REVISITANDO A ACESSIBILIDADE DE JOGOS PARA JOGADORES SURDOS OU COM DEFICIÊNCIA AUDITIVA

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Coorientador: Luiz Chaimowicz

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REVISITING GAME ACCESSIBILITY FOR DEAF AND HARD OF HEARING PLAYERS

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Revisitando a acessibilidade de jogos para jogadores surdos ou com deficiência auditiva

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Dissertação defendida e aprovada pela banca examinadora constituída pelos Senhores:

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This work is devoted to deaf and hard of hearing gamers.

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"It is better to light one small candle than to curse the darkness."

(Eleanor Roosevelt)

Resumo

Em jogos digitais, som e música desempenham um papel importante na experiência dos jogadores, pois eles são geralmente utilizados para transmitir informações importantes e também contribuem para a atmosfera de jogo. A não recepção de estímulos pode impor barreiras ao jogo, tornando os jogadores que não podem ouvir ou que têm algum grau de perda auditiva, no mínimo, em desvantagem em relação aos jogadores ouvintes.

Este problema de acessibilidade é comumente abordado com o uso de legendas e representações textuais dos sons chamadas de *closed captions*, como pode ser visto em diretrizes gerais de acessibilidade e de alguns poucos jogos *mainstream*. No entanto, nem todos podem se beneficiar plenamente do uso de alternativas textuais para os sons. De fato, sob certas condições, as pessoas que se tornam surdas antes de ter experiência adequada com o mundo sonoro podem apresentar dificuldades de leitura, já que a aquisição da linguagem oral (por exemplo, Inglês ou Português) deve ocorrer como uma segunda língua.

Neste trabalho, investigamos o impacto na experiência de jogo pelo jogador não receber estímulo de áudio. Como esse problema pode ser descrito como um problema de comunicação, recorremos à Engenharia Semiótica e ao Método de Inspeção Semiótica para identificar, sistematicamente, como o som e a música são usados no projeto de jogos para transmitir informações. Tomamos como estudo de caso um jogo de tiro em primeira pessoa chamado Half-Life 2, que foi muito bem avaliado por jogadores surdos e deficientes auditivos por oferecer a opção de *closed captions*.

Como resultado da inspeção, identificamos o uso de oito características distintas dos efeitos sonoros para transmitir informação (por exemplo, o volume percebido é usado para comunicar a distância até a fonte sonora), que foram utilizados em sete diferentes estratégias de comunicação (por exemplo, *feedback*). Essas características e estratégias foram então avaliadas de acordo com sua relevância para o jogo. Descobrimos também que o sistema de *closed captions* usado no jogo não comunica parte da informação transmitida via áudio.

Com as características dos efeitos sonoros identificadas e os resultados de um questionário exploratório que havíamos aplicado com pessoas surdas e pessoas com deficiência auditiva, propomos uma alternativa para as *closed captions* que apresenta os sons usando metáforas visuais. Ela é baseada no conceito de Sinestesia, uma condição neurológica em que as sensações de um estímulo são percebidas através de sentidos diferentes.

Como experiência, criamos uma modificação do jogo Half-Life 2 para avaliar se a abordagem da Sinestesia poderia ser usada para melhorar a experiência de jogo de jogadores surdos ou com deficiência auditiva. A modificação utiliza um modo simples do modelo de sinestesia, que foi testado com jogadores surdos e ouvintes para avaliar a qualidade da transmissão de informação dos sons pela modificação. Os resultados mostraram que a implementação da abordagem da Sinestesia foi capaz de comunicar visualmente conteúdo dos sons que normalmente não seria transmitido para jogadores que não escutam, complementando os outros recursos assistivos do jogo.

Palavras-chave: Acessibilidade de Jogos, Surdos e Deficientes Auditivos, Método de Inspeção Semiótica, Sinestesia.

Abstract

In digital games, sound and music play an important role in players' game experience, as they are usually used to convey important information and also to contribute to game atmosphere. Losing the reception of that stimulus may impose barriers to game play, rendering players who cannot hear or that have some degree of hearing loss, at least, disadvantaged towards hearing players.

This accessibility issue is mostly tackled by providing subtitles and textual representations of sounds called closed captions, as can be seen on general accessibility guidelines and in a few mainstream games. However, not everyone may fully benefit from the use of textual alternatives for sounds. In fact, under certain conditions, people that become deaf before having enough experience with the sound world may present difficulties in reading, as the oral language acquisition (e.g. English or Portuguese) must occur as a second language.

In this work, we investigate the impact of not receiving audio stimulus on game experience. As this issue can be depicted as a communication problem, we resorted to Semiotic Engineering and the Semiotic Inspection Method to identify systematically how sound and music are used in game design to convey information. We took as case study a first-person shooter game called Half-Life 2, which has been well appraised by deaf and hard of hearing player for offering the closed captions alternative.

As a result of the inspection, we identified the use of eight distinct features of the sound effects to convey information (e.g. perceived volume to communicate distance from the sound source), which were used in seven different communication strategies (e.g. feedback). Those features and strategies were then evaluated according to their relevance to game play. We also found that the closed caption system used in the game does not communicate part of the information conveyed through audio.

With the identified sound effect features and the results from an exploratory questionnaire we had applied with deaf and hard of hearing people, we propose an alternative for the closed captions that presents sounds using visual metaphors. It is based on the concept of Synaesthesia, a neurological condition in which sensations from one stimulus is perceived through different senses.

As an experience, we created a modification of the game Half-Life 2 to evaluate whether the Synaesthesia approach could be used to enhance game experience of deaf and hard of hearing players. The modification used a simple implementation of the Synaesthesia model, which was tested with deaf and hearing players to evaluate the quality of the transmission of the information from sounds. The results showed that the implementation was able to communicate visually sound content that normally would not be conveyed to non-hearing players, thus complementing the other assistive resources of the game.

Keywords: Game Accessibility, Deaf and Hard of Hearing, Semiotic Inspection Method, Synaesthesia.

Resumo Estendido

Introdução

Sociedades inclusivas devem garantir a todas as pessoas o acesso ao lazer em diferentes formas [Sassaki, 2006], como os jogos digitais. Nos Estados Unidos, 63% da população joga jogos digitais e 51% desta parcela o faz pelo menos uma vez por semana [Yuan et al., 2010]. Somando-se a isso, Chouteau and Orr [2008] mostraram que 20% dos jogadores de jogos casuais tem alguma deficiência e 94% deles afirma que jogar traz benefícios a suas vidas. Apesar dos diversos trabalhos de pesquisa em acessibilidade de jogos que foram realizados nos últimos anos, ainda são poucas as iniciativas de criação de jogos acessíveis, especialmente de jogos *mainstream* [Coutinho et al., 2011b].

No caso especial das pessoas surdas ou com deficiência auditiva, as questões de acessibilidade são ainda minimizadas na literatura especializada, já que a maior parte da interface dos jogos é apresentada de maneira visual [Yuan et al., 2010]. Em jogos digitais, som e música desempenham um papel importante na experiência dos jogadores, como eles são geralmente utilizados para transmitir informações importantes e também contribuem para a atmosfera de jogo. A perda desses estímulos pode impor barreiras ao jogo, tornando os jogadores que não podem ouvir ou que têm algum grau de perda auditiva, no mínimo, em desvantagem em relação aos jogadores ouvintes.

As diretivas de acessibilidade de jogos para pessoas surdas ou com deficiência auditiva encontradas na literatura e em comunidades de avaliação de acessibilidade de jogos contemplam, em sua maioria, a utilização de alternativas textuais para os sons, na forma de legendas ou de *closed captions* que, além de apresentar a transcrição de narração e diálogos, também transcrevem efeitos sonoros. De fato, a alternativa textual para os sons é frequentemente considerada a única e/ou suficiente diretriz de acessibilidade de jogos [IGDA, 2004; Bierre et al., 2005; Kimball, 2005; Bierre, 2006; Yuan and Folmer, 2008]. Muitos jogos oferecem a opção de exibição das legendas, mas poucos oferecem a opção de *closed captions*, como o jogo de tiro em primeira pessoa (FPS) Half-Life 2.

No entanto, nem todos os jogadores podem se beneficiar plenamente do uso de alternativas textuais para os sons. De fato, sob certas condições, as pessoas que se tornam surdas antes de ter experiência adequada com o mundo sonoro (i.e., pessoas com surdez pré-lingual) podem apresentar dificuldades de leitura, já que sua primeira língua é uma língua de sinais (e.g., Libras no Brasil) e a aquisição da língua oral do país onde vivem (por exemplo, Inglês ou Português) deve ocorrer como uma segunda língua. Uma situação ainda mais agravante para os surdos brasileiros se dá pela escassez de jogos traduzidos para o Português, já que boa parte dos jogos digitais comercializados no Brasil contêm textos e diálogos em Inglês, o que representa a necessidade de aquisição de uma terceira língua.

Cientes da problemática de aquisição de linguagem na questão de acessibilidade de jogos para pessoas surdas, nós consideramos importante repensar as soluções já propostas e propor um recurso assitivo que não dependa totalmente da leitura de textos em uma linguagem oral. Dessa forma, buscamos, primeiro, investigar o impacto da perda auditiva na experiência de jogo sob a perspectiva das pessoas surdas ou com algum grau de deficiência auditiva. Também investigamos, usando o Método de Inspeção Semiótica, a forma como o áudio dos jogos é utilizado para transmitir informações aos jogadores — e avaliamos o impacto da perda dessa informação na experiência de jogo. Com base na opinião das pessoas com perdas auditivas e nos resultados de como o áudio é utilizado nos jogos para comunicação, propusemos um novo modelo de recurso assistivo baseado na representação visual (não textual) do som, como se ele pudesse ser visto pelo jogador — o que chamamos de Abordagem da Sinestesia.

Identificação de Questões de Acessibilidade

Para investigar questões de acessibilidade de jogos sob a perspectiva de jogadores com perdas auditivas, aplicamos um questionário exploratório que foi distribuído na Internet, em boa parte em redes sociais e grupos relacionados a surdez e à Língua de Sinais Brasileira (Libras). O questionário foi composto por 21 perguntas divididas em três seções: perfil, expericência com jogos e opinião sobre recursos assistivos existentes.

Ao todo, 111 pessoas com algum grau de perda auditiva, variando de leve a profunda, responderam o questionário. Dessas, 61% responderam que já haviam jogado jogos digitais ou que ainda jogavam.

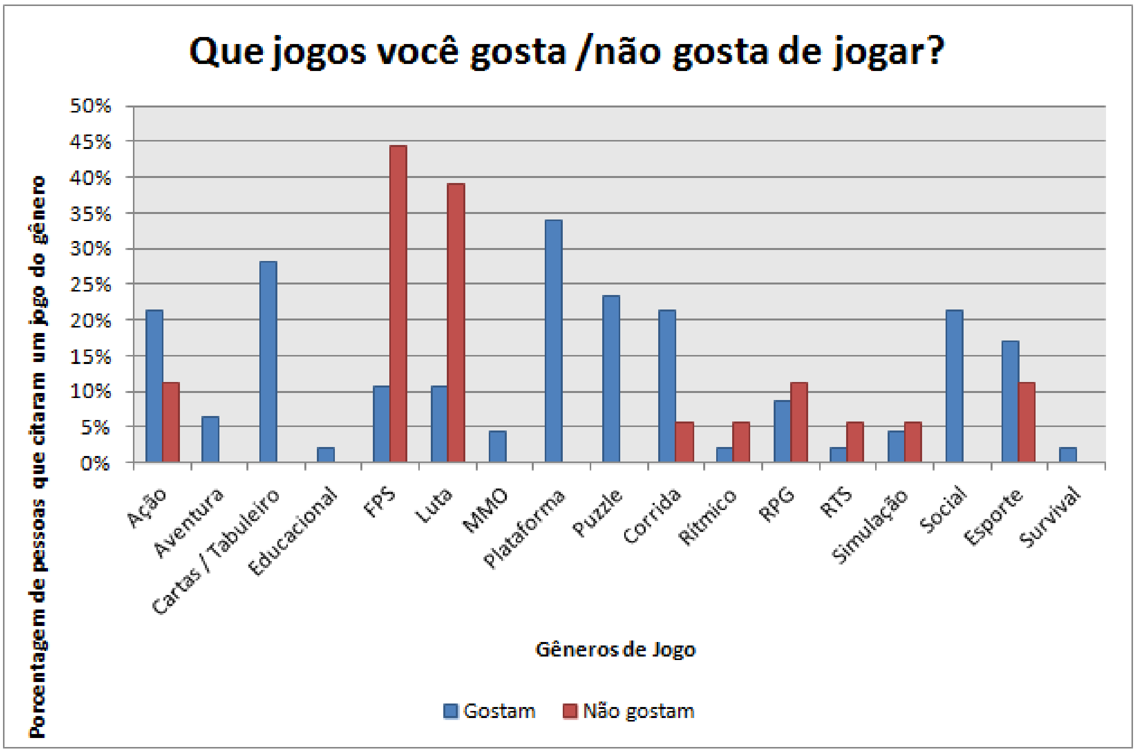


Figure 1: Gráfico mostrando os gêneros que tiveram jogos citados como gostados ou não pelos respondentes.

Resultados

Os participantes foram solicitados a escrever jogos que gostavam e jogos que não gostavam (veja a Figura 1). Nós agrupamos os jogos em gêneros e, como resultado, pudemos observar maior aceitação de jogos com regras simples como os dos gêneros Plataforma, Quebra-cabeça (Puzzle), Corrida, Social e Cartas. Por outro lado, outros gêneros tiveram maior rejeição do que aceitação, como Tiro em Primeira Pessoa (FPS), Luta, Rítmico, RPG, Estratégia em Tempo Real (RTS) e Simulação. Estes gêneros se diferem dos outros por apresentarem curvas de aprendizado mais íngremes (RPG, RTS, Simulação), ou por dependerem fortemente na leitura e interpretação de textos e regras (RPG), ou por beneficiarem jogadores com tempos de resposta menores (FPS, RTS), ou por usarem o som (do ponto de vista de comunicação de informação) de forma rica (FPS, Rítmico).

Quando questionados se acreditavam ter tido dificuldades para jogar devido à perda auditiva, 28% dos respondentes declararou ter tido dificuldades, 57% declarou não ter tido dificuldades e 15% não respondeu ou não se lembrou. Os que responderam afirmativamente foram solicitados a descrever as dificuldades que tiveram, que contemplam questões relacionadas a linguagem (jogos e instruções em língua estrangeira, uso de vocabulário complexo), uso de áudio para comunicação e regras e instruções de difícil aprendizado.

Sobre o uso de legendas e *closed captions* na televisão e cinema, 80% dos respondentes afirmaram ser auxiliados pelos recursos. Aqueles que declararam não ser auxiliados, foram solicitados a descrever o motivo. As respostas foram o uso de palavras que eles desconheciam e a presença de erros de "digitação" (no caso de closed captions de transmissões em tempo real).

Os respondentes também foram solicitados a sugerir mudanças em jogos para que melhor se adequassem às pessoas surdas. A maior parte das sugestões foi o uso de transcrições textuais, mas elas também contemplaram o uso de Libras nos jogos (para instruções, para a língua dos personagens), o uso de vocabulário mais simples, o uso de conteúdo visual e o uso de *feedback* háptico ou sonoro de baixa frequência. Vale ressaltar que alguns respondentes declararam não serem necessárias alterações nos jogos.

A análise do questionário nos permitiu fazer ao menos três observações relevantes: (1) pessoas surdas ou com alguma perda auditiva são potenciais jogadoras, já que 68% dos respondentes disseram jogar ou já ter jogado jogos digitais; (2) alguns gêneros de jogos foram mais rejeitados do que aceitos, dentre os quais FPS e Luta tiveram as maiores rejeições. Esse resultado pode ser devido ao componente de violência inerente a esses tipos de jogos, mas como pudemos observar a partir das declarações sobre dificuldades para jogar, a acessibilidade dos jogos desempenha um papel importante nesse resultado; (3) as respostas de várias perguntas mostraram que alternativas textuais como legendas e *closed captions* foram bem louvadas entre os respondentes, mas eles acreditam que existem outras alternativas que podem mostrar-se úteis para tornar jogos mais acessíveis a pessoas com perdas auditivas.

Comunicação por Áudio

Para identificar como o áudio dos jogos é utilizado para transmitir informações aos jogadores, recorremos à Engenharia Semiótica, teoria explicativa da Interação Humano-Computador que considera a interação dos usuários com sistemas interativos como um processo de comunicação dos projetistas dos sistemas com seus usuários, através da interface. A qualidade desta comunicação é denominada *comunicabilidade* e pode ser avaliada usando-se o Método de Inspeção Semiótica (MIS).

O MIS foi aplicado no jogo Half-Life 2, um exemplo de jogo de tiro em primeira pessoa (FPS) que oferece a opção de ativação de legendas para diálogos e narração e *closed captions* para a transcrição dos sons.

