuracy were reduced quite a bit, whereas enjoyability was only reduced a little when using haptic only. The Blind Hero study indicated similar findings, with scores increasing gradually as players became more familiar with their haptic device (Yuan & Folmer, 2008). It would be unsurprising to see blind players perform better or adapt quicker to the device used in this study, especially since there would be no familiarity or expectation with the game's visuals.

Haptic devices such of these show a great amount of potential in the future for use with phones or other more mobile computing devices, such as scenarios where a group of people needs to be cued and synchronized to music for a dance routine, or any other dance-related activity where there is no screen. Further, games could devise novel ways to utilize different "modes" involving haptics, where some modes may use haptics alone or others may utilize other combinations. As was demonstrated in the score distribution for haptic-only conditions, additional practice or refinement may be needed in order to increase the viability of haptics in scenarios requiring precise steps or inputs.

Although the correlations between (such as those between perceived difficulty and dance game experience) were weak, they could potentially suggest predictable trends, indicating that experience with dance games can not only increase performance, but also enjoyability, while negatively affecting perceived difficulty. They may also suggest that one's ability to perform well in such games decreases with age. This contrasts with another study which tested gamers, non-gamers, dancers and non-dancers on a full-body rhythm game; non-gamers had higher scores than gamers (Charbonneau, Miller, & LaViola Jr., 2011). The study attributed this to the fact that the participants with gaming experience were mostly familiar with titles like DDR and

Pump it Up, rather than full-body, choreographed games. Dancers also scored higher than non-dancers, as opposed to our study, where the correlation was not statistically significant.

One definite future consideration would be to examine alternate placements of the haptic devices used or acquire stronger vibration motors; many users specifically mentioned having difficulty discerning between the different motor locations on their heads. This could be due in part to the structure of the skull being a single structure. Different placements may help alleviate this issue. Despite these shortcomings, accuracy was surprisingly good (though varied, as shown in Figure 4-4) for many people during haptic-only trials, considering these participants had suddenly been denied all visuals and were relying solely on a largely new and foreign source of feedback for direction.

With this in mind, it is still important to note that a more robust prototype needs to be developed before this concept is taken and used in an experimental accessibility setting. These preliminary results are promising as an initial proof-of-concept, but further refinement could ensure greater viability for a wider audience.

5.3 Limitations & Future Work

Although our sample size of 50 was acceptable, an even bigger sample size could result in more interesting and complete findings. Additionally, many participants were "thrown in the deep end", with some of them never having played a dance rhythm game before. Exposing them to haptics in addition to this fact could have easily compounded confusion. Allowing users to have more time to practice and participate could help with familiarity as well as demonstrate a stronger learning effect and improvement in game score.

Further, the complexity of songs presented to participants was limited. In this experiment, we avoided using an excessive number of bi-directional arrow combinations, meaning a situation where a user must step on two arrows simultaneously. Additionally, “freeze” arrows (which are held down) were omitted from the songs. Additional studies could investigate ways to make interpretation of signals for these step types more viable.

Lastly, our device was merely a prototype, but could be substantially improved to be easier to distinguish and understand input from. This could take the form of better motors or a completely new device which is attached to another part of the body.

Future work could not only improve on these items, but also seek to find connections to blind individuals. Doing so would provide invaluable feedback from people who could greatly benefit from the development of such a system. Additionally, testing in other situations where visual displays are unavailable could also be interesting.

5.4 Conclusion

Haptics are an exciting and ever-developing field which has many new implications in the field of rhythm dance games. In this study, it was found that the use of haptics in tandem with visuals is comparable in enjoyment to visuals only and produces game scores similar to the standard game. Although a bit clunky, it was exciting to see individuals successfully matching game steps through the use of haptics alone while still enjoying the experience.

If this concept is further developed, it could have implications not only for sighted individuals seeking to create a more immersive gaming experience but could ultimately enable blind people to participate in an exciting category of game which heretofore has been completely inaccessible to them.

It is hoped that the future will see further development haptic-enabled dance games so that the experience can be both accessible and immersive for all.

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APPENDICES

Appendix A. Code for Haptic Device and SMPlayer

The haptic device used in the study relied upon two simple files of code. One file resided on the desktop running StepMania alongside SMPlayer. This code, which utilizes the library PyHook, was adapted from code supplied at https://stackoverflow.com/questions/44103635/how-to-run-function-on-keypress-while-in-background. The code runs and listens for the "return" key to be pressed, which is what the researcher running the experiment would do in order to start the song in StepMania. It then sends keyboard strokes automatically to SMPlayer so that the motors are synchronized with the game.

The second code file resided on the Raspberry Pi, which was listening for serial data sent from the desktop via SMPlayer. The codes for "on" and "off" for each dance move direction are sent as hex strings. This script interprets these hex strings, which are unique for each stepping direction, and vibrates the corresponding motor(s).

