Exploring the Impact of Action Audio Games on Creativity: Perspectives in Sonic Thinking

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Research on the effects of video games has evolved, initially focusing on potential negative effects, but now recognizing cognitive and educational benefits that often outweigh concerns. However, much of this research has overlooked non-visual game genres, such as audio games that rely solely on sounds to convey information. Drawing on research from action video games, this paper hypothesizes that playing action audio games may improve subsequent creative performance. To explore this, the audio game "OrbitCleaner" was designed, where players operate a spaceship to clean space of aliens, collect astronauts and avoid obstacles. While examining sound design choices in detail, two versions of the game were created: an action mode where players are required to maintain a wide focus of attention, and a non-action mode where a narrow focus of attention suffices. The impact of playing both versions on creative performance was assessed in a study with twenty participants. The results showed improvements in creative performance after playing the action audio game compared to the non-action version. These findings demonstrate opportunities for game design that encourages a wide or narrow focus of attention to elicit desired cognitive effects.

CCS Concepts: • **Human-centered computing** → *Participatory design*; **Laboratory experiments**.

Additional Key Words and Phrases: Creativity, breadth of attention, HCI, CST, action game, audio game, sonic thinking, assessment, measurement

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1 INTRODUCTION

The advances in technology and the accessibility of home systems in recent decades have drawn more and more people to video games [66, 78]. Initially, this trend was considered harmful with concerns raised about negative effects on users, such as aggression, addiction, social incompetence, and mental health issues [16, 18, 52]. However, as research in Human-Computer Interaction (HCI) focused on the potential positive effects of video games, initial concerns have been disproven or found to be outweighed by the benefits of playing video games. In particular, cognitive benefits such as visuospatial skills but also positive effects in the social, motivational, and emotional domains have been linked to video games [19, 26, 27].

Even so, with the vast number of games being released and the increasing variety of gameplay, researchers are constantly challenged to find new ways for assessment and have to iterate their understanding of the impact of video games on users. One area in HCI where researchers are exploring the effects of video games is that of creativity [39, 59]. The creativity discourse revolves around the exploration and understanding of creativity and is concerned with the evaluation of creative products or creative performance [29, 62]. Common video games like *LittleBigPlanet* [57] and *The Legend of Zelda: Tears of the Kingdom* [17] can serve as creative outlet where players are encouraged to find and produce original solutions to various problems or even create levels themselves [49].

To complement such efforts, a common practice in HCI is the use of creative support tools (CSTs), which are designed to enhance creativity during or before the ideation and design phases. [21, 22]. Shneiderman (2009) stated that the development of creativity support tools to leverage insights in multiple domains is one of the grand challenges of HCI [64]. It is therefore not surprising that researchers have successfully used video and motor games as CSTs [37, 40, 59]. Other studies have demonstrated, that engaging in video games can enhance creativity and activate cognitive processes associated with creative performance, such as the breadth of attention and cognitive flexibility [27, 76].

Typically, studies in this field focus on a subset of video games, namely action video games. Action video games are fast-paced and require several different attentional abilities as players must keep track of multiple stimuli and objects that appear scattered across the screen [27]. However, in addition to video games, there are less popular subsets of digital games that are often overlooked in research. One niche category that many casual gamers may not even be aware of is audio games. Unlike video games, audio games utilize sound as the sole means of conveying information, rather than providing visual information as a basis for navigation. Audio games provide an inclusive option for visually impaired individuals and have gradually grown in popularity and appeal. While the use of carefully designed audio content in video games is increasing, this has not yet resulted in a corresponding increase in the development of audio games, which remain largely underrepresented despite market demand [77]. As a result, research efforts in creative areas of audio games have been minimal, with the majority of studies focusing on training spatial hearing and navigation skills [4, 36].

This is in contrast to the aspirations of the HCI community, where Frich (2018) has identified a lack of interdisciplinarity as a shortcoming of creativity-oriented research [22]. Consequently, pursuing approaches in the auditive domain is rather promising as "creativity is precisely the kind of problem which eludes explanation within one discipline" [24, p. 66]. In addition, the auditive domain and therefore audio-based CSTs offer several practical advantages over applications in the visual domain. Firstly, deviating from vision, which typically carries a high perceptual load in daily life, allows for the exploration of the available cognitive capacities of individuals. Secondly, auditive stimuli can be easily modified and delivered to individuals in controlled environments with relative ease (headphones), therefore offering greater flexibility in their use. This is also relevant with uncontrolled, in-vivo CSTs, where the visual sensory channel is rarely unoccupied and easily distracted. Thirdly, participants are slower to experience fatigue of audio compared to visual stimuli. Finally, audio testing is suitable for individuals who are blind or have low vision and would otherwise be excluded from the discourse.

Nonetheless, to study the influence of action audio games as CSTs on creativity, it can be advantageous to leverage research methodologies commonly employed in the study of video games [76]. In this context, it is important to note that video game studies make no distinction between cognitive effects related to video or audio content. Given the pivotal role of audio elements (such as cues, emotional affect, and immersion) in numerous video games [11], it is plausible to assume that the observed cognitive effects, including those on creative performance, may be partly dependent on the exposure to auditive stimuli. Therefore, to provide nuanced perspectives to the creativity discourse regarding audio games and HCI, it is important to leverage domain-specific CSTs and creativity assessment tests. The corresponding domain of sonic thinking is recognized in intelligence theory [30, 31] and design thinking literature [44, 55], providing a theoretical basis for domain-specific creativity in this study.

Overall, to investigate the effect of action audio games on creative performance and sonic thinking capabilities, 20 participants play an action and a non-action audio game. This approach allows for the isolation of auditive stimuli from visual stimuli. A domain-specific sonic thinking assessment, a visual thinking task, as well as a common creativity test, are employed to ensure appropriate measurements. This research contributes to new lines of inquiry by utilizing audio games to (i) explore their real-world application as domain-specific creative support tools, (ii) illuminate cognition in the realm of audio, (iii) investigate empirical relationships between creative performance and sonic thinking, while also (iiii) providing a detailed design approach for researchers working in audio-related HCI.

2 RELATED WORK

This section provides an overview of how creativity is commonly defined and measured, as well as an introduction to creativity in action games.

2.1 Creativity Theory

In creativity literature, an idea is considered creative when it meets two criteria: (i) novelty and (ii) effectiveness [63]. An idea is deemed novel when it is uncommon, original, and unique. Effectiveness is attributed to an idea that is useful, appropriate, or valuable. An idea or product is only the emerging outcome of a creative pursuit. Another perspective is provided by examining creativity in terms of the cognitive processes that develop over time.

2.1.1 Divergent Thinking. The creative process involves a combination of divergent thinking and convergent thinking, as illustrated in the so-called Double Diamond Models in Fig. 1[14, 28]. According to the Double Diamond Model, the creative process involves both divergent and convergent thinking to first find a promising problem, and secondly, devise a specific creative outcome.

In real life, creative challenges are often so complex that people are "cycling repeatedly through a process of divergent and convergent thinking" [71, p. 412]. However, the creative process is more distinctly associated with the phase where individuals diverge in their ideas, therefore divergent thinking is of particular concern in this study. When individuals engage in divergent thinking they are exploring a multiplicity of different options, such as different ways of solving a given problem.

A classic test of divergent thinking, that is commonly applied to assess the effectiveness of CSTs [53, 61], is the Alternative Uses Task (AUT) [29]. Test-takers are required to generate uncommon uses for a given item, such as a brick,

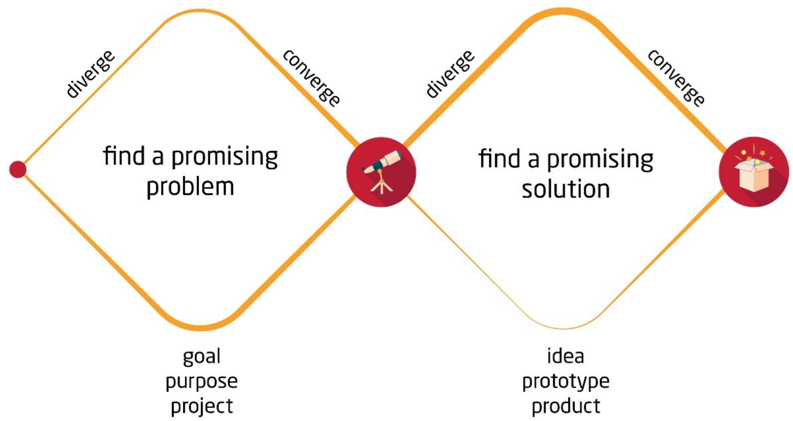

Fig. 1. A double diamond model of the creative process. The figure is reprinted with permission from von Thienen et al., 2023. [45]

under time constraints. To assess the creative performance of an AUT for key metrics are applied: fluency, originality, elaboration, and flexibility [28]. Fluency refers to the total number of options considered by the individual. Originality assesses the degree to which an option proposed by the individual is unique and novel relative to existing concepts in the world, or in comparison to the options proposed by other test-takers. Elaboration measures the level of detail with which an option is laid out. Flexibility inquires into the number of different strategies or categories explored by the individual.

