# Beat Saber: Performance of Expert and Novice Users and the Effect of Attentional Load

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## Introduction

Beat Saber is a rhythm game that provides an engaging mix of music, physical activity, and gaming in an immersive virtual environment (VE). In the game, players slash through incoming blocks to the rhythm of the music. The purpose of this study is to analyze the difference between novice and expert *Beat Saber* players and determine if an added attentional load task can reduce experts' performance to match the performance of novices. This is accomplished by studying two groups of players (experts and novices) performing three sessions of *Beat Saber* under three attentional load conditions. Two research questions are considered: RQ1: How do novices and experts differ in their performance in Beat Saber? And RQ2: Can the addition of an attentional load task reduce experts' behavior to match that of novices?

## Gameplay

During gameplay, players use their handheld virtual reality (VR) game controllers to hit incoming blocks to the rhythm of the music. These blocks are color-coded to match the left- and right-hand sabers. Each song presents players with a continuous stream of blocks, aligned with the song's rhythm and arranged in one of twelve positions on a 4x3 grid. These blocks are marked with arrows, indicating in which of eight possible directions the player must slice through them, or a dot, indicating that they can be sliced in any direction (Figure 1). Successfully slicing through a block awards the player points, calculated based on factors like the swing's length, angle, and precision.

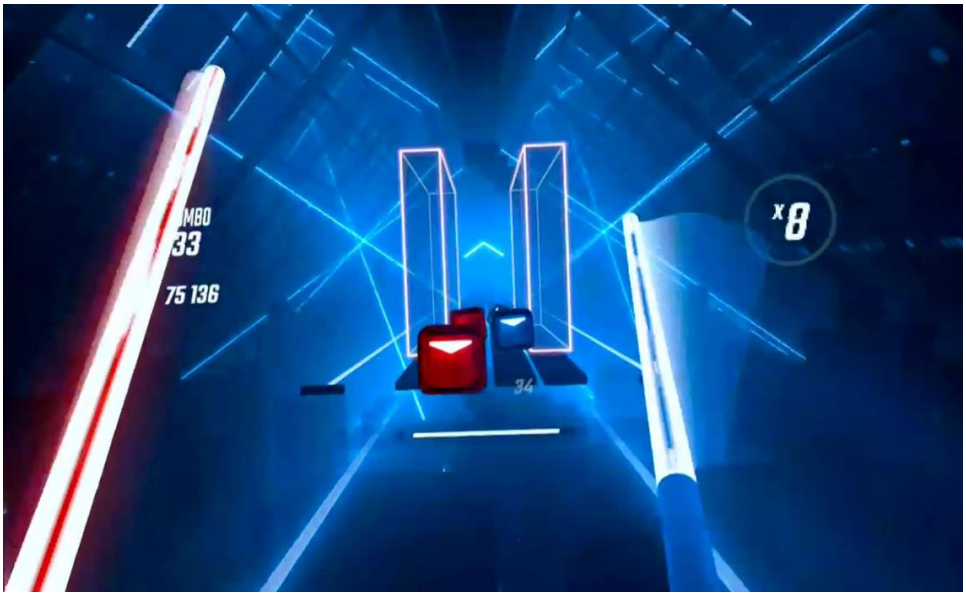



*Figure 1: Two wands (bright beams in the image foreground), corresponding to the VR controllers, are used to strike incoming blocks that correspond to musical notes in the song.*

At higher difficulty settings, *Beat Saber* introduces elements to increase the gameplay's complexity and challenge. These include bombs that players must avoid striking and incoming walls that players must duck or lean to avoid. Beneath the path of the blocks, a white bar gradually fills as the player successfully hits notes. Hitting a note in the wrong direction reduces this "energy bar" slightly, while missing a note causes a more substantial decrease. If the energy bar depletes completely, the level ends, but players can select a "no fail" setting to continue playing even after energy depletion. Achieving consecutive accurate hits (referred to as “good cuts”) results in combos, multiplying the score by a factor of up to eight. Playing with “no fail” mode applies a 0.5X multiplier to decrease maximum scores.

After the song concludes, the user is shown their performance results. The results include:

*Score*: The overall performance score. Each note is assigned a value from 0 to 115, according to the quality of the hit, then multiplied by the current multiplier (0.5X – 8X).

*Number of good cuts*: The number of blocks that the player hit in the correct direction.

*Max combo*: The maximum combo, or consecutive number of good cuts.

Users may also adjust the difficulty setting for each song. There are five levels, ranging from “easy” to “expert+.” The complexity of note patterns (e.g., the number/frequency of notes, the directional and color requirements), and the number of obstacles may increase with difficulty. Additionally, the health bar depletes more quickly at higher difficulty levels.

## Background of Beat Saber and rhythm games

Beat Saber was released in 2018 and builds on the legacy of prior rhythm games, such as *Guitar Hero*, *Rock Band*, and *Dance Dance Revolution (DDR)*. While earlier rhythm games used game-specific hardware (e.g., a dance mat or a guitar-shaped controller), *Beat Saber* uses the handheld VR controllers and places the user in an immersive VE. In this genre, the players are presented with incoming notes or blocks that correspond with the music and must be hit at the right time.