PyHook.py

```
from pyHook import HookManager
from win32gui import PumpMessages, PostQuitMessage
from time import sleep
import ctypes
import win32com.client
shell = win32com.client.Dispatch("WScript.Shell")

class Keystroke_Watcher(object):
    def __init__(self):
        self.hm = HookManager()
        self.hm.KeyDown = self.on_keyboard_event
        self.hm.HookKeyboard()


    def on_keyboard_event(self, event):
        print event.KeyID
```

```
        try:
            if event.KeyID  == 13:
                self.start_song()
        finally:
            return True

    def start_song(self):
#rewind SMPlayer to beginning of song
        shell.SendKeys("8")
#wait time between beginning the song and when song starts
        sleep(6.58)
        shell.SendKeys("5")
        pass

    def shutdown(self):
        PostQuitMessage(0)
        self.hm.UnhookKeyboard()


watcher = Keystroke_Watcher()
PumpMessages()
```

Motors.py

```
#!/usr/bin/python
import pigpio, asyncio, serial
from time import sleep
import RPi.GPIO as GPIO

#create serial connection, initialize GPIO pins
ser = serial.Serial('/dev/ttyS0',115200,timeout=0)
pi = pigpio.pi()

pi.set_mode(17,pigpio.OUTPUT)
pi.set_mode(16,pigpio.OUTPUT)
pi.set_mode(13,pigpio.OUTPUT)
pi.set_mode(18,pigpio.ALT5)

pi.set_mode(21,pigpio.OUTPUT)
pi.set_mode(22,pigpio.OUTPUT)
pi.set_mode(23,pigpio.OUTPUT)

pi.set_mode(4,pigpio.OUTPUT)
pi.set_mode(5,pigpio.OUTPUT)
pi.set_mode(6,pigpio.OUTPUT)

pi.set_mode(25,pigpio.OUTPUT)
pi.set_mode(26,pigpio.OUTPUT)
```

```
pi.set_mode(27,pigpio.OUTPUT)

pi.set_PWM_dutycycle(18,35)
pi.set_PWM_frequency(18,2000)

pi.write(17,1)
pi.write(16,0)
pi.write(21,1)
pi.write(22,0)
pi.write(6,1)
pi.write(5,0)
pi.write(25,1)
pi.write(26,0)

#Read in and decode incoming string. Check if step direction is
pressed or not for each direction.
#From that, calculate new "on/off" variables, one for motors needing
to be set high and one for low. Perform an OR with these variables for
each step direction, which then results in the complete string of
motors needing to be turned on or off.
#Set the motors high or low as a group/bank.
#0p/1p/2p/3p represent a different step direction. The code 1350
figuratively indicates a "high" voltage (step), 1500 a "low"
(release/no step).
#For more info see http://abyz.me.uk/rpi/pigpio/pdif2.html#set_bank_1

on = 0
off = 0

while True:
    if ser.inWaiting() > 10:
        cmd = ser.readline().decode('iso-8859-1')
        print(cmd)
        if "#0p1350" in cmd:
            #print("SAW 0H\n")
            on |= (8192)
        elif "#0p1500" in cmd:
            #print("SAW OL\n")
            off |= (8192)
        if "#1p1350" in cmd:
            #print("SAW 1H\n")
            on |= (8388608)
        elif "#1p1500" in cmd:
            #print ("SAW 1L\n")
            off |= (8388608)
        if "#2p1350" in cmd:
            on |= (134217728)
        elif "#2p1500" in cmd:
            off |= (134217728)
        if "#3p1350" in cmd:
            on |= (16)
        elif "#3p1500" in cmd:
```

```
        off |= (16)
    pi.set_bank_1(on)
    pi.clear_bank_1(off)
    on = 0
    off = 0
```

Appendix B. Post-Trial Survey

This survey was given to all participants at the very end, after they had completed all three conditions. The answers were anonymous and stored online using the Qualtrics survey software suite.

1) How comfortable was the haptic device to use and wear? (1-10 Likert Scale)
2) How distracting was the device from the goal of the game? (1-10 Likert Scale)
3) Sort the following ways to play the dance game in order from your most preferred (on top) to your least preferred (on bottom).
    a. Visual Display Only
    b. Visual Display plus Haptic Device
    c. Haptic Device Only
4) Explain why you ranked them the way you did. (Free-response
5) What did you like most about the haptic feedback? (Free-response)
6) How would you improve the haptic feedback? (Free-response)
7) Do you have any additional feedback about the experience? (Free-response)
8) What is your gender?
    a. Male
    b. Female
9) What is your age? (Free-response)

10) How experienced are you at playing dance-based games like the one you played today? (1-10 Likert Scale)

11) How experienced are you at dancing in general? (1-10 Likert Scale)

12) Do you own a wearable device that provides haptic feedback, such as a fitness tracker or smartwatch that vibrates?

    a. Yes

    b. No