Music Blocks: Audio-augmented block games for play-based cognitive assessment

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***Abstract*—Music Blocks are audio and musical games that use sensor-embedded cube blocks designed for play-based cognitive and motor skill assessments. Music Blocks allow the user to customize the sensory feedback, such as audio, visual, tactile, or a combination of any two or more, within the game design. Three Music Games were designed for preliminary evaluation: Direction Blocks, MineSweeper, and Password Blocks. New algorithms to support real-time game administration and data collection for these three games were also developed. For preliminary evaluation of technical function and usability, the games were tested on a small group of 17 participants. As a baseline cognitive assessment, three subtests of the Wechsler Adult Intelligence Test Fourth Edition (WAIS-IV: Block Design, Digit Span, and Matrix Reasoning) were also administered to all participants. Preliminary results showed that audio and visual stimuli have equal participant digit span performance in the Password Game (50%/50%), and audio portrays information well in tangible games (e.g. MineSweeper No-Visual Completion Rate: 64.7%). Individual Music Blocks games correlated with the WAIS-IV subtests.**

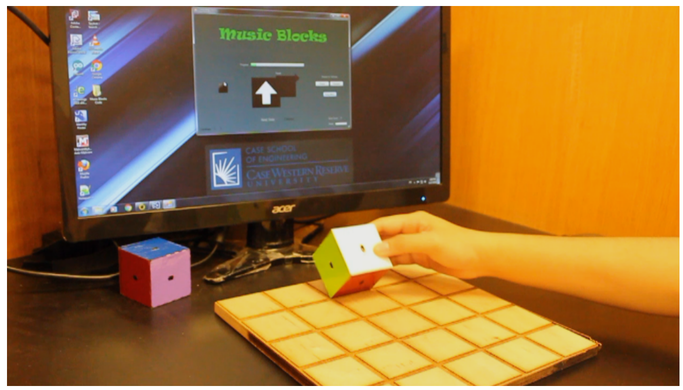

Fig. 1. Music Blocks play setup: a person playing a sample game (Direction Blocks) using a SIG-Block and an interfacing computer with a display. Link to a video demonstration [1]

I. Introduction

Music Blocks started with a simple objective: create an action-based music game using sensor-integrated geometric blocks, called SIG-Blocks (Fig. 1). Each equipped with a hybrid wireless communication capability, SIG-Blocks can communicate with each other and transfer information directly to a host computing device [2], [3]. Given the advantages of the SIG-Blocks technology, the main objectives of this research project include 1) developing new tangible games, called Music Blocks, with the emphasis on aural stimuli, 2) creating games that can assess in-game metrics which can run autonomously, and 3) evaluating how different sensory feedback, in particular aural feedback, affects performance in these games measured by speed and accuracy. For improved tactile feedback, a SIG-Block with bumps and textured surfaces was used for some games. This feature can be potentially useful for people with visual impairments [4], [5].

Various tangible block technologies with audio-feedback mechanisms have been developed. AudioCubes [6] are wireless synthesizers that communicate with a custom control station that modifies the sounds and the sound quality that emanates from each block. On these blocks, four of the six sides can be programmed with a specific parameter for audio modification or generation. In contrast, MusicBot [7] is used to teach people how music scales work by assembling the toy blocks in different configurations. By assembling the blocks in a horizontal line and pressing on the blocks, the sound playback pattern will follow the step spacing of a major scale [7]. Another music block assembly set, Block Jam [8], uses square-prism blocks topped with LED grid displays to play music loop samples based on the assembly structure. When a block within assembled Block Jam cluster is pressed, the sound playback starts on that block and continues through the network paths determined by the functions displayed on the top of the adjacent blocks [8]. Two other technologies, roBlocks [9] and Electronic Blocks [10] include sound generating blocks within their block sets. roBlocks use assemblies to teach children the basic concepts in robotics. The "action" blocks specifically take input from the "sensor" blocks and turn them into visual, aural, or kinetic feedback [9]. Electronic Blocks use similar principles as roBlocks, except the blocks are stacked up on top of each other [10].

