

Translated from English or created in Spanish? The reception of audio description for video games

An experimental pilot study

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Video gaming has gained immense popularity as a form of entertainment all around the world. However, most games are not fully accessible for players with visual disabilities. Audio description (AD) translates visual elements into spoken words, thus making games accessible to players with vision loss. The TransAD4games project aims to explore the creation and translation of audio descriptions for video games to improve game accessibility across languages and cultures. This article presents part of the research findings from the TransAD4games, reporting the outcomes of a reception study on players' preferences and opinion about AD for the game *Before I Forget* (3-Fold Games, 2020) translated from English into Spanish and AD created from scratch in Spanish. Results show that while players preferred the original Spanish AD created from scratch, they also appreciated the translated version, suggesting that translating AD is a viable and acceptable option to improve visual game accessibility.

Keywords: video games, visual game accessibility, audio description, reception study, blind and partially sighted players

1. Introduction

Playing video games offers numerous benefits, including enhancing cognitive skills, improving problem-solving abilities, fostering social connections, and relieving stress (e.g. Granic, Lobel and Engels 2014; Smirni et al. 2021). Despite the widespread popularity of video gaming, with 3.38 billion active gamers in 2023 (Newzoo 2023), many games remain inaccessible to the 1.3 billion people with significant disabilities, who comprise 16% of the global population (WHO 2024). This lack of accessibility poses a significant barrier, as people with disabilities

consistently express a strong desire and need to engage in gaming (Beeston et al. 2018). Xbox estimates that more than 427 million gamers with disabilities actively play video games (Mortaloni 2023). A study conducted by the Accessibility Foundation in Utrecht revealed that around 92% of individuals with some form of disability play video games for an average of 10 hours per week (Bolesnikov, Kang and Girouard 2022). This statistic underscores the importance of making games accessible, as it promotes inclusion and equality in society. Therefore, ensuring that persons with disabilities can fully participate in gaming and enjoy its benefits is crucial.

Game accessibility is defined as “effort, designs, products, and technological features that aim to make games playable by everyone, primarily people with disabilities” (Hassan 2024, 2337). It has been burgeoning in recent years, although game accessibility for users with visual disabilities is particularly challenging due to the inherently interactive and visual nature of the medium (Mangiron and Zhang 2016). Agrimi et al. (2024) advocate for a multimodal approach to the design of accessible games for players with vision loss, combining various sensory inputs to create a more inclusive gaming experience. This approach ensures that games are not only playable, but also enjoyable for everyone, regardless of their visual (dis)abilities. Audio description (AD) can contribute to improving game accessibility by translating visual elements into spoken words, making such content accessible to persons with visual disabilities.

AD is commonly used in films, TV, theatre, and other live performances. In recent years, AD has started to appear in cinematic elements in video games, such as trailers, demos, and cutscenes (Mangiron and Zhang 2022). The first game with professionally produced AD, *The Last of Us Part I* (Naughty Dog 2022), launched in September 2022. This marked a significant milestone in making video games more accessible to persons with visual disabilities. However, most of the AD in games is currently available only in English. Existing research suggests that translating AD scripts for films and TV is a feasible, cost-effective, and time-saving strategy for delivering AD across languages (Jankowska 2015; Jankowska, Milc and Fryer 2017; Liu 2023; López Vera 2006). This approach could potentially be applied to video games as well to make AD available in different languages.

The TransAD4games project explores methods of creating and translating AD for video games to improve accessibility across languages and cultures. As part of the project, an exploratory reception study was conducted on players’ preferences and opinions regarding AD translated from English into Spanish and AD created in Spanish from scratch, using the game *Before I Forget* (3-Fold Games 2020). This article presents the reception study’s findings. After this introduction, a review of game accessibility for blind and partially sighted (BPS) persons is outlined in Section 2. Section 3 describes the research design. Section 4 presents the

findings regarding players' preferences and their opinion about the different types of AD. The article concludes offering insights into the effectiveness of translating AD in video games and suggesting directions for future research in this emerging field.

2. Game accessibility for persons with visual disabilities

Video games, as interactive media, present three primary accessibility challenges (Yuan, Folmer and Harris 2011, 3):

1. Stimulus reception: Users may struggle to receive visual, auditory, or tactile stimuli. For instance, blind players might not process stimuli presented solely in visual formats, such as text and images.
2. Response determination: Players may find it difficult to establish the appropriate actions needed to progress in the game. This can occur if the stimuli are not received or are too complex to process.
3. Input provision: Once an action is decided, some users may be unable to provide input due to the interface device's complexity. This issue predominantly affects players with motor disabilities and those with cognitive disabilities, who may struggle with intricate controls. For blind users, using the mouse can be challenging.

The interaction of BPS users with a video game is often hindered in the first stage, as they cannot receive the stimuli from the game that are only presented in visual or textual format. And if they cannot receive the stimuli, they cannot determine what to do next nor provide input to the game to progress. Thus, accessibility barriers are likely to reduce their gameplay experience or may even prevent them from playing a game (Bolesnikov, Kang and Girouard 2022; Mangiron 2024, Yuan, Folmer and Harris 2011). Traditionally, BPS persons have played audio games, designed to be played without relying on visual elements, using only sound to convey all necessary information about the game world, actions, and events. The first audio game is generally considered to be *Touch Me*, released by Atari in 1974. This arcade game featured a series of lights that would flash with accompanying tones, and players had to reproduce the sequence by pressing corresponding buttons (Prazaru et al. 2020). However, while audio games have greatly expanded gaming opportunities for BPS persons, they often serve as a workaround that can isolate them from the mainstream gaming community they wish to join, rather than integrating them (Urbanek and Gldenpfennig 2019).

There are several technologies that can improve visual game accessibility, such as haptification and visual to auditory conversion. Haptification involves

using tactile feedback to substitute visual information. This feedback uses vibrations, forces, or motions to simulate the sense of touch, providing players with tactile sensations that correspond to in-game actions (Khusro et al. 2022). Haptic feedback can guide players through virtual environments by simulating textures, obstacles, and pathways, making it easier to explore and interact with the game world (Khusro et al. 2022). Several widely available haptic devices enhance accessibility:

1. Haptic gloves: Devices like the HaptX Gloves G1 simulate the sensation of touch, helping users interact with virtual objects and environments.
2. Haptic vests and suits: Wearables such as the Teslasuit provide full-body haptic feedback, allowing users to feel physical sensations across their body.
3. Joysticks and game controllers: Most of these devices include vibration feedback to enhance the gaming experience and provide tactile cues.