The primary attention zone is in the center of the screen, where players can see these incoming notes and receive visual feedback when they hit the notes. The secondary attention zone is around the perimeter of the screen, showing in-game stats, such as current score, combo, multiplier, and remaining time (Figure 2). Players do not need to attend to the secondary attentional zones, so they may ignore it unless they have enough bandwidth to divert their gaze away from the incoming blocks (e.g., when there are not many notes on the screen, or if they know a song well enough to perform some passages from memory).

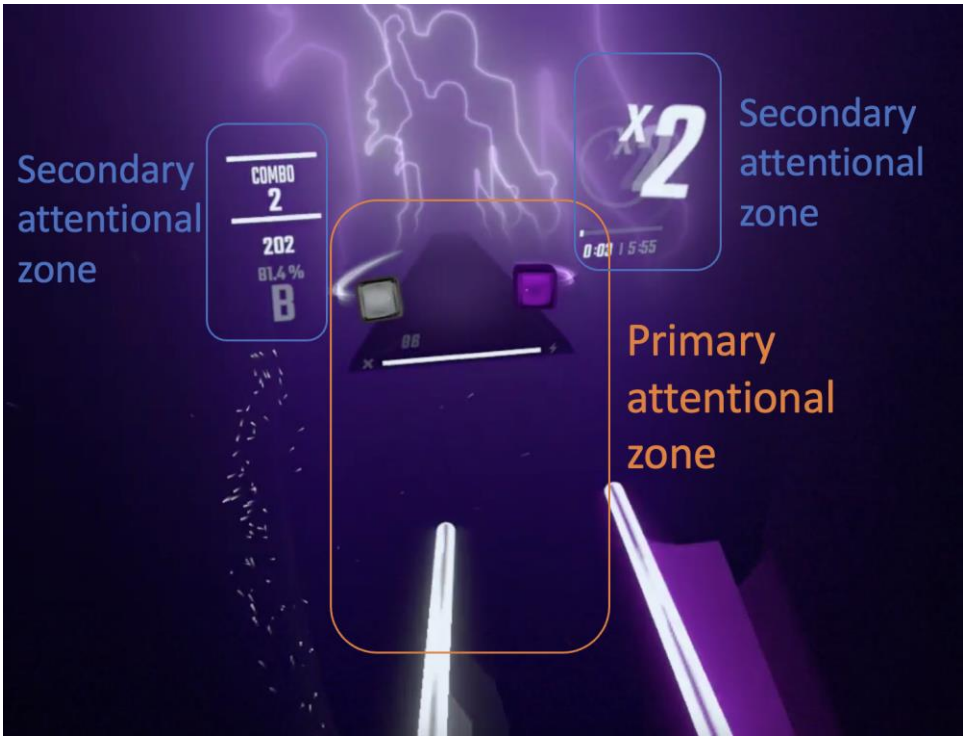



*Figure 2: The primary attentional zone (center) is defined by the incoming notes and the sabers. The secondary attentional zones (left and right of screen) show in-game metrics and timing.*

One notable similarity between Beat Saber and other video games, especially at higher difficulty levels, is the escalation of time pressure. While rhythm games inherently involve timing challenges, the intensity rises as players advance to more challenging songs or levels. The increasingly rapid succession and complex arrangement of approaching notes and obstacles is analogous to encountering more enemies and obstacles in other games. Although the inherent time challenge is similar to endless runner games, like *Temple Run*, the challenge increases in by advancing to more difficult songs, similar to level-based games like *Super Mario World*.

Other rhythm games have a similar approach to Beat Saber, offering multiple difficulty levels (DDR) or unlocking new songs to reward high performance (*Guitar Hero)*. They also feature similar game elements In *DDR*, players' accuracy in hitting notes affects the Dance Gauge, similar to the health bar in *Beat Saber*. *DDR* also introduce gameplay elements such as Freeze Arrows and Shock Arrows to increase challenge, similar to the obstacles in *Beat Saber*.

Although this study only used single-player gameplay, multiplayer gameplay is also a common feature among rhythm games. Beat Saber primarily emphasizes individual gameplay and high score achievements, but it was updated in 2021 to include online multiplayer games. Similarly, *Guitar Hero* and *DDR* include multiplayer challenges. *Rock Band* was designed to emphasize multi-player gameplay by enabling four players to perform different instruments on a song together.

## Related research

As of September 2023, a search for *"Beat Saber"* in Google Scholar returns 1190 results, which is indicative of the breadth of research that has used this game. *Beat Saber* has been used to study data privacy, finding that users can be individually identified from a database of 50,000+ users with 94.33% accuracy using 100 seconds of body motion data and 73.20% accuracy with 10 seconds of motion data (Nair et al., 2023). In the education domain, it has been used as the medium for a novel vocabulary learning tool in which users swipe from vocabulary words to corresponding images in the game (Hartfill et al., 2020). Other researchers have explored the lingering cognitive aftereffects of playing *Beat Saber* (Szpak et al., 2020).

Additionally, *Beat Saber* gameplay itself has been studied. One group of researchers was interested in how *Beat Saber* difficulty relates to users experiencing a state of psychological flow, in which they are fully engaged and immersed in the task at hand. They manipulated the song difficulty for each user to be too easy, too difficult, or just right, and they found that users experienced the greatest sense of flow, physiological arousal, and enjoyment when the difficulty was just right (Lemmens & von Münchhausen, 2023).