Aside from audio-block technologies, many other types of audio-tangible interfaces have been developed for gaming. One team of game developers made card games more interactive by adding an audio-visual interface via smartphones [11]. With the added audio interface, the study found that the game more cognitively interactive and makes group activities more sociable [11]. Some game interfaces were created for

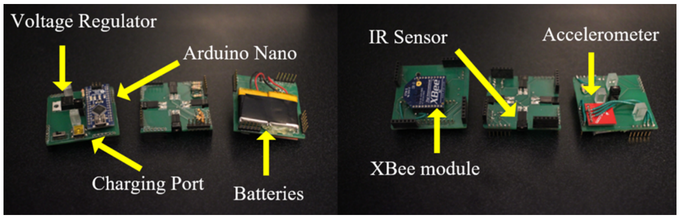

Fig. 2. Core electronic components in SIG-Block and integrating printed circuit boards (PCBs).

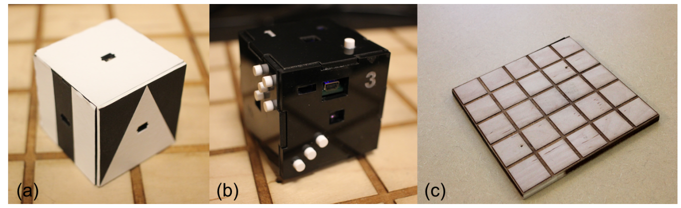

Fig. 3. SIG-Blocks and a wooden board for play: (a) original block with geometric patterns; (b) new Brail-Block; and (c) wooden board.

those with visual impairment. Dot matrix displays, which are tactile displays that can generate different textures based on the images displayed on screen, were developed and tested for people who are visually impaired [12], [13]. For example, Audio Haptic Maze [5] uses a haptic interface that provides both dot-matrix textures and haptic feedback during play. In blind-accessible games, having a user feedback mechanism to allow the users assess their performance via tactile or aural feedback during the game is crucial [14], [15].

In this paper, three Music Blocks games were designed and tested for preliminary feasibility evaluation. These games were tested on a small number of participants ($n = 17$) and their performance was measured by time, correctness, and accuracy. For baseline assessment, three subtests of Wechsler Adult Intelligence Test - Fourth Edition (WAIS-IV), i.e., Block Design (BD), Matrix Reasoning (MR), and Digit Span (DS), were also administered to all participants. The Wechsler series of tests stands as a "gold standard" for cognitive assessment in the realm of Psychology [2], [16]. The selected Wechsler tests target auditory working memory, perceptual reasoning, and processing speed [16], [17]. We first present the Music Blocks technology and the game design in Section II. Section III details our preliminary evaluation study design, methods, and results.

II. Music Blocks

This section presents new games designed for potential applications in play-based cognitive assessment. The hardware system, i.e. SIG-Blocks, used as a means of game control is first reviewed; the game design and protocols are then discussed in detail.

A. Overview of Game Hardware Platform

This project employed the core module of the previously developed SIG-Blocks [2]. The core module is made with six infrared (IR) reflective optical sensors (one on each side) for block-to-block communication, a triaxial accelerometer that senses the blocks orientation, an XBee module for block-to-computer communication, two 3.7V polymer batteries, a 3-Pin 5V power regulator to manage the input voltage, and an Arduino Nano (ATmega328) microprocessor to process all the sensor data to send an output via XBee module. Custom-printed circuit boards (PCBs) connect these components together in a compact $55 \times 55 \times 55$ mm^3 size [2].

The previous SIG-Blocks enclosure, shown in Fig. 3(a) was fabricated from laser cut mat-board, and the block graphics were cut from vinyl [2], [3]. A new block enclosure with dots and numbers on each side for blind-accessibility, called Brail-Block, was designed and fabricated for one of the Music Blocks games (Fig. 3(b)). Brail-Block uses laser cut acrylic squares, each with white dots on the lower left corner and a corresponding number on the upper right corner. A wooden game board was also fabricated to be used in Music Blocks games. Using a wooden board provides extra visual and tactile information that users can use within the games. The board, made from 1/2" plywood, has an etched 5×5 grid pattern. The grid lines in between the squares are laser-etched. This made block manipulation, such as rolling, much easier and more consistent than on a flat surface.

B. New Game Design

Three different types of Music Block games, i.e., Direction Blocks, MineSweeper, and Password Blocks. Each game design is detailed here.