In the context of this research, the factor of flexibility holds particular significance and shall therefore be expounded upon. Flexibility is considered a crucial aspect of creative thinking [28, 44]. Guilford (1950) defines it as the capacity to overcome established cognitive patterns and functional fixedness to arrive at novel associations [29]. Additionally, Braem and Enger (2018) characterize cognitive flexibility as the ability to swiftly reconfigure one's mindset when transitioning between different tasks [6, 60]. Considering the auditive domain, Darwin (2008) elucidates how cognitive flexibility allows individuals to focus on a particular speaker in a noisy setting by shifting their attention, filtering out competing talkers and noise, known as the "Cocktail Party Effect" [13].

2.1.2 Breadth of Attention. In addition to cognitive flexibility, a wide focus of attention has been repeatedly associated with increased creative performance [23, 25, 70]. Where focused attention entails concentrating on a particular task, stimulus, or piece of information, excluding other stimuli, wide or defocused attention involves a broader and less specific range of awareness. Kasof (1997) explains that ”individuals whose scope of attention is chronically wide focus on a larger range of stimuli at one time and tend to be more aware of extraneous or irrelevant stimuli” [46, p. 303]. Mendelsohn claims, ”The greater the attentional capacity, the more likely the combinational leap which is generally described as the hallmark of creativity” [56, p. 363] and argues ”that [a] chronically wide breadth of attention increases the probability that otherwise disparate ideas or stimuli will be brought into coherence, thereby facilitating creative performance” [46, p. 303].

2.2 Action Games

The term "action games" is used to refer to a subcategory of digital games. The majority of current research on digital games is concerned with video games, so Green’s (2006) characterization of action games is also based on video games [27]. Action video games are associated with moderate to fast-paced gameplay and often require the simultaneous processing of multiple objects. Objects in action video games follow different patterns of movement and may appear at the edges of the screen while events instantiate in the center of the screen. In addition, action games are characterised by the layering of game events on different time scales and often require players to make predictions about upcoming scenarios.

The definition implies that a broad focus of attention is required if the player is to keep track of the whole game, especially when objects appear in rapid succession and widely scattered locations. Considering that a broader attentional scope may be triggered by the particular activities for which it is needed [75], it is expected that playing action games will broaden the focus of attention and in turn facilitate creative performance.

In addition, players often require a flexible focus of attention in order to shift their attention from one object to another when the latter poses an immediate threat or benefit to the player. As noted in 2.1.1, players may benefit from cognitive flexibility when they have to respond to changing gameplay schemas or rule changes that are often incorporated into action games.

Notably, the beneficial effects of flexible and broad attention do not unfold only during the game activity. Instead, carry-over effects have been observed [76]. This means that people exposed to action games show improved cognitive performance on tasks they perform after gameplay.

In focusing on action audio games in this study, it is assumed that the definition of action video games and their cognitive benefits apply similarly to action audio games. In particular, individuals who are exposed to a variety of widely spaced auditory stimuli with flexible movement patterns will also benefit from a broad focus of attention after gameplay. Furthermore, McKim’s research into the trainability of specific thinking modes through exposure to appropriate stimuli and exercises [44], implies that comparable effects might be expected after playing an action audiogame. More specifically, individuals may show particular improvements in creative performance in the area of sonic thinking.

2.3 Sonic Thinking

Sonic thinking is the perception, imagination, or expression of content through sound. It is distinct from processing content in other modalities, such as visual, olfactory, semantic, and symbolic thinking. Sonic thinking can include non-musical elements and musical elements, where one might express oneself in tones, timbres, and rhythms or perceive the soundscape of a scenery rather than looking at it. It has primarily been adopted in the field of design thinking and is used as a means of communication or to facilitate problem-solving [54]. In line with approaches in HCI, design thinkers are trained to appreciate and use different viewpoints, experiences, and interdisciplinary collaboration as valuable resources for creative developments with a strong consideration of human needs in contemporary society. To complement this practice, design thinkers learn to be flexible in their use of different modes of thinking [44]. McKim (1959/2016) and von Thienen et al. (2019) underscore the significance of sonic thinking in creative pursuits, highlighting that sound is often neglected in product design [43, 54]. This oversight can result in products that are uncomfortable to listen to and ultimately frustrate, rather than serve, fundamental needs. Design thinking pioneer Robert McKim further highlights why it is important that problems are tackled with consideration in different domains: “Another aspect of physical needs in design is the task of accommodating design to the senses. This [. . .] [involves] getting [. . .] sound levels low enough. [. . .] I am especially concerned with some of the appliances in my own home which are extremely noisy and offensive to the ear. A good deal of adrenalin is lost in our house every week, for example, when the solenoid valve in our dishwasher shuts with the sound of a pistol shot." [54, p. 203]. Perhaps a creative solution to this problem necessitates considerations in the domain of sonic thinking rather than in visual or symbolic thinking.

2.4 Sound Design in Audio Games

One area where sonic thinking can be applied is sound design for digital games. Naturally, games designed for research purposes are not particularly concerned with graphics or pleasant sound aesthetics, as long as they don't break the immersion, but rather with functional game mechanics and well-designed spatial content that allows easy discrimination between different objects and actions. In addition, the successful localization of sound sources, especially those that are intended to be interacted with, is of particular interest. In this study, it is imperative that players perceive sounds as widely spaced and can mentally follow their movement paths. Only then can action audio games be expected to activate similar cognitive effects, i.e. to expand the breadth of attention, as action video games. For this reason, the design and implementation of spatial audio will be discussed in detail in this study. All considerations are based on localization within the confines of binaural processing and headphone playback.

2.4.1 Binaural Audio. Typically, a binaural processing chain uses dry mono recordings as source material. Dry recordings are made in an anechoic chamber to ensure that the recordings do not contain unwanted reflections or noise. Desired manipulations to the signal are made by considering the characteristics of the room using a Binaural Room Impulse Response (BRIR) and accounting for individualized filtering using Head Related Transfer Functions (HRTFs) [73].

A BRIR is typically calculated using the mirror image source method or ray tracing while the accuracy of the model depends on the available computing power and the need for a realistic representation.[73]. Based on the chosen environment, these models calculate the effect of acoustic phenomena such as reflections, absorption, or diffraction on the dry source signal. For analytical purposes, a binaural room impulse response can be split into three parts: the direct sound, several early discrete reflections, and the reverberation tail. Depending on their ratio the room size and the distance of a sound source is perceived differently. While intensifying early reflections and direct sound relative to that of other sound sources signal a close proximity, sound sources with a longer reverberation tail are perceived to be further away [51]. In addition, applying a low-pass filter as a function of distance, especially to early reflections and reverberation, but also to direct sound [51], accounts for air absorption and further improves realistic distance perception [7].

Binaural playback systems can further improve the accuracy of the perceived position of sound sources by utilizing Head Related Transfer Functions (HRTFs). For any given location of the sound source in virtual space, a corresponding HRTF can be retrieved from the system's storage. HRTFs are the key components of a spatial sound system and allow the listener to determine the direction of a source. They are either individually recorded (fitted HRTFs) or modeled and compute incoming sound so its properties can be resolved by the central nervous system as in a real situation. HRTFs account for interaural time differences (ITD) and interaural level differences (ILD) of the incoming sound as well as the spectral shaping due to the physical components of the body, such as the torso, shoulders, head, and pinnae [51]. It is agreed that the most significant localization effect extracted from the spectrum of a sound source can be attributed to the outer ear or, pinnae [51].

ITD occurs due to the spatial separation of the ears, which causes the signal to arrive at each ear with a different delay. This effect is related to the ability of the hearing system to detect interaural phase differences below about 1 kHz when they move through or diffract around the head. In contrast, ILD are caused by a shadow effect from the scattering of sound waves with frequencies above 1 - 1.5 kHz as they hit the head. This results in a reduced level at the ear further from the source compared to the ear closer to the source. For certain regions around the head, typically referred to as the cone of confusion, the values of ITD and ILD are identical over an area [73]. The corresponding front-back and height ambiguity is usually resolved by moving the head. In virtual spaces, this is achieved with head-tracking hardware, but in environments where this is impractical, the listener relies solely on spectral cues for localization in these areas. The confusion is particularly strong at frequencies where ITD takes over from ILD, around 1.5 kHz [51]. Generally, subjects using fitted HRTFs perform better in localization studies than subjects using modeled HRTFs or HRTFs that are fitted for other individuals. However, due to the complicated and often insufficient modeling, most spatial sound systems use non-individualised HRTFs.

