RESULTS FROM THE CURAT SONIFICATION GAME

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ABSTRACT

In 2020, we released the CURAT sonification game, a multi-platform game for the remote evaluation of our three-dimensional psychoacoustic sonification. In this paper, we present an evaluation of the initial results. These indicate that gamification is a reliable means for the remote evaluation of sonification. But the game should be kept simplistic, as many players only play the default modes. The performance results are comparable to results from laboratory experiments and underline that interaction tremendously improves the precision with which users can interpret the sonification.

1. INTRODUCTION

In early 2020, the COVID-19 pandemic made it almost impossible to carry out experiments with human participants in the laboratory. Reasons included regulations by the state and by research affiliations, and reserve among citizens. As a solution to carry out experiments, we developed the CURAT sonification game [1] to evaluate our sonification design. CURAT fulfills the criteria for games [2, 3] and gamification [4]. A small marketing campaign was carried out to recruit players[5].

One aim of CURAT was to evaluate our psychoacoustic sonification remotely. The main question was whether people could interpret the sonification with high precision. While the use of game-like evaluations of sonifications is not uncommon — see, e.g., [6–9] — risks of a remote evaluation of sonification via a video game are that

1. not many players play the game and share their game statistics
2. results could be biased due to impatient players who click randomly and quit before understanding the sonification
3. server errors, database errors or bugs could impede the collection and evaluation of game statistics.

Consequently, the second aim of the CURAT sonification game was to investigate whether the remote, video-game-like evaluation of sonification seems reliable. To achieve this, we counted the number of game plays and compared the results from the game statistics with experiment results from the laboratory.

In [10], we presented a cognitive trainer for minimally invasive surgery. In that paper, we argue that including sonification in the surgical training is an important step towards acceptance of sonification in real surgery. Furthermore, we raise the assumption that long-term experience with the sonification through the cognitive trainer may reduce the time needed to learn the sonification in actual surgery. In that spirit, our third aim was to promote sonification in general, i.e., familiarize people with the idea of abstract sound as the main source of information.

The remainder of the paper is structured as follows: First, the CURAT sonification game is introduced. Then, the collected and analyzed game statistics are we described. The results section includes visualizations and statistical analyses of the data. These are discussed in relation to our experiment results in the laboratory, followed by a conclusion that also contains an outlook.

2. THE CURAT SONIFICATION GAME

The CURAT sonification game consists of five mini-games. All of them utilize the psychoacoustic sonification for one-, two- or three-dimensional navigation. Even though the games have a graphical user inter interface, too, players need to interpret the sonification correctly to achieve the goal. Like many video games, CURAT provides a so-called campaign to introduce the players to the game control, the scenery and the goal [11][p. 59]. In the campaign, all of these mini-games are played with increasing level of complexity and difficulty. It is recommended, but not obligatory, to play the campaign as a training. The campaign starts simple. Here, players have to achieve certain goals or scores to unlock the next, more difficult level. To finish the campaign, all three dimensions of the sonification have to be interpreted passively and interactively, from each single dimension over all combinations of two dimensions to the three-dimensional sonification.

Any mini-game can be played in the arcade mode. The arcade mode is adaptive. It starts with the easiest level. The difficulty level depends on the hit rate. The level can increase as well as decrease. If players hit the first target, their hit rate is 100%, leading to the highest difficulty level. To stay there, players have to hit the target over and over again. As soon as they miss, the next round will be easier to solve. The earlier the player misses, the lower the next difficulty level will be. If players miss in the first trial, they will stay in the easiest difficulty level until they hit. The next difficulty level depends on the number of trials needed for the first hit. This means it may take several rounds until the adaption algorithm finds the current expertise level. However, when players lose their lives or quit the mini-game, CURAT will remember their last performance. This way, the adaption does not start over every time

CURAT is played. Upon permission, pseudo-anonymized game statistics from the arcade games are transferred to our server.

In this paper, we only present two of the mini-games, as we are still in the phase of capturing and analyzing the data.

A teaser video of the CURAT sonification game can be found on YouTube, the game can be downloaded from the CURAT website and the Google PlayStore.