In addition to haptic feedback, visual to auditory conversion techniques are often used to increase visual accessibility, such as sonification, text-to-speech, and sound-based cues (Agrimi et al. 2024). Sonification in game design refers to the process of using sound to convey information about game objects, events, or environments (Sekhavat et al. 2022). This technique translates data into auditory cues, allowing players to perceive and interpret information through sound. Sonification can enhance the gaming experience by adding layers of feedback and immersion, particularly for BPS players, by using variations in sound pitch, volume, or rhythm to indicate proximity of objects, intensity of actions, or changes in the game environment (Sekhavat et al. 2022).

Also, BPS players rely on screen readers to interact with computers, smartphones, and other devices. Screen readers convert the contents of the graphical user interface into audio via a text-to-speech module or into Braille via a Braille display. Braille displays are hardware devices that translate text from a computer into Braille (Prazaru et al. 2020). If an application, such as a game, is not accessible to screen readers, it becomes nearly impossible for a BPS player to use it without assistance from a sighted person. This can lead to frustration, counteracting the primary goal of a game, which is to entertain players (Bolesnikov, Kang and Girouard 2022).

Another important feature that can foster visual game accessibility is AD, which is widely used in other audiovisual media. However, its presence in video games is a recent phenomenon, although there have been voices from the industry, academia and the community advocating for its inclusion for over a decade. As regards the industry, the Game Accessibility Guidelines (Ellis et al. 2012/2023) propose including AD as an advanced accessibility feature in cut-scenes, especially where gameplay is already accessible through sound design or text-to-

speech. The guidelines also highlight the challenges with dynamic real-time content AD. Moreover, Microsoft's Xbox Accessibility Guidelines (2023) include Guideline 111, "Audio Descriptions," which aims to ensure full motion videos and in-game cinematic events provide an audio track describing essential visual information. As regards other in-game areas where AD could be implemented, Microsoft (2023) mentions in-game advertisements or promotional videos for downloadable content and tutorials or in-game "how-to" guides that are prerecorded and scripted.

From academia, in 2016 Mangiron and Zhang advocated for the inclusion of AD in the cinematic scenes of mainstream games, starting with genres like story-driven action games, role playing games, and visual novels that do not require a fast response from the player. In 2019, the RAD project (Researching Audio Description: Translation, Delivery and New Scenarios) at Universitat Autònoma de Barcelona investigated user preferences for AD in games by means of a survey that obtained 106 valid responses and 15 follow-up interviews (Larreina-Morales and Mangiron 2024). Results showed that AD was the second most popular accessibility option after screen readers, and that participants would like to have AD implemented in both cinematics and gameplay for information about scenarios, objects, and characters (Larreina-Morales and Mangiron 2024).

In 2021, the AD4Games project, funded by the Brinstow Institute at the University of Bristol, was conducted with the aim of investigating how AD can improve game accessibility by working with professional audio describers, game developers, and persons with visual disabilities (Zhang, n. d.). In 2022, the follow-up project, TransAD4games, in which this article is framed, was carried out with the objective of establishing whether translating AD would be a feasible option to increase visual game accessibility in different languages.

Also in 2022, Mangiron and Zhang proposed adding audio introductions to games for main characters and scenarios. They also emphasized the need to design games with accessibility in mind from the pre-production stage to avoid costly reprogramming and suggested using a distinct voice for the AD to address challenges like non-linearity and sound interference (Mangiron and Zhang 2022).

In 2023, Larreina-Morales, Di Rosa, and Dupire reported on the development of *Death of Internet* (Cnam-Enjmin 2023), a single-player, first-person, point-and-click game for PC, which was developed by a group of MA students with the assistance of an AD researcher as part of their Master's project in game development. The game features a "Blind Mode" with Point of Interest navigation and dynamic AD for scenarios, objects, and events. Text-to-speech technology was also used to read all on-screen text.

In addition to industry guidelines and academic research, since 2018 the Transcribing Games Project (Sightless Kombat 2023), led by blind British player

Sightless Kombat, provides AD transcripts for several commercial games,¹ such as *God of War* (SIE Santa Monica Studio, 2018), *Mortal Kombat* for the PlayStation 3 (NetherRealm Studios 2011), *Mortal Kombat 10* (NetherRealm Studios 2015), and the opening scene of *Bioshock 2k Boston* and *2K Australia* 2007. The project's website also offers links to videos with examples of audio described scenes for other games.

As regards the inclusion of AD in video games, in 2020, Ubisoft began audio describing the trailers of some of their games, such as *Assassin's Creed Valhalla* (Ubisoft 2020), although this did not increase access to video games for BPS players, as in-game cutscenes were not described. In 2022 several titles were released featuring AD, such as *The Last of Us Part I* (Naughty Dog 2022), the first mainstream commercial game to feature AD in different languages. In addition, several indie games also included dynamic English AD for gameplay, such as *Cyberchase: Duck Dash* (Bridge Multimedia 2022), *Brok the InvestiGator* (COWCAT Games 2022), and *Stories of Blossom* (Soft Leaf Studios 2022). These games include AD to describe locations, characters, scenes, and event sequences, combining AD with other accessibility features, such as text-to-speech.

Subsequently, other mainstream games have incorporated AD. For instance, *Forza Motorsport* (Turn Studios 2023) includes AD in the cinematics in English. Similarly, *Mortal Kombat 1* (NetherRealm Studios 2023) features English AD for the cinematics of fatalities, the dramatic finishing moves in fights. *Marvel's Spider-Man 2* (Insomniac Games 2023) includes AD in different languages for cinematic scenes. The inclusion of AD in games is becoming more common, enhancing accessibility for BPS players, although in most cases it is only available in English. As a result, those games remain inaccessible for BPS players who speak other languages. Effectively implementing AD across languages is thus essential for future development, ensuring that gamers who speak languages other than English can enjoy these advancements. Against this background, the current study was conducted to investigate players' preferences for different AD styles, working with English and Spanish, two of the working languages of the researchers.