A questão de pesquisa a ser respondida na aplicação do MIS era *"que estratégias de comunicação por meio de áudio os jogos usam?"*. Para responder a pergunta, nosso foco foi menos orientado à segmentação e reconstrução da (meta) comunicação dos projetistas ao usuários, e mais voltado à identificação de classes signos de áudio e em como eles eram utilizadas para comunicar. Como resultado, identificamos uma lista de estratégias de comunicação baseadas nas classes de signos de áudio. Também identificamos potenciais rupturas na meta-comunicação que foram utilizadas para a avaliação da acessibilidade do jogo.

Para cada signo de áudio, nós identificamos que informação estava sendo transmitida ao jogador; por sua vez, para cada informação transmitida, nós respondemos às seguintes questões: (a) quais características dos efeitos sonoros foram usadas para comunicar essa informação? (b) havia redundância dessa informação em outros signos? (c) quanto a perda dessa informação impacta na experiência de jogo?. Então, as características dos efeitos sonoros similares foram consolidadas em classes, que foram usadas na reconstrução das estratégias de comunicação. Por fim, foi realizada uma apreciação da acessibilidade dessas estratégias.

Resultados

Ao todo, 8 classes de signos de áudio foram identificadas, sendo elas (1) volume do som, (2) distribuição do som, (3) timbre, (4) momento, (5) fala, (6) passo, (7) música e (8) frequência percebida.

As classes de signos de áudio foram usadas para comunicar informações aos jogadores em diferentes estratégias: (1) permitir a localização de sons, (2) caracterizar elementos do jogo, (3) comunicar ameaça, (4) *feedback* de interação, (5) transmissão de informação pela fala, (6) instigação de sensações e sentimentos e (7) permitir a inferência de velocidades de fontes sonoras.

As potenciais rupturas de comunicação que identificamos mesmo na presença de *closed captions* revelaram limitações das implementações desses recursos no jogo, como o fato de eles não possibilitarem a inferência de localização dos sons (apenas sua presença) e o de requererem que os jogadores desviem sua atenção do jogo para a leitura de textos.

Os resultados obtidos com a inspeção do Half-Life 2 foram triangulados com os resultados obtidos nas inspeções de outros dois jogos do gênero FPS: XIII e Call of Duty: Modern Warfare 2. A triangulação revelou que as classes e estratégias identificadas são em grande parte compartilhadas entre os três jogos inspecionados, sugerindo que essas formas de utilização do áudio para comunicação são bem representativas para o gênero FPS.

A utilização do MIS com o objetivo de avaliação de acessibilidade de jogos para pessoas com perdas auditivas expandiu a aplicação do método para um novo domínio, para o qual nunca havia sido utilizado. Considerando a acessibilidade para pessoas com perdas auditivas em termos de como transcorre a comunicação dos projetistas do jogo aos jogadores, o MIS mostrou-se um método extremamente apropriado à tarefa de avaliação de acessibilidade.

A Proposta da Sinestesia

Utilizando o conceito de sinestesia artística, nós propusemos um novo modelo de recurso assistivo em jogos para pessoas com perdas auditivas. Em vez de usar textos para representar os sons, a Abordagem da Sinestesia visa a representação dos sons por meio de metáforas visuais dentro do mundo do jogo (e não no plano da tela — o HUD —, como as legendas e *closed captions*). Dessa forma, os jogadores não precisam dividir sua atenção entre o mundo do jogo e o HUD, além de ser facilitada a localização das fontes sonoras de acordo com a posição em que as metáforas visuais são exibidas.

Nós propusemos um modelo de implementação da Abordagem da Sinestesia em 4 passos: seleção de informação sonora, o retrato visual dos sons, o mapeamento da informação sonora para atributos visuais e a implementação da abordagem. Para cada passo, discutimos as decisões e os compromissos das diversas alternativas de implementação.

Também propusemos uma forma semi-automatizada de implementação, chamada de Abordagem da Sinestesia Algorítmica. Nessa abordagem, a criação das metáforas visuais pode ser realizada com base em informações extraídas à partir dos arquivos de efeitos sonoros dos jogos utilizando-se técnicas de processamento digital de sinais. Dessa forma, a etapa de implementação da Abordagem da Sinestesia pode ser automatizada, tornando mais factível a incorporação desse novo recurso assistivo aos jogos.

Experimento e Avaliação

Para ilustrar e validar a proposta da sinestesia, criamos uma modificação do jogo Half-Life 2, com uma implementação bastante simples da Abordagem da Sinestesia. Para cada passo da abordagem, descrevemos as decisões que tomamos para a instanciação do modelo proposto.

As informações presentes no áudio selecionadas foram o volume do som, o momento e o passo. Também optamos por permitir a localização das fontes sonoras. A metáfora visual criada consiste em um conjunto de pequenas partículas com caudas que emanam das fontes sonoras, movimentado-se concentricamente para longe e dissipando depois de um tempo. Os parâmetros configuráveis do efeito visual são a cor das partículas, seus tamanhos, a taxa e o momento em que surgem e sua velocidade de movimento. O mapeamento entre as informações sonoras e os parâmetros visuais foi realizado da forma:

- permitir a localização do som → posição da metáfora visual no mundo do jogo;
- volume do som → tamanho das partículas;
- momento → o momento em que as partículas são geradas;
- passo → a taxa com que as partículas são geradas e sua velocidade de movimentação.

Avaliação do Experimento

Uma avaliação preliminar do experimento foi conduzida com os objetivos de averiguar a aceitação da Abordagem da Sinestesia como um recurso assistivo, para avaliar nossa instância do modelo proposto e para iniciar a investigação do modelo em si.

A avaliação foi conduzida como um teste com usuários em ambiente controlado. Seis pessoas participaram dos testes, sendo que três eram surdas (com surdez profunda) e três eram ouvintes. Os dois recursos assistivos que o Half-Life 2 oferece (legendas e *closed captions*) e a implementação da Abordagem da Sinestesia foram os objetos de avaliação do teste. Os resultados foram baseados na análise da observação da experiência de jogo dos usuários e em suas opiniões sobre o uso dos três recursos assistivos considerados.

Os resultados mostraram que todos os usuários conseguiram localizar fontes sonoras (e.g., sons de inimigos) utilizando a sinestesia, mas não com a legenda ou o *closed caption*. A sinestesia também auxiliou na identificação dos interlocutores em diálogos, o que não foi conseguido com os outros recursos.

A Abordagem da Sinestesia foi bem aceita pelos usuários, sendo que os 3 usuários surdos disseram que usariam o recurso ao jogar. Dois dos 3 usuários ouvintes disseram que usariam o recurso em situações em que não tivessem acesso ao áudio. Quando inquiridos sobre que recursos assistivos eles usariam, se precisassem, dos 5 usuários que disseram que usariam a sinestesia, 4 também usariam *closed captions*.

Conclusões

Nesta dissertação, nós lidamos com a acessibilidade de jogos para pessoas surdas ou com deficiência auditiva.

Aplicamos um questionário a pessoas com perdas auditivas a respeito de sua experiência de jogo e descobrimos que os jogos que dependem fortemente do uso de textos, ou que têm regras complexas, ou fazem uso muito relevante do áudio, foram mais rejeitados do que aceitos. O gênero FPS foi o mais rejeitado.

Nós investigamos como o áudio é utilizado para transmitir informações aos jogadores em jogos FPS utilizando o Método de Inspeção Semiótica. Foram identificadas 8 características dos efeitos sonoros, que são utilizadas em 7 diferentes estratégias de comunicação.

Com estes resultados, propusemos um novo modelo de recurso assistivo baseado na representação visual (e não textual) dos sons, chamado de Abordagem da Sinestesia. Essa proposta foi implementada de forma muito simples no jogo Half-Life 2, que foi utilizado como objeto de estudo para uma avaliação preliminar da abordagem. Uma avaliação na forma de testes com 6 usuários foi realizada para averiguar a aceitação e validade do recurso assistivo e os resultados revelaram que a implementação conseguiu complementar os outros recursos assistivos do jogo, comunicando informações por eles não contempladas. Constatamos que a Abordagem da Sinestesia foi bem aceita pelos usuários, surdos e ouvintes.

List of Figures

List of Tables

Contents

Chapter 1

Introduction

As societies shift towards the Inclusivism paradigm, granting access to all kinds of activities has become a primary concern. Sassaki [2006] states that an inclusive society must *"adapt (itself), in its general social systems, to include people with special needs"* (p. 39). Indeed, having the option to enjoy different sorts of leisure, including playing digital games, is a matter of quality of life [Bierre et al., 2005].

In the United States, approximately 63% of the population plays digital games and 51% of them do it at least once a week [Yuan et al., 2010]. Despite the high portion of the population interested in games, accessibility has yet to find its way into the game industry, as mainstream games usually lack support for players with impairments [Coutinho et al., 2011b; IGDA, 2004]. Nevertheless, some games in the industry are more appealing than others to impaired game players, frequently because of their simpler rules and interaction: the casual games.

A research conducted by Information Solutions Group [Chouteau and Orr, 2008] revealed that more than 20% of players of casual games have a degree of impairment. In addition, 94% of them state that playing games brings benefits to their lives, being it physically or mentally. By having important roles in people's lives, games must ensure to be accessible by the broadest audience possible. Grammenos and Savidis [2009] state that games should be made universally accessible: *"games pro-actively designed to optimally fit and adapt to individual gamer characteristics and to be concurrently played among people with diverse abilities, without requiring particular adjustments or modification"* (p. 8). However, instead of broadening game access in various directions, we address the specific case of deaf and hard of hearing players.

Game accessibility issues for deaf and hard of hearing people are frequently minimized. Since most part of game interfaces are presented in a visual form, accessibility engaged developers and the specialized literature often focus on other types of impairments. Little effort has been dedicated in order to make the gaming experience balanced between players with and without impairments. In particular, those with partial or total loss of hearing have their experience affected in games in which the sound information is important and there is no alternative form to receive that information. An example is the first-person shooter (FPS) game Counter Strike, in which one can hear the footsteps of other players to discover their position, but that information is only conveyed through sounds.

Most games do provide the choice of enabling subtitles for dialogs and narration. A lot fewer games provide the option to enable closed captioning, whose intent is to present textual descriptions for sound and music considered important to players. In fact, most of the literature about game accessibility cites providing subtitles and closed captioning as the main - and, sometimes, the only - accessibility guideline for deaf and hard of hearing players. However, using textual alternatives for sounds may not provide a really accessible alternative for them.

Beyond the obvious problems of not being able to hear game music and audio cues, people born deaf or that have lost hearing ability before sufficient contact with the sound world (usually before 2 years old, called prelingual deaf) do not acquire the oral language of the country they live (e.g., Portuguese in Brazil) in a natural way and, very frequently, their native language is a sign language (e.g., Libras in Brazil, ASL in the United States).

Their acquisition of the oral language must happen as a second language and is influenced by problems like the unpreparedness of schools and the educational system [Sassaki, 2006], late learning of the sign language and self-stigmatization characteristics pointed by Botelho [2005]. Those problems often lead to difficulties with reading and writing [Bernardino, 2000; Botelho, 2005]. Considering that most games are not translated to Portuguese, but to only a few languages or just English, the accessibility issue is even worse, as it requires prelingual deaf game players to know a third language. So, text based approaches for assistive resources may still present barriers for prelingual deaf players.

The sign language explores the space-visual field and is frequently how deaf people communicate. The use of the sign language among deaf people is a characteristic so distinguishing that has led to the existence of Deaf Communities - identity groups that share similar values, styles and attitudes, which differ from those of the hearing culture [de Sá, 2006].

In the United States, according to the American Census, an estimate of 2.35% of the country's population present some degree of hearing loss [Census Bureau, 2008]. In Brazil, that percentage is even higher. In 2000, it was 3.38% (i.e, 5,735,099 people)

[IBGE, 2000] and, in 2010, it has changed to 5.10% (i.e., 9,722,163 people) [IBGE, 2010]. The distribution of people in age groups can be seen in Figure 1.1[1].

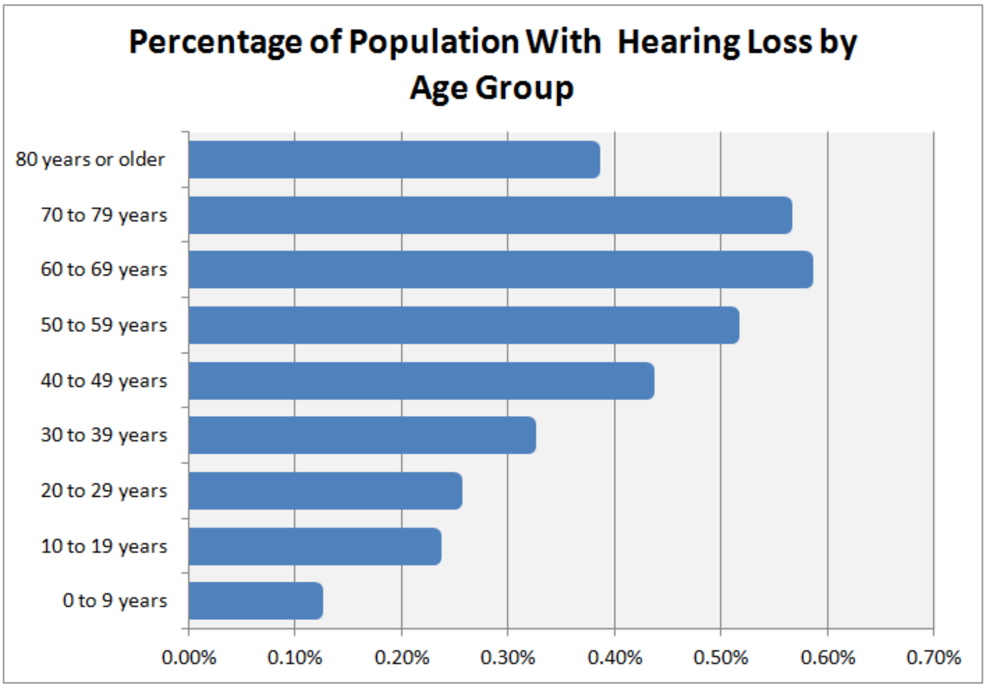


Figure 1.1: Estimate percentage of total population with some degree of hearing loss in Brazil in 2000 by age group.

Considering that there is an expressive growth in the percentage of hearing impaired people in the population as age increases and that the generation Y - born and raised along with digital games - is getting older, it is expected that the gaming industry will need to adapt to the reality of its target audience and enable their games so they can be played by hearing impaired people.

To be able to create games that are accessible to those players, it is imperative for game creators to have a better understanding of how the gaming experience is affected by having limited to no experience with the sound world. To approach this matter, some questions need to be addressed:

- What are the preferences and opinions of deaf and hard of hearing players about current game accessibility alternatives?
- Do the text based approaches for assistive resource (i.e., subtitles, closed captions) convey all the relevant pieces of information from audio to players?

[1] As of the publication of this dissertation, IBGE has not released information of disability related to age from the 2010 census yet.

- How can the accessibility of a game be evaluated for the scenario of players with hearing impairment?
- Could the information conveyed through sounds be accessible for players who cannot hear in an alternative way other than how they are conveyed in text based approaches?

Our objectives in this dissertation contemplate finding answers to those questions.

1.1 Dissertation Objectives

By revisiting game accessibility for players who cannot hear, our main objectives comprise (i) the exploration of accessibility issues from the perspective of deaf and hard of hearing players, (ii) the identification of communication strategies through game audio and the evaluation of the impact on game experience for not receiving that information and (iii) the proposal of an alternative assistive resource for games that explores the space-visual field.

1.2 Main Contributions

The investigation conducted during the research described in this dissertation has brought some new contributions, which are listed as follows.

- A preliminary identification of the main *game accessibility issues from the perspective of the hearing impaired players* (goal (i)).
- The *identification of how game audio is used to convey information* to players in systematic strategies of communication and the characteristics of the sound effects used by those strategies (goal (ii)).
- The *proposition of a model for assistive resource* that explores the space-visual field to visually convey information from sounds in a metaphoric sensory translation process (goal (iii)).

As a side effect of the development of this work while pursuing goal (ii), we also had three other contributions that were not pursued from the beginning.

- We were able to *generate an epistemic tool in the area of Game Design*, as we uncovered the strategies of transmission of information through game audio in

FPS games, which may aid game designers in the creation of new games with similar strategies and also offers the possibility to have a systematic thinking about their accessibility.

- Our application of the Semiotic Inspection Method together with its underlying Semiotic Engineering Theory proved extremely *useful and appropriate for the evaluation of game accessibility* for hearing impaired players.

- As we applied the Semiotic Inspection Method to a novel domain - to evaluate the accessibility of FPS games, we discussed aspects of the applicability of the method, considering also how to frame auditory signs found in the inspected games in the types of signs of Semiotic Engineering: metalinguistic, static and dynamic.

1.3 Terminology

In this section, we present relevant terminology used throughout this dissertation.

Deaf vs. Hard of Hearing —In this dissertation we use two terms to indicate people with hearing impairments: deaf and hard of hearing. We differentiate them such that the former refers to people that have lost high degrees of hearing, usually in their tender age, and the latter refers to people that have lost some degree of hearing but were able to acquire the oral language of the country they live in naturally. The phrases "with hearing loss", "who cannot hear", "hearing impaired" and "unable to hear" are used interchangeably to refer to both deaf and hard of hearing people when a distinction is not necessary.