2.1. Psychoacoustic Sonification

The sonification implemented in and evaluated through the game is the psychoacoustic sonification that has been proposed in [12] for two dimensions and evaluated with passive and interactive users in laboratory experiments [13, 14]. The extension to three dimensions has been proposed in [15] and evaluated in a passive and an interactive laboratory experiment in [16–18]. The core element of the sonification is a Shepard tone [19] that represents a coordinate (also referred to as *target* in the game). The sonification is kept in mono. The polarities (or directions) of each dimension are mapped to different sound attributes. The distance along the direction are mapped to the magnitude of the respective sound attribute.

The x-dimension is related to pitch. In particular, the direction along the x-dimension (left/right) is mapped to the direction in which the chroma cycles. A clockwise chroma cycle sounds like a rising pitch and denoted a target to the right. An anti-clockwise chroma cycle sounds like a declining pitch and denotes a target to the left. The distance along these directions is represented by the speed at which the chroma cycles, i.e., how quickly the pitch rises or falls. A conspicuousness of Shepard tones is that the apparent pitch can rise or fall forever, while in fact it is the chroma that cycles.

The y-dimension is divided in two (up/down). The positive polarity is represented by loudness fluctuation. The negative polarity is represented by auditory roughness. How much the target lies above is represented by the speed at which the loudness fluctuates. How much the target lies below is represented by the degree of roughness.

The z-dimension is also divided in two (front/back). The front is represented by sharpness. The back is represented by auditory fullness. The further the target lies to the front, the sharper the timbre gets. Sharpness is a psychoacoustic term of a phenomenon that is related to or even equal to auditory brightness [20, 21]. The further the target lies to the back, the less full the timbre will sound. Fullness is a psychoacoustic term and describes how emphasizing bass and treble frequencies increases the fullness of sound [21, 22].

Note that the psychoacoustic sonification has been utilized in the context of pulse oximetry [23, 24], image-guided surgery [10, 17, 18], neural network enhancement [25], leveling a table [26], assistance for blind shooting [27], an interactive alarm clock [28], and it served as the basis for an acoustic spirit level app [29].

2.2. Noisy Nuts

Noisy Nuts is the shell game. A coin is hidden under a nutshell. Then, the nutshells are shuffled. The sonification tells the player under which nutshell the coin is hidden. The default is an arrangement of nutshells along the x-dimension. To get points, players have to identify the right nutshell. The faster they choose, the higher their score, given that their answer is correct. Depending on the performance, between 2 and 9 nutshells are shuffled. Players can manually switch to the y-mode, the z-mode, and combined x-y-, x-z-, and y-z-mode. All modes are illustrated in Fig. 1. In the combined modes, players have to identify the right nutshell out of $2 \times 1 = 2$ to $9 \times 9 = 81$ nutshells. This game is passive. Players have to interpret the sound without interacting with it. Players have to give the correct answer quickly to receive 100 points. If they take too much time, they will receive fewer points.

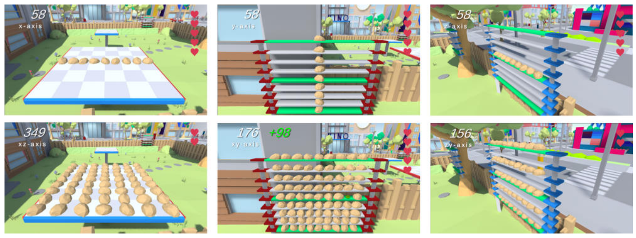

Figure 1: *Noisy Nuts is the shell game along the x-, y-, or z-dimension (upper row) and its combinations (lower row) with a coin under one out of* 2 *to* $9 \times 9 = 81$ *nutshells.*