2.4.2 Further Design Considerations. It is good practice to avoid emotionally evocative sounds, as emotional qualities are often used in games to create specific moods. Given the evidence on how emotional states affect the breadth of attention and vice versa [76], in most studies, this effect should be limited where possible. Additionally, Friberg (2003) notes that most audio games have a limited amount of background music and assign very obvious sound effects to the player's (inter)actions so that the players immediately know whether the sounds are generated by their actions or by the computer. One of the challenges of sound design in audio games is to convey the semantics of sounds because, without visual support, sounds are often susceptible to very individual interpretations. For this reason, it is essential to establish "early agreements" between the players and the game, building on metaphors and associative patterns [20]. To build on pre-existing associative patterns, the sounds should fit their actions and match the overarching theme of the game. Early agreements of these matches can be built in a tutorial stage, where players can listen to the available sounds. To create a convincing illusion of space, audio games must provide their players with sound sources that can be distinctly located.

In localization studies, participants are often exposed to pulsed white noise to achieve optimal localization accuracy [74]. White noise has an even energy distribution across all frequencies, and any spectral deviation from white noise typically reduces localization performance. For this reason, listeners are generally very poor at localizing sine waves and very narrow-band signals [73]. In addition, narrow-band signals are associated with location reversals of sound sources [48]. This can be partially compensated for by consistent movement patterns, allowing participants to predict the location of an object. Sharp attack transients of less than 50-100 ms produce a momentary burst of energy across the entire audible frequency range and help to localize the sound source [48]. Therefore, similar to a sonar used in submarines, a moving sound source with repeating attack transients continuously updates the listener's judgment [48]. In addition, Mondor (1995) has found that spatial cues that precede a sound event alert the listener and shift auditory attention to the source, thus aiding localization [58]. Furthermore, sound designers have to be mindful of localization errors of approximately 10° in the horizontal plane and adjust the size of objects accordingly [32].

3 HYPOTHESES

This research sets out to test the following hypotheses:

H1: Audio games that encourage a flexible and wide focus of attention (action audio games) increase creative performance more than games that encourage a rigid and narrow focus of attention (non-action audio games).

This hypothesis is based on related literature, as discussed in section 2.1.1. Specifically, the literature suggests a causal relationship between people's focus of attention to their subsequent creative performance. In addition, this hypothesis aims to replicate a pattern in playing action vs non-action games found by Yeh (2015) [76] in the realm of video games while now investigating the effect of action audio games on creative performance tasks in different domains.

H2: Action audio games improve creative performance compared to non-action audio games most significantly in the domain of sonic thinking.

This hypothesis builds on the empirically often observed pattern that people show the best creative performance when they have experience in a domain [47, 55, 65] When people play an audio game, they gain experience in the auditive domain, while the level of experience does not increase in the visual domain. Therefore, it is expected that people's subsequent creative performance after playing an action audio game specifically benefits creative performance in the auditive domain. By contrast, fewer benefits are expected in the visual domain when creative performance is measured by Schaeffer's Charades in the visual mode.

H3: Effective Schaeffer's Charades narratives score higher in diverse creative performance metrics (C-Score, fluency, flexibility, originality) than narratives that are non-effective.

This hypothesis investigates the relationship of outcome scores obtained from varying instruments and analysis approaches. Overall, it inquires that different methods produce consistent outcomes. This is a matter of construct validation [8, 12], establishing the appropriateness of the research methods.

The way in which people craft narratives in Schaeffer's Charades is very unique. One prompt is, for instance, ”Attending a grill party with some friends in a park”. Participants may be used to conveying such scenarios by talking about them (using natural language), or by capturing video. However, conveying such a scenario via only 24 selected pictograms or sounds is highly unusual, requiring the test-takers to be creative in order to solve the task (cf. [30]). Thus, it can be assumed that effective Schaeffer's Charades stories, whose prompts are guessed correctly by at least three out of the available four judges, are also more creative.

4 METHODS

The objective of this study is to investigate whether playing an action audio game may enhance people's subsequent creative performance more than playing a non-action audio game. This section provides the demographics of the participants and introduces the instruments used as well as the study procedure.

4.1 Participants

The study involves 20 participants (N=20), comprising 6 females and 14 males. The participants were recruited via a university's mailing lists and social networks. No financial remuneration was provided, instead, students acquired 75 minutes of "experiment-time", they needed to pass a course. The vast majority were aged between 25-34. Participants' self-rated ability to work with music varies, with 10 individuals considering themselves at an intermediate level and 10 at an advanced level. All 20 participants report regularly listening to audio content. In terms of video game engagement, 9 participants rarely or never play video games, 6 play occasionally, and 5 play regularly. Only 3 participants have taken a creativity test before, and none have previously played an audio game. Participants in this study exhibit variations in expertise regarding their familiarity with audio content and digital games. Importantly, the experiment adopts a within-subject design [9], mitigating potential confounding factors related to differences in expertise or other demographic factors.

4.2 Instruments

To evaluate the influence of an action versus a non-action audio game on people's subsequent creative performance, it is crucial to have two strictly parallel audio games that differ only in the aspects defining an action versus a non-action game. Additionally, to test the subsequent creative performance of participants in different domains, tailored creativity tests and analysis tools are employed. This section discusses tools that meet these criteria.

4.2.1 OrbitCleaner. Despite reviewing existing audio games on the platforms "AudioGames.net" and "Audiogame Store" [35, 38], no suitable pair of two audio games was identified. Consequently, a new audio game named OrbitCleaner was designed and implemented in the game engine Unity [68]. This section provides information about the design goals, the underlying mechanics, and the synthesis of the sound effects for OrbitCleaner.

OrbitCleaner is a 2D audio game. The game is played through audio cues, with no visual information provided to the player for navigation so players must familiarise themselves with the soundscape before the test. Additional confines of a study situation require that participants understand the core mechanics of OrbitCleaner in a short time without human supervision. For these reasons, a visual tutorial, as illustrated in Figure 2, is implemented as a preliminary step to the main phase.

The objective of the OrbitCleaner is to clear the space of stray aliens, collect astronauts, and shield itself from lasers and asteroids. To achieve this, the player utilizes action beams. The ship is fixed in the center of the screen and can only rotate around its z-axis. Action beams are fired from the tip of the ship. The tip of the spaceship is always facing the mouse pointer.

Every play-through involves the tutorial and the main phase. The main phase is the critical part, where the cognitive effects are expected to be most intense. In five minutes, players progress through five one-minute stages, which run in sequence, regardless of the player's actions. During each stage, pre-defined objects spawn in random order and are positioned in a fixed circle around the spaceship on the median plane. As suggested by Mondor [58], each object spawning event is preceded by a spatial cue to alert the listener and shift auditory attention to the object's eventual spawning position to aid localization. At a constant speed, they will then either radiate towards the ship or travel in a straight line until they collide with the ship or are destroyed by the player. Either of these events will trigger an object re-spawn sequence. Objects are located and identified by a distinctive sound loop that plays from their exact location while they are active on screen. The volume of the loop increases as the objects get closer to the ship. Players can interact with an object as soon as it is in range of a beam. This happens quickly after they spawn, so good players will

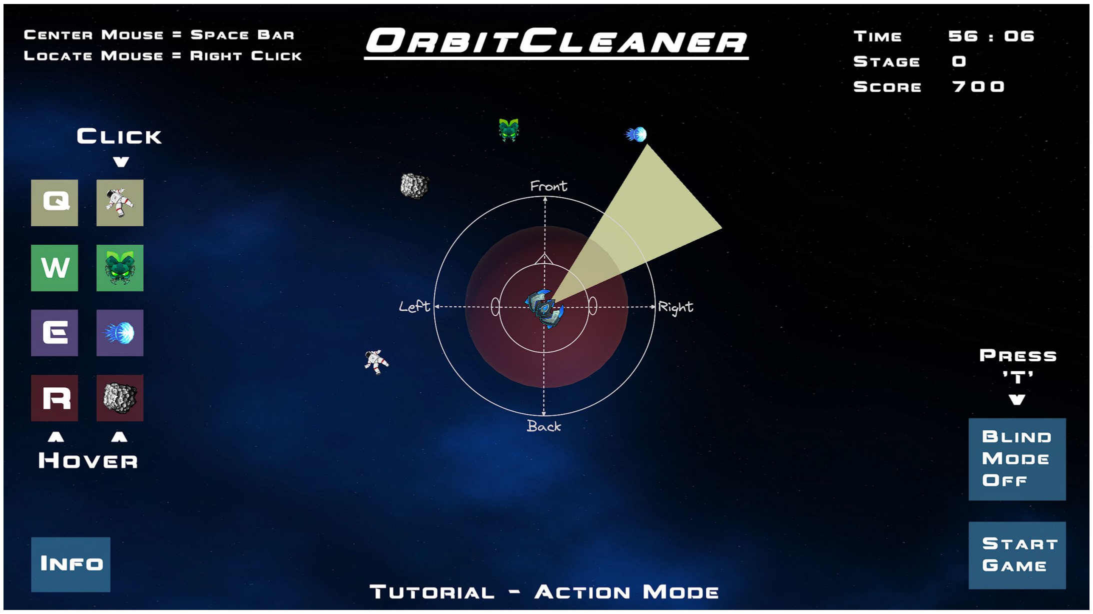

Fig. 2. The tutorial of the action mode of OrbitCleaner. Currently, all four objects have been spawned and the player has activated the circle beam to hit the asteroid and the cone beam to hit the astronaut.