Closed captions vs. Subtitles —Jelinek Lewis and Jackson [2001] describe captions as the *"type-written version of the audio component of television that provides a visual display of the dialog, narration, and audio effects for those who cannot hear."* (p. 1). Closed captions are one version of captions, one which gives the option of being turned on and off (as opposed to open captions).

In this text, we differentiate between closed captions and subtitles according to their main objectives towards audiovisual content that, in the former case is to enable access for those who cannot hear and, in the latter, is to transcribe dialogs and text considered relevant to comprehension, commonly used as an internationalization measure for different languages.

Casual vs. Hardcore Games —According to Novak [2008], casual games are those which *"take a relatively short amount of time to play (or that can be stopped and started at any time) such as Web and cell phone games [...] they are short, easy-to-learn, entertaining ways to pass the time"* (p. 52), whilst hardcore games are those that require greater commitment and dedication of players due to the greater complexity of rules, more playing time, commitment to character development, mechanical action that require quick reflexes, etc.

Mainstream game —A game is considered mainstream if it has achieved a considerable commercial success. We use the term in this dissertation in opposition to games created as academical works, proofs of concept and those created by the game industry but that did not reach great popularity.

1.4 Dissertation Outline

To explore game accessibility from the perspective of deaf and hard of hearing people (goal (i)), we used an online questionnaire. To identify how audio is used in games to convey information and to evaluate their accessibility for hearing impaired players (goal (ii)), we applied the Semiotic Inspection Method using both its technical and its scientific approach. To propose an alternative accessibility resource (goal (iii)), we used the results of the audio usage to convey information and based on the artistic concepts of synesthesia, we, then, developed an experiment of implementing our proposal in a mainstream first-person shooter game called Half-Life 2 and evaluated it with user tests.

Thus, this dissertation is structured in 7 chapters. Its remainder is organized as follows.

Chapter 2. [**Related Work and Theoretical Reference**] —In this work, we revisit the state of game accessibility for deaf and hard of hearing people. In Chapter 2 we review game accessibility in general, but focusing on the works related to the impact of hearing impairments in game experience and the alternatives already proposed. We also present a recent model of game audio classification to aid in our discussions in further chapters (4 and 5).

Chapter 3. [**Identification of Accessibility Issues**] —As we identified few works on the case of game accessibility for hearing impairment, in Chapter 3, we present the results obtained with the application of a questionnaire targeted at people with any degree of hearing loss to better understand their gaming experiences and to gather their opinion on the theme (goal (i)).

Chapter 4. [Communication Through Audio] —One of the observations we were able to retrieve was that games of the FPS genre were the most disliked by the respondents. That led us to choose a game of that genre as a case study in chapter 4. Based on the fact that FPS games usually make a significant use of game audio and the opinions gathered from the respondents, we conducted a semiotic inspection in the game Half-Life 2 to discover how the game audio was used for communication with players and evaluated the impact on game experience for not receiving that stimuli (goal (ii)).

Chapter 5. [The Synesthesia Proposal] —Using the artistic concept of synesthesia, we propose, in Chapter 5, a different approach of assistive resource in games for players who cannot hear (goal (iii)). Based on a translation process from auditory to visual stimuli, the Synesthesia Approach uses the findings from Chapter 4 as a framework for the selection of information conveyed through audio that needs a visual representation.

Chapter 6. [Experiment and Evaluation] —To validate the Synesthesia Approach, we developed a modification of Half-Life 2 with a proof-of-concept version of the Synesthesia Model and evaluated it with preliminary user tests comprised of one group of three deaf players and another of three hearing players. The collected data comprised of observations of the players experience during the test and post-test interviews.

Chapter 7. [Conclusions] —In the last chapter, we conclude this work by discussing our results, limitations and suggesting future works to further enhance game accessibility for deaf and hard of hearing players and also other possible directions of further research.

Chapter 2

Related Work and Theoretical Reference

In this chapter, we present a review of the game accessibility literature for different impairments, but focusing on hearing loss. Our objective lies both on identifying similar works that also tackle game accessibility for hearing impaired players and on investigating how it is depicted, i.e., what are considered good and bad practices when designing accessible games.

We also present in this chapter a reference model for the categorization of game audio, which we used to refer to game audio in a systematic way in other chapters.

2.1 Game Accessibility

Providing access to games can be viewed as removing barriers that may limit players' ability to play due to limiting physical and cognitive conditions. In an extensive survey on game accessibility, Yuan et al. [2010] proposed a generic interaction model for games, in which player interaction can be described in three steps, namely, receiving stimuli (step 1), determining response (step 2) and providing input (step 3) (see Figure 2.1). Stimulus was classified according to the relevance of the information it provides to players: primary stimuli must be perceived to *enable* gaming experience, whereas secondary stimuli is supplementary to primary, but its absence *does not fully compromise game play*. The vast majority of games relies heavily on visuals, what frames it as a primary source of stimuli. Audio and haptic feedback usually supplement visuals, being considered secondary in most cases.

An international classification of impairments is defined in a World Health Organizations manual [IGDA, 2004], which spans four groups of impairment: visual, hearing,

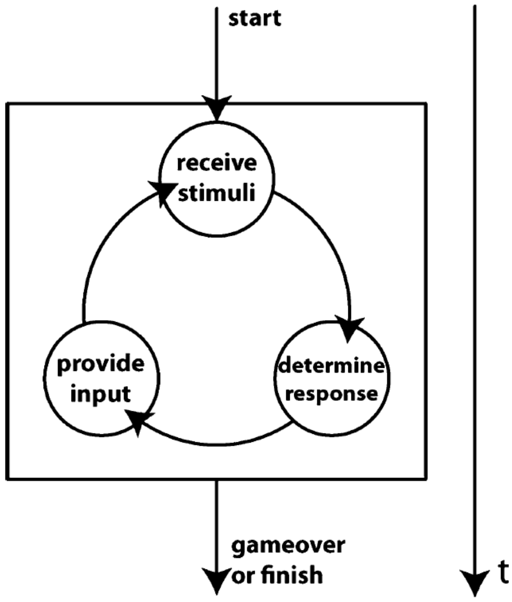


Figure 2.1: A game player's interaction model according to Yuan et al. [2010].

motor and cognitive. For each of those groups, Yuan et al. [2010] discuss which steps of the interaction may present barriers to people with those types of impairments and how those barriers can be attenuated or removed.

Cognitive impairments are very broad, spanning memory loss, diverse mental disorders, autism and learning disabilities like dyslexia, among others [Coutinho et al., 2011b]. They may compromise mainly the players' ability to cognitively formulate a response (step 2). Some guidelines have been proposed to aid in the design of games for people with these types of disability [Yuan et al., 2010] and a few games have been developed targeting specific cognitive impairments like one addressing children with down syndrome [Brandão et al., 2010] and another targeted at people with autism [Ohring, 2008].

Motor impairments include weakness, involuntary muscle control, paralysis, joint problems and lack of members [Bierre et al., 2005; IGDA, 2004; Coutinho et al., 2011b] and compromise providing of input (step 3). A common guideline to enable access to people with this kind of impairment is by providing different forms of input that can range from special types of keyboards, mouse and joysticks, to speech, eye tracking [Jönsson, 2005] and even a single button that enables control of the entire game [Colven and Judge, 2006; Ellis, nd; Folmer, nd]. Enabling access to a mainstream game through a single switch button has already been done before [Folmer et al., 2011], in this case it also requires that some parts of the game be automated to players.

Visual impairments range from color blindness to low vision to total blindness and compromise reception of primary stimuli (step 1) [Coutinho et al., 2011b]. People with low vision or blindness may also have a barrier with providing input. Despite the similar nature of the impairments, each one has been approached differently [IGDA, 2004]. In case of blindness, a common approach is the creation of audio games, in which players use only audio stimuli to receive instructions [Westin, 2004]. Another approach is the use of haptic stimuli [Yuan and Folmer, 2008]. Players with low vision may benefit from the use of screen magnifiers and the possibility of using a high contrast filter in the game. Color blindness may be approached by using an adequate color palette to objects that could be identified by color or by letting players change those colors by their own [IGDA, 2004; Yuan et al., 2010].

Hearing impairments may vary from mild hearing loss to profound deafness and affect mainly the reception of stimuli (step 1). They can be classified in four levels according to the intensity of the hearing loss [Kano et al., 2009; Pereira, 2008]:

- mild hearing loss (26 to 40 dB),
- moderate hearing loss (41 to 70 dB),
- severe hearing loss (71 to 90 dB),
- profound hearing loss (91 dB on).

When hearing loss occurs in childhood, Pereira [2008] describes the degrees of hearing impairment as (translated and summarized from p. 29, 30):

> *"Children with mild hearing loss speak almost perfectly, forgetting one or another phoneme. Children with moderate hearing loss only perceive the strong voice and have difficulty in speech, with many errors. Children with severe or profound hearing loss have no contact with the world of sound and have great difficulty in learning oral language by natural means."*[1]

[1] Original excerpt in Portuguese:
"Uma criança com surdez leve só não consegue perceber a voz cochichada, percebendo todos os outros tipos. Pode adquirir linguagem naturalmente, podendo ter apenas alguma dificuldade na fala, trocando ou omitindo alguns fonemas. Costuma ser desatenta, insegura e ansiosa."

"A criança com surdez moderada não percebe a voz fraca nem a média, utilizada na conversação normal, ouvindo apenas a voz forte. Este fato permite que adquira linguagem, porém sua fala apresenta-se com muitos erros. Em alguns casos, a linguagem é insuficiente para conseguir expressar-se ou fazer-se entender. Necessita da repetição e da ajuda da visão."

"A surdez severa e a profunda são bem mais sérias, impedindo que a criança perceba os sons produzidos em seu ambiente familiar, o que impossibilita a tomada de consciência do mundo sonoro, fazendo com que fique privada dos modelos linguísticos oferecidos por seu ambiente familiar, não conseguindo adquirir linguagem pelos processos naturais."

In games, sounds are usually used as secondary stimuli, supplementing visuals. In this case, not perceiving them may still enable those games to be played by deaf and hard of hearing people. However, this is not always the case, as sometimes relevant information is conveyed exclusively through audio, causing a reduced game experience [Yuan et al., 2010]. Many games already provide subtitles for narration and dialogs. But only a few provide closed captions — that also transcribe sound effects, such as Zork: Grand Inquisitor (1997), Half-Life 2 (2004), Doom 3[CC] (2004 — an unofficial modification of the game Doom 3) and Left 4 Dead 2 (2009). In those games, captions are usually displayed following a formatting code with different colors, use of italics, bold or regular format and brackets to indicate whether a caption is from a speech or a sound, who is talking (in case of speech) etc.

For the hearing impairments, we reviewed content from the game accessibility academic literature and from accessibility evaluations of games for deaf players from specialized websites as well, so we could have a clearer view on the guidelines from the perspective of deaf players. We present, first, our review on the accessibility ratings from websites.

DeafGamers.com[2], AbleGamers.com[3] and GameBase.info[4] are websites dedicated to rating games according to their accessibility. While the latter two let the community users publish their own reviews in any type of impairment, the first one is not usually open for user reviews and is focused on the evaluation from the perspective of deaf players.

We conducted a non-exhaustive investigation on the game reviews for deaf and hard of hearing players from those websites to detect the criteria used to measure accessibility. Fifteen game reviews were randomly selected from each source and their content was analyzed in search of the game features that were considered positively towards the game accessibility. Some of the features considered good practices are:

- the presence of subtitles and captions for speech and sound effects;
- the use of a formatting code to display the captions;
- the coverage of the captions - i.e., whether they transcribe all the relevant sounds or not;
- the ability to change the speed and repeat dialogs;

[2]DeafGamers: `http://www.deafgamers.com`. Last access on 03/31/2012.
[3]AbleGamers: `http://www.ablegamers.com`. Last access on 03/31/2012.
[4]GameBase: `http://www.gamebase.info`. Last access on 03/31/2012.

- the possibility of separately adjusting music and sound effects volume, which may help players with mild to moderate hearing loss focus on more relevant sounds;
- enabling the identification of the interlocutors in dialogs; and
- the use of a type of radar in the interface that enables the localization of enemies in the proximity of the main character.

In the reviews, text based alternatives were highly praised. Although they may be used to easily transcribe the game sounds, they might still not be enough for severe and profound deaf players that might not have good reading skills.

In the academic side, the general game accessibility literature often ignores the possible language acquisition issues of deaf people, focusing much more on the need to represent textually the information from sounds. Indeed, providing subtitles and closed captions is cited as the only and/or sufficient accessibility guideline by many works [IGDA, 2004; Bierre et al., 2005; Kimball, 2005; Bierre, 2006; Yuan and Folmer, 2008]; one work suggests the use of spatially located captions [Grammenos and Savidis, 2009]; but only a few cite alternatives that do not rely on text only [van Tol, 2006; Yuan et al., 2010]. Yet, not even these last works discuss the limits of text based alternatives for deaf players. What they actually do is to present how some games had features that turned out to aid in providing support for hearing impaired players, but that were not necessarily conceived as accessible measures.

Figure 2.2 shows games[5] that use different strategies that contribute to the accessibility: (a - The Sims 3) depicts sounds as if they could be seen, using colors, shapes and animations as a metaphor to how they sound: a ringing phone emanates a series of concentric circles, a guitar emits colorful song notes and so on; (b - XIII) uses onomatopoeia to represent sounds where they are emitted, similar to what is done in comic books; (c - Multi Trilhas) is an educational game specially crafted with the purpose of helping deaf children learn written Portuguese as a second language by using videos with instructions and vocabulary in Libras [Couto et al., 2005]; and (d - Xenosaga III) does not replace texts, but uses character portraits in dialogs to emphasize which character is currently speaking. Except for the game in (c - Multi Trilhas), all others are mainstream games that do not claim to be accessible for deaf and hard of hearing people (at least in their public release of game features), but have uncovered resourceful strategies to improve game accessibility.

[5]The Sims 3 website: `http://www.thesims3.com/`. Last access on 03/31/2012.
XIII website: `http://www.ubi.com/US/Games/Info.aspx?pId=39`. Last access on 03/31/2012.
Multi-Trilhas website: `http://www.multi-trilhas.com/`. Last access on 03/31/2012.
Xenosaga III website: `http://www.bandainamcogames.co.jp/cs/list/xenosaga3/index.php`. Last access on 03/31/2012.

Figure 2.2: Screens from the games (a - top left) The Sims 3, (b - top right) XIII, (c - bottom left) Multi-Trilhas and (d) Xenosaga III.

Some works describe initiatives that purposely address game accessibility for hearing impaired in educational contexts. An interesting approach is illustrated by CopyCat, a game that can recognize gestures as input in order to help deaf children practice American Sign Language (ASL) skills [Brashear et al., 2006]. A similar approach was used in the game SMILE, which is an immersive virtual learning environment for teaching basic science, math and ASL for deaf children [Adamo-Villani and Wright, 2007].

Despite those approaches, so few mainstream games have been developed with accessibility for deaf and hard of hearing players as an objective. All the solutions used in those games are mostly based on text replacements for sounds but, as we present in chapter 4, captioning alone may not be able to convey all the relevant information to players. Moreover, considering the use of a sign language by deaf people, exploring the visual-space field with images and animations to represent the information from sounds may be a lot more beneficial and friendlier for them. No academic work has addressed the accessibility problem for hearing impaired players in its full spectrum, also considering those aspects when proposing accessible solutions.

In this dissertation we focus on the game accessibility problem for hearing impaired people, taking into consideration that due to language acquisition issues, textual representations may not be alone a good enough solution to the problem.

2.2 Sound in Game Design

Digital games are a special type of multimedia experience which very frequently explores human perception through multiple senses. Visuals and audio have always been present in conjunction to stimulate the respective senses.

Most games use audio as a feedback strategy to players and also to enhance game experience [Huiberts, 2010]. In early games, designers relied on simple synthesizers that produced only beeps with little variation and the sounds were produced to attract players' attention. The hardware and the game industry evolution enabled game designers to develop new usages of audio, making it possible to create really convincing atmospheres inside games. Nowadays, the game hardware that is commercially available is capable of producing sounds in multiple channels, enabling sound localization, and also of executing digital processing algorithms in real time.

Those advancements in hardware and the natural growth in players expectation of a games' quality have led designers to propose new and creative ways of using audio. Some of those techniques involve the use of distributed channels to enable sound localization, music that dynamically adapts to situations in games according to their intended mood and the use of music features such as pitches and beats to set game variables, e.g., spawning a new enemy every beat.