3. Research design

The growing trend of including AD in video games highlights the importance of this accessibility feature, although it presents a more significant challenge than AD in other media because both dynamic AD during gameplay and non-dynamic AD for cinematic scenes would be required to make a video game

1. For details, please see <http://www.transcribinggames.sightlesskombat.com>.

more accessible for BPS players. In AD4Games, a previous project, AD was created and implemented in the game *Before I Forget* (3-Fold Games, 2020). It is a slow-paced, story-driven environmental narrative game, nominated for a 2021 British Academy Games Award in the Game Beyond Entertainment category. In *Before I Forget*, the player guides Sunita Appleby, a scientist with early-onset Alzheimer's disease, to navigate through her house. Interacting with various objects triggers memories and helps her remember her past. The game is played from a first-person perspective, and the player must solve puzzle-like elements, such as remembering where certain mementos are. The game includes dynamic AD for the main scenarios and for the objects the player can interact with. When players walk into a new room, they can press a button that delivers the description of the room. When they approach an object, if they can interact with it, they can hear a sound cue, and by pressing a button they can hear the item description. The game also includes other accessibility features, such as an audio tutorial, subtitles with a customisable font, and text-to-speech technology that reads aloud other textual elements, such as inserts, e-mails, and notes. The version with English AD was tested with English-speaking players in the UK, and results, which are forthcoming, indicated that AD enhanced accessibility for BPS players.

Building on the research findings and outcomes of the AD4Games project, the TransAD4Games project aims to explore ways to make an audio described game available in different languages, such as Spanish, and to elicit whether BPS players would prefer AD originally made in Spanish or AD translated from English into Spanish. First, the English AD was translated by a professional translator, while a professional audio describer created the Spanish AD from scratch. Then, the translated AD scripts were voice recorded in Spanish and integrated into the game, which had already been localized into Spanish, but lacked AD. Next, the game developer prepared and tested the Spanish version of the game with AD. Once the Spanish version containing AD was available, an exploratory reception study with four participants was conducted. Due to the challenges of recruiting blind and low vision participants, convenience sampling was employed, but only four persons agreed to take part in the study. Two participants (P₁, P₄) were acquaintances of one of the researchers, while the other two (P₂, P₃) were referred by P₁.

The tests were conducted both face-to-face (P₁, P₃) and online via Microsoft Teams (P₂, P₄), to facilitate participation. During the online tests, participants shared their screens, allowing researchers to observe their faces and reactions in a small window. The length of the study was approximately two hours per participant, an hour playing the game and an hour for a pre-playing questionnaire and a post-playing questionnaire. The pre-playing questionnaire gathered information about participants' profiles, their usage of AD, gaming habits, and visual

disability (see Table 1). This helped us understand the background of each participant. The post-playing questionnaire included questions about participants' preferred style of AD (see Tables 2, 3, 4 and 5) and an open-ended question about their overall experience and any additional feedback on the experiment, AD or game accessibility. All the required ethical standards were followed, and the project was approved by the Research Ethics Committee at the University of Bristol.

Among the participants, P1, P2, and P3 had low vision, while P4 was blind (see Table 1). Three participants were male and one female. All participants shared a common interest in gaming, despite varying levels of engagement and different gaming platforms, such as mobile phones, tablets, computers, PlayStation, and Xbox. Their experience with AD varied, with two participants regularly using it (P1, P4), one seldom using it (P3), and one never using it (P2). Their game preferences also differed, ranging from turn-based and simulation games to Massively Multiplayer Online Role-Playing Games (MMORPGs) and narrative adventures. Despite these differences, their shared experiences in gaming and accessibility highlight the diverse ways players with visual disabilities interact with video games.

To determine participants' preferred AD style, in the post-playing questionnaire they were asked to listen to two sets of AD: one created from scratch and one translated. The order of presentation was randomized to prevent participants from identifying which was the translated AD and which was the original AD. Participants were then asked to choose their preferred AD style for each fragment and explain their choice, and their responses were meticulously noted for analysis. This approach allowed gathering detailed insights into participants' preferences and the effectiveness of each AD style.

Six script fragments were used, including four item descriptions (a magazine, a framed photograph, and two descriptions of a constellation map which are part of a mini game) and two room descriptions (the study and the bathroom). The reasons for choosing these specific examples were mainly three: (a) to include a varied sample of items that were important to gather information about the story, the characters, and the setting; (b) to test the reception of AD related to gameplay and game mechanics, and (c) to include fragments in which there were significant differences between the translated AD and the AD created from scratch, as the original Spanish AD was longer, more detailed and literary (see Zhang and Mangiron 2025). Also, the translated AD and the original Spanish AD included different information regarding controls, as the original Spanish AD talked about using the mouse, and the translated AD referred to the arrow keys, which are more accessible for players with vision loss. The full excerpts are available in Table A1 in the Appendix.

Table 1. Participants' profile

Participant	Profile
P1	Thirty-year-old male. He is interested in games and plays occasionally. He plays on his mobile phone or tablet. He tends to play games that do not involve immediate actions or reactions that rely on visual input and instead prefers turn-based or simulation games. He has 25% vision. He always uses AD if it is available, in Video on Demand platforms and theatre plays.
P2	Twenty-seven-year-old female. She describes herself as an avid gamer. She mainly plays on her computer. She tends to play MMORPGs, such as <i>World of Warcraft</i> (Blizzard 2004 – to date), or games such as <i>Dark Souls</i> (FromSoftware 2011/2018) or <i>Portal</i> (Valve Corporation 2007), despite finding them difficult to play. She has 25% vision. She has never used AD and thinks there is not a wide offer of movies and series with AD.
P3	Thirty-two-year-old male. He does not usually play games nowadays, but he used the PlayStation console in the past. He likes games such as <i>Dark Souls</i> (FromSoftware 2011/2018). He has 18% vision. He usually does not activate AD because he has enough residual vision to see what is happening. However, his partner uses AD and P3 sometimes notices things that he would not have noticed without the AD.
P4	Thirty-six-years-old male. He describes himself as a gamer. He plays everything he can. He thinks playing in the PS5 is easier than in the PC. He also plays with the Xbox, the PC and a little with his mobile. His favourite genre is narrative adventure. He is totally blind since he was 18. He is a regular user of AD.

4. Findings and discussion

The exploratory study revealed that the original Spanish AD was mostly preferred. Tables 2, 3, 4 and 5 indicate which was the preferred AD style for each participant for the six AD excerpts that were tested (marked with an x), which are available in Table A1 in the Appendix, and the reasons why.