1) Direction Blocks: Direction Blocks displays a series of arrows indicating different roll directions and a black square for a lift command as target manipulation tasks. This game plays a song as the user inputs the commands correctly; at the end of the game, the user is asked to guess the song. This method primarily uses die mapping to keep track of the orientation and relative grid coordinate. All sequences are randomly generated and constrained to stay within the 5×5 grid space. At the beginning of the game, the first command is always shown as "forward" (i.e., an upward arrow) as shown in Fig. 4 so that the system can determine the absolute orientation of the block using the embedded accelerometer within the grid space. The songs used in this game includes Twinkle Twinkle Little Star, Ode to Joy, Bingo, Row Row Row Your Boat, and Chopsticks. These songs can be selected by opening the song menu.

2) MineSweeper: This is a spin on the classic MineSweeper game by making it a tangible game using SIG-Blocks (Fig. 5). The numbers displayed on a screen denote the mines adjacent to that square including diagonals. This iteration of MineSweeper randomly generates mines in a strict 5×5 grid. The user must find all mines and click on them using their mouse. The current format of this game is not a very block-intuitive design as it requires an additional input device, i.e. computer mouse. It can be eliminated by programming the

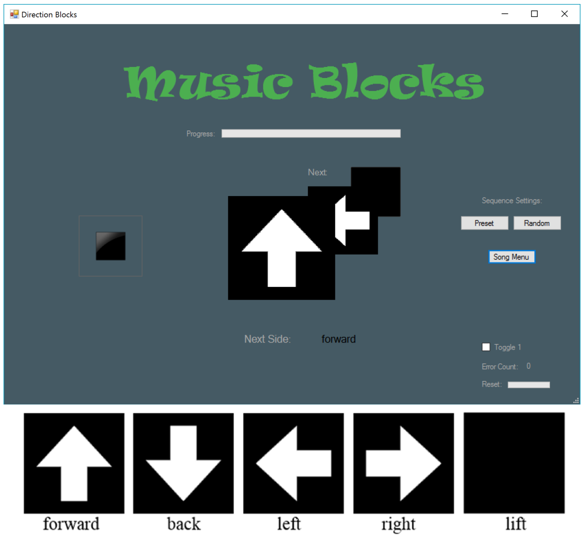

Fig. 4. GUI layout for Direction Blocks. The user uses a SIG-Block to roll up, down, left, right, or lift following the sequeneces of four types of arrows and the black square shown at the bottom.

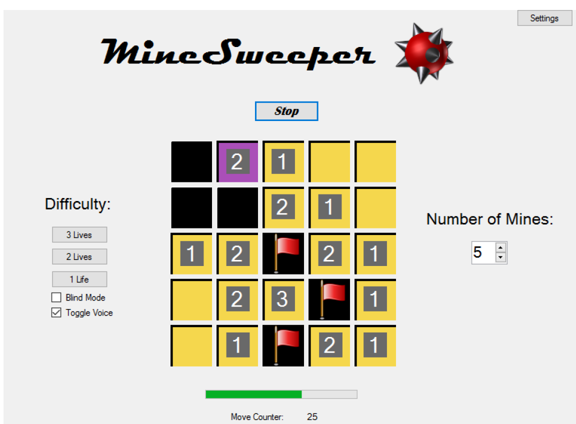

Fig. 5. GUI layout for MineSweeper. The player starts at the bottom left corner and rolls the block around to locate all mines on the grid.

block to detect another type of motion, such as lift or shaking, and rolling into the direction the supposed mine is located. During play, the system generates a voice saying the number of mines around the square where the block is currently placed. If there is none, a snare drum sound plays. If the player lands on a mine, the game makes a loud explosion sound. All stimuli and difficulty toggles are displayed on screen. The difficulty is varied by changing the amount of lives per game and the total number of mines generated (1 - 10). The default numbers of lives and mines are set to 3 and 5, respectively. The bottom-left corner was chosen to be the starting position, and therefore, no mines were placed right front or on the right side of the starting position.