An example of a recent game that uses those techniques is Fallout: New Vegas[6]. Lawlor, the Audio Director behind it, has published an online article about the game's audio production [Lawlor, 2010]. We retrieved an excerpt of it to show an example of how audio is used in the game (p. 2):

> *"When approaching an area in the desert* ***we want to draw the player in****, [...] (he) starts to see a house on the horizon, the first layer (of three) starts to play.* ***The player hears the tension change****. As he nears the house, a second layer comes in, and once he is in the center of town, the whole music track plays".*

Game audio assets are usually categorized in three types, according to its production process: voiceovers, sound effects and music [Novak, 2008; Huiberts, 2010]. However, as Huiberts [2010] pointed, a better typology should be more concerned with the functional use of the audio. In his thesis, he presents the IEZA framework, a model for game audio design that contemplates a typology that considers the communication of meaning and information of sounds. We briefly explain its main concepts hereafter, as they are later used in chapters 4 and 5.

[6]Fallout: New Vegas Website: `http://fallout.bethsoft.com/`. Last access on 03/31/2012.

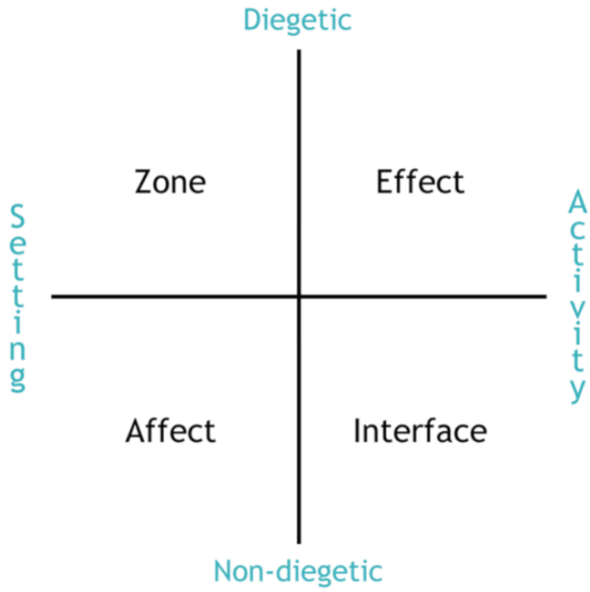


Figure 2.3: The IEZA model of game audio typology by Huiberts [2010].

The model uses two dimensions to classify game audio. The first one is according to diegesis[7] and is divided in two poles: diegetic and non-diegetic. It indicates whether a sound communicates about something that exists *in the game world* (diegetic) or if it communicates about something *outside it* (non-diegetic). The second dimension is related to the interdependence of sounds and is also divided in two poles: activity and setting. A sound is categorized into activity if it communicates to the player events and situations happening in the game environment, whereas it is considered into setting if communicates about the surroundings with the aim of composing the game atmosphere. Those poles form four domains of game audio, namely **I**nterface, **E**ffect, **Z**one and **A**ffect, hence the acronym (see Figure 2.3).

The domain **Effect** represents sounds that are emitted from objects inside the game world, e.g., characters' footsteps, dialogs, weapon sounds. In other words, Effect sounds are those that can be heard by the players' avatar in the game (diegetic) and that inform players about situations in the game.

The domain **Zone**, also on the diegetic pole, represents sounds related to the environment which are usually called ambient, environmental or background sounds in other typologies. Examples of Zone sounds are the noise of transit in a city environment, the chirping of crickets and the hooting of owls in a farm or forest environment at night. Those sounds are mostly used to set a convincing atmosphere to the game and usually

[7]The concept of diegesis here is appropriated from its use in film sound theory and means the binding of something (in case, sounds) to the game's narrative [Huiberts, 2010].

are not affected by player interaction.

On the non-diegetic pole, the **Interface** domain represents sounds that actively support and reacts to the player (Active) but does not originate from the game world, but rather from the game interface. For example, the game Half-Life 2 plays a specific sound as a feedback for players indicating that an action is not possible.

Last, the **Affect** domain represents the background music that is played throughout or in selected parts of the games. According to the framework's author, the affect sounds are used to make references to social, cultural or emotional aspects. As examples, he cites the use of punk music in the game Tony Hawk Pro Skater 4 as a reference to the skaters culture, which makes the game more appealing to its intended target audience.

Chapter 3

Investigation of Accessibility Issues

Reviewing both the game accessibility literature and online game accessibility communities in search for issues and the existent solutions to accessibility provided good insights on the current state of the game accessibility problem. However, we considered it necessary to complement our literature review and to explore the opinions of hearing impaired players on the issue, so that we could consider the accessibility problem from the perspective of deaf and hard of hearing people.

To this end, we resorted to the application of an online questionnaire to people with some degree of hearing loss. We wanted to gather information about good and bad game experiences they had had and how they considered games could better fit their needs. The questionnaire format was chosen instead of the execution of interviews for its broader reach and easier distribution. However, that decision also brought a limitation to our data, as due to the possible unfamiliarity of the prelingual respondents with written Portuguese, they may have had difficulties to read the questions and write their responses. Anyway, as our goal rested more on the exploration of issues rather than on confirmation of hypothesis, the gathered data was still valid for our purpose.

In this dissertation's statement, the results of this chapter contribute to the objective (i) — exploration of accessibility issues from the perspective of deaf and hard of hearing people. Partial results of the questionnaire have already been published by the authors [Coutinho et al., 2011a], but a more thorough explanation is presented as follows.

3.1 Questionnaire

We elaborated an online questionnaire composed of 21 questions, of which nine were designed to characterize the profile of participants, seven were related to the characterization of their gaming experience and the other five requested their opinion on common accessibility solutions for games, movies and TV (see Appendix A)[1]. In the profile part, participants were asked about their degree of hearing loss, what languages they used to communicate, their schooling level etc; in the game experience part, they were asked about games they had played and liked or disliked, platforms on which they had played and if they had experienced difficulties when playing due to hearing impairment; and, in the last part, they were asked about the use of subtitles and closed captions in television and movies and also how they would make games different to better suit their needs.

As the questions were written in Portuguese, we carefully crafted their text to make them more easily understandable by people who do not have good Portuguese reading skills. Two Libras specialists analyzed the vocabulary used and the forms of writing the questions in such a way to facilitate their understanding by the respondents. A pilot test was conducted and the text was adapted with the feedback from a deaf person. Only then the questionnaire was distributed. Although we have taken such measures, we can not guarantee that all the questions have been properly understood by the respondents. If affordable, a safer approach would be to present the questionnaire in both Portuguese and Libras.

Because of its digital format, it was published mainly on the Internet in Brazilian deaf-related social networks (e.g., Orkut communities, Facebook groups), discussion groups, mailing lists and blogs, but also in deaf culture associations from different states in Brazil.

3.1.1 Application

The questionnaire was open for participation for 23 days between 06/27/2011 and 07/20/2011 and could only be answered after participants were presented with an initial page containing a consent form with a description of the research and how the results would be used (see Appendix A). It was distributed through many groups aimed mostly at deaf people: Orkut communities for the deaf (e.g., "Surdos de Minas Gerais", "Surdos da Bahia", "Surdos no Orkut") and communities aimed at Libras (e.g., "Amo Libras", "Intérpretes de Libras", "Letras / Libras"), Facebook groups (e.g., "Surdos do Brasil", "Surdos no Facebook"), Online mailing lists related to deaf topics (e.g., "SURDOS-BR", "MAIS Universidade"), Associations of deaf people in Brazil and personal contacts of

[1]In fact, the questionnaire also contained questions related to the use of social networks, which was part of an investigation conducted by (at the time) fellow M.Sc. student Glívia Barbosa.

those responsible for the research. A sample broadcast message used to distribute the questionnaire can be seen in Appendix A.

Altogether, 111 people with some degree of hearing loss ranging from mild to profound, distributed in all five regions of Brazil, answered the questionnaire. In the next sections, we present our analysis of the questionnaire according to the three topics investigated: profile, game experience and opinion on accessibility resources for other types of media than gaming.

3.1.2 Respondents Profile

In the profile group of questions, participants were asked about their degree of hearing loss, their communication preferences, whether they belonged to the Deaf Community or not, about their education and which state they lived in. These three questions could help us better understand the participants answers and some of them seemed to be intervening in their opinions on game accessibility.

Among the participants, 86.5% considered themselves part of the Deaf Community, 8.1% were not and 5.4% could not answer whether or not they belonged to the community.

The degree of hearing loss ranged from mild to profound. Among the participants, 5.4% had mild hearing loss, 6.3% had moderate hearing loss, 31.5% had severe hearing loss , 49.5% had profound hearing loss and 9.9% could not describe their degree of deafness or did not remember it (see Figure 3.1).

Regarding the preference for communication, 13.5% said they preferred to communicate only through Libras, 8.1% though orofacial reading, 37.9% through orofacial reading and Libras and 35.1% though Libras and written Portuguese. Also, 5.4% did not indicate how they preferred to communicate.

About schooling level, it was observed that most participants (57.6%), had attended or were attending higher education. 9.0% had incomplete post-graduation and 14.4% had completed it. 15.3% had incomplete college, while 18.9% had it completed. Among others, 32.4% completed high school, 2.7% had secondary school, 4.5% completed elementary school and 2.7% had incomplete primary education. With regard to the type of school, the survey revealed that 22.5% of the participants studied in special schools while 53.2% studied in inclusive or regular schools. The other participants, 24.3%, studied in both special and inclusive schools.

The questionnaire had the participation of deaf people from all regions of Brazil. 68.5% were from the Southeast of the country (of which 48.7% were from the state of

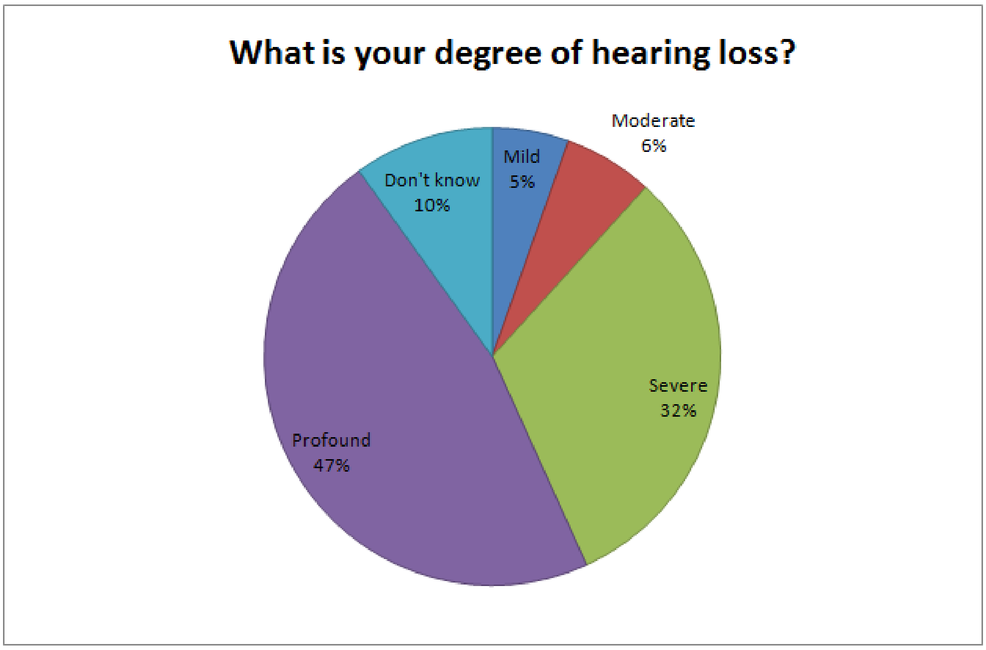


Figure 3.1: Chart showing the percentage of respondents with a each degree of hearing loss.

Minas Gerais, where this research was conducted), 16.2% live in the South, 4.5% in the Midwest, 8.1% in the Northeast and 2.7% in the North.

3.1.3 Results

Of the total number of respondents, 61% reported to usually play or to have played a game before. The questions of the second group were displayed only for those who had had any contact with games.

3.1.3.1 To Play or Not to Play

The first question related to gaming experience inquired about whether the respondent had had any contact with gaming. Its statement was “Do you play or have ever played a game?” and, the questions in the same group that followed were only displayed if they answered positively to that question.

Of the people who play (61% of respondents), all those with mild hearing loss responded affirmatively. Of those people with moderate hearing loss, (43%) and, in both other groups (severe and profound), the number of people that play is 60% (see Figure 3.2).

The fact that all respondents with mild deafness have played may be due to low representation of people with this profile in the sample (only 9% of participants).

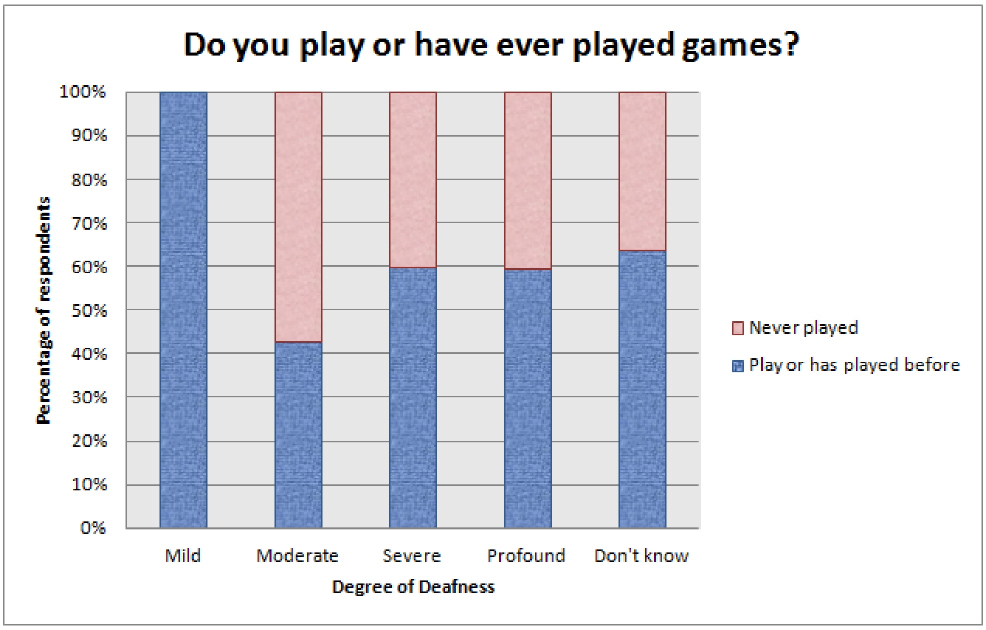


Figure 3.2: Chart showing whether the respondents had played games by their degree of hearing loss.

Considering only the respondents that played or that had played games, some respondents with higher degrees of hearing loss play with less frequency than those with milder (see Figure 3.3). The fact that the respondents with severe and profound deafness play less frequently than others may be due to a sampling artifact - the lower presence of people with lower degrees of hearing loss in the sample - or it may suggest that games are less appealing for people with higher degrees. However, a deeper study is necessary to explain this observation.

3.1.3.2 Game Genres and Platforms

In other questions, respondents were asked about the gaming platforms (the hardware, e.g., computers, video games, cellphones) they usually played on and the games that they liked or disliked playing.

The results can be seen in Figure 3.4, in which the vertical axis represents the number of respondents who play / have played in the platforms and the horizontal axis contains the gaming platforms.

Although participants were asked their opinion on games they had liked or disliked, our intention rested more on identifying their opinion on game genres. However, we opted not to ask them that directly, as there is no standard classification of games. Furthermore, respondents might not know the genre of the games they had played and finally to avoid inconsistency among respondents classification. In this way, we

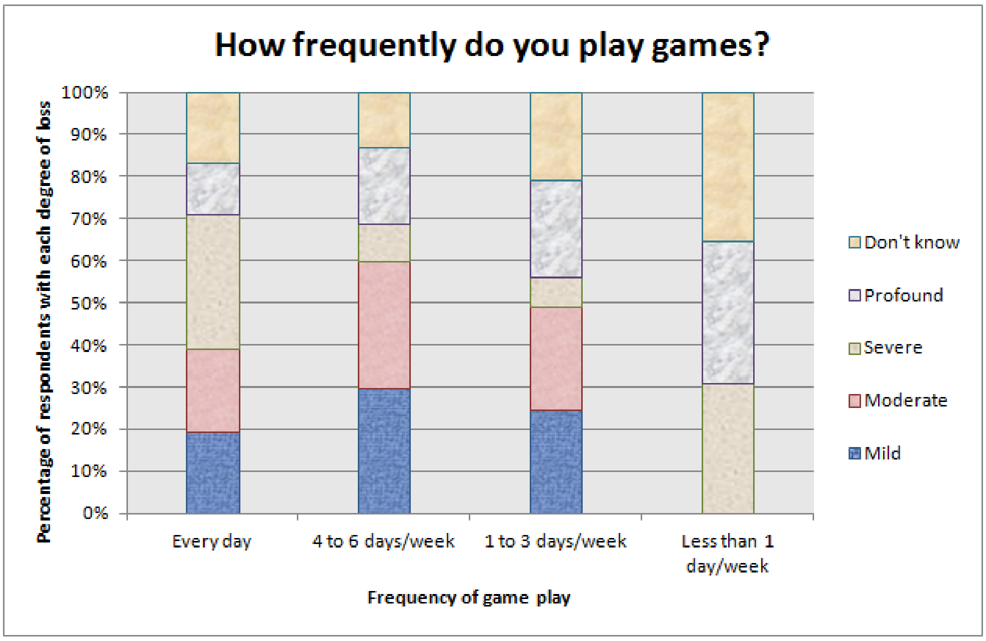


Figure 3.3: Chart showing the frequency of gaming of the respondents by their degree of hearing loss.

classified ourselves the games and, for that, we used an adapted set[2] based on the one provided by Novak [2008]. The adapted set is:

- Action
- Adventure
- Cards / Board
- Educational
- First-Person Shooter (FPS)
- Fighting
- Multi-Massive Online (MMO)
- Platform
- Puzzle
- Racing
- Rhythmic
- Real Time Strategy (RTS)
- Role Playing Game (RPG)
- Simulation
- Social
- Sports
- Survival

Some respondents did not write game names in the answering field, but wrote characteristics of games or game genres (e.g., "fighting games", "games with violence", "3D games"). For some of those answers, the categorization in game genres was possible, e.g., the "fighting games" answer counted for the Fighting genre, "games with violence"

[2]Novak [2008] presents a hierarchical genre set (with genres and sub-genres). For instance, Platformers, Shooters, Racing and Fighting were all grouped in the same genre. We basically flattened the set by considering some sub-genres as genres themselves.