Table 2. Participant 1 preferred AD style

Example	Translated ES AD	Original ES AD	Reasons
1		x	It is more complete and allows one to create a mental image of the object, the context, and the character's environment.
2		x	It describes the people in the image, so one can form a mental image.
3	x		P1 prefers to play with the arrow keys; using the mouse can be more cumbersome for someone with vision loss. The other AD option does not mention the keys and instead instructs the player to use the mouse.
4		x	This AD version describes the portrait of the woman without outright saying she is Indian, which allows the player to form a mental image based on the information given.
5		x	The more information you are given, the better.
6	x		P1 prefers to play with the arrow keys. The other option does not mention the keys and instead instructs the player to use the mouse. Nevertheless, the participant also stated that the more detailed description created a more detailed mental image.

P1 preferred longer and more detailed descriptions, because they allowed him to create an accurate mental image of what was happening on the screen. However, there were two occasions in which he preferred the translated AD, when instructions were provided about how to play the game. This is because the translated AD talks about the arrow keys and the original Spanish AD mentions the mouse. In this case, the preference had to do with game mechanics and playability, as BPS players have difficulties using the mouse.

Table 3. Participant 2 preferred AD style

Example	Translated ES AD	Original ES AD	Reasons
1		x	It is more complete, with more headlines in the magazine, and the description of the woman helps you imagine her.
2		x	It gives the listener more information about the photo, even if certain elements, such as the guests, might seem superfluous. An audio description must be like a book and give you all the necessary information so that you can imagine the characters.

Table 3. (continued)

Example	Translated ES AD	Original ES AD	Reasons
3		x	It gives the player more information and describes where the stars are.
4		x	It provides more information, although P2 also liked the other version of this AD. P2 believed it might be a good idea to allow the player to speed up the audio description.
5	x		P2 preferred the use of the word <i>translúcida</i> ("translucent") over <i>mate</i> ("matte").
6		x	It provides more information, although the player must pay careful attention not to miss anything.

P2 preferred the original Spanish AD in all instances except one. She preferred it because it provided more information and helped her imagine the scene and the characters better. In the only instance in which she preferred the translated Spanish AD it was because she preferred one term to another, so it was a stylistic choice. In addition, she mentioned that it would be good if the AD could be sped up, which is related to gameplay and the possibility of progressing faster in the game. This is a feature that could be considered when implementing dynamic AD in games.

Table 4. Participant 3 preferred AD style

Example	Translated ES AD	Original ES AD	Reasons
1		x	It is more descriptive.
2		x	It contains more information.
3		x	It contains more information than the alternative.
4		x	It is more descriptive.
5		x	It is more descriptive and contains more information.
6		x	It is more descriptive and contains more information than the alternative.

P3 preferred the original Spanish AD in all instances, always stating that it was more descriptive, and that it contained more information than the translated AD. He did not provide more details, but he showed a clear preference for the original Spanish AD.

Table 5. Participant 4 preferred AD style

Example	Translated ES AD	Original ES AD	Reasons
1		x	It first describes the character objectively and then it names her. It also provides more information about the magazine.
2		x	P4 selected the original ES AD, although he stated that he was not quite satisfied with any of the versions. He suggested starting with the first one and then continuing with the second one, so that you would also have the name of the characters in the AD.
3		x	It provides more information and explains in more detail how to play.
4	x		It mentions that the woman is Indian, which may be relevant for gameplay. P4 said that the information should be provided at the same time that the sighted player will discover it, so that it does not alter the gameplay experience.
5		x	It is more literary. P4 found the first description more objective and shorter. However, he also thought they were both rather long and said that when there was too much information, he felt mentally exhausted.
6	x		Some of the information provided in the other description was not important. The original ES AD contained too much information, and it was impossible to remember it all, so he switched off.

P4, who is the only blind player, also preferred the original Spanish AD in general, because it was more detailed and more literary. However, in two instances he preferred the translated AD. In example 4, where the portrait of an Indian woman is described, he liked the fact that her ethnicity was mentioned. It is the opposite of what P1 felt, who did not like that her ethnicity was mentioned. This highlights how difficult it can be to find an AD that suits everybody's tastes, as personal preferences may differ. It should also be highlighted that in the UK, several AD scholars and practitioners are advocating that information on ethnicity should be provided, not to assume that everybody is white by defect (Fryer, 2016; Hutchinson, Thompson and Cock, 2020). However, Spanish AD guidelines do not include information about ethnicity, although scholars such as Jiménez Hurtado (2007) include it as one of the features that can be described about characters.

P4 also preferred the translated AD in example 6, about the constellation map, because the original Spanish AD provided too much information. He felt overwhelmed and could not remember everything and he was afraid he would miss something important during gameplay. Therefore, the degree of detail that participants would like to have in the AD may depend on personal preferences or in the degree of vision loss. The blind participant thought he would like to have less information in some instances because the cognitive effort he had to make to remember all the information was higher, as he was only relying on the AD, unlike the other participants, who had residual vision. The question of what content should be described and to what extent remains a subject of ongoing discussion (see, for example, Remael, Reviers, Vercauteren 2025; Schaeffer-Lacroix, Reviers, and Di Giovanni 2023; VocalEyes, 2024) and it has not been researched in relation to video games nor dynamic AD. Larger-scale studies with more blind participants are needed to determine the type and amount of information that should be included in video game AD to facilitate gameplay.

As a summary, looking at the aggregate results of all participants, they preferred the original Spanish AD 19 times out of 24 and the translated Spanish AD 5 times out of 24 (see Figure 1).

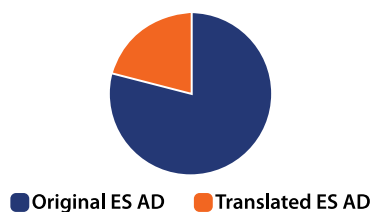


Figure 1. Players' preferred AD style

However, in the post-experiment discussion, when participants were asked whether they thought that translating AD would be a feasible option to include AD in video games, they all replied "Yes". Previous studies have also demonstrated that participants are receptive to translation as a means of enhancing the availability of AD, such as Jankowska (2015) and Liu (2023). In addition, participants felt that it was important to include AD for different reasons. For example, P1 felt that AD made the game more "poetic and immersive, like a story taken from a book". P2 stated that she appreciated being able to hear the main information needed to progress in the game. P3 remarked that the descriptions were excellent, as they did not make the game easier, but instead they simply described the room the player was in. P4, the blind player, found the AD helpful, but not sufficient to make the game accessible for blind users. He had difficulty locating the items available for interaction, which were the ones that included

AD. He suggested using spatial audio to provide cues and to indicate where the sounds were coming from. This solution has also been mentioned by blind participants in other studies (see Larreina-Morales and Mangiron, 2024).