2.3. Piñata Party

Piñata Party is an interactive, one-dimensional mini-game. The setting is a birthday party in the backyard. The avatar is blindfolded, and the goal is to hit the piñata with a bat. An interactive sonification guides the players to the piñata. Players have to approach the piñata and then swing the bat. In every round, they may only swing once. They either strike or miss. However, to receive 100 points, players have to hit the piñata with a deviation of less than 0.1% from the target. The larger the deviation, the fewer points they will receive. The range of the bat is modified based on the hit rate. Players start with a bat that covers 95% of the backyard. This means the chances to hit the piñata is up to 95%. However, the lower the deviation, the higher the score. Consequently, players should always try to strike as exactly as possible. Note that the bat range may halve when the piñata hangs in one of the corners. A blue bar indicates the bat range, as illustrated in Fig. 2. In the uppermost example, the bat only covers 2.5% of the backyard, because it is maneuvered to the right corner where the piñata is assumed. The screenshot in the middle shows the full 5% coverage. The screenshot at the bottom shows a 95% coverage. Every player starts with 95%. Here, a random guess would lead to a hit rate between 47.5% and 95%. The most successful players have a 5% coverage, where a random guess would yield a hit rate between 2.5% and 5%.

By default, Piñata Party is played in the x-dimension. However, users can manually switch to the y- and z-dimension.

3. METHOD

Upon permission, the players' pseudo-anonymized game statistics are transferred to our server. The data contains information about the game being played, the mode, the level, and a binary score (hit vs. miss) of every trial. This data allows counting how often a game, mode, and level has been played. These counts address the risks 1 and 2, i.e., whether enough players share their game statistics and to what extent impatient players bias the results. In addition, we measure the hit rate, which has been used in several previous sonification studies [30, 31]. We have evaluated the hit rate already in previous experiments, which serve as a

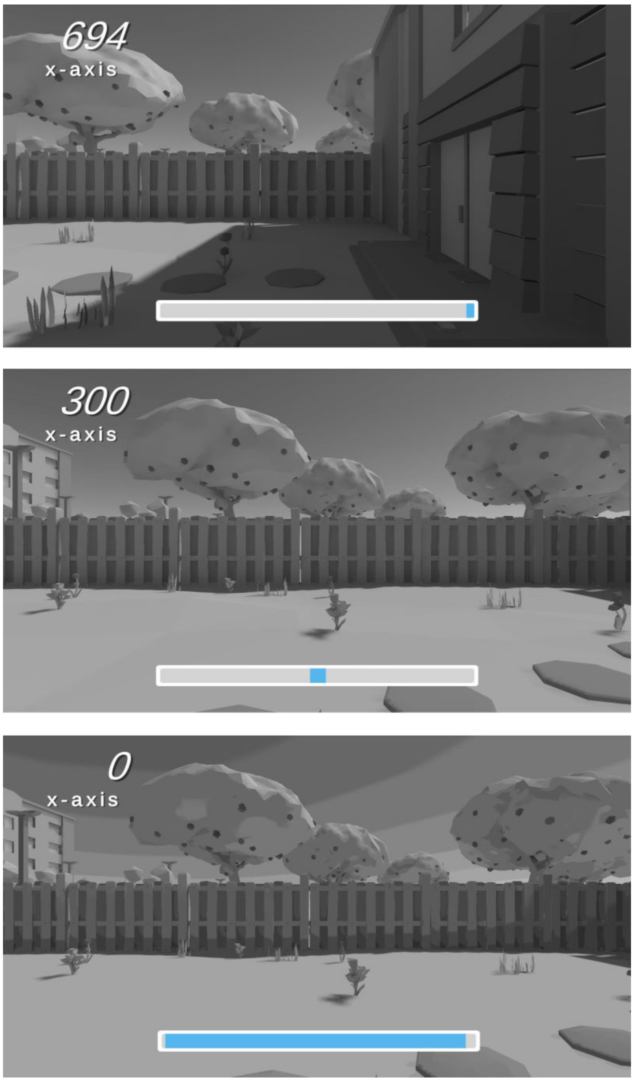

Figure 2: *Target range of 5% when the target lies in the corner (top), usual target range of 5% (center) and target range of 95% for beginners (bottom)*

benchmark. Of course, the higher the hit rate, the better the performance. However, a hit rate of 50% seems low when chances of guessing correctly lie at 50%, too. In contrast, a hit rate of 50% does not seem that low when the chances for a correct guess lie at 5%, as a much more nuanced interpretation of the sonification was necessary in this case. Therefore, we define the *success rate* as the hit rate divided by the chance level. The success rate is a performance measure for a better comparability between different mini-games and difficulty levels. Moreover, the success rate can be derived from our previous experiments, so again, they can serve as a benchmark. Note that the success rate for the Piñata Party is defined as the ratio of hit rate and bat size. This may be an underestimation, as the actual guessing probability lies between 0.5 and 1 times the bat size, i.e., the success rate could as well be doubled.