be rewarded for quick reactions. By pressing *Q, W* or *E* players can activate the cone beams, whose angle is at least 10° to account for localization errors in the median plane. When using *Q*, it collects humans, while using *W* neutralizes the aliens. The button *E* is used to shield against incoming lasers and pressing *R* activates a beam with a circular hitbox that surrounds the ship and shields against approaching asteroids. Multiple actions can be performed simultaneously, but each action has a short cooldown time before it can be used again. This mechanic is in place so that players have to actively listen and make a conscious decision to activate a beam, rather than mindlessly using an action on repeat.

Players are tasked with attempting to achieve the highest score possible. Every time the player destroys an object with a beam, the score increases. Each time the player performs an action or an object collides with the spaceship, the score decreases. These values are set so that players who are quick to locate and destroy objects will have a higher overall score than players who tend to let the objects travel for some time before interacting with them. As players have no good way of confirming their mouse position on the screen without visual feedback, pressing the space bar will center the mouse pointer on the screen, and pressing or holding the right mouse button will play a sound from the position of the mouse.

Each level is more difficult than the one before. By increasing either the object variance, the maximum number of simultaneous objects, their spawning frequency, or the speed at which they travel, the different stages are tweaked so that the intensity increases with each level.

In the action mode, the player faces four different objects and can use all four actions. While it would have been possible to introduce even more objects, upon play-testing it seemed unreasonably difficult to memorize more than four sounds and move fingers between different keys. Players found comfort in a scenario where they could rest their hand in one position for the duration of the game, especially since rearranging the fingers is difficult without visual support.

The astronaut and the alien radiate in a circle towards the ship, but their trajectory is reversed several times during a stage. The laser and the asteroid always travel in a straight line towards the ship. The asteroid travels faster than the laser, and if it collides with the ship, it will prevent the player from making any beam inputs for five seconds. For this reason, asteroids spawn less frequently and only in the first forty seconds of a stage. With further insights from play-testing, the maximum number of objects that can be active at the same time was set to three and the minimum to one, while only objects of the same type can be active at the same time.

Although the outcome of the game is not the focus of this research, it is crucial that players are not overwhelmed to the point of giving up altogether. This is done to maintain their motivation at a level that would not unduly influence subsequent creative performance [72]. Accordingly, the pace of the game, which is determined by the maximum object speed and the number of objects that can appear in the game at the same time, is set based on playtests from the author and other players. Nevertheless, the increase in difficulty throughout the game is quite steep, as new objects are introduced rapidly, object speed increases and re-spawn time decreases.

Returning to the definition of action games in the introduction, this paragraph illustrates why it is reasonable to assume that the action mode of OrbitCleaner qualifies as an action audiogame: The action mode promotes a wide breadth of auditory attention as objects spawn at random and widely distributed locations. Their cohesive travel paths cover the entire screen, and the later levels force the player to divide their attention between the peripheral auditory field and the center of attention, as some objects may be closer to the spaceship, while others may have just spawned in the outer circle. Several different auditive stimuli appear simultaneously, further dividing the player's attention. In addition, players are exposed to objects with varying priorities. This is due to their differing movement patterns, with some objects approaching the player faster than others. For example, objects that move in a circle will approach the player more slowly than objects that travel in a straight line. This means that the players must shift their focus from circling objects to objects that travel in a straight line to defend against the immediate threat. In particular, the *Asteroid* quickly grabs the player's attention due to its ominous sound, high speed, and effects upon impact. The player therefore benefits from flexible attention to quickly focus on the objects close to the spaceship and reject less important information such as other objects or the background ambience. This is particularly difficult when two objects of the same type are active, as their sounds overlap and create new rhythms. The re-spawning of objects is dynamic. Apart from a few initial spawned objects at the beginning of each level, they always spawn after a fixed time whenever the player destroys them. This leads to the layering of events on different timescales throughout the game, as players sometimes destroy objects in very quick succession or even in one action. Contextual switches are prevalent in stages that either introduce new objects and hitboxes or change the movement patterns of previously introduced objects. The continuous increase in object speed forces the player to be flexible in timing and predicting object locations.

To eliminate as many potential confounding variables as possible, the control condition - non-action mode - is, with a few exceptions, cloned from the action mode and therefore inherits many of its characteristics. The basic sequence of playing through five progressively more challenging levels, as well as the controls, hitboxes, rewards, penalties, and sound design, have all been retained. What is different, are movement patterns and spread of the objects, their speed, and their variety. The non-action mode has a smaller variety of objects and therefore requires fewer actions from the player. It contains only the astronaut and the alien, who have simplified movement patterns and move more slowly. In addition, they can only spawn in a certain area of the front section, move in a half circle, and always keep the same distance from the spaceship. If they complete a half circle and reach the rear section, i.e. cross the y-axis, they will be destroyed and the player's score will decrease. There are two simple variations of this travel pattern. When objects spawn to the left of the player, they travel towards the right side. When they spawn to the right side, they travel to the left. This effectively reduces the listening experience to stereo where the volume remains the same, hence locating objects is far less difficult than in the action game.

The sound design of the objects in the game is based on sound localization theory previously discussed in section 2.4, but also on the aspiration to create a cohesive and immersive game experience. Therefore, the sound effects match common sci-fi sound effects that one would expect in space. Sound design considerations apply mainly to objects that the player actively interacts with, namely, the astronaut, the alien, the laser, the asteroid, and the cue sound. For the spatialized sounds, dry mono samples are either synthesized or taken from sample libraries. In this study, they are processed in Ableton Live [1] and Audacity [67]. Unity's internal audio engine is bypassed and instead, Audiokinetic Wwise [3] was chosen for its spatialization capabilities and is used for all sound events. In Wwise, the Resonance Audio plugin [2] is used to spatialize the sound sources, and the early reflections are modeled using the WWise native Reflect plugin. Some additional reverb is added using a Wwise native room reverb effect.

Figure 3 shows the sounds of the four objects in the time domain (left column) and in the frequency domain (right column). All the sounds are normalized to produce a coherent mix where the sound levels depend only on their distance from the spaceship. There are no quiet passages longer than 0.5s, which corresponds to the position update cycles for the standard speed of the objects. If the sounds were looped at a slower rate, the listener would experience jumps in the position of the objects. To account for the increasing speed of the objects throughout the game, the pitch of the sound increases dynamically as a function of the speed of movement.

In this research, the possibility of head tracking is neglected. For this reason, it is important to synthesize sounds with broad frequency bands to avoid front-back ambiguity and to enable a sufficient use of ITD and ILD cues.

Upon examination of the frequency spectrum of the astronaut and the laser, it is evident that both have significant energy at frequencies above 2 kHz. This is roughly the range, where the localization proficiency from the pinnae takes over. As the laser travels in a straight line, participants are unable to determine movement patterns by comparing past and present positions, as opposed to circular movement patterns. For this reason, the frequency spectrum of the laser shows considerable energy in almost all frequencies above 500 Hz. In contrast, the alien has a narrower frequency band, so the localization accuracy should decrease compared to the astronaut, even though they have the same movement pattern. The asteroid has no significant energy above 2 kHz. This is not a problem for the game, as the corresponding collider has a circular hitbox, so that reactions based on volume alone, i.e. when the asteroid is close enough to the spaceship, are sufficient to successfully interact with the asteroid. To expand the frequency spectrum of the sounds, they are all saturated and distorted, with the constraint that the listening experience remains pleasant and authentic. The sounds have different rhythms and overtone structures to help participants memorize them and distinguish them from others.