The reasons why participants preferred the original AD primarily included its greater detail and literary quality, which helped them form a more vivid mental image of the scene (see Tables 2, 3, 4 and 5 to see participants' comments). In a couple of instances, players also referred to the gameplay experience, either indicating they preferred one version over the other one because of the description of the controls (P1, Examples 3 and 6) or suggesting the possibility of being able to speed up the AD to facilitate gameplay (P2). P4 also stated that in some cases the AD included too much information that may saturate blind players, although he also said that the AD should provide the same information that sighted players receive in order not to alter the gameplay experience. However, participants with low vision did not object to the amount of information provided. As P4 could only rely on the AD, the cognitive effort he needed to make to retain all the information and interact with the game was probably higher and, therefore, more concise descriptions may have helped him progress in the game more efficiently. Existing literature on how long AD should be and the kind of information that should be included mainly focuses non-interactive AD. However, in this case, it was dynamic AD during gameplay: players did not only need to listen to the AD, they also had to provide input to the game based on the AD in order to progress. Therefore, further studies about dynamic AD in games, with more participants and a more balanced sample of blind and low-vision participants, would be necessary to determine the appropriate amount of information provided by video game AD.

As regards the overall accessibility of the game, P4 felt that although the game included AD and text-to-speech technology, it was not fully accessible for blind players, as players needed to navigate through the different rooms and there was no navigation assistance. Therefore, although AD improves accessibility for with BPS players, it must be combined with other accessibility features to make a game fully accessible, such as spatial sound, sound cues and navigation assistance from one point of interest to another point of interest in the game.

Although this exploratory reception study of AD in games is pioneering, as it is the first of its kind, it is important to acknowledge its limitations. The sample size was limited to four participants, which does not represent the broader population of BPS players. Also, due to recruitment difficulties, the sample was not balanced, as there were three players with low vision and only one blind player; three males and only one female, and their gaming experience varied. However, as already mentioned, the nature of the experiment was exploratory, and the main objective was to detect possible trends that can be further explored in larger scale future studies. Moreover, other reception studies related to video games and audio

games involve smaller sample sizes, such as O'Hagan's (2009) study on the game-play experience of a single player, the study by Araújo et al. (2017), with two blind users, and Borges and Campos's research (2017) with one blind user and one sighted user.

Another limitation of the study is that participants only played the game with one version of AD before being presented with six excerpts with both AD styles at the end. Ideally, the game should have included both versions of AD, allowing participants to experience them directly during gameplay. Alternatively, having different groups play each version and comparing their data could have provided more robust insights.

Despite these limitations, the study emphasizes the need for game developers to prioritize high-quality AD, either translated or created from scratch, to improve accessibility for BPS persons, who would play more games if they were more accessible (Larreina-Morales and Mangiron, 2024). Additionally, the findings highlight the need for integrating AD with other accessibility features, such as text-to-speech technology, screen readers, spatial sound, auditory cues, and navigation assistance. These results can contribute to the existing body of literature in Translation Studies and Accessibility Studies by introducing dynamic AD and exploring its application in the realm of video games. They also stress the importance of understanding players' needs and preferences, thereby underscoring the crucial role of translation as a strategy for making video games accessible across different languages.

5. Conclusions

AD in video games is a very recent phenomenon that still requires academic attention, especially because games can include dynamic AD, during gameplay, and non-dynamic AD in cutscenes, which is similar to the AD used in other audio-visual media. The objective of this study was to elicit the opinion of blind and low vision players about translated AD and AD made from scratch in Spanish, to assess whether translating AD could be a viable option to increase the presence of AD in video games across languages. The findings reveal that AD made the game more playable and accessible for all participants, and that they had a strong preference for the original Spanish AD over the translated AD. The original Spanish AD's detailed and comprehensive nature was highly valued, as it significantly enhanced the players' ability to visualize and engage with the game. This could be because the original Spanish AD followed the style and norms of AD used in other media in Spain, with which participants were familiar. However, participants also thought the translated AD was acceptable and even preferred it in 5 out

of 24 instances, so translating AD could be a cost-effective way to include AD in more games and languages.

Future research should continue to explore the impact of different AD styles on the gameplay experience. Also, investigating ways to optimize dynamic AD for various gaming genres and platforms could further enhance accessibility. Additionally, expanding the sample size and including a more diverse group of participants, with more blind players, would provide a more comprehensive understanding of players' needs and preferences. The next step of the project consists of a follow-up experiment, which will be conducted in China, to replicate the study in a different cultural setting and with more users.

In conclusion, translating AD seems like a feasible and cost-effective option to enhance game accessibility. By incorporating AD in their games in different languages, game developers can create more inclusive and enjoyable gaming experiences for players with visual disabilities of different cultural backgrounds. The insights gained from this research could not only inform future accessible game development practices but could also contribute to the broader goal of making digital entertainment accessible to all.

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References

-  Agrimi, Emanuele, Chiara Battaglini, Davide Bottari, Giorgio Gnecco, and Barbara Leporini. 2024. "Game accessibility for visually impaired people: a review." *Soft Computing* 28, 10475–10489.