Note that benchmarks are utilized frequently in auditory display studies, e.g.,[7, 26, 32–36].

4. RESULTS

The statistics from the one-dimensional Noisy Nuts game are illustrated in Fig. 3. The default x-dimension has been played most frequently (1366 times), followed by the y- (399 times) and the z-dimension (228 times). In all cases, the hit rate was far above chance level. The hit rate lay between 48% and 100% but did not reveal any visible trend over dimension or difficulty level. This is supported statistically. One-way ANOVA revealed that the hit rate in the x-dimension (0.60 ± 0.10), the y-dimension (0.81 ± 0.17) and the z-dimension (0.64 ± 0.12) did not differ significantly ($p = 0.063$), but multiple comparison revealed that the hit rate along the x- and the y-dimension differed with $p = 0.058$ according to the Tukey post-hoc test. Given the relatively low statistical power of $1 - \beta = 0.447$, it cannot be precluded that the hit rate is actually larger along the y- than along the x-dimension. A linear regression of hit rate over difficulty level explained $R^2 = 11\%$ of the variance, with a significance level of $p = 0.205$. This underlined the observation that the hit rate had no trend over difficulty level.

The success rate lay between 1.3 and 6.7. A fairly linear rise from the easiest to the hardest difficulty level was visible. ANOVA revealed that the success rate did not differ significantly ($p = 0.914$) between the x- (3.1 ± 2.0), y- (3.5 ± 1.6), and z-dimension (3.1 ± 1.5), so we could combine the data and predict it using linear regression. The linear regression explained $R^2 = 89\%$ of the variance, with $p < 0.001$. This underlined the linear rise of success rate over difficulty level.

Results from Noisy Nuts in two dimensions are summarized in Fig. 4. The x-y-mode has been played for 390 trials, the x-z-mode for 140 trials and the y-z-mode for 60 trials. The hit rate ranged from 0 to 100%. One-way ANOVA revealed that the hit rate in the x-y-mode (0.57 ± 0.27), the x-z-mode (0.49 ± 0.37) and the z-mode (0.56 ± 0.48) did not differ significantly ($p = 0.791$) and followed no linear trend, i.e., a linear regression explained only $R^2 = 18.9\%$ of the variance. The hit rate was slightly lower than in the one-dimensional mode.

The success rates ranged from 0 to 39 and peaked between 28 and 39. In the x-y mode, the trend of linearly rising success rate over difficulty level was observable and a linear regression of success rate over difficulty level explained $R^2 = 76.3\%$ of the variance. In the x-z- and y-z-mode, the success rate peaked at $3/4$ of the maximum difficulty level. However, the number of trials was quite low here. This could mean that the observed performance can be considered the initial performance of untrained players. After some more trials, the performance could have improved, and the distribution of hit rates and success rates could have looked more like those in the x-y-mode. ANOVA revealed no significant success rate difference between the x-y- ($13.76 \pm 11, 47$), x-z- (7.12 ± 7.81), and y-z-mode (11.39 ± 11.91) ($p = 0.174$). But the success rate was much higher than in the one-dimensional modes.

The results from the interactive Piñata Party are summarized in Fig. 5. Visually, they resemble the results from the one-dimensional Noisy Nuts: The default x-mode has been played most frequently, the hit rate varied a lot, and the success rate raised with increasing difficulty level.

In the x-dimension, 1088 trials had been counted, which was more than 4 times the number of trials in the y-mode (255 trials) and almost 19 times the number of trials in the z-mode (58 trials).