3) Password Blocks: Password Blocks is a computerized digit span test, allowing different combinations of sensory feedback. When a sequence of numbers is displayed on-screen while playing Password Blocks, the player must use

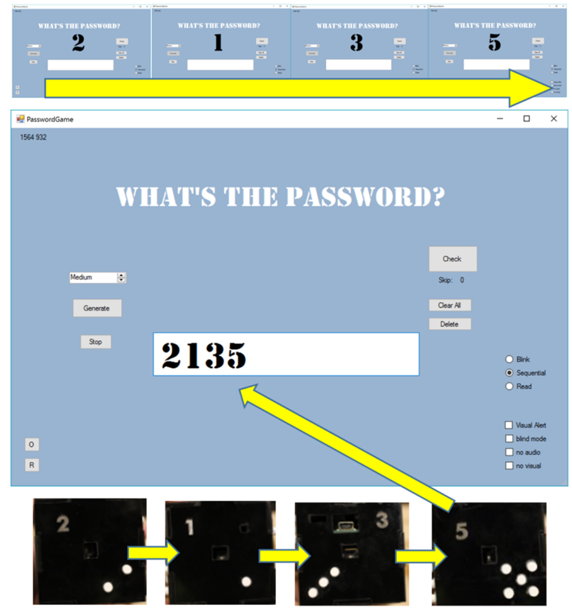

Fig. 6. GUI layout for Password Blocks and sample item with user input sequence using the Brail-Block.

a Brail-Block with a prescribed value from 1 - 6 to input their answer (Fig. 6). On the block, all numbers are displayed by using both dots and numbers as shown in Fig. 3(b) and Fig. 6. The numbers are randomly generated, and like the WAIS-IV Forward Digit Span test, two numbers are not repeated in succession, e.g. 6454. There are 4 types of stimuli: visual, audio, audio-visual, and blind with audio. For the blind portion, the user is asked to power off the monitor, close their eyes, and use only the audio and block texture to play the game. The max digit obtainable digit span for Password Blocks is currently set to 11 digits.

C. User Interface Design

The Graphical User Interface (GUI) for the games was developed in Visual C# using Visual Studio 2013 Community. Separate Window forms were developed for each game, and each game initializes when the first game items or commands are generated. Games can be played by simply pressing "Play" to start or pressing "Stop" to discontinue playing. If an item is successfully completed or conversely contains excessive mistakes, the games end automatically. Note that the games only run when an input is received. During testing, both the administrator and the user see the same exact GUI. This allows the administrator to monitor the participants and potential technical issues, such as in-game glitches, sensor failure, or a participant misunderstanding the game rules. To generate sound in the Music Block games, the Windows Media Player Library was used to call the built-in WindowsMediaPlayer function. This function plays the sounds through the headphone jack or speakers of the computer. A library of sounds is stored within the game. The main audio samples come from

Garage Band and Apple's Text to Speech Software. Additional no-copyright samples were also used.

III. Preliminary Evaluation

A small-scale human subject study was conducted to evaluate the functionality and usability of Music Blocks. In this early stage of evaluation, the study focused on whether the game designs were appropriate to play, whether their performance was affected by the various types and combinations of sensory feedback, and if the performances in the Music Blocks games related to the participants' cognitive skills measured by the three WAIS-IV subtests: Block Design (BD), Matrix Reasoning (MR), and Digit Span (DS).

A. Participants

A total of 17 participants were recruited between the ages of 16 - 70 with 13 males and 4 females. 15 participants were between the ages of 18 - 40. The other two participants were within the age groups of 40 - 60 and 60+. Three participants had English as their second language. Upon test completion, participants were given a gift card. This study was approved by the Case Western Reserve University's Institutional Review Board (IRB). At this early stage of game development, we focused on feasibility evaluation, and thus, participants' gender, age, and other variables were not controlled. Therefore, the results must be interpreted with caution.

TABLE I
STUDY PROTOCOL: LIST OF TESTS, NUMBER OF ITEMS IN EACH TEST, AND ADMINISTRATION DURATION.

Test Set	Max Number of Items	Length [min]
	Music Blocks	
Direction Blocks	5	10
MineSweeper	5	10-20
Password Blocks	48	30-60
	WAIS-IV	
Block Design (BD)	48	10
Digit Span (DS)	14	10
Matrix Reasoning (MR)	22	10
	Total	90-120

B. Protocols

Table I lists six sets of tests used in our study. The entire test administration took about 1.5 to 2 hours to complete. Each participant was administered a set of three Music Blocks games (Password Blocks, MineSweeper, Direction Blocks) and three subtests from WAIS-IV. There was an optional 5 - 10 minutes break in between Music Blocks or WAIS-IV. The administration order was randomly decided between the two. The WAIS-IV subtests were administered in a specific order as instructed by the user manual. The order of the three Music Blocks games were randomized.