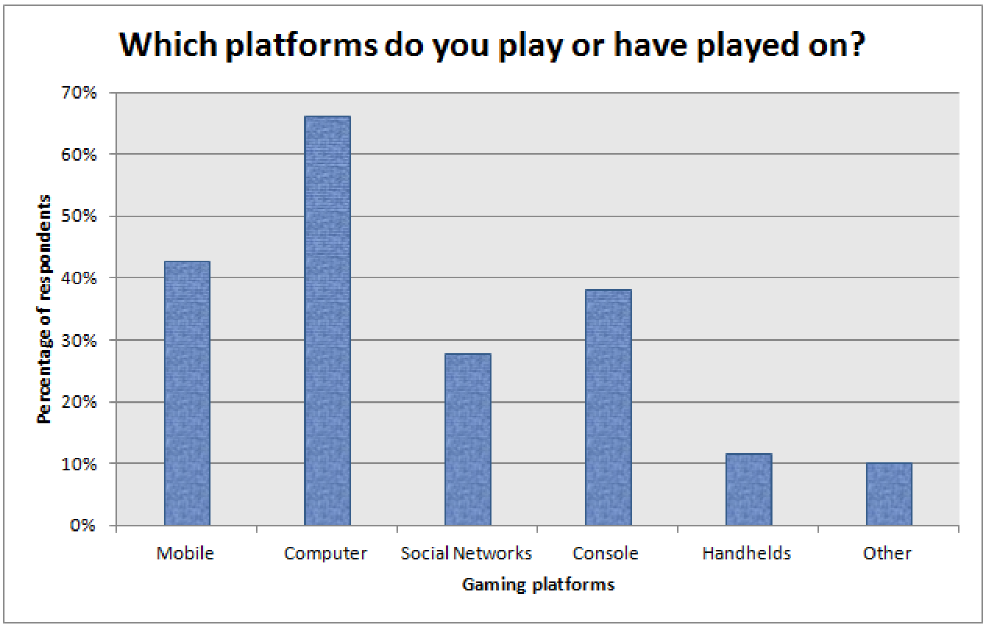


Figure 3.4: Chart showing the percentage of respondents that played or had played games on each gaming platform.

for both Fighting and FPS as violence is an inherent component in those genres. But others were ignored (e.g., "3D games").

Figure 3.5 shows the results. Respondents mentioned they liked, mostly, games of genres with simple mechanics and that could be easily understood like Platform (e.g., Super Mario, Sonic), Puzzle, Racing, Social and Cards. Of these genres, only one (Racing) had a game cited as disliked. On the other hand, some game genres had higher levels of rejection than acceptance, like FPS, Fighting, Rhythm, RPG, RTS and Simulation. Except for Fighting, all those genres have steeper learning curves (RPG, RTS, Simulation), or rely heavily on reading and interpreting texts and rules to progress in the game (RPG) or benefit players with lower response times to situations and have a very rich use (from the viewpoint of communication) of the game audio (FPS, Rhythmic). The aforementioned characteristics may be part of the cause of the respondents acceptance / rejection to the games. The respondents' reports on difficulties they had when playing (as shown later in Table 3.1) help support that possibility.

3.1.3.3 Difficulty to Play

One of the questions asked respondents whether they believed to have had difficulties due to their hearing loss: 28% reported having difficulties, 57% reported not having difficulties and the others (15%) said they did not remember or they did not answer.

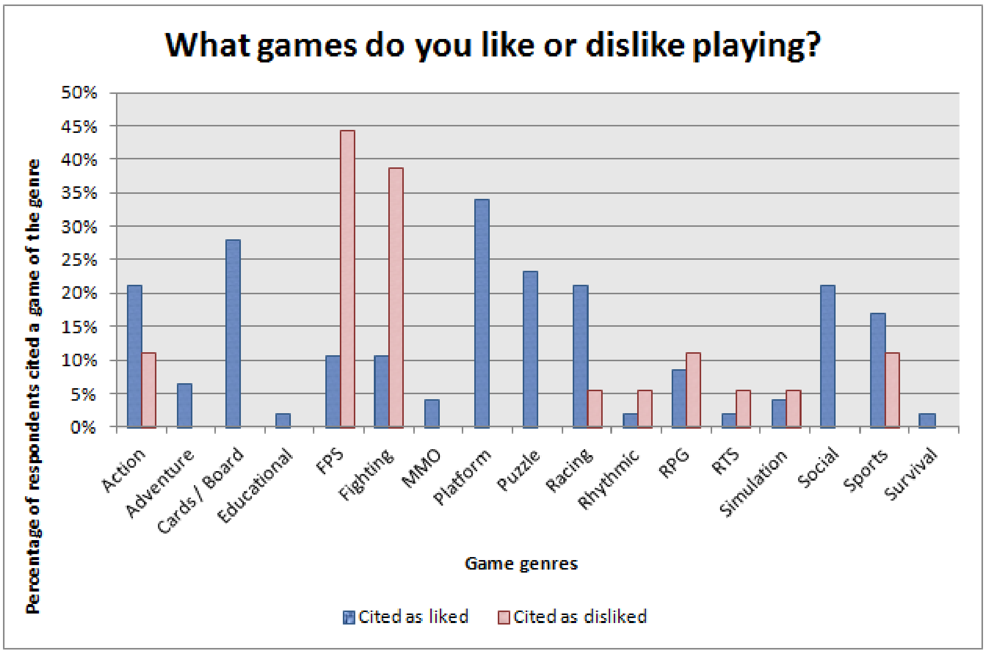


Figure 3.5: Chart showing game genres that had games cited as liked or disliked by respondents.

By crossing the responses from people who reported difficulty with their degree of hearing loss (see Figure 3.6), it is possible to make two observations:

1. People with mild hearing loss reported not having problems.
2. The higher the degree of hearing loss, the (proportionally) less respondents reported having had difficulty to play.

The second observation draws one's attention, since we would expect that the higher the degree of hearing loss, the more difficulty people would face when playing. However, those observations show the opposite: apart from the people with mild hearing loss, the higher the loss, the less difficulties to play. The questionnaire did not enable us to understand the cause of this observation, but we can raise some points that could be considered to explain: either (1) as respondents did not have a chance to hear, they only choose games that do not depend on sounds, or (2) they did not want to admit they had problems, or (3) they did not realize they had lost relevant information and that any problems could be caused by this reason.

The possibility that players that did not have difficulties because they did not play games in which sound is more relevant (1) is due to the fact that a big portion of the players that declared not having had difficulties also cited they liked simpler games like Casual, Platform and Cards. However, a few respondents (with severe and

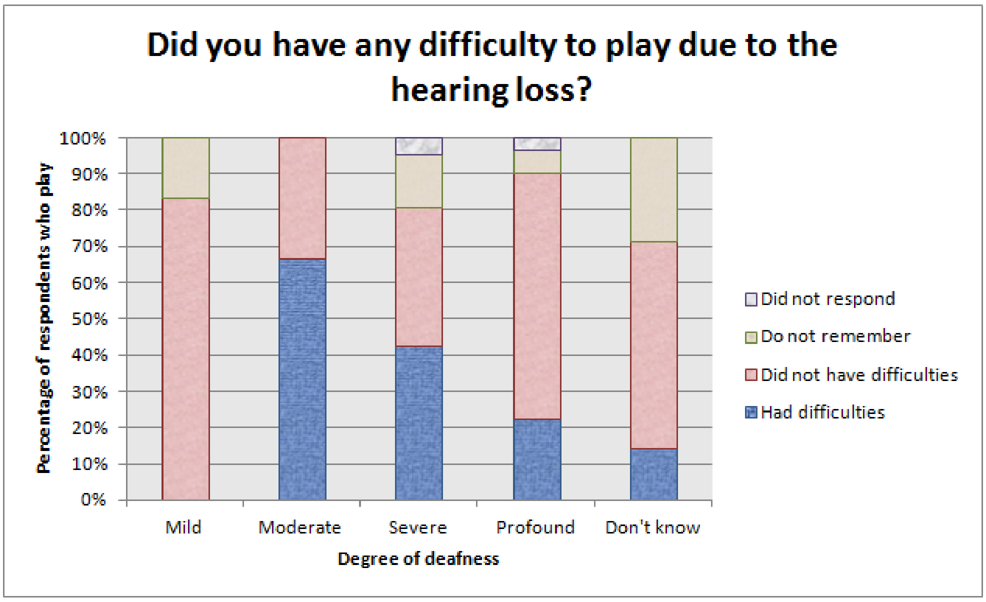


Figure 3.6: Chart showing whether participants answered they had difficulties playing due to the hearing loss, categorized by their degree of deafness.

profound deafness) said they liked games like FPS and RTS and they did not had any problems due to their hearing loss.

The possibility that respondents may have denied having difficulty to play (2) is based on observations from Botelho on some characteristics resulted from a self-stigmatization process that is common among deaf people: the denial and minimization of difficulty, which the author exemplifies in the context of interpretation of texts in oral language in her book [Botelho, 2005].

The explanation that respondents who had less difficulties playing by not realizing they were missing information (3) is based on the fact that by not knowing of what is being missed they do not get frustrated for missing it. However, to better investigate those observations, further data must be collected, possibly in an interview with deaf game players.

Those who said they had trouble playing because of the hearing loss, were asked to write about difficult situations they had experienced. This information was classified into three types of problems which are listed in Table 3.1. The language related problems show that, in fact, the use of texts can present a barrier to game experience. Actually, most games still do not get translated to Portuguese and the use of a foreign language may present an even bigger barrier for deaf players, as it would require the acquisition of a third language.

The reported problems show indeed that not perceiving information conveyed through audio may present a barrier to game experience to the extent that it may even

Table 3.1: Difficulties to play reported by respondents in the questionnaire.

Type of Problem	*Description*
Language related	Games in foreign language
	Unknown vocabulary
	Instructions in foreign language
Audible feedback	Use of audio cues in game progress without other alternatives of communication
Game rules	Game rules difficult to understand
	Instructions not understood

prevent players to progress in the game. Below, a very interesting story[3] reported by one of the participants who had to be assisted by his family to resume making progress in the game:

"In the only game that (I) had spent a week trying to solve a puzzle and after finishing it I never replayed it was Resident Evil 3 — Nemesis, because (there was) the part that was needed to plug a pin that was necessary to hear. I even had help from relatives [...]"

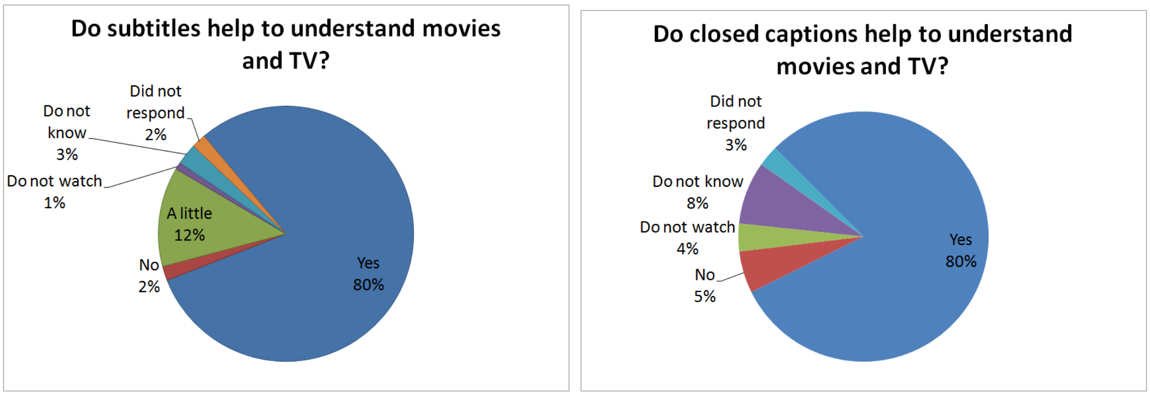
Moreover, the same story shows that some elements of recent games contribute to provide access for people who cannot hear:

"[...] And the other shooting games, mostly, I was looking for shots of the enemy, but today has facilitated because of the radar and when I am hit the red image appears with the alert."

3.1.3.4 Subtitles, Closed Captions and Suggestions of Improvement

Two questions were posed in the questionnaire in order to raise potential problems with common assistive technologies for audiovisual content. In one, they were asked about the effectiveness of the subtitles and in the other, the effectiveness of closed captions and were responded by 109 and 108 people respectively (out of 111). The two assistive resources were very well accepted, being considered helpful by 80% of the respondents (both).

[3]The story was written in Portuguese by a participant in the questionnaire and literally translated to English, including the difficulties to express himself orally. The original text is:
"No único jogo que passe quase uma semana tentando resolver um puzzle e depois de zerar nunca mais voltei a jogar foi o Resident Evil 3 — Nemesis, pois teve a parte que precisava plugar um pino que era necessário ouvir. Até tive ajuda de parentes, na época não tinha detonados na Internet, uns 1997, e na revista demorava bastante para lançar o detonado. E os outros jogos de tiro, na maioria, ficva procurando os tiros dos inimigos, mas hoje tem facilitado por causa dos radares e quando eu for atingido aparece a imagem vermelha com a indicação."



(a) Subtitles (b) Closed captions

Figure 3.7: Chart showing the response of whether subtitles and closed captions provide help when watching TV and movies.

If respondents selected that there were problems in subtitles or closed captions, they were asked to explain their nature (see Figure 3.7). Although we explained the closed caption term in the formulation of the question (see Appendix A), it is possible that respondents may have had trouble differentiating the two terms, since they are sometimes used interchangeably.

With respect to the subtitles, all complaints relate to the use of difficult words which lead to the misunderstanding of the text. With respect to the closed captions, the complaints also involved the fact that the presence of "typing" errors, which indeed may happen in broadcast / live transcripts[4]. There were no complaints about the time available for reading the subtitles and closed captions.

At the end of the questionnaire, respondents were asked to suggest improvements in games so that they could best fit the needs of people with hearing loss. Their comments were grouped in Table 3.2. Three very frequent suggestions were the use of subtitles, use of closed captions and videos in Libras. It was also suggested that the language of communication between the game characters should be Libras. Another important consideration to notice is that some respondents stated that adjustments in games to suit their needs were unnecessary.

The suggestions of including subtitles and closed captions were very recurring among participants. One probable reason might be the fact that these two alternatives are the ones that are mostly used, and could be best known to participants.

When we crossed the suggestions with the respondents preferred communication

[4]In TV content, the closed caption is usually previously typed and do not contain errors when the content being transmitted has already been recorded (e.g., a movie), but is typed in real-time by a human operator in live transmissions, then, being more susceptible to errors.

Table 3.2: List of most relevant suggestions made to improve games to those with some degree of hearing loss. Texts in italics are literal translations from Portuguese to English as they were written in the questionnaire by participants.

Type of Suggestion and occurrences	*Description*
Language related (9)	Communication happening in Libras inside games.
	Instructions in Libras.
	Translation of texts to Libras using videos.
	Use of more accessible vocabulary.
Employment of visual content (2)	Use of images in conjunction with texts *"since symbolic elements are better understood by the Deaf"*.
	Use images whenever possible so both adults and children may better comprehend games.
Providing of transcriptions (22)	Exploration of other manifestations of communication as acting and dancing.
	Closed captions: *"Explanation of sounds"*.
	Subtitles: *"Use of subtitles to enable comprehension of what is being said, what is happening"*.
Haptic feedback (1)	Vibration in joysticks and other input devices.
	Use of low frequency sounds so they feel its vibration.
No changes(4)	No need to change games.
Other suggestions (2)	To create games with Deaf Culture and Libras themes.
	Exploring games with educational purposes for deaf.

language, we could make interesting observations (see Figure 3.8). Those who prefer to communicate orally mostly presented suggestions based on transcriptions, which indicates that text based approaches for accessibility may fit them well. In turn, those who prefer to communicate through signing suggested the use of transcriptions, but also suggested the use of more accessible vocabulary and the use of Libras as a language. Another observation is that all the respondents who claimed that games need no adaptations for deaf players responded to prefer to use Portuguese, be it in oral or in written format.