Another group of researchers was interested in the way that exercise games (also known as exergames) combine music synchronization with cognitive challenge based on reaction times and memorization (Albert et al., 2022). They wondered how important the music synchronization is to user performance and set up an experiment with three conditions: 1) synchronized (music and gameplay are in sync), 2) offset (music was offset from gameplay by three quarter notes), and 3) non-synchronized (music tempo and gameplay do not match). During post-test, semi-structured interviews, they found that about 50% of the participants noticed the asynchrony. For users who noticed the asynchrony, better performance (measured by number of notes hit), greater enjoyment, and decreased workload were associated with the synchronized control condition. No significant effects were found for participants who did *not* notice the asynchrony. On average, participants who noticed the asynchrony were more likely to play video games (and rhythm games, specifically) often and have more experience playing musical instruments, but dancing experience was not associated with either group membership.

## Methodology

This research aims to answer two questions: RQ1: How do novices and experts differ in their performance in Beat Saber? And RQ2: Can the addition of an attentional load task reduce experts' behavior to match that of novices? The experiment was a 2x3 factorial design, with one between-subjects variable (expert vs. novice) and one within-subjects variable (no attentional load, 2-back load, 3-back load). All participants first completed a pre-task survey to collect demographics (e.g., age, gender, past experience playing Beat Saber). Novices then completed Beat Saber's built-in tutorial to acquaint themselves with game mechanics. All users completed a practice song ("Eye of the Tiger" by Survivor) as a warm-up session. They then performed three rounds of "Bohemian Rhapsody" by Queen, progressing from no attentional load, to 2-back attentional load, to a 3-back attentional load (Figure 3). They concluded the study by completing the exit survey, which included subjective ratings of difficulty.

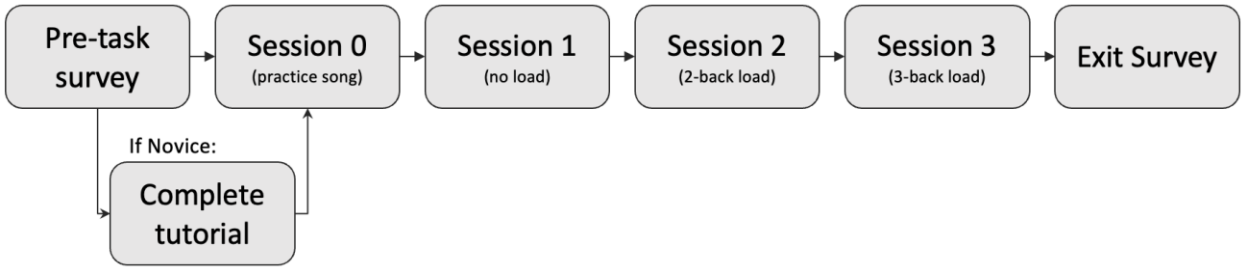



*Figure 3: Tasks included pre- and post-task surveys, one practice session, and three sessions with data collection. Novices also completed a tutorial.*

The testing was all completed with one or more team members present to explain the experiment instructions, ensure that screen recordings were captured, and facilitate the attentional load task. Testing took place in three locations (Seattle, WA, San José, CA, and Ames, IA). The sessions in Seattle used an Oculus Quest 2 headset and an Amazon Alexa speaker for the attentional load task. The sessions in San José and Ames used a second Oculus Quest 2 headset and a laptop for the attentional load task. Before each session, participants were instructed to use the headset's screen recording feature to capture video and audio from the gameplay and attentional load task.

The pre-test survey collected user demographics and checked for a history of cybersickness. Because any interaction of cybersickness effects could be amplified in study with few participants, only participants that did not report a history of cybersickness were included in this study.

### Game analysis

Two *Beat Saber* songs were used in this analysis. "Eye of the Tiger" by Survivor was selected for the practice session, due to its widespread familiarity, clean lyrics, and relatively low difficulty (109 beats per minute for a duration of 4:06 minutes). "Bohemian Rhapsody" by Queen was also selected for its familiarity and clean lyrics. It has an average of 144 beats per minute for a duration of 5:54 minutes, and its mix of calm and energetic passages provide an opportunity to analyze how performance varies with song complexity.

The game performance metrics discussed above (overall score, number of good cuts, max combo) were collected after each session and compiled in a spreadsheet for analysis. The team considered creating a log of which notes were hit and missed throughout the entire song for each session, which could have been used to further analyze patterns, identify difficult passages, and compare the performance of experts and novices. However, the team did not find an existing tool to automate this process and was unable to do it manually within the project time constraints.

### Human analysis

The attentional load task was based on an existing secondary attentional load task, in which a list of numbers is read to participants at a pace of one word every 1.5 seconds, and users

identify pairs or trios of consecutive odd numbers (Craik, 1982). The participants are instructed to say "now" when they heard a pair or trio.

During pilot testing with a novice, the player observed that the 2-back attentional load task (identifying pairs of odd numbers) was not as challenging as expected. Thus, for this experiment, the numbers were replaced with direction words (up, down, left, and right). Because the location of the incoming blocks and the directional arrows on the blocks are both critical to gameplay, it was hypothesized that retaining direction words in working memory would be more likely than retaining a list of numbers to interfere with gameplay. During the first data collection session, the participant was not strongly affected by the 2-back attentional load task (identifying consecutive pairs) using directions either, so the experiment design was modified to also include a 3-back attentional load task (identifying trios of consecutive directions) for him and all remaining participants. Two lists of direction words were generated (referred to as List A and List B), and presentation order of these lists for the 2-back and 3-back attentional load task was planned to be counterbalanced among participants.