1) Direction Blocks protocol: The Direction Blocks test comprises of one sample item that plays the C Major scale and 5 music test items. Among these items, there are three songs: Twinkle Twinkle Little Star, Bingo, and Row Your Boat. For both Twinkle Twinkle and Bingo, the participant must identify what song it was within the trials to receive a point. The person gets an extra point for identifying the song on the first trial. The participant can identify the song at any point during their play or within a minute after they complete either trial. Incorrect guesses are given a score of 0. Alternative guesses for Twinkle Twinkle, such as "ABC song" or "Mozart Lullaby," were also given a point. For Row Your Boat, the song name was given to the participant prior to play.

For each item, the actions are randomly generated. The participant always starts at the center of the board, i.e. the coordinate of (3,3) if the bottom-left corner is (1,1). For block calibration, the first direction shown is always forward. The following actions consist of lifting the block, rolling forward, rolling backwards, rolling to the left, and rolling to the right. After each action is completed successfully, the note for that action is played and the next action item is displayed. If an action is completed incorrectly, an "uh-oh" sound is played, and an incorrect action is recorded. The accompanying note does not play until the action is entered correctly. When all notes are played, the game ends automatically. The minimum number of actions needed to complete each song are as follows: Twinkle Twinkle = 41, Bingo = 37, and Row Your Boat = 23.

The participant's rhythm is also evaluated by listening to the spacing between each roll of the block. If this spacing matches close to the rhythm of the actual song, the participant receives a point for that trial. However, if the participant rushed through the song and did not play the correct note values, they received a 0 for rhythm. If the participant had no semblance of rhythm or stopped for long periods of time, they also received a score of 0. Lastly, the participant's ability to roll the block in the correct directions for each trial was evaluated by comparing their ending coordinate with the Direction Block's calculated final coordinate. If the two match, i.e. the participant made no mistakes in rolling, the participant gets a point for Coordinate Match. Otherwise, the participant gets a 0. If the participant tries to adjust the block after the song ends or if the block is in between two squares on the grid line, the participant also receives a 0.

2) MineSweeper protocol: The MineSweeper portion consists of 5 trials: two audio-visual, one no-audio, one no-visual, and one blind. The test is administered in this order to give every participant the opportunity to learn the game while going through each trial. Note that the "no-visual" trial means that the display is powered off, and the participant only has the block and board to look at. If the participant accidentally rolls the block illegally or loses track of their block during the no-visual or blind portions, the test administrator can reposition the block with no consequences. Due to its frequency, this error was not penalized during the final scoring.

At the beginning of the set, the participant is explained how MineSweeper works, regardless if she or he claims to have played MineSweeper before. This ensures every participant has a level playing field. The participant is told that numbers denote the amount of mines around that square. If participants ask if the number value includes adjacent squares, diagonally adjacent squares, only cardinal squares, or any other questions that give away the strategy of this game, the test administrator explains that numbers on each square mean around that square. All color coding and flagging information are explained as they are provided in the instruction GUI. Flagging mines is done by clicking blank squares or detonated mines. Rolling over flags is allowed. However, this action is penalized when a blank square is flagged. The administration for MineSweeper begins once the participant confirms they are comfortable with the information provided.

Each trial consists of 5 mines randomly generated on a 5×5 grid. To complete each trial, the participant must either flag all 5 mines or land on all spaces without mines. If the participant makes 3 mistakes, including landing on a flag where there is no mine underneath, the game ends automatically, showing where all 5 mines were located on the board. The time, amount of moves, amount of mines flagged, and the amount of mines destroyed were recorded during each trial. The completion rate is measured by the number of games the participant found all 5 mines for that trial. The total score indicates the total number of mines the participant found over the 5 games. The accuracy for each trial is calculated the amount of mines found over the amount of mines found and destroyed. In this round of testing, final scores were not scaled by a participants' move count or the time elapsed.

3) Password Game protocol: Password Blocks is a computerized, tangible digit span with 4 types of stimuli audio-visual, audio, visual, and blind. The order of these sets are chosen at random, with the exception of blind. Blind is always administered at the end. For the blind section, the participant is told that opposite sides add up to 7 to help the participants find the numbers faster. The test starts off with 2 sample audio-visual digit span items — one with 3 digits and another with 4. After completing these two items, the scored sets begin. Each set, e.g. audio-visual, starts with a digit span of 4. Each number is read out in order with the corresponding stimuli. Each digit within the digit span is randomly chosen from 1 to 6 with no repeating numbers in a row. The spacing between the reading of each digit is one second. Block input is disabled during the duration of the reading. After the reading finishes, the participant may enter their memorized numbers. Once the entry is complete, the participant must tell the tester "I am finished" or an equivalent phrase to confirm their answer.