The hit rate ranged from 0 to 100%. On average, the hit rate was 0.63 ± 0.17 for the x-, 0.79 ± 0.28 for the y-, and 0.73 ± 0.24

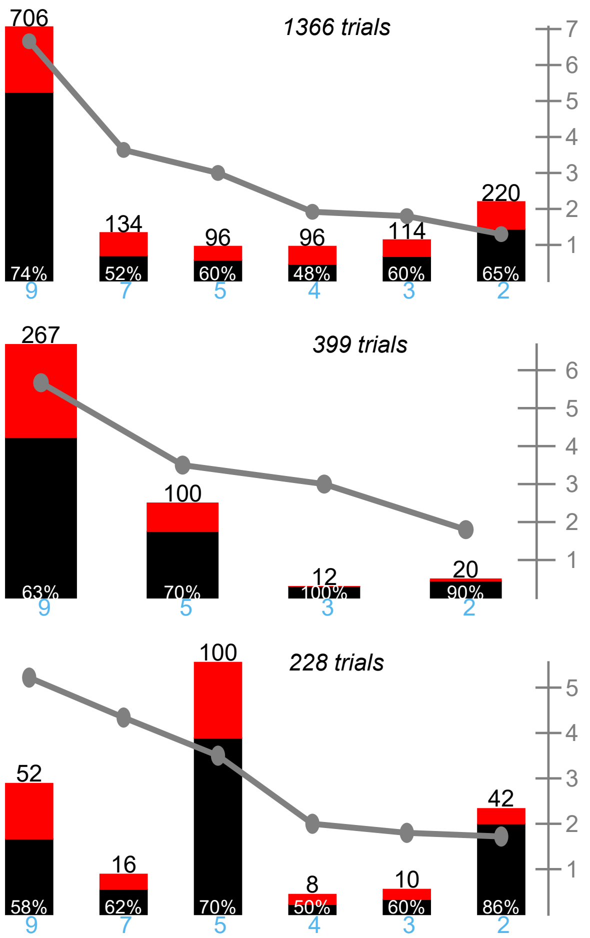

Figure 3: *Hit rate (black bars and white percentage values) over number of nutshells (blue numbers at the bottom) and number of trials (bar length and number above bars) for Noisy Nuts in the x- (top), y- (center) and z-dimension (bottom). The gray graph shows the success rate.*

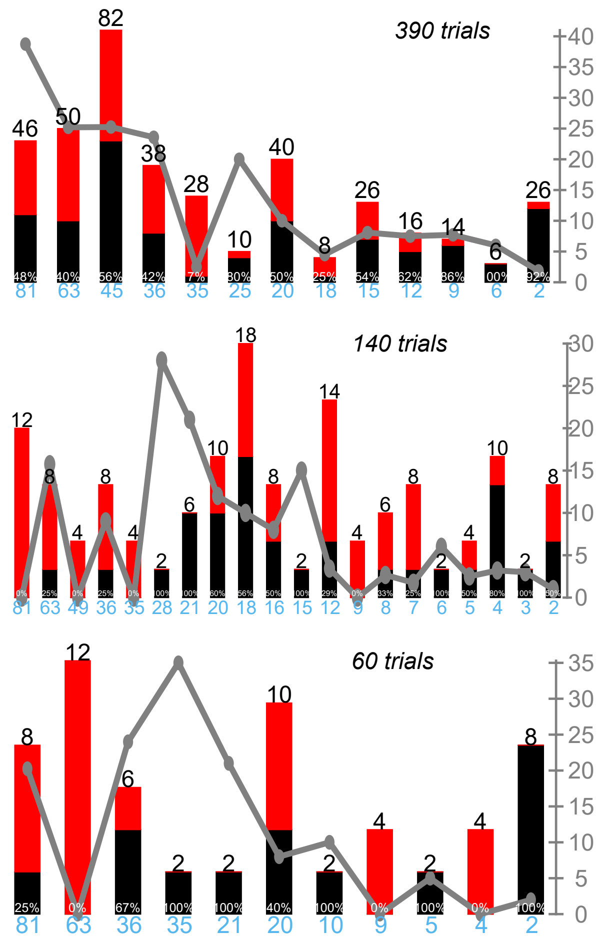

Figure 4: *Hit rate (black bars and white percentage values) over number of nutshells (blue numbers at the bottom) and number of trials (bar length and number above bars) for Noisy Nuts in the x-y- (top), x-z- (center) and y-z-mode (bottom). The gray graph shows the success rate.*