Interesting enough, those observations may be due to the fact that those respondents that have gone through the process of oralization have integrated themselves into

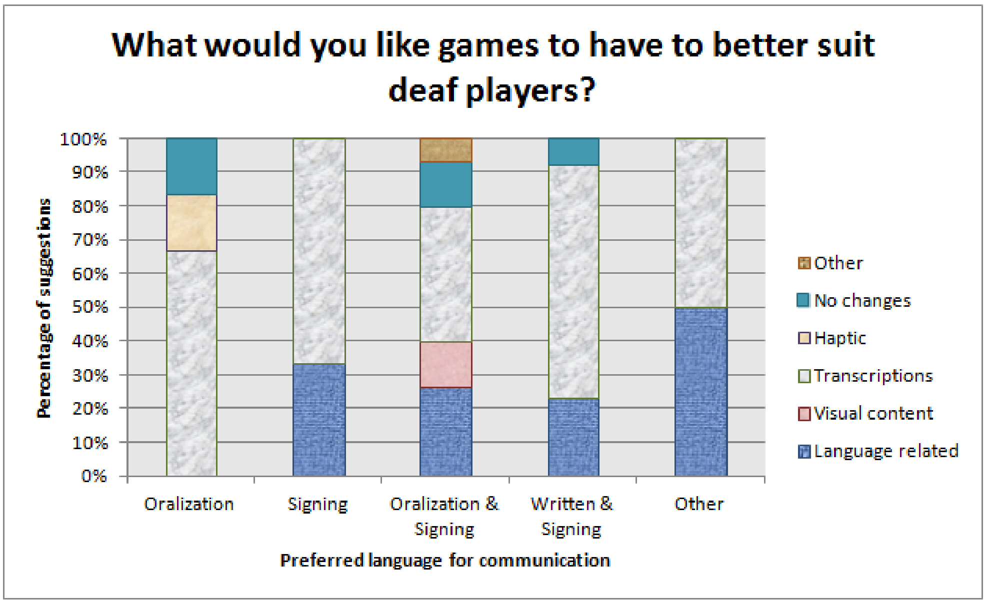


Figure 3.8: Chart showing respondents suggestions to improve game accessibility for deaf players.

the society and do not require adaptations to be done in games that already present transcriptions. However, their opinions (from Table 3.2) show that transcriptions are not the only improvement to aid in game accessibility, what can be seen by the significant presence of suggestions related to the use of Libras, more accessible vocabulary and the use of visual content.

3.2 Chapter Summary

In this chapter, we presented a report of the application of an online questionnaire to investigate game accessibility for hearing impaired players through their own game experiences. There was a total of 111 respondents, of which 68 had ever played a digital game.

With the answers to the questions about games the respondents had liked or disliked, we detected some game genres with high acceptance (Platform, Puzzle, Social, Racing) and others with more rejection than acceptance (FPS, Fighting, RPG, RTS, Simulation, Rhythmic). Their reports on the difficulties they had when playing due to the hearing loss (i.e., language related, audible feedback and game rules) and some of their suggestions for improving the accessibility of games (i.e., language related, exploration of visual content) help support the observation that games that rely heavily on texts, or that make a very relevant use of sounds, or that take more effort to learn are less accessible or, at least, less appealing for deaf people.

Overall, the observations we could make with the questionnaire help us support the point that text based approaches for assistive resource may not necessarily be the best solution for all hearing impaired players. The results concerning the suggestions given by respondents by their preferred communication language may have even delineated a possible characterization of the hearing impaired players game accessibility needs and preferences according to their profile, in that the degree of hearing loss and the preference for communication did intervene in the sample results. However, further investigation is necessary to collect broader results, as well as to better understand the context and profiles related to the different possibilities.

Beyond supporting our motivation, the results of the questionnaire also pointed us to the next step of this dissertation, which was to identify systematically how the game audio is used to convey information to players. We used one game of the most rejected genre identified with the questionnaire (FPS) called Half-Life 2.

Chapter 4

Communication Through Audio

To better understand the impact on game experience of not receiving auditory stimuli in games, it is necessary to know how game audio contributes to the communication of relevant information with players.

In this chapter, we present our investigation of how audio is used to convey information to players in the special case of FPS games. Thereby, it was possible to evaluate the accessibility of the identified strategies of communication.

For that task, we used the Semiotic Inspection Method, which is explained, along with its underlying Semiotic Engineering Theory, in the next section. In the second section, we present the results of the application of the method to the FPS game Half-Life 2, of which partial results were published in Coutinho et al. [2011a] and in Coutinho et al. [2012].

In the dissertation's statement, the results of this chapter contribute to achieve the objective (ii) — identification of the use of game audio to convey information and its impact to hearing impaired players experience. The study has also brought contributions related to the methodology employed, as we present in the methodology appraisal in the chapter summary.

4.1 Foundation

As the use of sound as communication means may impose a barrier for those who have difficulties or cannot hear, in this case, the accessibility of games may be measured by the quality in which players receive that communication through other means. So, as we faced our problem in terms of assessing the quality of how *communication* takes place in a game, we resorted to Semiotic Engineering as a foundation theory.

4.1.1 Semiotic Engineering

Semiotic Engineering (SemEng) is a theory of Human-Computer Interaction *"that allows us to understand the phenomena involved in the design, use and evaluation of an interactive system"* [Prates and Barbosa, 2007, p. 267]. It considers that software interfaces communicate to their users the software designers' intent. More specifically, in SemEng, any interactive system contains a designers-to-users message regarding the designers' conception of who the users are, what are their needs and expectations and, more importantly, how they have designed the system to meet these requirements [de Souza, 2005]. Users grasp the content of the designers' message as they interact with the system. This (meta) communication can be modeled as what SemEng calls a meta-message, that is a textual representation of the designers' intention. The following snippet contains a generic template of a meta-message, as can be found on [de Souza, 2005, p. 25]:

> *"Here is* ***my understanding of who you are****, what I've learned* ***you want or need to do****, in which* ***preferred ways****, and* ***why****. This is* ***the system*** *that I have therefore designed for you, and this is* ***the way you can or should use it*** *in order to fulfill a range of purposes that fall within this vision."*

The process of communication between designers and users may be measured by how effectively and efficiently it occurs and this quality of user experience is called *communicability* [Prates et al., 2000]. According to de Souza and Leitão [2009], by presenting an *effective* communication, a software's interface must allow users to comprehend the purpose of the system, to whom it has been built for, how its functionalities can be used and other designer's decisions that may be relevant to enable productive interaction - in other words, how completely the interface presents the intended meta-message. By being *efficient*, that communication must also happen with the least noise possible - in other words, how clearly the interface presents the intended meta-message. However, when a problem in that communication does occur, it may compromise user interaction either temporarily or permanently. SemEng names those communication disrupting problems as *communication breakdowns*.

As SemEng is based on Semiotics, an important concept that comes from the underlying theory is that of a *sign*, which is, according to Pierce [1931], anything that means something to someone. A deeper explanation on the Semiotics concepts that were appropriated by SemEng can be found on de Souza [2005], Prates and Barbosa [2007] and Barbosa and da Silva [2010].

For SemEng, software designers encode information in the form of signs in the interface and the users are expected to properly decode them. SemEng classifies signs in three different types: metalinguistic, static and dynamic [de Souza et al., 2006]. *Metalinguistic signs* are those that refer to other signs, and they are usually used as a direct form of communication to the user about software functionality, e.g. a tooltip containing a description of a button, an error message, a help system. *Static signs* comprise interface signs that do not require user interaction to be interpreted and usually express the state of the system, e.g. a grayed out button indicating that it is not enabled for interaction, the button itself, the screen size. *Dynamic signs*, in turn, correspond to the systems behaviors and do require users to interact or time to elapse to be properly identified and interpreted, e.g. the opening of a window when a button is clicked, the change of a mouse pointer image when hovering on different parts of the screen, a sound effect played when a time consuming task finishes performing.

Two methods from SemEng aim to evaluate an interactive system's communicability: the Semiotic Inspection Method [de Souza et al., 2006; de Souza and Leitão, 2009; de Souza et al., 2010] and the Communicability Evaluation Method [Prates et al., 2000; de Souza, 2005; de Souza and Leitão, 2009]. Both methods are interpretative and qualitative. The first one, as the name implies, is performed as an inspection and involves the reconstruction of the designer's intended meta-message. The second one, in turn, involves the observation of users in a controlled environment performing tasks that have been previously defined. The evaluator identifies breakdowns experienced by the users and based on them identifies the problems in the designer's intended meta-message. That way, the inspection method evaluates the quality of the meta-message being sent by the designer, whereas the other evaluates the quality of its reception by the users.

In the next section, we detail the Semiotic Inspection Method, since it was used to investigate how audio signs were being used by FPS game designers.

4.1.2 Semiotic Inspection Method

SIM is an inspection method and, therefore, does not involve users directly. The evaluator inspects the interface assessing the quality of the meta-message encoded in signs by designers, from the perspective of an intended user profile that will use the system. During inspection, the evaluator identifies ambiguities and inconsistencies that may be characterized as potential communication breakdowns that can hinder or even impede the user to interact with the system. The outcome of the method is qualitative, what makes it *"depend directly on the interpretation, thus on the experience, culture*

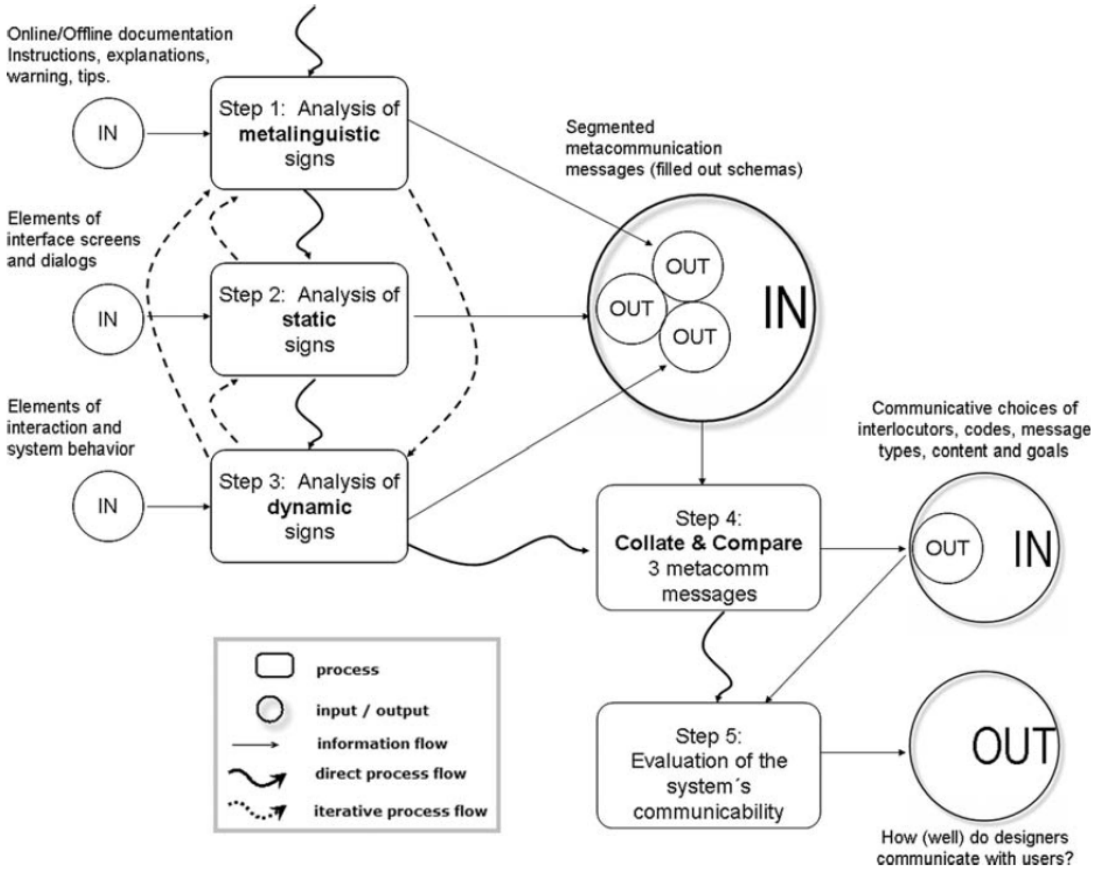


Figure 4.1: An overview of SIM's steps as depicted by de Souza et al. [2010].

an values, of the evaluator" [Prates and Barbosa, 2007, p. 273].

Like other evaluation methods from Human-Computer Interaction, SIM requires a preparation phase with the definition of its objectives and the inspection scope; it also involves an informal inspection and the creation of scenarios describing and contextualizing the inspection. Besides preparation, the method comprises of five steps, as can be seen on Figure 4.1 and are described as follows.

The inspection itself is conducted in the first three steps, when signs are identified according to their types: *in step 1*, the evaluator searches and analyzes metalinguistic signs; *in step 2*, static signs; *in step 3*, dynamic signs. In each step, each sign type is analyzed by what it represents as encoded in the system's interface by designers. At the end of each step, the intended meta-message considering only the current type of sign is generated. In addition, potential communication breakdowns and classes of signs are identified.

After step 3, the evaluator has generated three segmented meta-messages and, *in step 4*, she combines them into one final meta-message. This process is carried out by comparing and collating the text in search for ambiguities and contradictions. The potential communication breakdowns that had been identified when considering only one type of sign are then reevaluated, considering all three types of signs. That may result in some potential communication breakdowns being considered more or less prominent, as the mixture of different types of signs may generate consistent interpretations or they can be ambiguous or contradictory.

In step 5, a final appreciation of the quality of the meta-communication is generated, considering the consolidated meta-message, the potential communication breakdowns and the classes of signs identified.

4.1.2.1 Technical vs. Scientific Approach

Those steps describe the process for evaluating the communicability of software, which is called a technical use of SIM. However, de Souza and Leitão [2009] and de Souza et al. [2010] present how SIM could be used scientifically, with the main goal of generating new knowledge in Human-Computer Interaction.

In the scientific approach, the method's application is oriented by a research question stated in the preparation phase. The same five steps must be executed accordingly.

In step 5, the evaluator's is said to *"use his/her background to frame her systematic interpretation[...] (as) he/she unveils unknown associations between phenomena or give new meanings to already known problems"* [de Souza et al., 2010, p. 29]. However, for those findings to be validated as knowledge, a triangulation must be done and it must generate consistent results with those found by the evaluator.

The task of triangulation may be performed with endogenous and/or exogenous sources. Endogenous sources share the same domain of the application that was evaluated, e.g. other evaluations of the same system performed by different people, evaluations of other systems similar to the one whose findings are to be triangulated. Exogenous sources do not share the same domain of the evaluated application, but they do share design features directly related to the interpretation that will be validated.

In case the triangulation does not provide consistent results, the evaluator must reassess her interpretations, generate new theories and possibly broaden the number of sources for triangulation.

4.1.2.2 Other Applications of SIM to Games

SIM was proposed as a general purpose communicability evaluation method. However, since games often have a different logic than conventional task-based systems it is worth discussing its applicability to the domain of games. Authors believe that because the method was based on the communicative aspects of an interface they could be used in any domain [de Souza et al., 2006]. This hypothesis was confirmed by Reis and Prates [2011] in which two works that used SIM in the domain of games were identified[1].

Peixoto et al. [2010] used the scientific approach of the method to investigate the research question "how the system's feedback is communicated to users during interaction". The authors chose to evaluate an educational simulation game called SimSE[2], which aims to help in the learning of Software Engineering, and the inspection was focused on the instructional and informative feedback provided. The results present various aspects that must be considered for the design of educational simulation games.

Brandão et al. [2010] presents the application of the technical approach of SIM to evaluate a game crafted specially for children with Down syndrome in pre-scholar age. The game is called JECRIPE[3] and is comprised of several puzzle mini-games. As in Peixoto et al. [2010], the inspection was focused on the quality of the feedback provided by the system and the goal was to identify potential communication breakdowns and the quality of the communicability. Results pointed to some issues in the game's interface and were triangulated - despite the use of the technical approach - with the observation of a user playing the game.

Although those works present the application of SIM to digital games, most of the design aspects of the evaluated games are similar to those from conventional software. In both genres - educational simulation and educational puzzle, the games' interfaces usually are not so different from conventional softwares' screens and a help system is also usually available.

4.1.2.3 Use of SIM to Evaluate Accessibility

In her dissertation, de Abreu [2010] applied SIM to three games that aimed at supporting teaching Portuguese to deaf children with the use of Libras. The research question the author wanted to answer was (p. 43) *"What communication strategies were used by designers in the interfaces of systems aimed at teaching Portuguese to deaf children?"* [de Abreu, 2010]. The identified strategies were used to compose a series of accessibility guidelines for the design of systems targeted at deaf children.