-  Araújo, Maria C. C., Agebson R. Façanha, Ticianne G. R. Darin, Jaime, Sánchez, Rossana M. C. Andrade, and Windson Viana. 2017. "Mobile audio games accessibility evaluation for users who are blind" in *Lecture Notes in Computer Science: Vol. 10278 LNCS*, edited by Margherita Antona and Constantine Stephanidis. Springer.
-  Beeston, Jean, Christopher Power, Paul Cairns, and Mark Barlet. 2018. "Characteristics and motivations of players with disabilities in digital games." *ArXiv preprint*.
-  Bolesnikov, Adrian, Jin Kang, and Audrey Girouard. 2022. "Understanding tabletop games accessibility: exploring board and card gaming experiences of people who are blind and low vision." In *Proceedings of the Sixteenth International Conference on Tangible, Embedded, and Embodied Interaction*, 1–17. Association for Computing Machinery.
-  Borges, Olimar Texeira, and Campos, Marcia de Borba. 2017. "I'm blind, can I play? Recommendations for the development of audiogames." in *Lecture Notes in Computer Science, Vol. 10278 LNCS*, edited by Margherite Antona and Constantine Stephanidis. Springer.
- Ellis, Barrie, Gareth Ford-Williams, Lynsey Graham, Dimitris Grammenos, Ian Hamilton, Ed Lee, Jake Manion, and Thomas Westin. 2012/2023. "Game accessibility guidelines". Accessed July 3, 2024. <http://gameaccessibilityguidelines.com>
-  Fryer, Louise. 2016. *An introduction to audio description: A practical guide*. Routledge.
-  Granic, Isabela, Adam Lobel and Rutger C. Engels. 2014. "The benefits of playing video games." *American psychologist*, 69(1): 66–78.
-  Hassan, Lobna. 2024. "Accessibility of games and game-based applications: A systematic literature review and mapping of future directions." *New Media & Society*, 26(4): 2336–2384.
- Hutchinson, Rachel, Thompson, Hannah, and Matthew Cock. 2020. "Describing Diversity: An exploration of the description of human characteristics and appearance within the practice of theatre audio description." VocalEyes. Accessed July 3, 2024. <https://vocaleyes.co.uk/describing-diversity-report-published/>
-  Jankowska, Anna. 2015. *Translating audio description scripts: Translation as a new strategy of creating audio description*. Peter Lang.
- Jankowska, Anna, Michał Milc, and Louise Fryer. 2017. "Translating audio description scripts... into English." *SKASE Journal of Translation and Interpretation*, 10(2): 1–16. http://www.skase.sk/Volumes/JTI13/pdf_doc/01.pdf
- Jiménez Hurtado, Catalina. 2007. "De imágenes a palabras: la audiodescripción como una nueva modalidad de traducción y de representación del conocimiento" [From images to words: audio description as new modality of translation and knowledge representation], in *Quo vadis Translatologie?*, edited by Wotjak Gerd, 143–160. Frank and Timme.
-  Khusro, Shah, Babar Shah, Inayat Khan, and Sumayya Rahman. 2022. "Haptic feedback to assist blind people in indoor environment using vibration patterns." *Sensors*, 22(1), 361: 1–20.
-  Larreina-Morales, Maria Eugenia, Alan Di Rosa, and Jérôme Dupire. 2023. "Gameplay Audio Description: Death of Internet as a Pilot Study." in *Entertainment Computing – ICEC 2023. ICEC 2023. Lecture Notes in Computer Science*, Vol. 14455, edited by Paolo Ciancarini, Angelo Di Iorio, Helmut Hlavacs, and Francesco Poggi, 335–340. Springer.

- doi Larreina-Morales, Maria Eugenia, and Carme Mangiron. 2024. "Audio description in video games? Persons with visual disabilities weigh in." *Universal Access in the information Society*, 23(2): 577–588.
- doi Liu, Yuchen. 2023. "Audio description translation from Spanish into Chinese as an alternative to creating audio description: A reception study." *Parallèles*, 35(2), 1–20.
- López Vera, Juan Francisco. 2006. "Translating audio description scripts: the way forward? Tentative first stage project results." in *MuTra 2006 Audio Visual Translation Scenarios: Conference proceedings*, edited by Mary Carroll, Heidrun Gerzymisch-Arbogast and Sandra Nauert. Saarland University. https://www.euroconferences.info/proceedings/2006_Proceedings/2006_Lopez_Vera_Juan_Francisco.pdf
- doi Mangiron, Carme, and Xiaochun Zhang. 2016. "Game accessibility for the blind: Current overview and the potential application of audio description as the way forward." in *Researching audio description: New approaches*, edited by Anna Matamala, and Pilar Orero, 75–95. Palgrave Macmillan.
- doi Mangiron, Carme, and Xiaochun Zhang. 2022. "Video games and audio description." in *The Routledge Handbook of Audio Description*, edited by Christopher Taylor, and Elisa Perego, 377–390. Routledge.
- Microsoft. 2023. "Xbox Accessibility Guideline 111: Audio descriptions." Accessed August 19, 2024. <https://learn.microsoft.com/en-us/gaming/accessibility/xbox-accessibility-guidelines/111>
- Mortaloni, Anita. 2023. "Xbox Celebrates Commitment to Accessibility on Global Accessibility Awareness Day 2023." *Xbox Wire*. Accessed August 19, 2024. <https://news.xbox.com/en-us/2023/05/18/xbox-celebrates-commitment-to-accessibility/#:~:text=Improved%20Xbox.com%20Experience&text=A%20new%20update%20on%20the,with%20over%2017%20supported%20languages>
- Newzoo. 2023. "Global Games Market Report." *Newzoo*. Accessed August 19, 2024. <https://newzoo.com/resources/trend-reports/newzoo-global-games-market-report-2023-free-version>
- O'Hagan, Minako. 2009. "Towards a cross-cultural game design: an explorative study in understanding the player experience of a localised Japanese video game." *The Journal of Specialised Translation* 11, (1): 211–233. https://jostrans.soap2.ch/issue11/art_ohagan.php
- doi Prazaru, Anca, Oana Balan, Alin Moldoveanu, Florica Moldoveanu, Anca Morar, and Silviu Ivascu. 2020. "Overview on visually impaired gamers and game accessibility." in *EDULEARN20 Proceedings*, 5491–5501. IATED.
- Remael, Aline, Nina Reviers, and Gert Vercauteren. 2015. *Pictures painted in words: ADLAB audio description guidelines*. EUT Edizioni Università di Trieste. <https://www.openstarts.units.it/entities/publication/be626243-8361-4b94-a74e-05224e6120ae/details>
- doi Schaeffer-Lacroix, Eva, Nina Reviers, and Elena Di Giovanni. 2023. "Beyond Objectivity in Audio Description: New Practices and Perspectives." *Journal of Audiovisual Translation* 6(2): 1–7.
- doi Sekhavat, Yoonas A., Mohammad Reza Azadehfar, Hossein Zarei, and Samad Roohi. 2022. "Sonification and interaction design in computer games for visually impaired individuals." *Multimedia Tools and Applications*, 81(6): 7847–7871.
- SightlessKombat. 2023. "Transcribing Games: Game Transcripts and Guides Index". Accessed 3 July 2024. <http://www.transcribinggames.sightlesskombat.com>