for the z-dimension, and varied significantly between groups ($p < 0.05$) according to ANOVA. However, a Tukey post-hoc test did not confirm a significant difference between group means. A linear regression of hit rate over difficulty level explained $R^2 = 0.4\%$ of the variance, underlining that the hit rate had no linear relationship with the difficulty level.

The success rate ranged between 0 and 16.4, with an average of 2.51 ± 3.69 for the x-, 3.26 ± 3.93 for the y-, and 3.43 ± 3.04 for the z-dimension. ANOVA revealed no significant difference between group means ($p = 0.74$). A linear regression of the success rate over bat size explained $R^2 = 49\%$ of the variance. This finding provides evidence that the success rate is a meaningful measure that reveals the relationship between success and difficulty level better than the hit rate. From visual inspection of the plots, it can be seen that the relationship between chance level and success rate is exponential, rather than linear. This means the success rate became exponentially higher with increasing difficulty level. In fact, regression with a reciprocal function explained $R^2 = 90.4\%$ of the variance, as plotted in Fig. 6.

5. DISCUSSION

The study revealed several tendencies and allows drawing conclusions. However, as this is just a case study, one cannot generalize the results with high confidence. Evaluation of all our mini-games and a detailed look at the performance of individual players may reveal a much deeper insight into the interpretability of the sonification and the degree of variance between individual performances.

5.1. Evaluation of the Sonification

In the two CURAT mini-games, the mean hit rate lay between 49% and 81%, while the chance level lay between 1.2% and 50%. The mean success rate ranged from 2.51 to 13.76. No significant differences have been found between the dimensions x, y, and z, or between the combinations x-y, x-z, and y-z. These observations indicate that players could interpret all dimensions and their combinations similarly well. With 72%, the mean hit rate was largest in

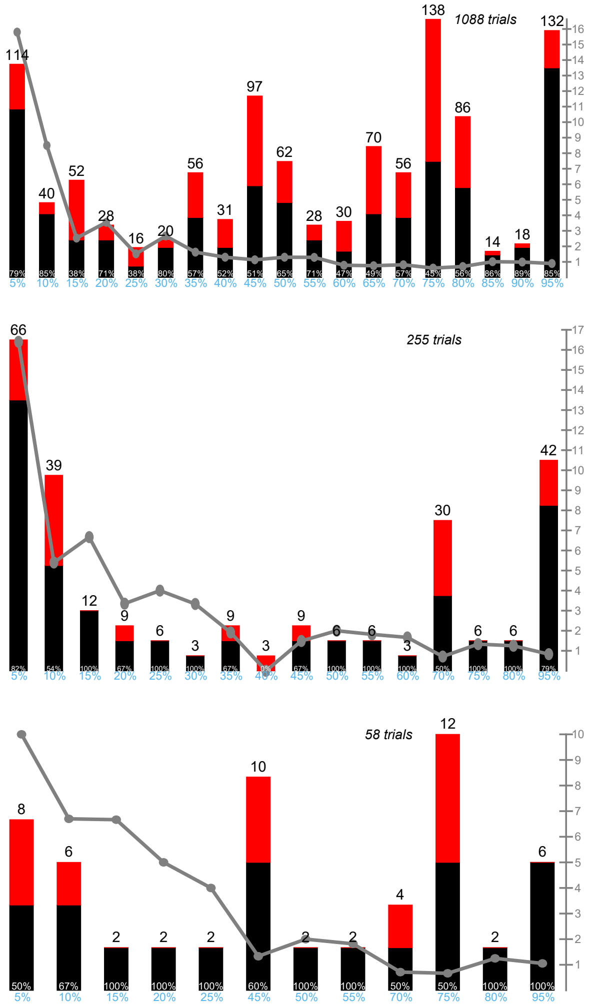

Figure 5: *Hit rate (black bars and white percentage values) over target range (blue percentage values at the bottom), number of trials (bar length and number above bars), and success rate (gray graph) for the Piñata Party in the x- (top), y- (center), and z-dimension (bottom)*