## Results

### Game analysis

The three *Beat Saber* game metrics discussed above are included in the game analysis (Table 1: Game performance metrics include the overall score, good cuts, and max combo scores.). In all figures and tables, the number of participants reported reflects the total number of participants in this study. However, due to data loss errors with the screen recordings, there is no data for one novice during the no-load condition or for a second novice during the 2-back load condition. Thus, for these two conditions with novices, the actual number of participants is two, not three. While this is not ideal, the team decided to still include all available data for those participants.

*Table 1: Game performance metrics include the overall score, good cuts, and max combo scores. Overall performance scores are rounded to three significant figures for readability.*

| | | ***Novice*** *Mean (std dev)* | ***Expert*** *Mean (std dev)* |
|---|---|---|---|
| *Overall performance score* | No load | 52,000 (41,900) | 187,000 (32,300) |
| | 2-back load | 56,600 (66,800) | 189,000 (28,200) |
| | 3-back load | 65,700 (75,700) | 191,000 (36,500) |
| *Good cuts (count out of 644 total notes)* | No load | 314 (11.3) | 617 (18.9) |
| | 2-back load | 326 (5.9) | 624 (18.7) |
| | 3-back load | 342 (25.5) | 622 (0.03) |
| *Good cuts (percentage of total notes)* | No load | 49% (2%) | 96% (3%) |
| | 2-back load | 51% (1%) | 97% (3%) |
| | 3-back load | 53% (4%) | 97% (3%) |
| *Max combo* | No load | 7 (2.8) | 131 (63.8) |
| | 2-back load | 9 (0.6) | 151 (84.1) |
| | 3-back load | 13 (4.7) | 146 (47.6) |

The overall song score (a composite of notes hit, the angle at which notes were hit, and a combo score multiplier), is indicative of overall performance. A clear difference can be seen between the novice and expert players (Figure 4), with experts earning higher scores. All three novices showed an increase in overall song score over time. The higher mean performance score and standard deviation under attentional load for novices was primarily driven by one participant who quickly learned the game mechanics.

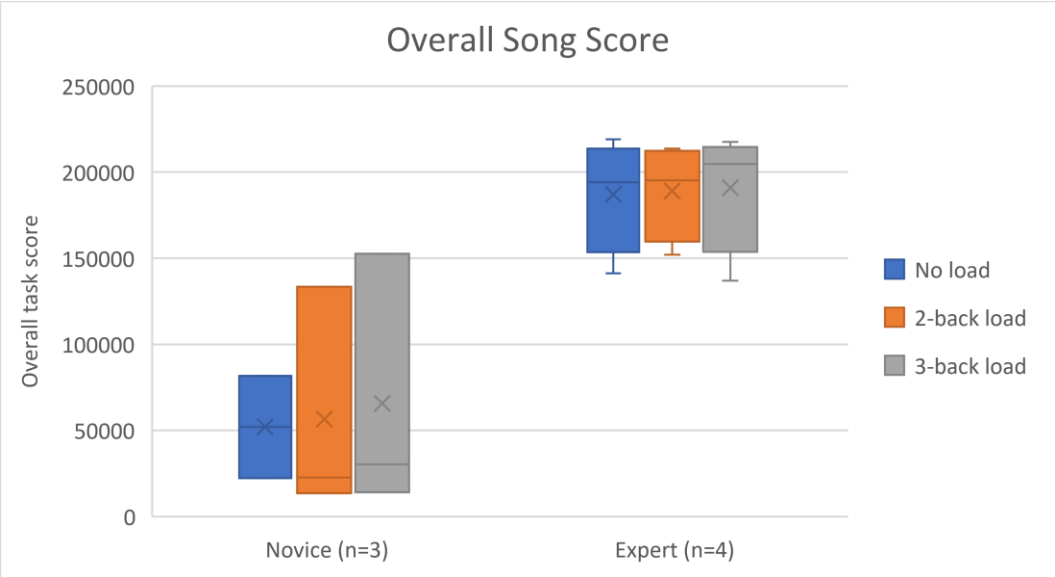



*Figure 4: The overall scores for novices increased with the addition of an attentional load but was consistently lower than that of experts.*

The number of "good cuts" refers to a count of blocks/notes hit out of a possible 644 and could be considered a measure of hit accuracy (Figure 5). Again, novices have significantly lower performance than experts, but there is less variability within the two groups of participants. Experts consistently had near-perfect performance, hitting 96-96% of notes during all three trials. Novices hit about half of notes, but their performance increased by about 2% with each subsequent trial.