If the participant enters the 4-digit number correctly, the test moves on to a 5-digit number. Every time the participant gets a number correct, it moves on to the next digit span one digit higher than the previous. If the answer is incorrect for the first item, however, the game generates another 4-digit number. If they get it correct, it moves on to the next digit span item. If the participant incorrectly answers two entries in a row, the set ends automatically, and their score is recorded. This repeats for the remaining 3 stimulus sets. If the participant makes an input mistake using the block, they can tell the tester to delete the last number or clear all. If the participant forgets a number, or would like a new number, the tester can grant two number skips per stimulus set, e.g. 2 skips during audio-visual. If the participant chooses to skip more than twice, the testing sequence ends automatically.

4) WAIS-IV Protocol: The three WAIS-IV subtests were administered and scored as outlined in the test manual. BD and MR subtests consist of items that measure perceptual reasoning [16], [17].

C. Results

Music Blocks and the BD, MR, and DS subtests from WAIS-IV were compared using the Pearson's correlation constants (r and p) via MATLAB. In this paper, $|r| < 0.5$ is considered weak to no correlation [25]. A very strong correlation is indicated by $|r| > 0.8$; a strong correlation exists in the range $0.6 < |r| < 0.8$; and moderate has a range of $0.5 < |r| < 0.6$ [24], [25]. A significance level of $\alpha = 0.05$ is used.

For Password Blocks, the total score correlates strongly with the DS raw score as well as the BD raw score. With the exception of audio-visual, the BD test correlated well with all Password Blocks digit span scores. MineSweeper does not correlate well with most items administered, as it is a very abstract game that requires arithmetic and spatial reasoning. Even though Direction Blocks and MineSweeper have similar motor-skill behaviors, i.e. rolling the block on a grid, none of their variables correlated well with one another. However, MineSweeper Total Score correlates moderately to strong with BD and MR — two tests that focus on perceptual reasoning [16], [17]. For Direction Blocks, the combination of the rhythm scores, song identification scores, and coordinate matching scores correlate well with BD (see Table II). Note that this score does not factor in how long the participants took to complete the task — it simply measures if the tasks were done correctly and sums each obtained point together. The time elapsed for all Direction Blocks items correlates strongly with BD, but no scoring scale has been developed yet to include the amount of time taken. Possible future work would include scaling time elapsed with all the other metrics.

Throughout the evaluation study, the performance of participants was measured using time, accuracy, and correctness. The participants overall showed that 1) audio-visual has the highest accuracy and highest digit span average, 2) participants have similar performances between audio only and visual only, and 3) that most participants have their best digit spans, i.e. max digit span, in the visual category.

From the average results and accuracy percentages for each Password Block stimulus, audio-visual have both the highest accuracy (54.2%) and highest digit span average (6.23), despite most people having visual as their maximum digit span (34.0% of participants). The average digit span between audio (6.00) and visual (5.93) is almost the same. From these results, audio-visual stimuli indeed have the strongest memory retention out of all the types, and based on participant performance, both audio and visual stimuli are provide information effectively in this tangible game implementation. More participants will be needed to further strengthen and confirm the results obtained.

TABLE II
CORRELATIONS AMONG THE THREE MUSIC BLOCK GAMES AND THE THREE WAIS SUBTESTS.

Music Blocks vs. WAIS-IV Correlation Results Abbreviated, r(p)							
	Password Blocks					**Minesweeper**	**Direction Blocks**
	Audio-visual	**Visual**	**Audio**	**Blind**	**Total**	**Total Score**	**Sum Score**
WAIS-IV Digit Span	0.49 (0.04)	0.44 (0.07)	0.55 (0.02)	0.42 (0.09)	0.65 (0.02)	0.41 (0.09)	0.65 (0.00)
WAIS-IV Block Design	0.46 (0.06)	0.51 (0.03)	0.67 (0.00)	0.62 (0.01)	0.78 (0.00)	0.30 (0.24)	0.78 (0.00)
WAIS-IV Matrix Reasoning	0.25 (0.31)	0.33 (0.19)	0.51 (0.03)	0.46 (0.06)	0.42 (0.06)	0.36 (0.15)	0.42 (0.09)

TABLE III
SUMMARY OF RESULTS FROM THE THREE MUSIC BLOCK GAMES.