4.2.2 Semantic Divergent Thinking Task. CollaboUse [41] introduces a semantic divergent thinking task, building on the logic of the AUT as explained in section 2.1.1. Participants receive a prompt and are instructed to generate as many original solutions as possible within three minutes. Administered in the English language, participants input their responses into text fields. An example prompt is ”tools to survive in the wilderness”. Participants receive 10 random objects, which they can combine to craft solutions that satisfy the overarching creative prompt. For instance, a test-taker may combine the objects ”sticks” and ”blanket” to create the solution "tent." They can also use the object "sticks" to formulate the solution of a ”campfire”. Both the tent and the campfire can be useful for survival in the wilderness.

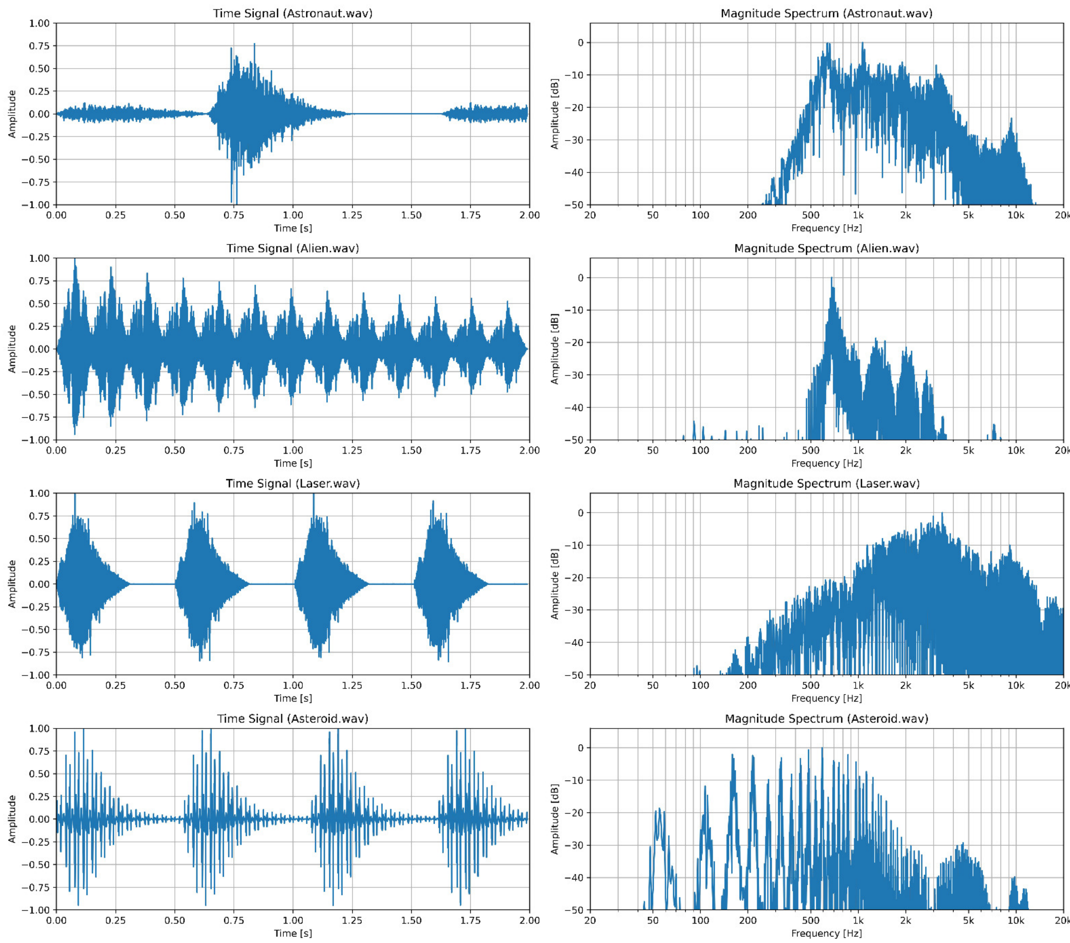

Fig. 3. Representations of the object sounds in the time domain (amplitude over time in seconds) on the left and in the right the frequency domain (amplitude over frequency in Hz). From top to bottom: astronaut, alien, laser, asteroid

In terms of metrics obtained from the test, similar parameters are observed as in the AUT. Fluency is assessed via the number of ideas submitted by the test-taker. Flexibility is evaluated based on the number of different objects used by a test-taker, with a value ranging between zero and 10. The two prompts used in this study are:

1. Decorating items for a science fiction movie.
2. Entertaining games for a group of friends.

4.2.3 Auditive and Visual Storytelling Task. This creativity test [34] introduces a storytelling task that is designed to be analyzed by using the standard parameter for creative performance. Even though it does not strictly mirror established divergent thinking tasks, participants still engage in similar activities. What uniquely defines Schaeffer's Charades is that it measures creative performance in both the visual and sonic domains, employing an analogous procedure.

This enables direct comparisons of people's achievement scores across the domains of sonic versus visual thinking. Schaeffer's Charades has been co-developed by the author of this paper.

In the test, participants are tasked with creating a mini-story that others can interpret and understand. The story is conveyed using either visuals or sounds. Every narrative unfolds over six scenes in time, resembling a comic with six boxes depicting different situations happening one after the other. In the experiment, each participant is presented with one story prompt per test run. Over the entire experiment, every participant creates mini-narratives for all four available prompts. The ordering of prompts is systematically varied in the study so that, for instance, each prompt appears equally often as a task for visual storytelling as it appears in sonic storytelling. These are the four prompts:

1. Having an argument about the dinner place with your partner. *(Pair 1)*
2. Ecstatic conversation about a football match with a stranger. *(Pair 1)*
3. Attending a grill party with some friends in a park. *(Pair 2)*
4. Sitting around a Campfire in the wild and your friend's birthday is at midnight. *(Pair 2)*

During each test run, participants are only concerned with the single prompt they are given; they are not informed that paired prompts exist. Once participants receive their prompt, they have 8 minutes to craft a mini-narrative by placing objects in a 2D space, as depicted in Fig. 4.

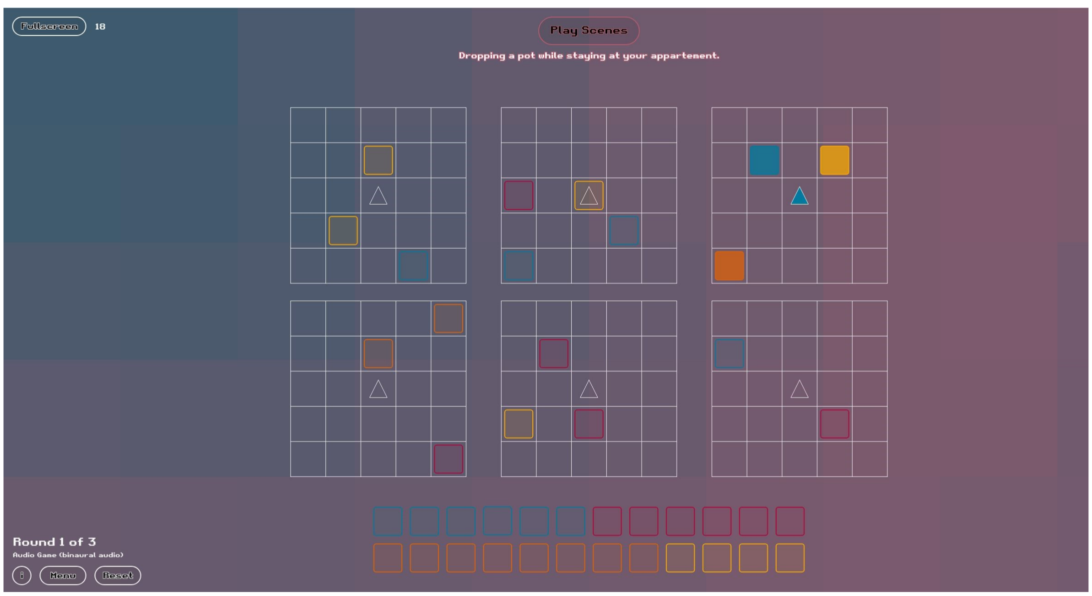

Fig. 4. A screenshot of the auditive mode of Schaeffer's Charades. The chosen story can be seen above the 6 grids and the 24 available objects are located at the bottom of the screen. Some objects are already placed in the grids around the listener's position, represented by the white triangles in the center of each grid.

At the bottom of the screen, 24 objects are available, allowing the test-taker to craft their story by placing these elements on the 6 grids, each of which represents one scene of the story. Every object is reusable as often as desired. The elements are categorized into four groups: Lifeless Nature (stones or water), Living Nature (birds or insects), Lifeless Anthropophony (machines or door creaks), and Living Anthropophony (laughter or clapping). Both the sounds and visuals are designed to be strictly analogous, ensuring, for instance, that the sound of a water drop in the sonic version aligns with the pictogram of a water drop in the visual condition.