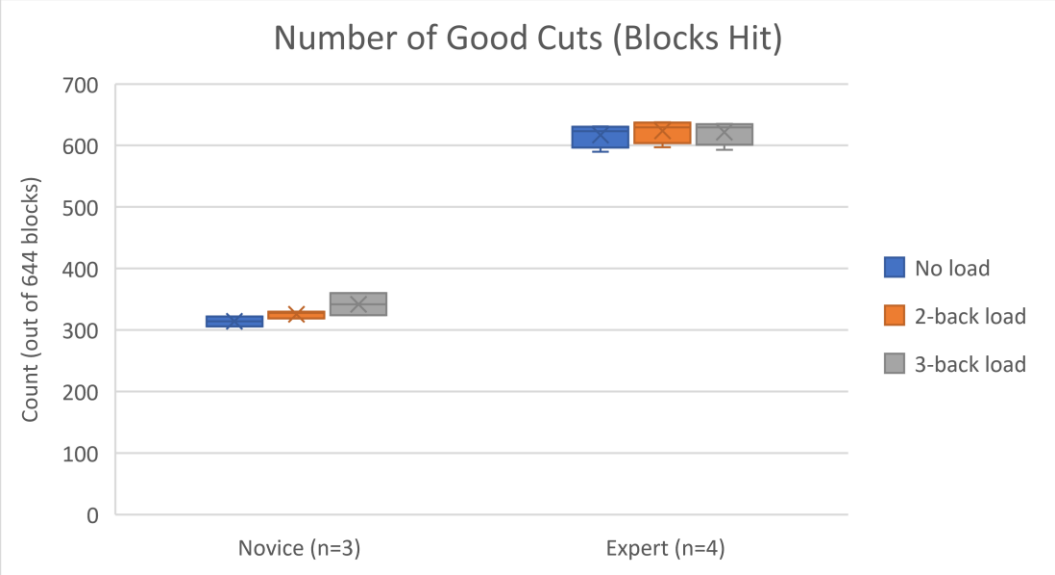



*Figure 5: The number of blocks hit differs for experts and novices. Novices show improvement over time, while expert performance is stable.*

The third in-game metric is the maximum combo score, referring to the maximum number of consecutive notes hit by the player (Figure 6). Once again, there is a significant difference between novices and experts. In this case, the amount of variation in scores is small for novices and large for experts. Novices show a slight improvement in subsequent trials with the attentional load, while experts' scores were relatively stable.

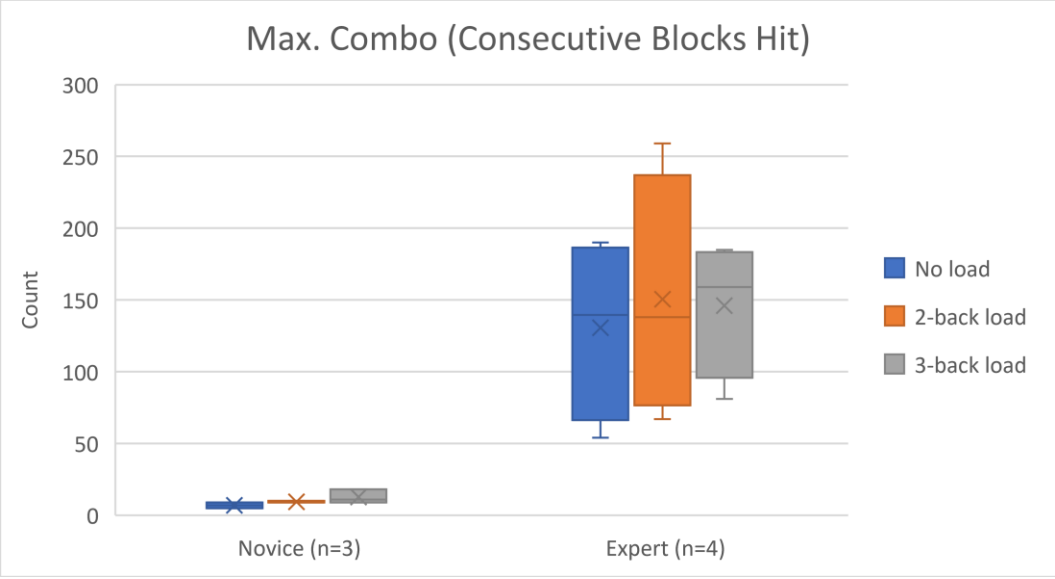



*Figure 6: Maximum combo scores were consistent among novices, while experts' combo scores were higher and more variable.*

## Human Analysis

The human analysis includes an assessment of their performance during the attentional load task, subjective ratings of difficulty collected at the end of the experiment, and a review of open-ended participant feedback.

### *Attentional load task*

While the attentional load task was not originally intended to be a dependent variable of interest, the team included it in the analysis to explore possible causes for the attentional load task having minimal effect on performance. Figure 7 reports on performance of the 2-back and 3-back attentional load task in both user groups. Due to an error in the list generation, List A and List B had a different number of matches during the song's duration (40 vs. 42 matches for the 2-back task, and 10 vs. 11 matches for the 3-back task). Additionally, some participants identified false positives, so the team decided to exclude these false positives by calculating the raw count as:

> *(Matches correctly identified) = (Total number of matches during song) – (Total number of missed matches during song)*

To account for the different number of matches in each list for the two tasks, the results are also reported as a percentage:

> *(Percentage of matches correctly identified) = (Matches correctly identified) / (Total number of matches during song)*

Performance was lower for the 3-back task than the 2-back task in both user groups. Overall, experts correctly identified more matches than novices, particularly for the 3-back task. The standard deviation was similar for all groups and conditions (Table 2).