-  Smirni, Daniela, Elide Garufo, Luca Di Falco, and Gioacchino Lavanco. 2021. "The playing brain. The impact of video games on cognition and behavior in pediatric age at the time of lockdown: A systematic review." *Pediatric reports*, 13(3): 401–415.
-  Urbanek, Michael, and Florian Güldenpfennig. 2019. "Unpacking the audio game experience: Lessons learned from game veterans." in *Proceedings of the annual symposium on computer-human interaction in play*, edited by Joan Arnedo and Lennart E. Nacke, 253–264. Association for Computing Machinery.
- VocalEyes. "Resources." Accessed October 3, 2024. <https://vocaleyes.co.uk/services/resources/>
- WHO. 2024. "Disability." Accessed August 19, 2024. https://www.who.int/health-topics/disability#tab=tab_1
-  Yuan, Bei, Eelke Folmer, and Frederick C. Harris. 2011. "Game accessibility: a survey." *Universal Access in the information Society*, 10(1): 81–100.
- Zhang, X. n. d. "AD4Games." Accessed August 19, 2024. <https://brigstowinstitute.blogs.bristol.ac.uk/2022/05/23/ad4.games/>
-  Zhang, Xiaochun, and Mangiron, Carme. (2025). Audio description in video games? Translation or Creation. *Babel*. https://benjamins.com/catalog/babel.24170.zha?srltid=AfmBOor3IaOHTneBTnD_hgW5ceONtmZEL63EgTvwUOof4J74STj-SE_.

Gameography

- 2K Boston, 2K Australia. *BioShock*. 2K, 2007. <https://store.steampowered.com/app/7670/BioShock/>
- 3-Fold Games. *Before I Forget*. 3-Fold Games, 2020. https://store.steampowered.com/app/1126600/Before_I_Forget/
- Atari. *Touch me*. Atari, 1974.
- Blizzard Entertainment. *World of Warcraft*. Blizzard Entertainment, 2004 — to date. <https://worldofwarcraft.blizzard.com/>
- Cnam-Enjmin. *Death of Internet*. Cnam-Enjmin, 2023. <https://manaut.itch.io/death-of-internet>
- COWCAT Games. *Brok the InvestiGator*. COWCAT Games, 2022. <https://www.brokgame.com/>
- FromSoftware. *Dark Souls*. FromSoftware (Japan), Namco Bandai (USA), 2011/2018. <https://es.bandainamcoent.eu/dark-souls/dark-souls-remastered>
- SIE Santa Monica Studio. *God of War series*. Sony Interactive Entertainment, 2005 — to date. <https://www.playstation.com/en-us/god-of-war/>
- Insomniac Games. *Marvel's Spider-Man 2*. Sony Interactive Entertainment, 2023. <https://www.playstation.com/es-es/games/marvels-spider-man-2/>
- Naughty Dog. *The Last of Us Part I*. Sony Interactive Entertainment, 2022. <https://www.playstation.com/es-es/games/the-last-of-us-part-i/>
- NetherRealm Studios. *Mortal Kombat 1*. Warner Bros. Interactive Entertainment, 2023. <https://www.mortalkombat.com/en-us>
- NetherRealm Studios. *Mortal Kombat X*. Warner Bros. Interactive Entertainment, 2015. https://store.playstation.com/es-es/product/EP1018-CUSA00970_00-MORTALKOMBATX000/

- NetherRealm Studios. *Mortal Kombat 1*. Warner Bros. Interactive Entertainment, 2011. <https://www.mortalkombat.com/en-us>
- Soft Leaf Studios. *Stories of Blossom*. Soft Leaf Studios, 2022. https://store.steampowered.com/app/1581680/Stories_of_Blossom/
- Turn 10 Studios. *Forza Motorsport*. Xbox Game Studios, 2023. <https://www.xbox.com/es-ES/games/forza-motorsport>
- Ubisoft Montreal. *Assassin's Creed Valhalla*. Ubisoft, 2020. <https://www.ubisoft.com/en-gb/game/assassins-creed/valhalla>
- Valve Corporation. *Portal*. Valve Corporation, 2007. <https://store.steampowered.com/app/400/Portal/>
- WNET-Thirteen, PBS KIDS, Bridge and Relish Studios. *Cyberchase: Duck Dash*. Bridge Multimedia, 2022. <https://www.pbslearningmedia.org/resource/duck-dash-game/cyberchase/>

Appendix

Table A1. Different AD styles

	Original EN AD	Translated ES AD	Original ES AD	Original ES AD back translation
1	Modern Scientist Magazine. February 1974. Indian Cosmologist Sunita Appleby Boldly going where no woman has been before. Sunita's picture appears on the cover.	<i>Revista de Científicos Contemporáneos. Febrero de 1974. La cosmóloga india Sunita Appleby Boldly llega donde ninguna mujer ha llegado antes. En la portada hay una foto de Sunita.</i>	<i>Revista de Científicos Contemporáneos. Febrero de 1974. Una mujer morena de unos treinta años aparece en la portada de la revista. Superpuesto en la fotografía de la mujer: La cosmóloga india Sunita Appleby Boldly llega donde ninguna mujer ha llegado antes. Debajo de la fotografía siguen los titulares: "Los cúmulos de galaxias y el misterio de la masa perdida. Construye tu propio calentador solar de agua". En la parte inferior derecha de la portada: "Microprocesadores: Un vistazo al Scelbi (Escelbi) ocho hache".</i>	Modern Scientist Magazine. February 1974. A brunette woman in her thirties appears on the cover of the magazine. Superimposed on the woman's photograph: Indian cosmologist Sunita Appleby Boldly goes where no woman has gone before. Below the photograph, the headlines continue: 'Galaxy clusters and the mystery of lost mass. Build your own solar water heater.' In the bottom right corner of the cover: 'Microprocessors: A glimpse of the Scelbi (Escelbi) eight H.'