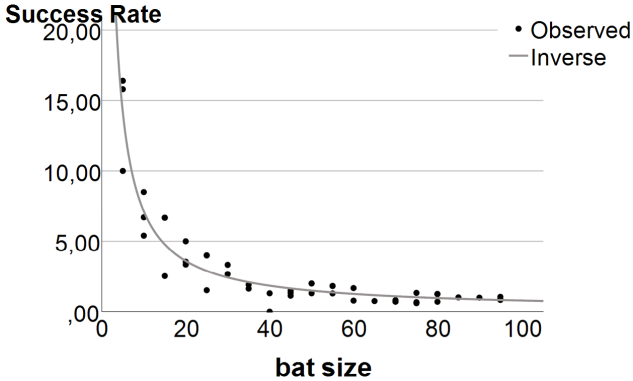

Figure 6: *Reciprocal regression of success rate over bat size in the Piñata Party mini-game.*

the Piñata Party, followed by the one-dimensional mode in Noisy Nuts with 68%, and the two-dimensional Noisy Nuts mode with 54%. This may imply that interaction with the sonification improved the performance. The hit rates are in fair agreement with various laboratory experiments, where hit rates between 41% and 90% [31] and between 79% and 95% [30]have been reported. In our own laboratory experiment, a hit rate of 41% in a passive sonification interpretation task, and 92% in an interactive sonification task has been observed [37]. As in CURAT, we have not observed a significant difference between the performance in the x-y-mode, the x-z-mode and the y-z-mode in the laboratory [16],

One could assume the hit rate to decrease with increasing difficulty level. After all, players have to interpret the sonification with increasing precision. For example, it should be easier to distinguish two sounds representing 2 nutshells compared to identifying one out of 9 nutshells just from the intensity of a sound attribute. Still, out of $1,366$ trials in the x-dimension, the hit rate was 65% for 2 nutshells but 74% for 9. This observation is an exception, but it is true for the game mode that has been played most frequently. This is probably caused by a training effect. If people have played this game repeatedly, they may have learned to interpret it with very high precision. Such a training effect has not taken place in those modes that have not been played frequently, like the x-z-mode and the y-z-mode in Noisy Nuts. Here, the hit rate of some levels was even 0. One explanation for the high hit rate and success rate at the highest difficulty levels is that those players who understood the sonification best got to the highest level over and over, interrupted by some trials in the lower levels. This means, the best-performing players mostly increase the hit rate and the success rate at the highest level, and not at the others. Detailed analysis of the player-IDs is necessary to confirm whether the game has been played a lot by some individuals, who increased the overall hit rate. For most of the games, the hit rate showed no linear relationship with difficulty level. This may imply that the performance depends less on the number of targets to choose from, than on the abilities of the individual player.

For those modes that have been played most frequently (say over 200 times), the success rate clearly rose with difficulty level. This observation cannot be made for those modes that have been played only a few times. This may underline the importance of the training effect mentioned above: It seems that the highest levels can only be solved when the players have made sufficient experience with that game/dimension. The average success rate of the one-dimensional mode in Noisy Nuts was 3.23. Compared to that, the mean success rate of the Piñata Party was 3.19. These numbers seem similarly high. However, as mentioned above, the chance level of the Piñata Party is underestimated and could as well be doubled to 6.38. This observation provides additional evidence that interaction improves the performance. However, a more striking evidence that interaction improves the interpretability of sonification is the fact that we observed a linear rise of the success rate over difficulty level in the passive game, but an exponential increase in the interactive game.

The two-dimensional Noisy Nuts modes have not been played frequently. And even though its hit rates were lower than the hit rates of the one-dimensional Noisy Nuts mode and the Piñata Party, the success rate was much higher. This observation supports the finding from previous studies [16, 38], that the dimensions of the sonification are in fact orthogonal, i.e., perceptually independent.