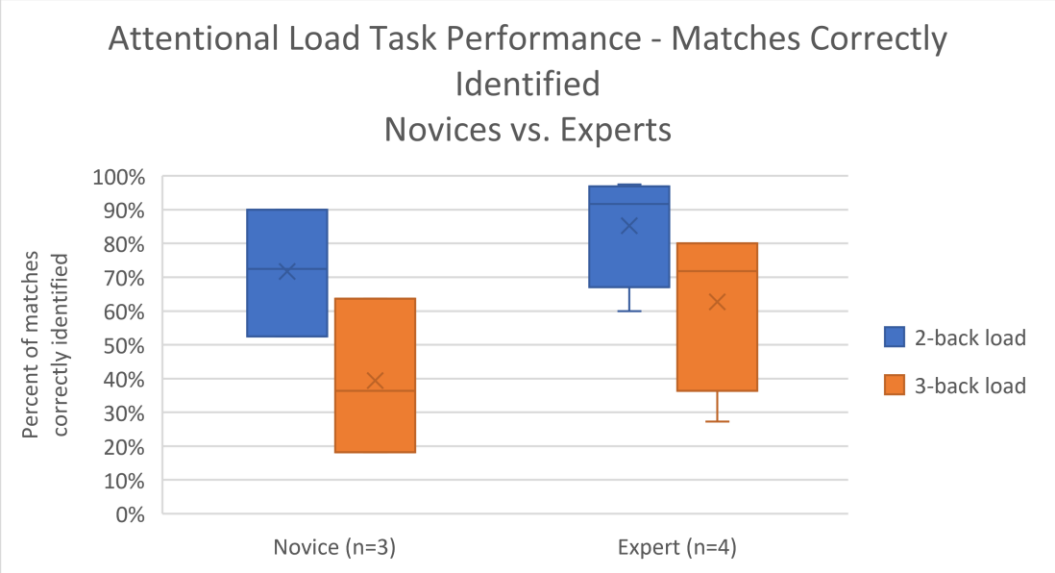



*Figure 7: On average, novices identified fewer matches in the attentional load task than experts. Mean number of matches is lower with the 3-back task than the 2-back task for both user groups.*

*Table 2: Mean percentage of matches correctly identified is lower in the 3-back task than the 2-back task for both user groups. On average, novices missed more matches than experts.*

| | **Novice** Mean (std dev) | **Expert** Mean (std dev) |
|---|---|---|
| 2-back load | 72% (19%) | 85% (17%) |
| 3-back load | 39% (23%) | 63% (25%) |

During exploratory analysis of the results, the team noticed that performance on the attentional load task was worse in the most energetic part of the song (roughly 4:12-5:00) for four users (three novices and one expert), suggesting that the tasks were more demanding at that point, particularly for novices. Further analysis could also explore the timing and cause of the false positives and to understand how high performance scores must be to exceed that of random chance.

Performance on the attentional load task also appears to interact with which list was used. Performance is considerably lower for List B than List A in the 3-back test (Figure 8). This could suggest a difference in timing (e.g., perhaps the matches appear in more difficult parts of the song for one list), or it could be a result of the asymmetric number of participants in each group. While the intent was to counterbalance which participants used List A and List B for the two attentional load tasks, this detail was missed when collecting data from participants across three locations and multiple experimenters. Table 3 shows the attentional load results for each list as a percentage of total matches and as a raw count of matches correctly identified.

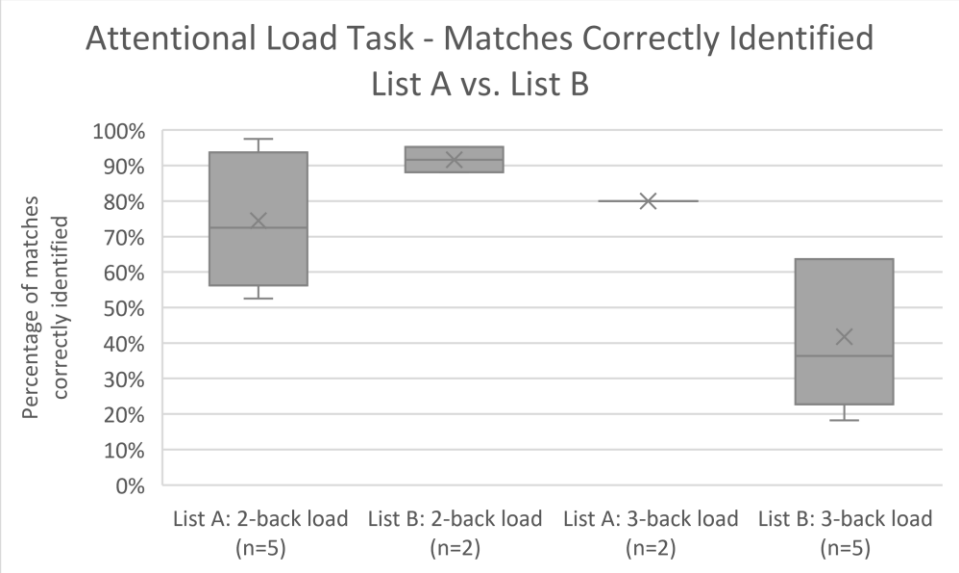



*Figure 8: Attentional load performance variability is related to number of participants.*

*Table 3: Means and standard deviations of matches correctly identified are shown for List A and List B*

| | **List A** Mean (std dev) | **List B** Mean (std dev) |
|---|---|---|
| 2-back: % of total | 75% (19%) | 92% (5%) |
| 3-back: % of total | 80% (0%) | 42% (21%) |
| 2-back: count/total | 29.8/40 (7.7) | 38.5/40 (2.1) |
| 3-back: count/total | 8/10 (0) | 4.6 (2.3) |

### *Subjective feedback*

During the post-test survey, the participants reported the perceived difficulty of each session on a 1-5 Likert scale (1 = not difficult, 5 = extremely difficult). Novices rated the sessions with attentional load as being more difficult with the addition of the attentional load tasks, while expert ratings were more consistent across all three conditions (Figure 9).