When participants engage in Schaeffer's Charades in the sonic mode, they use headphones. The objects are displayed in a monochrome format, but come equipped with distinct sounds. Four colors distinguish the four content categories. Each of the six grids, representing different moments in time, has a central point that defines the position of the listener. All sounds are binaurally rendered so that players perceive the object sounds as if they are listening from this point of reference. Test-takers can listen to their evolving sonic stories either by hovering over a scene with the mouse or by pressing the 'Play Scenes' button. At the end of a session, each scene plays once in consecutive order, moving from the top left to the bottom right grid, to record the created solution. When test-takers engage with Schaeffer's Charades in the visual mode, the objects are displayed as pictograms, reflecting the semantic properties of their sonic counterparts. The process parallels that of the auditive domain; however, at the end of the session, a screenshot is taken to document the created solution. After collecting all the data from the participants, the resulting 80 mini-narratives (20 participants times 4 stories) are split into visual stories versus sonic stories and randomized within each group. They are presented to four independent judges, who do not know which treatment condition yielded which story. This committee consists of two audio experts and two students. Individually, the judges are presented with both options from a prompt pair, such as:

1. Having an argument about the dinner place with your partner. *(Pair 1)*
2. Ecstatic conversation about a football match with a stranger. *(Pair 1)*

The four judges need to guess for each story which prompts from the available two elicited the narrative. A test-taker's solution is considered "effective" when three or four judges (higher than chance) correctly identify the prompt that was given to the participant for that narrative. Additionally, the judges assign values of originality to each of the mini-narratives. Scores range from 1 (not original at all) to 5 (highly original). To conduct a more in-depth analysis of the behavioral data derived from the CollaboUse and Schaeffer's Charades, a validated algorithmic approach is employed, implemented as the C-Tracer [33].

4.2.4 Analysis Tool. The C-Tracer [5] provides an algorithmic approach for analyzing any digitally recorded behavioral sequence, yielding measures of creative performance. The evaluation approach builds on the standard definition of creativity, asserting that a creative solution is both novel and effective (cf. section 2.1). On such grounds, the C-Tracer calculates the average novelty (or differentness) across all effective solutions of a participant.

For the CollaboUse this means that all idea submissions by an individual are inputted to C-Tracer when they are deemed complete and task-appropriate upon manual inspection. For instance, in a task to generate tools for surviving in the wilderness, the solution "tent," combining the objects "sticks" and "blanket," is considered effective and included in the analysis. A test-taker achieves a high C-Score by using various items across different submitted ideas. For example, if the first idea involves sticks and the blanket, while the second idea involves sticks only, this results in two sequences that differ in one element only. A test-taker who consistently uses the same set of provided objects in the task would receive a low C-Score. In essence, this approach implies that test-takers who construct solutions of different lengths (elaboration) and with different elements (flexibility) score high on this metric. When the C-Tracer is applied to Schaeffer's Charades, sequences of six stages are compared. A test-taker who consistently uses the same objects, such as the water droplet, across the six stages of their story, obtains a lower C-Score compared to someone who makes a more varied use of the 24 available elements. The C-Tracer, as utilized in this study, has been successfully employed in related contexts [42, 50].

4.2.5 Questionnaire. To provide a more comprehensive characterization of the participant sample, an online questionnaire is administered. This survey collects a comprehensive set of metrics related to the individual's audio expertise, gaming experience level, and further demographic information.

4.3 Study Procedure

Each study session began with informed consent, followed by a brief introduction to CollaboUse and Schaeffer's Charades. Next, participants were allowed to adjust the internal mouse course speed to a comfortable level, being advised by the experimenter to reduce it slightly below their usual settings. Then, they receive a written manual for OrbitCleaner (game controls and mechanics), are equipped with headphones, and play the tutorial. During the tutorial, participants can explore the game at their own pace, with no time limit. Once they feel prepared, participants cover their eyes with a sleep mask and initiate the main phase of the game.

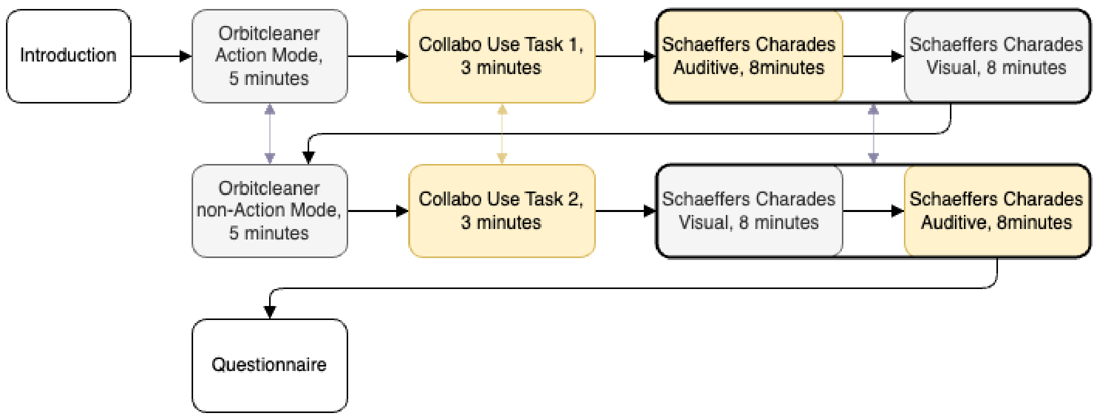

Fig. 5. A graphical display of the study procedure. The colored arrows illustrate eight possible, counter-balanced variations of the procedure.

After completing the play-through in either action or non-action mode, participants take three different tests: CollaboUse as well as Schaeffer's Charades in the auditive and visual mode (c.f. Fig.5). The sequence of auditive versus visual testing is systematically varied, ensuring a counterbalanced study design. More specifically, one possible timeline experienced by a participant is as follows: In the first OrbitCleaner block, they play five levels of OrbitCleaner for a total of 5 minutes. After completion, their eyes are uncovered, and the headphones are removed. Next, the participant completes the CollaboUse test for 3 minutes. They are given the headphones again and play the auditive version of *Schaeffer's Charades* for 8 minutes. Following that, they are given another concept and have 8 minutes to complete the task using the visual mode of *Schaeffer's Charades* without headphones. After completing the first half of the test battery, the participant returns to OrbitCleaner but plays the non-action mode for 5 minutes. The participant then takes the CollaboUse test with a second task and repeats the Schaeffer's Charades combination in reverse order. Finally, the participant completes the questionnaire. Overall, the procedure takes about 75 minutes.

5 RESULTS

This section provides a detailed analysis of the hypotheses. Outcomes are computed using the software IBM SPSS Statistics (version 29.0.2.0).

5.1 Does Action Audio Gameplay Enhance Creativity?

The first analysis evaluates the data concerning the following hypothesis.

H1: Audio games that encourage a flexible and wide focus of attention (action audio games) increase creative performance more than games that encourage a rigid and narrow focus of attention (non-action audio games).

To assess these effects, average creative performance scores measured after participants played OrbitCleaner in the action versus the non-action mode are compared. Each intervention entails eleven performance metrics as shown in Fig. 6. For all eleven performance metrics, it is predicted that the average score is higher after participants have played the action game compared to when they have played the non-action game.

Test	Domain	Metric	Context
Collabou Use Divergent Thinking Task	Semantic	C-Score	Average differentness of object combinations in submitted ideas
		Fluency	Number of ideas submitted
		Flexibility	Number of different objects used out of the ten available
Schaeffer's Charades Story Telling Task	Auditive	C-Score	Average differentness of object used between all effective grids
		Fluency	Number of objects placed in one story
		Flexibility	Average number of unique objects placed in one grid
		Originality	Average originality rating assigned by four independent judges
Schaeffer's Charades Story Telling Task	Visual	C-Score	Average differentness of object used between all effective grids
		Fluency	Number of objects placed in one story
		Flexibility	Average number of unique objects placed in one grid
		Originality	Average originality rating assigned by four independent judges

Fig. 6. The eleven metrics retrieved from CollaboUse and Schaeffer's Charades split in their respective domains. Any grid in Schaeffer's Charades in which at least one object is placed is considered effective.

Table 1 provides an overview of the statistics related to the CollaboUse. In Table 1 and all respective Tables, an *all* subscript refers to metrics that were computed for each of the 20 participants. All values can range between zero and any positive float. Although the p-values of paired-samples t-tests do not reach statistical significance, the metrics consistently show a trend of higher performance scores associated with the action game. The effect sizes are small to medium. For reference, Cohen [10] suggests interpreting an effect size of d = 0.2 as small, d = 0.5 as medium, and d = 0.8 as large.