Despite the mentioned work use SIM to evaluate games' accessibility, we could not identify in the literature an application of the method to evaluate mainstream games, specially those which make a rich use of game audio, as those of the FPS genre usually do.

[1]We relied on the Systematic Literature Review conducted by Reis and Prates [2011] about the applications of SIM in different contexts.

[2]SimSE's website: `http://www.ics.uci.edu/~emilyo/SimSE/`. Last access on 03/31/2012.

[3]JECRIPE's website: `http://www.jecripe.com/`. Last access on 03/31/2012.

As stated in the literature about game accessibility [Yuan et al., 2010; Coutinho et al., 2011b], visual and auditory impairments may impose barriers to receiving stimulus from the game. Thereby, by evaluating a game's communicability considering user profiles with sensory impairments, we believe a game's accessibility is evaluated accordingly. Moreover, as SIM is a tool for inspecting the emission of the communication in the designers-to-users message, it enables evaluators to identify accessibility issues by seeking potential communication breakdowns.

4.2 Case Study: A Semiotic Inspection of Half-Life 2

We conducted an evaluation of Half-Life 2 (HL2) using the scientific approach of SIM. The research question we wanted to answer was *"what audio communication strategies do FPS games use"*. The choice of the FPS genre was influenced by the results from the questionnaire, which pointed it as the most disliked among hearing impaired players, but also by the importance of the use of sounds, as pointed by [Droumeva, 2010, p. 145]: *"the player literally has to listen through the character's ears in order to play and succeed in the game. Sounds of shots, enemies in the background or out-of-the-frame sounds are extremely important, as are user interface sounds including warnings and alarms that often require immediate attention and split-second decisions"*.

We chose Half-Life 2, an FPS game that was awarded the "Game of the Year" title by 39 different publications in 2004 and had sold more than 6.5 million copies by 2008. A distinguishing feature of the game is that it provides transcriptions of the sounds in the form of closed captions and has been appraised by deaf and hard of hearing players. A typical scene of the game is illustrated by Figure 4.2.

The main objective of the evaluation was to investigate how game audio had been used to transmit information to players. But, as the scientific approach of SIM involves a technical evaluation, we also had as a result an evaluation of the game according to its communicability and accessibility for deaf and hard of hearing players. Anyway, our focus lies on the results of the scientific approach, i.e., the answer to our research question.

To contextualize the inspection, the following scenario was used:

"Joaquim is a college student who has always enjoyed playing video games and computer, especially shooters. His main motivation to play is the challenge of achieving mastery in the game, reaching the final. He also loves games with complex storylines, because he believes that a compelling story makes the game experience more immersive.

Figure 4.2: A typical scene of the game Half-Life 2.

Two years ago, he had a health problem that caused him a high degree of hearing loss (severe deafness) and not even sound amplification devices could benefit his hearing ability. Since then, Joaquim stopped playing games. However, last week, his girlfriend Joanna decided to give him the game Half-Life 2 as a gift, because she discovered that the game had a closed captioning system. Joaquim, then, starts playing the game with the hope to have fun again."[4]

By definition from de Souza and Leitão [2009], signs are considered to be static if they can be interpreted within the context *"present on the interface at a single moment in time"* (p.19), whereas they are considered dynamic if their interpretations require interaction, as they are *"bound to temporal and causal aspects of the interface"* (p.19). Based on those definitions, we considered the ambient sounds to be static signs, as they can be heard independently of player interaction; on the other hand, we considered sound effects to be dynamic signs, as they require player interaction or may be triggered by time-based events. In HL2, game music is played only on certain situations like in a more difficult battle or on some events. Thus, we also considered them to be dynamic signs.

[4]We chose a scenario of someone that became deaf after having acquired good reading and writing skills so that the closed caption alternative could properly fit the access need of the character.

The segmentation and later reconstruction of the meta-message revealed some potential communication breakdowns in the game, most of which due to the use of sounds with no visual redundancy (even with the closed captioning system), but none imposing definitive barriers to gameplay. However, the main results of the application of the method came from the classification of signs.

After the identification of auditory signs, we grouped those with similar properties into classes that represented *what features of the sound effects were used* to convey information, like volume, timbre etc. We also identified *how the classes of sound features were used* to communicate and grouped them into strategies. These classes and strategies are described in the next section.

For each audio sign, we identified (a) which information was being conveyed to the player; again, for each type of information, we answered the following questions: (b) What features of the sound effect were used to communicate that information? (c) Was there redundancy of that information in other signs? and (d) To what extent could missing that information impact game experience?. A sample audio sign we identified can be seen on Table 4.1.

Table 4.1: A sample sign identified in HL2 inspection.

Sign: main character footsteps
Information conveyed (a): 1. the speed of the character; 2. type of surface the character is walking on. **Sound features used** (b): The *pace* in which the sound effect is repeated indicates (1), whereas the *timbre* of the footstep sound indicates (2). **Redundancy** (c): (1) is redundant with the speed in which the camera moves in the game world, whereas (2) is redundant with the image textures used to represent surfaces. **Impacts gameplay** (d): Yes. The surface where the character is standing may indicate different types of enemies that can be encountered. The visual redundancy may not be perceived as quickly as the auditory sign.

After the identification of signs, similar sound effect features were consolidated into classes that were used in our reconstruction of the communication strategies. In the example provided, two different characteristics of the sound effects were used to convey information: the pace at which a sound is played and its timbre, which are two example of classes used by strategies. Finally, we evaluated the accessibility of those strategies based on a scenario of a profound deaf game player with good reading skills.

For the sake of feasibility, we restricted the inspection scope to the first 3 (of 14) chapters of the game: “Point Insertion”, “A Red Letter Day” and “Route Kanal”. As our interest rested only on communication through audio, our inspection was limited to the evaluation of audio signs.

4.2.1 Results

In this section we describe the classes of sound effects features we found to be used to convey information to players. We also present how those classes were used in the game.

Class 1: **Sound volume** — The sound volume is used as a clue to how far its emission source is from the player’s character: the more intense it is perceived, the closer the player is to its source.

Class 2: **Sound distribution** — The game sound volume is split among stereo channels to simulate the direction of its source relative to player’s character’s position in 3D world. In other words, if players use properly placed speakers or headphones, they can distinguish the direction from where sound is being emitted an by taking into account the volume of the sound perceived from each speaker.

Class 3: **Timbre** — Some characteristics make sounds distinct from each other, like frequency, timbre and voice. Considering those characteristics, players are able to distinguish interlocutors in dialogs, identify types of enemies, situations and events.

Class 4: **Timing** —Timing is not a characteristic of the sound effect itself, but rather of which moment in time it is played, ceased or substituted by another sound. It indicates change in the state of the game at some level, e.g., an enemy starts to emit a different sound prior to attacking the player’s character.

Class 5: **Speech** —The content of speech is used to contextualize the player and also to give instructions.

Class 6: **Tempo** —Some things in the game may be viewed as a magnitude and measured in a scale, like the player’s walking speed. The pace in which the sound effects are played is used to represent a value in that scale, e.g., when a player is running, his footsteps sound effects have a faster pace than when he is walking.

Class 7: **Music** —Music by itself is a form of communication that can stimulate feelings and emotions in players.

Based on the use of audio signs observed, we identified the game's audio communication strategies. We now present those strategies, linking them to examples of use in the game and evaluating their accessibility for deaf and hard of hearing players.

Strategy 1: Enabling sound localization

Together, classes 1 (sound volume) and 2 (sound distribution) are used to provide clues on the location of enemies, NPCs (non-playable characters), or anything that is also a sound source and is positioned in the 3D world. This strategy is complementary to the possibility of identifying positions by visual signs in that it enables location of game elements without (or before) making visual contact with them.

We extracted a snippet of the final reconstruction of the meta-communication that illustrates the use of this strategy:

"Throughout the game you will encounter flying robots called Scanners. They will not attack you directly, but observe you and eventually try to dazzle you with a flash. When that happens, if you're looking at them, you will become unable to see for some time, what may cost you health points if you are being attacked by other enemies at the same time. Therefore, to avoid the obfuscation, you cannot keep them in your visual field when the flash becomes imminent. In this situation, you can try to infer the approximate location of robots and if there is threat of obfuscation through sound effects or closed caption. The latter sign does not communicate the position and direction of the robot nor its initial approximation, only the moment it is about to use its flash."

Players that cannot hear are unable to infer approximate locations of sound sources, what makes them slightly-to-moderately disadvantaged in the game. In the example, the closed caption may soften the communication breakdown, but as it does not convey positional information, those players may be more susceptible to the obfuscation effect. Furthermore, in order to read the closed caption they may have to take their attention off other important visual elements of the game.

Strategy 2: Characterizing game elements

Class 3 (timbre) applies naturally to every sound effect in the game in that it refers to their uniqueness. This strategy is the use of that property to make elements in the game world distinguishable thus characterizing them. There is more than one reason to properly characterize game elements, but one that justifies characterization per se is to provide the means for immersion to players.

Immersion is known to be an important part of game experience and Brown and Cairns [2004] found that players tend to be more immersed towards games they consider to have provided a cohesive atmosphere by composing visuals, plot and sounds in a convincing way. Another characteristic found to enable immersion is empathy, which is the growth of attachment the player has with the game atmosphere. In special, in games that excel for realism like Half-Life 2, the sound effects in composition with graphics and physics work together to compose a convincing experience.

Ambient sounds also play an important role on game atmosphere, as was depicted in another snippet of the reconstructed meta-communication:
"In the different scenarios where your character will pass through in the game, I added typical sounds of the environment and situation to increase the realism and try to make you feel "inside" the game. If you cannot hear, the game does not give you the opportunity to receive this information."

The loss of this information may not impose disadvantages on players, but it has yet to be further studied its impact on immersion and then on game experience as a whole.

Strategy 3: Communicating threat

In an FPS game like Half-Life 2, the player must keep his character alive while managing to progress in the plot. The game supports players on the task of survival in a variety of ways using audio signs to advise them about risks. For example, as the game uses the features in classes 1 (sound volume) and 2 (sound distance), players can infer that someone is coming their way, before having visual contact, thus being able to be prepared for the encounter. In addition, because of the feature in class 3 (timbre), players may also manage to identify what kind of enemy is coming their way, enabling them to choose better strategies for the encounter.

An interesting sign identified during inspection is the sound effects of player movement, which varies according to the type of surface the character is moving on. So, by interpreting that sign, players can infer the type of surface they are on, which happens to indicate which kinds of enemies they might encounter there. Some enemies can appear more in a type of surface than in others. An example is the Barnacle (Figure 4.3), which is stuck to the ceiling and is usually found where the ground is moist and sticky. When players walk on this type of terrain, the sound of their footsteps refers to viscosity which, in turn, may remind them of the threat presented by Barnacles.

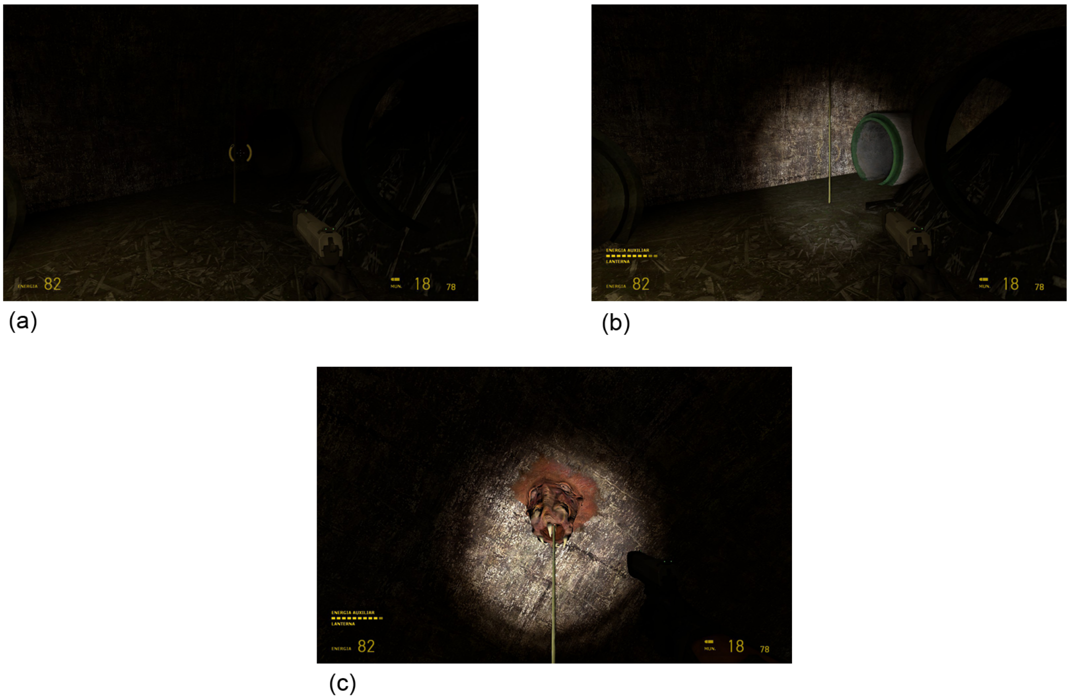


Figure 4.3: A Barnacle enemy, very frequent in places where the ground surface is wet and sticky. In (a), visual signs barely indicate the presence of the enemy that is very close to the player's character. By turning on the flashlight (b), it is possible to see the enemy's tongue, which is how it pulls the character from the ground to its mouth. (c) shows the Barnacle stuck to the ceiling.

The use of class 4 (timing) also conveys information about risk level. One example is the Scanner robot that emits a slightly different sound (and blinks his light) a few moments before flashing (attacking). In this case, a caption `[Scanner Click]` appears at the same time, helping deaf and hard of hearing people to be aware of the risk. On the other hand, the helicopter in "Route Kanal" has a similar behavior to the robot and changes his sound effects accordingly to demonstrate it is going to start firing, but neither caption nor visual sign complement the sound.

Another example of a sign that communicates threat to players uses class 6 (tempo). At a certain point in "Route Kanal", some radioactive material puddles are scattered throughout the scenario and stepping on them may reduce the player's character life points. The game informs players about the danger by playing a statics sound effect that has a faster pace when the character is closer to those puddles. It is possible to detect the presence of the puddles visually, but they were designed in the game in such a way that blends with the scenario, making it very important to listen to the static sounds as an indicator of their proximity.

During the game, when the player is under attack by firearm, he can again use classes 1 (sound volume), 2 (sound distance) and 3 (timbre) to identify his enemies and adapt his strategy accordingly. When hit, if shooting was done outside his view range, a red sign evoking blood is displayed on the HUD indicating the direction from which the shot was fired (Figure 4.4).

Figure 4.4: Visual effect (in red, to the right, circled in white - by us) displayed indicating that the player's character received a shot that was fired from somewhere to his right.

Not receiving the information communicated through this strategy greatly compromises game experience as players may become frustrated for not being able to keep their character alive. The inspected portion of HL2 showed only one severe communication breakdown in this strategy (the helicopter); on the other hand, it presented an interesting solution to the problem of locating shooting enemies (red sign evoking blood), but that only works when the character has already been hit.

Strategy 4: Interaction feedback

Sound effects are also used as feedback from player's interaction. They usually complement visual feedback, like when reloading the gun, opening a door and shooting.

Deaf and hard of hearing players can use closed captions which provide a nice replacement for this strategy.

Strategy 5: Transmission of information through speech

The speech itself conveys information in an oral language but can be easily transcribed to subtitles or closed captions.

In Half-Life 2, missing the speeches and dialogs may not lead to disadvantages, but rather may compromise players' engagement with game plot, which may represent a barrier to immersion [Brown and Cairns, 2004].

Furthermore, by reading all the text from dialogs, a player may split his attention between the text on the interface and the game world, what may increase his chances to survive in the game.

Strategy 6: Instigation of sensations and emotions

The game does not use constant background music as is quite common in other games genres. However, at times, short clips of music (class 7) are played with the goal of evoking feelings and emotions on players.

For example, in chapter "A Red Letter Day", when the player's character puts on the same equipment he used throughout the predecessor game (Half-Life), a short song is played. The song is the same that was played every time one starts Half-Life. So, for those players who had previously played the predecessor game (and, therefore, started the game several times), listening to that clip once again may evoke the feeling of nostalgia.

As another example, in some situations of longer and more dangerous battles, a hectic music starts playing, which contributes to creating an atmosphere of tension and alerting the player. Indeed, according to Novak [2008], music in games and entertainment in general communicate to players how they should feel and react about situations.

By missing this information, players may have a less immersive experience with the game (for the same reason as Strategy 2).

4.2.2 Triangulation

For the triangulation of results required by the scientific approach of the method, we chose other endogenous sources as case studies. SIM was applied to two other games with the same research question. The games chosen were Call of Duty: Modern Warfare 2[5] (MW2) and XIII[6], both being of the FPS genre. MW2 was released in 2009 and puts the player under the control of a war soldier. XIII was released in 2003 and is based on comics. Neither games present a closed captioning system nor claim to be accessible for

[5] MW2 website: http://www.modernwarfare2.com/. Last access on 03/31/2012. The game was released in 2009.