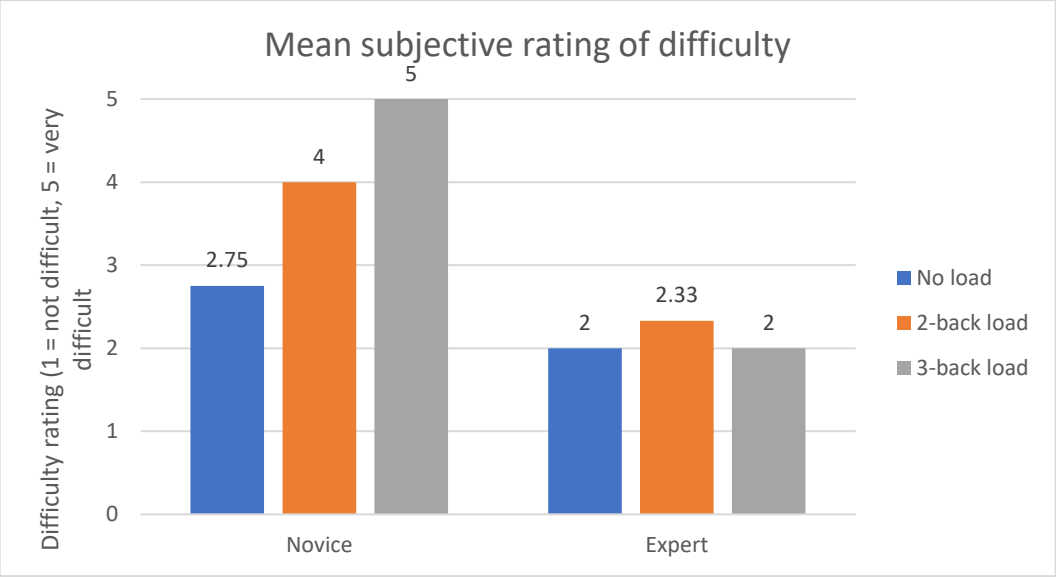



*Figure 9: Novices rated the task as being more difficult under attentional load, while experts gave more consistent ratings across all three conditions.*

An analysis of the participant comments reveals several themes and insights about the differences between experts and novices, particularly regarding the attentional load task. Novices were more likely than experts to comment on the direction words conflicting gameplay, with one novice noting that "the most challenging element was trying to remember the direction to hit the block, while also focusing on the directions/patterns said out loud." An expert, on the other hand, commented that the attentional load task heighted their focus by making the overall task more challenging and engaging.

Both novices and experts commented on some confusion about the attentional load task instructions. In the word lists, a direction would sometimes occur four times in a row (e.g., "up,

up, up, up"). Some participants were uncertain about whether that counted as two back-to-back pairs, or if it counted as three consecutive matches.

## Discussion

The results of this experiment will be discussed in the context of the two research questions. The analysis provides a partial answer to the first question but suggests that further work is needed to answer the second. Limitations of this study and opportunities to improve the methodology will also be discussed.

### RQ1: How do novices and experts differ in their performance in Beat Saber?

In all three game performance measures (overall score, number of good hits, and maximum combo), the mean score of experts was higher than that of novices. The mean overall game score was lower for novices than experts in all three conditions, although the standard deviation grew with each subsequent trial for the novices. This can be attributed primarily to one novice who was quick to pick up on the game mechanics. His overall game score approached that of experts by his final session.

On average, experts hit roughly twice as many notes in all three trials (96-97% for experts vs. 49-53% for novices). The combo scores differed by an even greater factor, with experts hitting 11-18 times as many consecutive notes as novices. This result is interesting to consider in the context of overall performance scores. While the quick-learning novice had a high overall song score for third session, his combo score (and thus, multiplier) was still significantly lower than experts (he achieved a max combo of 11 on the 2-back task, compared to the average maximum combo of 146 for experts in the 2-back task). This could suggest that this novice quickly learned the ideal way to strike the blocks to maximize points, but it could also be indicative of the 0.5X multiplier handicap that was applied due to using "no fail" mode during this experiment.

### RQ2: Can the addition of an attentional load task reduce experts' behavior to match that of novices?

The results from this experiment show that this attentional load task was not sufficient to negatively impact experts' game performance, which could be attributed to several potential causes. One possibility is that the song was not difficult enough. All three sessions were played at the "normal" difficulty setting so that it was not too challenging for novices. However, this might have also made the task so simple that experts had still had enough cognitive bandwidth to easily manage a second demand on their attention. While increasing the song difficulty is likely to challenge the experts, the data suggest that song difficulty may not be the primary root cause. Lower game performance scores indicate that unlike the experts, novices were challenged by this song. However, even their performance was not strongly impacted by the attentional load task. In fact, their mean scores increased in all three metrics under attentional load.