Table 2 provides an overview of statistics for Schaeffer's Charades. Significant differences are found in the average expert ratings of originality in the visual domain (p = 0.004) with a medium effect size. Additionally, statistically significant differences are found in the average scores for fluency in the visual domain (p = 0.028) with a small effect size.

Among the eight comparisons computed for Schaeffer's Charades, five delta-values are positive, indicating that participants perform better after playing the action game than after playing the non-action game. These are associated

Metric	$\text{Action}_{\text{all}}$	$\text{Non-Action}_{\text{all}}$	p-value	Cohen's d
C-Score	2.77	2.68	0.772	0.066
Fluency	4.65	4.0	0.108	0.377
Flexibility	7.85	6.8	0.27	0.536

Table 1. Average Scores of the CollaboUse (N = 20)

Metric	$\text{Action}_{\text{all}}$	$\text{Non-Action}_{\text{all}}$	p-value	Cohen's d
Auditive C-Score	6.75	7.37	0.446	-0.174
Visual C-Score	7.80	6.94	0.074	0.423
Auditive Fluency	18.35	18.75	0.768	-0.067
Visual Fluency	21.8	18.8	0.031	0.521
Auditive Flexibility	3.32	3.68	0.305	-0.236
Visual Flexibility	3.88	3.44	0.074	0.422
Auditive Originality	2.95	2.51	0.052	0.463
Visual Originality	3.14	2.68	0.004	0.723

Table 2. Average Scores of Schaeffer's Charades (N = 20)

with Cohen's d effect sizes in the range of 0.314 to 0.723. Two comparisons are associated with a negative delta value, with Cohen's d assuming the values of -0.236 and -0.067. The latter are much closer to zero compared to the positive delta values.

Overall, the data reveals partial support of **H1** as the comparison of fluency and originality in the visual domain was found to be statistically significant. Additionally, in 8 out of 11 comparisons, the average measures of creative performance are higher for participants after playing the action audio game than after playing the non-action game. The remaining three comparisons show results close to zero. However, it is important to note that the presence of carry-over effects from playing the action version before the non-action version has to be considered. To get further insights on this matter, we can split the participants into two groups. Firstly, into a group that started with playing the action version and such might benefit from beneficial carry-over effects in all subsequent tests, and secondly, into a second group where participants started the study by playing the non-action version. Upon inspection, it was found that overall scores and differences in creative performance of action and non-action are consistent between both groups, indicating that potential carry-over effects didn't affect the study significantly.

5.2 Does an Action Audio Game Specifically Enhance Creativity in Sonic Thinking?

OrbitCleaner is uniquely designed to be an audio game. Therefore, by playing this game in either the action or non-action mode, people make experiences in the medium of sound, engaging in sonic thinking. It might therefore be the case that enhanced creativity is specifically observed for the auditive domain, as tested by Schaeffer's Charades in the audio mode. Therefore, the following hypothesis looks into the domain-specific effects of playing OrbitCleaner.

H2: Action audio games improve creative performance compared to non-action audio games most significantly in the domain of sonic thinking.

For this analysis, a delta metric is computed by comparing the participants' average performance scores after playing OrbitCleaner in the action versus non-action mode. This comparison is conducted separately for each medium, thus distinguishing between sonic, visual, and semantic thinking. A positive delta value aligns with **H1**, indicating that participants score higher after the action game compared to the non-action game. Conversely, a negative value suggests that participants score higher after the non-action game.

However, for the assessment of **H2**, the size of the delta values is particularly relevant. **H2** predicts that the delta score is specifically large and positive in the sonic thinking domain, as assessed with $\Delta Schaeffer_{auditive\_all}$. By contrast, delta values are expected to be lower in the domain of visual thinking, assessed with $\Delta Schaeffer_{visual\_all}$, and in the domain of semantic thinking, represented as $\Delta CollaboUse_{semantic\_all}$ in Table 3.

Metric	$\mathbf{\Delta Schaeffer_{auditive\_all}}$	$\mathbf{\Delta Schaeffer_{visual\_all}}$	$\mathbf{\Delta CollaboUse_{semantic\_all}}$
C-Score	-0.62	0.86	0.091
Fluency	-0.4	3	0.65
Flexibility	-0.36	0.44	1.25
Originality	0.44	0.46	-
Effective Solutions	3	1	-

Table 3. Differences in performance after playing the action mode versus the non-action mode for each domain (N=20)

Unexpectedly, in three out of four comparisons of deltas retrieved from Table 1 and Table 2, the most substantial benefits are observed in other thinking domains, not in sonic thinking. Consistent improvements are specifically pronounced in the visual domain. These results indicate that playing an action audio game generates the most significant improvements in creativity within the visual rather than the auditive realm, thus antagonizing **H2**.

5.3 Do Different Methods of Performance Measurement Entail Consistent Results?

The second analysis looks into methodological relationships, contributing to the estimation of validity in the applied instruments.

H3: Effective Schaeffer's Charades narratives score higher in diverse creative performance metrics (C-Score, fluency, flexibility) than narratives that are non-effective.

Among all originality metrics obtained in this study, one measure stands out for its high quality and robustness. This is the measure of whether stories crafted in the Schaeffer's Charades task are effective or not. Since the test-takers are not used to conveying stories by utilizing a specific set of 24 pictograms or sounds, they have to find a new way in order to effectively convey a story prompt. This caters to the two aspects defining a creative solution, novelty and effectiveness. An objective measure of effectiveness is obtained by four independent judges that need to guess the correct prompt underlying a story. Instead of merely providing expert judgements as to how effective they find the stories (where the answers of judges could be biased or imprecise), a highly precise and non-manipulable effectiveness measure is obtained, because the judges either succeed or fail in identifying the underlying prompt.

By contrast, the originality metric used in this study requires more careful scrutiny into their validity, as it relies on subjective estimates.

As shown in the first column of Table 4, the judges are able to identify the underlying prompt for 21 visual stories. By contrast, the underlying prompt is identified correctly only 11 times with regard to sonic stories.

Furthermore, Table 4 provides twelve comparisons of creative performance metrics, contrasting average scores for effective stories with non-effective ones. Across all twelve comparisons, it is predicted that the average creative performance scores are higher among effective stories than among non-effective ones.

Metric	$\text{Action}_{\text{eff}}$	$\text{Non-Action}_{\text{eff}}$	$\text{Action}_{\text{non-eff}}$	$\text{Non-Action}_{\text{non-eff}}$
Auditive Runs Amount	7	4	13	16
Visual Runs Amount	11	10	9	10
Auditive C-Score	7.04	7.71	6.52	7.29
Visual C-Score	8.83	6.89	6.56	6.99
Auditive Fluency	19.42	17.75	17.77	19.0
Visual Fluency	25.09	17.5	17.77	19.7
Auditive Flexibility	3.52	3.85	4.44	3.39
Visual Flexibility	3.22	3.65	3.22	3.49
Auditive Originality	2.92	2.37	2.96	2.5
Visual Originality	3.22	2.82	3.03	2.53

Table 4. Average scores of effective and non-effective Schaeffer's Charades runs.

Since effective and non-effective stories have different numbers of cases, to test **H3**, the variables are not analyzed for significant differences via t-Tests. Instead, sum-averages across all effective stories versus all non-effective stories are compared, as depicted in Table 5.

Metric	$\text{Performance}_{\text{eff}}$	$\text{Performance}_{\text{non-eff}}$	ΔPerformance
$\text{C-Sore}_{\text{avg}}$	7.69	6.88	0.81
$\text{Fluency}_{\text{avg}}$	20.56	18.58	1.98
$\text{Flexibility}_{\text{avg}}$	3.83	3.42	0.41
$\text{Originality}_{\text{avg}}$	2.83	2.75	0.08

Table 5. Average scores of the performance in effective and non-effective runs of Schaeffer's Charades

$\textit{C-Sore}_{avg}$ refers to the average C-Score from both the visual and sonic stories. For instance, the mean C-Score value for effective stories is computed as 7.69, resulting from (7.04 + 7.71 + 8.83 + 6.89) / 4). This combines C-Scores for effective stories from the auditive domain in the action (7.04) and non-action (7.71) condition, alongside the C-Score for effective stories from the visual domain in the action (8.83) and non-action (6.89) condition.

Likewise, $\textit{Fluency}_{avg}$ and $\textit{Flexibility}_{avg}$ refer to their respective average scores from both the visual and sonic stories. $\textit{Originality}_{avg}$ refers to the average expert rating of originality on behalf of both visual and sonic stories. $\textit{Performance}_{eff}$ refers to the average creative achievement scores among effective stories, while $\textit{Performance}_{non\text{-}eff}$ refers to average creative achievement scores across those stories that were ineffective, as the judges failed to identify the correct underlying prompt.