Music Blocks Average/Percentages			
Password Blocks			
	Average Digit Span		Average Accuracy
Audio-visual	6.235		54.33%
Visual	5.931		50.65%
Audio	6.000		50.21%
Blind	5.529		50.63%
MineSweeper			
	Average Completion Rate	Average Number of Moves	Average Time Elapsed
Trial 1	41.18%	24.00	168.6 s
Trial 2	58.82%	26.64	176.3 s
No-Audio	58.82%	26.40	125.1 s
No-Visual	64.70%	51.18	231.2 s
Blind	41.18%	56.82	295.8 s
Direction Blocks			
Twinkle Twinkle	Song Identification %		58.82%
Bingo	Song Identification %		23.53%

Overall, MineSweeper had a very low completion rate for most participants. The completion rate, or the rate at which participants found all 5 mines per game, was the highest for the no-visual category (64.70%), and lowest for both the First Trial and Blind (41.18%). The average completion rate for all games was 52.90%. Out of the 17, only two participants attained a perfect score of 25 mines. Participants on average did much better playing the game on the Second Trial than the First Trial (58.82% vs 41.18%).

As a whole, Direction Blocks had varied results. From all the participants, 58.8% were able to identify "Twinkle Twinkle." Only few participants (23.53%) could identify Bingo, even though some were able to identify a tune with similar melodies, i.e. "Old McDonald" and "Yankee Doodle." Due to the complex rhythms, Bingo may have been too hard to guess for this study, and could explain the low percentage for the song identification. Comparing the Coordinate Match at the end of each song and the overall time elapsed (speed), there is no relationship to the performance of participants rolling the block and the speed at which they roll the block. Therefore, rolling faster neither increases nor decreases participants total Coordinate Match score.

IV. DISCUSSION

Conclusion

This study concluded that when comparing audio and visual stimuli in Password Blocks, the performance between audio and visual digit span length were the same (50%/50%). This result was obtained because some participants had the exact same digit span for both sets, and thus their performance was weighted evenly when calculating the overall stimuli preference. Out of all the trials, audio-visual had the highest accuracy (54.2%), i.e. how many items were correct over the total items a participant attempted, and the highest average digit span (6.23). This agrees with the literature that says audio-visual has the highest accuracy in memory [26], [27]. A higher number of participants will be needed to verify if audio and visual stimuli have such an even distribution as shown in the test. For MineSweeper, the highest completion rate was no-visual (64.7%), i.e. the trial that uses only audio and the tangible interface to play. The study also concluded that rolling during Direction Blocks faster does not cause players to make more mistakes and does not decrease your Coordinate Match score. All Music Blocks games correlated strongly with BD; some of the individual games correlated well with MR and DS. Although the p values were less than α = 0.05, more testing is needed to have a higher resolution and strength for these correlation results.

Limitations

Throughout this preliminary testing, the blocks did run out of battery on occasion (5 times in 17 tests). Sensors tended to fail more than expected (3 times in 17 tests). Participants did not remark on the latency between block input and sound output (40 - 50ms). The sensing algorithms had little to no issues during the testing of the games with the exception of blocks having low battery. Obtaining participants was extremely difficult given the test length (1.5 to 2 hours). Another limitation is the low amount of test items. Games like Password Blocks and MineSweeper only had one test object for each item type, e.g. only one trial of no-visual MineSweeper. Some test participants may benefit from a higher number of test items as their initial results may not be reflective of their actual ability.

Potential

In the future, these games can be used as a benchmark for both tangible games and automated cognitive assessment.

These games provide a variety of test items with different stimuli (tangible, aural, and visual). All of these stimuli can be combined in different ways to assess how people perform with other types of cognitive information. With various games to play, users can also train their motor and cognitive skills via Music Blocks. Some of these games, such as MineSweeper and Direction Blocks, can be used for cognitive training over time. Games are easily modified, provide many stimuli toggles, and contain various difficulty increasing metrics. With a few more tweaks to the hardware, these games can be used not only in a research lab setting, but also in a commercial or home setting. As a whole, the TAG-Games project hopes to forward the field of tangible gaming with new ideas and solutions for tangible game design.

ACKNOWLEDGMENT

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