A second possibility is that the attentional load task was not challenging enough. The team modified a well-known procedure, hypothesizing that using direction words instead of numbers would evoke thoughts about directions that conflict with the in-game block positions and

arrows. While one novice commented that this was confusing, other participants described the automaticity of the tasks (e.g., they could respond to the incoming blocks in the game while using their working memory to store the recent word from the list). It's possible that these participants also thought of the words as meaningless phonemes, or perhaps it was easy to separate the visual and motor tasks in the game from the audible and verbal tasks of the attentional load task.

A third possibility is that participants devoted less attention to the attentional load task than the gameplay. In spite of the attentional load task being relatively simple, no participants correctly identified all of the matches. Even expert performance in the 3-back load task ranged from 27% to 80% accuracy, while those participants were achieving 92-99% accuracy hitting blocks in the game. Playing *Beat Saber* while attending to an attentional load task could be thought of as a multitasking scenario, and researchers have proposed that there are five main factors that influence human's choices to switch between tasks: salience, priority, interest, difficulty/mental workload, and time on task (Lee et al., 2017; Wickens et al., 2015). While the experimenters ensured that the attentional load task was loud enough to be heard, it may have been *less salient* since it came from external speakers and not from the game environment in which the participant was immersed. The relatively long *time* between matches, particularly in the 3-back task (10 or 11 trios of consecutive words over a 5:56 minute song) may have made it compelling for participants to stay focused on the gameplay. The attentional load task is *less interesting* than the vibrant, musical, immersive gameplay. Relative *difficulty* of the two tasks may differentially influence novices and experts (e.g., game difficulty varies for novices and experts, but attentional load task does not) and may not be a significant factor in this analysis. While the experimenters asked participants to prioritize the attentional load task, this instruction may have been less impactful than the tasks' relative salience, interest, and timing.

A fourth possibility to consider is the interaction between the attentional load task and learning effects. One limitation of this study is that the sequence of the three loading conditions was not counterbalanced across participants, so the attentional load task difficulty increased as the participants gained experience in the song and gameplay. It is possible any negative impact on performance from the attentional load task was offset by positive learning effects. This seems unlikely to be a significant factor for the experts, whose high performance was relatively stable and approached an upper threshold (e.g., they hit 96-97% of notes and achieved high maximum combo scores). On average, novices' performance improved in subsequent trials, so the positive learning effect appear to be more influential than the attentional loading task.

### Limitations

While the lack of effects from the attentional load task is consistent among the seven participants in this study, the strength of these results may be influenced by several limitations. First, the geographic spread of experimenters and participants may have introduced some variability. There were two sets of hardware (headsets and speakers for the attentional load task), although the experimenters accounted for this by synchronizing settings and ensuring that the load task was loud enough to hear during gameplay.

Second, the test conditions were not counterbalanced across all participants. The attentional load task progressed in the same sequence for all participants (no load task, then 2-back load task, then 3-back load task), making it difficult to isolate attentional load effects from learning effects. Additionally, the order in which participants used List A versus List B for the attentional load task was not counterbalanced across all participants (five participants used List A first, and two used List B first).

Third, the two attentional load tasks themselves were not optimized. Due to an error in liste generation, the number of matches that occurred before the end of the song differed between the two lists. The lists could also be improved by ensuring that matches occur during passages of the song with equivalent difficulty.

Fourth, the power of these results is limited due to the small number of participants and the simplicity of the data analysis. This could be improved by first calculating the number of participants required for the desired statistical power, then recruiting a diverse pool of participants of that size. The results could also be analyzed using formal statistical methods, such as a two-way ANOVA, to measure the effects of two independent variables (*Beat Saber* experience and attentional load condition) on each of the continuous gameplay dependent variables (overall score, number of "good cuts," and max combo).

## Conclusion

This study explored the differences between novices and experts in *Beat Saber*, an immersive, VR-based rhythm game. Experts achieved higher scores in all three game performance metrics. The additional of an attentional load task requiring participants to identify matching pairs and trios of direction words was not sufficient to reduce expert players' performance. Novice performance improved in subsequent trials with the added attentional load task, but it is unclear how much interaction there was between learning effects and cognitive demands of the attentional load task. Further work could use more challenging songs in *Beat Saber* or explore alternate attentional loading tasks. This could include increasing the complexity of the direction task, perhaps by asking users sort and match words into more broad categories (e.g., horizontal and vertical directions), which might put more demands on their phonological loop. Alternately, the task complexity could be increased by asking users to track in-game elements, such as remembering the direction of previous blocks. Further work could also explore whether the results extend to other rhythm games, in which the user is less immersed in an environment and the attentional load task may be more salient.

## Contributions

The experiment design was developed by Ashley and Amanda. Amanda researched related work. Data collection was completed by Ash and Ashley, with assistance from Amanda for two sessions. Amanda generated the attentional load word list, and Ash created an audio file of it. Ashley and Ash compiled the data into a spreadsheet. Amanda conducted the analysis of the game performance, and Ashley conducted analysis of the human performance. Ash provided a template and some background content for the presentation, and Amanda and Ashley populated the slides that they presented. Amanda created the paper outline and edited the final version. All three authors provided writing contributions to the paper.

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