Effective stories score higher on average for C-Scores (7.63 > 7.205), fluency (25.1 > 23.85), flexibility (3.83 > 3.42) and originality expert ratings (2.83 > 2.75). Therefore, all four comparisons are consistent with **H3**.

5.4 Does the Action Game Intervention Benefit Some Participants More than Others?

This study has found a beneficial impact of playing OrbitCleaner in the action mode on people's subsequent creative performance. However, it might be the case that some people benefit more from the intervention than others. In particular, OrbitCleaner is a digital game, and it is played by sound. Do participants who are more familiar with digital games or audio content benefit more from the intervention compared to novices?

For this assessment, the analysis returns to demographic factors. The study population is split into contrasting groups, depending on whether people score below or above average. First of all, participants who report below-average familiarity with digital games are contrasted with the remaining participants who report above-average familiarity. Similar to section 5.2, delta values are considered that reflect how much people benefit from playing the action game as opposed to the non-action game. The analysis considers delta values for the C-Score, fluency, flexibility, and expert-rated originality across Schaeffer's Charades in the auditive and visual domain, thus encompassing eight delta values. A t-Test for independent samples finds no statistically significant difference across all eight of these benefit scores. Likewise, when the dataset is split based on people's above or below average number of years they have worked in the audio domain, or their self-reported above vs. below average level of auditive ability, no statistically significant difference is found for how much people benefit from the action game intervention.

Overall, playing OrbitCleaner in the action version, as opposed to the non-action version, appears to have a stable effect on people's subsequent creative performance, irrespective of whether people are audio experts or have much experience with digital games.

6 DISCUSSION

The objective of this study is to investigate the impact of playing an action audio game compared to a non-action audio game on individuals' subsequent creative performance. To this end, an audio game named OrbitCleaner has been developed, comprising two analogous play modes: an action mode and a non-action mode. The action mode is designed to induce a wide focus of attention, whereas the non-action mode is intended to induce a narrow focus of attention. This research extends known empirical patterns from the visual to the auditive domain. To test these patterns, a randomized experiment with 20 participants was conducted employing a within-subject design. Participants played both versions of the game and completed a battery of domain-specific creativity tests after each game intervention.

The results demonstrate no consistent increase in creative performance following gameplay of the action game in comparison to the non-action game. However, playing the action game did elicit statistically significant differences in two metrics: fluency and originality in the visual domain. Additionally, in eight out of eleven comparisons, creative performance was found to be higher following gameplay of the action game. This partial support for **H1** may be explained by the action audio games' capacity to encourage a broad focus of attention and increase the cognitive flexibility of participants. This may result in elevated levels of creative performance, in accordance with the creativity theory. These findings may be attributed to two design choices. Firstly, a broad focus of attention may have been induced by the exposure to objects distributed across the entire attentional auditory space, which can emerge from all directions. The mental representation of semantically and locally distant items simultaneously may facilitate the formation of more unconventional idea combinations and, ultimately, foster the generation of more original solutions. Secondly, in the action mode, players must shift their attention between objects. For example, fast-moving items may demand priority treatment compared to slower-moving ones, or objects that inflict greater damage may need to be addressed preferentially compared to less impactful items; this design element promotes cognitive flexibility. The design principle of requiring players to shift their attention back and forth between different objects might stimulate flexible thinking more generally, helping individuals to consider varying options quickly and routinely. This is reflected by the higher flexibility scores observed in the visual domain for both CollaboUse and Schaeffer's Charades, demonstrating a non-domain-specific effect.

It is noteworthy that these effects manifest rapidly, within a few minutes of gameplay. In contrast, the literature reports experience-related benefits in terms of enhanced creative performance in a certain medium after extended exposure periods, such as weeks, months, or years [55, 65]. In this experiment, participants engaged with the action audio content of OrbitCleaner for just five minutes. Consequently, the exposure-related effect of engaging in sonic thinking may unfold only gradually, necessitating much longer and repeated exposure before stronger impacts might be observed.

In addition, the design choices of the non-action mode of OrbitCleaner may help to explain the lack of statistically significant differences. While the non-action mode is less cognitively demanding than the action mode, it may still facilitate a broader focus of attention. As objects are located in different places, albeit not as spread, players still have to mentally follow their changing positions to swiftly interact with them. Consequently, players may have benefited from playing the non-action mode in subsequent creativity tasks, thereby reducing the differences in performance between the two conditions.

A second hypothesis proposed that engaging with the action mode of OrbitCleaner would significantly enhance creative performance, particularly in the sonic thinking domain. To control this, this study utilized a creative storytelling task employing analogous procedures in the visual and auditive domains. Contrary to the hypothesis, the data indicates no such benefits in sonic thinking. Consequently, the effects of exposing participants to sound stimuli in the experiment failed to elicit any unique advantages in the sonic thinking domain. This might be attributed to the limited exposure time allotted in the experiment as well as a difficulty effect. Even participants with audio-based demographics seem to be more accustomed to expressing ideas verbally or through visual storytelling, making sound-based storytelling a relatively unusual task. As evidenced by the findings in **H1**, familiarity with a domain appears to be a substantial requirement to exhibit improvements in creative performance. Consequently, individuals have performed less proficiently in the audio exercise overall. The sonic storytelling task might have been too challenging for participants to reveal slight improvements in sonic thinking ability after just ten minutes of gameplay.

Nevertheless, given that each game intervention lasted only five minutes, the observed increases in creative performance, as measured by various metrics and instruments, indicate a promising pattern. The application of short, audio-based CSTs appears to be a feasible means of eliciting a targeted impact on people's subsequent cognitive performance. This could be an indicator for the accessibility and gaming sector, as well as for the field of HCI, which is concerned with interdisciplinary collaboration and domain-specific tools. Game designers can utilize specifically designed stimuli or even mini-games in phases before or during creativity-demanding sections to prime players. For their ease of integration and other benefits outlined in the introduction, audio stimuli present an excellent fit for these implementations. The development of new applications could provide valuable insights into the potential of audio-based CSTs and pave the way for further research including visually impaired individuals.

7 LIMITATIONS

It is important to acknowledge the limitations of this study. Firstly, the sample size was relatively small, with only 20 participants. Future research may aim to study a larger sample of participants to achieve appropriate statistical power and a higher number of statistically significant differences. Secondly, the sampling strategy was very much a binary one, as the majority of the participants had a musical background. Although no specific benefits in the domain of sonic thinking were found, it is not yet clear whether effects in other domains after playing an action audio game apply to a wider population. Third, the within-subject design employed in this study is susceptible to potential carry-over effects. Despite the absence of evidence that participants who started with the action audio game performed better in the second set of tests than those who started with the non-action version of OrbitCleaner, it cannot be ruled out that carry-over effects may have influenced the results. Appropriate methods of mitigation or further investigation into the long-term persistence of the creative boost can help to eliminate this ambiguity.

8 CONCLUSION AND FUTURE WORK

Despite their growing demand and reputation, audio games remain an incomplete research field. However, the HCI community might be concerned about understanding the effect of audio games on players, as this insight can be leveraged to utilize audio games as creativity support tools. This study has found that playing an action audio game can lead to an increase in creative performance. Additionally, it has identified design goals for audio games in research and audio-based CSTs. For subsequent studies aiming to replicate or expand the impact of action audio games on creativity, it is noteworthy that withholding the game score from participants might prove beneficial, given its potential impact on their emotional state – a factor known to influence creative performance [37, 69]. However, players might be disoriented in the absence of feedback in a digital game and feel less motivated. Furthermore, simplifying the non-action mode, which arguably still contains some low-action elements, may be considered to further minimize cognitive demands. Additionally, the Wisconsin Card Sorting Test [15] may serve as a source of inspiration, as it introduces rule changes on the fly. A similar approach may be endorsed with OrbitCleaner. For example, when an alien collides with the spaceship, it will take control of it. This necessitates a shift in perspective from that of a human to that of an alien. From the perspective of an alien, humans are to be neutralized, while aliens are to be collected. Consequently, the player must be flexible to utilize the action buttons (Q, W) in a swapped manner.

In terms of accessibility, further studies may include creativity tests that can be taken without visual support. Including visually impaired individuals in audio-based studies will present a more holistic picture of human cognition and might provide explicit insights into the domain of sonic thinking. Furthermore, a purely audio-based approach might help to tackle an often recognized weakness of CSTs – their availability to researchers and the public alike [21]. The absence of a visual presentation allows for seamless transitions between in-vitro and in-vivo applications, thus facilitating the integration of CSTs into the work of individuals engaged in creative pursuits, such as musicians, writers, and visual artists. These professionals may be encouraged to engage with such games during break periods.

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