5.2. Evaluation of Gamification

In CURAT, the default game has been played much more often than the other games. This is something to consider when utilizing (video-)gamification to evaluate a sonification: When working with several mini-games, all mini-games may be played similarly often (in our case 1366 Noisy Nuts trials and 1088 Piñata Party trials), but other modes are played significantly less frequently (between 60 and 399 trials for Noisy Nuts and between 58 and 255 trials for the Piñata Party). The reason may be that many people quickly click through the menu without changing the settings. This behavior can be explained by the dominance of so-called *casual gamers* and *casual games* in the market [11, p. 19 and p. 56]. The issue becomes apparent when looking at the game menu as presented in Fig. 7. To select a mode other than the default, players have to open a dropdown menu and, depending on the desired mode, even scroll down to make their choice. This seems to be a big obstacle.

Figure 7: *Menu for selecting the desired mode of a game. Depending on the desired mode, players may have to open a dropdown menu and scroll down.*

Those modes that have been played frequently are in good agreement concerning the hit rate and the relationship between difficulty level and success rate. The games that have not been played very often are neither in good agreement with these results, nor with each other. There are plausible explanations for this observation: All players start at the lowest difficulty level. Many may have started an arcade game right away, e.g., without knowing what the game is about, or even with muted sound. It is quite normal that people download an app, try it out for a minute, and if they do not understand or like it right away, they never open it again. One game review shows that the game does not make sense for everybody right away [5]. After all, many people have never been exposed to sonification in their lives, and a game built around the interpretation of multiple sound attributes is definitely uncommon. Such players certainly decrease the overall hit rate of the lowest level for sure, and of the highest level if they hit on the first trial (chances are $50 : 50$), and potentially of every level in between. So clearly, a high number of trials is necessary to reduce this bias towards a random performance. Otherwise, the results are biased towards the random performance of people who have not understood the task or the sonification, or who have little experience (yet). Based on this observation, a simplistic video game for the remote evaluation of sonification seems advisable. At least in our case, the high number of manually selectable modes has led to an unreliably low number of trials for all modes except the default.

Overall, the fact that the results from CURAT are in line with our results from experiments in the laboratory is evidence that video-gamification is indeed a reliable means to evaluate sonification remotely. However, this is only true after a sufficiently high number of trials. Before that, the performance is comparably low and random.

Analyzing the rest of the mini-games will allow for a more nuanced look at the game and the performance results. Most importantly, other mini-games require interaction with the two- and three-dimensional sonification and not just the single ones.

In principle, it is possible to retrieve only the game statistics of single players from the database. The need for longitudinal studies of interaction with sonification has been expressed before (e.g., [39]). Analyzing the success rate of individuals over time could be one way of gathering longitudinal data. However, a cooperation with professional video game developers may be necessary to create a game exciting and captive enough so that people would play it for hours over months and years.

6. CONCLUSION

In this paper, we presented the CURAT sonification game as a means for remote evaluation of sonification using video-gamification. Initial results indicate that gamification a) allows for remote sonification evaluation, b) produces plausible results, comparable to laboratory experiments, when a sufficient number a trials exists, and c) with a complicated menu structure prevents players from playing modes other than the default, and d) underlines the importance of interaction with the sound for precise and accurate interpretation. Further analysis of the game statistics are necessary to provide a more complete picture of the CURAT sonification game as a means to evaluate sonification. Additional studies utilizing video-gamification are necessary to ensure which observations only applied to CURAT and which observations may be generally valid for remote sonification evaluation using video-gamification. To investigate how well the CURAT results generalize to video-gamification, studies with other sonification games will be necessary. The CURAT sonification game could serve as a means to compare the interpretability, accuracy, and precision of various sonifications for three-dimensional navigation. However, even though the Sonic Tilt Competition

[40] brought forth many two-dimensional sonifications [41–48], not many three-dimensional sonifications have been described yet. The development of new multidimensional sonifications is important future work.

7. ACKNOWLEDGMENTS

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