	Original EN AD	Translated ES AD	Original ES AD	Original ES AD back translation
2	A framed photograph of Sunita and Dylan smiling on their wedding day	<i>Un marco con una foto de Sunita y Dylan sonriendo el día de su boda.</i>	<i>Un marco con una fotografía de una boda. Los novios miran sonrientes al objetivo. Ella es morena, lleva el pelo recogido, un vestido blanco y sostiene un ramo de flores. Él es rubio, más alto, lleva americana, camisa y una rosa en el bolsillo de pecho. Tiene los brazos alrededor de la novia. Tras ellos, los invitados los miran con alegría.</i>	A frame with a photograph from a wedding. The bride and groom smile at the camera. She is brunette, with her hair up, wearing a white dress and holding a bouquet of flowers. He is blond, taller, wearing a jacket, shirt, and a rose in the chest pocket. His arms are around the bride. Behind them, the guests watch them joyfully.
3	A flashback. Looking out at a vast starry sky in India then a more confined tunnel view through the telescope. The view can be panned by using the movement keys.	<i>Flashback. En La India, un vasto cielo estrellado da paso a una vista a través del telescopio. Puedes moverte a través del cielo mediante los botones de movimiento.</i>	<i>Flashback. Miras a través del telescopio dorado hacia el cuadro colgado en la pared. Junto a un río en La India, una mujer y una niña contemplan el cielo nocturno a través de un telescopio. Las estrellas brillan intensamente en el firmamento. En la esquina superior izquierda se muestran los puntos cardinales. Mueve el ratón hacia arriba para ir al norte, hacia abajo para ir al sur, hacia la izquierda para ir al oeste y hacia la derecha para ir al este.</i>	Flashback. You gaze through the golden telescope at the painting hanging on the wall. By a river in India, a woman and a girl gaze at the night sky through a telescope. The stars shine brightly in the firmament. In the upper left corner, the cardinal points are displayed. Move the mouse upwards to go north, downwards to go south, leftwards to go west, and rightwards to go east.
4	Study. Back in the study. A painting of an Indian woman on the wall with a scarf	<i>Despacho. De nuevo en el despacho. En la pared ahora hay un cuadro de una mujer</i>	<i>Despacho. De nuevo en el despacho. En la pared ahora hay un cuadro de una mujer</i>	Study. Back in the office. On the wall, there is now a painting of a dark-skinned

	Original EN AD	Translated ES AD	Original ES AD	Original ES AD back translation
	draped around her head and shoulders. A chessboard has appeared on the coffee table in front of the sofa.	<i>india con un pañuelo que le cubre la cabeza y los hombros. Sobre la mesa de café frente al sofá ahora hay un tablero de ajedrez.</i>	<i>de piel oscura con el pelo largo, negro y ondulado que mira pensativa al frente. Lleva la cabeza cubierta con un pañuelo blanco y los labios pintados de rosa. Sobre la mesa de café frente al sofá ahora hay un tablero de ajedrez.</i>	woman with long, black, wavy hair looking thoughtfully ahead. She has her head covered with a white scarf, and her lips are painted pink. On the coffee table in front of the sofa, there is now a chessboard.
5	Bathroom. The floor and walls are tiled. A toilet with the lid up. Towels and bottles stand on shelves at the foot of the bath. There's a frosted window above the bath looking out onto the street. A small sink has a shelf above it with a pillbox on top.	<i>Baño. Las paredes y el suelo son de baldosa. Hay un váter con la tapa levantada. A los pies de la bañera, en unas estanterías hay toallas y botellas. En la pared junto a la bañera, hay una ventana translúcida que da a la calle. En el baño también hay un lavabo sobre el cual hay una balda con un pastillero.</i>	<i>Baño. Unas baldosas cuadradas de mármol se extienden en el suelo y las paredes del cuarto de baño. Cerca de la puerta de entrada hay un inodoro con la tapa abierta. Unas ventanas de vidrio mate con la persiana subida dan al exterior. Debajo de las ventanas hay una bañera, una estrecha repisa con dos toallas dobladas y un jarrón con flores. En el suelo, cerca de la bañera, se encuentra una alfombra de baño, un cubo y un estante con toallas y varios botes. En una pared hay un lavamanos con espejo y un estante en el que reposan un vaso, jabón de manos y un pastillero.</i>	Bathroom. Square marble tiles cover the floor and walls of the bathroom. Near the entrance door, there is a toilet with the lid open. Frosted glass windows with the blinds up provide a view outside. Below the windows, there is a bathtub, a narrow shelf with two folded towels, and a vase with flowers. On the floor, near the bathtub, there is a bathmat, a bucket, and a shelf with towels and various containers. On one wall, there is a sink with a mirror and a shelf holding a glass, hand soap, and a pillbox.
6	A flashback. Up close on the details of an antique star map showing the	<i>Flashback. Detalle de un mapa celeste antiguo con constelaciones e</i>	<i>Flashback. La carta estelar se amplía. Puedes mover el ratón sobre la carta estelar.</i>	Flashback. The star chart expands. You can move the mouse over the star chart. At the

Original EN AD	Translated ES AD	Original ES AD	Original ES AD back translation
constellations and illustrations of a winged horse in the bottom left-hand corner and a swan in the top right-hand corner. The view can panned by using the movement keys.	<i>ilustraciones de un caballo alado en la esquina inferior izquierda y un cisne en la esquina superior derecha. Puedes moverte a través del mapa mediante los botones de movimiento.</i>	<i>En la parte superior, un cisne vuela del revés. En la parte inferior, un caballo galopa del revés. Una estrella brilla en tonos morados y azules. Una línea une Markab (Marcáb) con Scheat (Sheat). Una línea une Scheat con Alpheratz (Alferáz). Una línea une Alpheratz con Algenib. Las líneas forman un cuadrado. De la esquina superior izquierda del cuadrado salen otras dos líneas que forman las patas delanteras del Pegaso. De la esquina inferior izquierda sale otra línea que se dobla, imitando el cuello y la cabeza del animal mitológico.</i>	top, a swan flies upside down. At the bottom, a horse gallops upside down. A star shines in shades of purple and blue. A line connects Markab to Scheat. A line connects Scheat to Alpheratz. A line connects Alpheratz to Algenib. The lines form a square. From the upper-left corner of the square, two more lines extend, forming the front legs of Pegasus. From the lower-left corner, another line extends, bending to mimic the neck and head of the mythological creature.

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