[6] XIII website: http://www.ubi.com/US/Games/Info.aspx?pId=39. Last access on 03/31/2012. The game was released in 2003.

hearing impaired people, but were chosen for being a fairly recent and famous example of the FPS genre (MW2) or by offering an accessible feature of presenting localized textual representation for sounds in the form of onomatopoeias (XIII), as depicted on Figure 4.5.

Figure 4.5: An onomatopoeia shown when an enemy dies in the game XIII.

These inspections were conducted by two other researchers [Nogueira and Soares, 2012] as an extension of our Half-Life 2 inspection to validate the findings related to communication through sounds in FPS games. An overview of the classes and strategies can be seen on Table 4.2 and Table 4.3, respectively.

Table 4.2: A comparison of which *classes of sound features* were identified on the inspections of the three games: Half-Life 2, Call of Duty: Modern Warfare 2 and XIII. A tick (√) indicates that a class was identified in a game, whereas a slash (-) indicates it was absent in that game or was not identified in the inspection.

#	*Class*	*HL2*	*MW2*	*XIII*
1	Sound volume	√	√	√
2	Sound distribution	√	√	√
3	Timbre	√	√	√
4	Timing	√	√	√
5	Speech	√	√	√
6	Tempo	√	√	-
7	Music	√	√	√
8	Perceived frequency	-	√	-

All the classes identified in HL2 (1 through 7) were also identified in both other games, the only exception being tempo (class 6), which was absent or was not identified during inspection on XIII. This shows that those classes represent a consistent set of characteristics that are explored by FPS game designers to convey information. During the inspection of MW2, a new class was identified (class 8), which is the change in the perceived frequency of a sound effect:

Class 8: **Perceived frequency** — The perceived frequency of a sound effect can change according to the relative velocity of its sound source to the player's character position, as may happen with the sound of a rocket that was shoot in the direction of the player in a simulation of the Doppler Effect.

All previous identified strategies of communication through audio were identified in both games. The authors also detected a seventh strategy, described as follows.

Strategy 7: Inference of velocities of moving sound sources
Class 6 (tempo) is used to enable the inference of the approximate velocity of moving elements, e.g., the pace of footsteps sounds indicating whether someone is running or walking.

After the triangulation we reviewed the usage of the classes by the strategies in HL2 and we were also able to detect the presence of strategy 7. We could also detect the use of class 1 (sound volume) by the same strategy to enable the inference of the velocities of vehicles - the sound of engines getting louder as their speed increased. Table 4.3 contemplates which classes were used by each strategy. The "-" indicates the strategy was absent or was not identified in the game.

Table 4.3: A comparison of which *strategies of sound usage* that were identified on the inspections of the three games: Half-Life 2, Call of Duty: Modern Warfare 2 and XIII. The table relates which classes were used in each game for each strategy.

#	*Strategy*	*HL2*	*MW2*	*XIII*
1	Enabling sound localization	1, 2	1, 2, 8	1, 2
2	Characterization of game elements	3	3	3
3	Communication of threat	1-4, 6, 7	1-8	1-4, 7
4	Interaction feedback	3	3	3
5	Use of speech to transmit information	5	5	5
6	Raising emotions and sensations	7	7	7
7	Inference of velocities of moving sound sources	1, 6	1, 6, 8	-

4.2.3 Discussion

With the semiotic inspection, seven strategies of communication through audio signs were identified and revealed very distinct usages of sounds. While some of them (strategies 2, 4, 6 and 7) were used mainly as a contribution to the game atmosphere and thus, enabling deeper immersion for players [Brown and Cairns, 2004], others (strategy 1, 3 and 5) conveyed important-to-vital information that, if lost, may decrease players' chances of progress in the game.

In HL2, a good portion of the information conveyed through audio is represented textually by closed captions: dialogs, radio transmissions and the large majority of sound effects that give out information relevant to gameplay. The portion that is not represented may not prevent players from making progress as the game provides functions that enable changing of difficulty levels and retrials, like anytime saving and auto-save. However, there's a chance that deaf and hard of hearing people may have a reduced gaming experience.

Figure 4.6: s
howing the sound radar and some closed captions.]A clipping of Doom 3[CC] showing the sound radar and some closed captions. Note the colors of the captions correspond to the colors of the dots in the radar.

The closed captioning approach used in HL2 does not indicate positional information about the origin of sounds in space, which represents the loss of very useful information for hearing impaired players. This issue was circumvented, for example, in the game Doom 3[CC], by providing a sound radar on the HUD that indicates where sounds are coming from (Figure 4.6). Considering deaf people's possible problems with reading, there is an even deeper problem with using textual alternatives to enable access. It has been suggested by participants in the questionnaire as an improvement in game accessibility the use of simpler language constructs and less elaborate vocabulary. Another general problem with replacing speech by text is that paralanguage information like intonation and voice is lost [van Tol, 2006]. However, this problem is unlikely to impact deaf and hard of hearing players' chances to make progress in HL2, but it could be relevant in other games.

An alternative to closed captioning that was not explored much is the use of visual metaphors to somehow represent sound. This alternative was outlined in some participants' suggestions in the questionnaire and has already been used in the game The Sims 3, as shown in chapter 2. In HL2, the only usage we could identify of this alternative is the blood effect on the HUD (Figure 4.4).

As stated before, it has yet to be studied the impact of not perceiving sounds and music in game immersion for deaf and hard of hearing players.

4.3 Chapter Summary

To investigate the use of audio as a form of communication in FPS games and its impact on the game experience of deaf and hard of hearing players, we performed a semiotic inspection on the popular game Half-Life 2. The results of the inspection were then triangulated with the results of the inspections of two other FPS games, Call of Duty: Modern Warfare 2 and XIII.

We were able to identify eight classes of auditory signs and seven different strategies of communication through game audio, which compose the answer to our research question. The triangulation with other FPS games provided classes and strategies consistent among the three FPS games, which validates those findings. This suggests that the classes and strategies are common to games in the genre, but to confirm it, more inspections in different games must be done. Another source of future work is to investigate the classes and strategies used in other game genres.

The strategies of communication were, then, evaluated in regard to the relevance of the information conveyed to players and also to the existence of alternative ways of receiving that information. As a result, a list of potential communication breakdowns was identified, which gave a measure of the quality of the game accessibility for hearing impaired players. As our inspection focused on auditory signs, we noticed that it would be more fruitful in the identification of breakdowns to segment the signs in such a way that could enable us to detect the presence (or absence) of redundancy among auditory, textual and visual signs, instead of using the categorization of metalinguistic, static and dynamic. However, further investigation in this topic must be done.

The use of the Semiotic Inspection Method proved a very appropriate and useful tool for evaluating the accessibility of games for hearing impaired players (via the technical approach) and also for answering our research question (via the scientific approach). In fact, it has given rise to the hypothesis that the evaluation of a game's accessibility for hearing impaired players can be given by a communicability evaluation with a proper scenario, as we did in this chapter. Theoretically, it would mean that when the designer is communicating to users with a specific impairment, the communicability evaluation includes involving its accessibility as well. This matter was further discussed in Coutinho et al. [2012], but still needs to be further applied to other systems and different focus of accessibility. If the hypothesis proceeds, it will be an interesting contribution to Semiotic Engineering, as the Semiotic Inspection Method could be recognized as a proper tool for evaluating game accessibility without the requirements of adaptations.

By identifying and characterizing the classes of signs and the strategies of communication, we hope to have given one step into providing an epistemic tool about designing games accessible to deaf and hard of hearing people. With the characterization of the strategies, new approaches to solving accessibility issues to those players can be proposed. This represents a contribution for both game design and accessible design.

Indeed, we have used ourselves the findings of the classes and strategies of communication through game audio to propose a new alternative of assistive resource for game accessibility for hearing impaired players. But that is a topic to discuss in the next chapter.

Chapter 5

The Synesthesia Proposal

Given the language acquisition problematics that deaf people might undergo and the higher effort they may need to spend in order to read texts in games, we felt it would be interesting to propose a new approach of assistive resource in games for deaf and hard of hearing people; one that explores, instead of texts, the space-visual field, that is usually their natural communication medium through the use of a sign language.

When formulating our proposal, we were inspired by the comments made by the questionnaire respondents about their gaming experiences (see chapter 3) and also by a character from the TV series Heroes [Kring, 2006]. The series tells the stories of ordinary people that suddenly acquire superhuman powers. One of those people is Emma, a physician that became deaf in her adulthood. One day, she started to be able to *see the sounds* in the environment (see Figure 5.1). In her visualization experiences, each type of sound (e.g., music, an explosion, claps), under different conditions (e.g., loudness, movement), resulted in different visual representations.

Figure 5.1: A picture of the TV series Heroes [Kring, 2006] showing Emma and her visualization of a sound.

To this effect, we went on to study the concept of *synesthesia* in search of a way to empower deaf and hard of hearing people while they are playing games. In the next section, we describe that concept and present a brief selection of related studies to situate the following arguments.

5.1 Foundation

The etymology of the word synesthesia refers to a Greek origin and is formed by the prefix *syn* - with, together, united - and the word *aisthesis* - feeling, perception, sensation[1]. As so, it means a unification of sensations or, more specifically, experiences of cross-sensory perception.

The concept of synesthesia has been largely appropriated in arts. In literature, it is a figure of speech that makes use of the quality of one sense attributed to another, e.g., "It is a green shadow, soft and vain."[2] presents a mixture of visual and tactile senses. In music, painting and other types of arts, synesthesia refers to multi-sensory experiments that provide simultaneous perception of multiple stimuli as one experience. One example is the *Son et lumière*[3], a show in which special lighting effects are displayed on the façade of a building simultaneously and synchronized with music.

Apart from the artistic use of synesthesia, it also means a neurological condition by which an estimate of 4% of the world population is affected [Sagiv et al., 2009]. Sagiv et al. defines it as *"a condition in which stimulation in one sensory modality also gives rise to a perceptual experience in other modalities"*. It means that synesthetes - people with the neurological condition - may, for example, actually see the colors of sound notes or tastes, or maybe have tactile experiences by smelling different odors. The literature has named as *inducers* the stimuli that triggers the different sensations and *concurrent* the modality in which the sensation is experienced [Ward and Mattingley, 2006; Sagiv et al., 2009]. The most common forms of synesthesia are the colored-hearing: when spoken words or sounds (inducer) trigger visual experiences (concurrent) and the grapheme-color: when the reading of digits and letters (inducer) is associated with colors (concurrent). Curiously, the grapheme-color is an exception form of synesthesia in that both inducer and concurrent belong to the same modality (visual). But, as the phenomena shares a lot from the characteristics of the neurological condition, researchers consider it as an authentic form of synesthesia.

[1] Etymology definition from: `http://dictionary.reference.com/browse/synesthesia`. Greek stems dictionary from: `http://www.macroevolution.net`. Last access on 03/31/2012.

[2] A verse from the poem Ladies Shadow in Flower, translated to English, from the Brazilian writer Carlos Drummond de Andrade. The original text is: *"É uma sombra verde, macia, vã"*.

[3] French for sound and light.

Synesthesia as a neurological condition has been researched since late 19^{th} century and has recently — since the 80s — regained attention with the advancements from cognitive neuroscience. Indeed, a special issue of the journal *Cortex* — devoted to the study of the nervous system and behavior — has been published in 2006 presenting recent studies on the topic [Ward and Mattingley, 2006]. What has been found, so far, is that the condition is *usually*:

- **unidirectional**, e.g., a synesthete that sees colors when hearing words does not necessarily hear words when seeing colors [Heer, 2000; Sagiv et al., 2009];
- **effortless**, i.e., occurs unconsciously and passively [Heer, 2000; Hubbard and Ramachandran, 2005];
- **stable over time**, i.e., mappings from inducers to concurrents do not change over time [Heer, 2000; Marks, 1975];
- **unelaborated**, i.e., perceived concurrents are usually primitives such as colors, simple shapes, the feel of rough or smooth textures rather than complex structures [Heer, 2000; Hubbard and Ramachandran, 2005];
- **idiosyncratic**, e.g., two grapheme-color synesthetes do not necessarily map the same color to the same vowel [Heer, 2000; Head, 2006; Sagiv et al., 2009; Marks, 1975].

There are many open questions and hypotheses to be investigated. To name a few: the development of a robust framework for the authenticity verification of the condition; at which state in processing does the synesthesia effect occur; how to characterize differences in experiences of synesthetes with the same modality; whether there is a global patterning in the relations of inducers to concurrents among synesthetes of the same modality or if it is completely idiosyncratic. In fact, this last question is considered the Holy Grail of the research of a specific modality: sound pitch (inducer) to color (concurrent).

In 1975, Marks conducted an extensive review on colored-hearing synesthesia and part of his research was followed by Head [2006] and Ward et al. [2006] more recently. Their findings have shown that there are, in fact, some universal, cross-modal relations, among synesthetes. Marks [1975] demonstrated that sounds of higher *density* (a measure from sound frequency and sound intensity) were attributed by non-synesthetes *brighter* colors and, when perceived with higher *volume*, were considered bigger *sizes*. This observation was baptized the *Marks whiteness*.

Head [2006] further investigated Marks findings, trying to detect consistent relations of pitch to colors (not only whiteness) among synesthetes. The author conducted an experiment in which participants were required to assign a color to sound notes they heard. Colors were picked from an RGB color pallet instead of asking participants to write its name or pick a color chip, so the color space was not restricted by colors names each participant knew or the available colors from the chips, as had been done in older experiments. Additionally, he would be able to evaluate that relation for each color dimension separately, as well as testing for whiteness as a combination of the dimensions. Results pointed that synesthete participants more frequently than non-synesthetes assigned the same color to a pitch they heard multiple times (pitches were repeated through the experiment). Synesthetes also assigned colors to variations of a tone (say, C+, which is between C and C#) significantly closer to the midpoints in RGB space of the colors they assigned for the enclosing correspondent semitones (following the example, C and C#) than non-synesthetes. Another observation was that synesthetes with absolute pitch[4] (AP) assigned the same (or very similar) colors to octave pitches (e.g., C1 and C2), whereas non-synesthetes and non-AP synesthetes followed Marks whiteness scale. Last, there was also premature but suggestive evidence about between-synesthetes patterning as within localized regions of RGB space there seems to be covariance in their global association of pitch and color.

At the same time, Ward et al. [2006] conducted a research investigating to what extent the mechanism which colored-hearing synesthetes use for mapping sounds (not only pitches) to colors is similar to the one used by non-synesthetes. Instead of using RGB colors, the authors chose the Munsell color space, which represents colors in lightness (light to dark), chroma (gray to colored) and hue (red, yellow, green, blue or purple). Results support the hypothesis that there can exist *intrinsic sensory correspondences* of sound to colors mapping among colored-hearing synesthetes and non-synesthetes. The same differences that were found on Head [2006] between synesthete and non-synesthete groups were also found in these experiments, e.g., synesthetes presenting significantly higher consistency in colors chosen for the same sounds in test-retest. Both groups were found to share the same mapping mechanism for the relations of pitch to lightness (a very similar measure to whiteness) and also of timbre to chroma.

Although there is not sufficient evidence to say that there is a shared mechanism that governs the mapping of auditory to visual stimuli among all individuals, researchers keep trying to further investigate the issue. If they manage to prove that

[4] The ability to identify a note without an external reference.

Table 5.1: A systematization of the terminology employed in the synesthetic listening of the fifth movement of the Turangalîla symphony by Bragança [2010].

Concurrent	*Positive pole*	*Negative pole*
Brightness	Light	Dark
	Shining	Gloomy
Transparency	Transparent	Opaque
Color	Violet	Red
Density	Rare	Dense
Energy	Weak	Energetic
Space	Foreground	Background
	Wide	Constricted
Pressure	Light	Heavy
Movement	Non-directional	Directional
	Accelerated	Decelerated
	Increasing	Decreasing
	Angular	Linear
	Rising	Descending
	Calm	Agitated
	Slow	Fast
Order	Regular	Chaotic
	Symmetrical	Asymmetrical
Temperature	Cold	Hot
Texture - surface	Smooth	Rough
Texture - plot	Unilinear	Intricate

there is a *latent synesthesia* present in everyone and that synesthetes present just an exaggerated version of that mechanism, consequences would be threefold. First, cognitive neuroscience could better understand the human intra-modal and cross-modal perception and the processes involved in cognition [Ward and Mattingley, 2006]. Second, methods for training individuals to develop their synesthesia abilities could be investigated. And third, assistive technologies could be proposed for sensory impaired people, exploring these shared mechanisms to maybe provide artificial, but congruent, translation of senses.

In another research, Bragança investigates the latent synesthesia in the context of Music [Bragança, 2008, 2010]. He intends to discover how musical perception relates to other senses. He explains that, in the field of music signification, the meaning of music is idiosyncratic, but part of the cognitive process of the construction of meaning may be shared among individuals. In particular, he suggests that synesthesia transposes the auditory stimuli to other senses and only then listeners make extrinsic relations to feelings, emotions, images, ideologies or any other references. Upon that hypothesis, he proposes a *synesthetic listening*, which is the avowed use of terms from different senses to describe music. He also suggests that the systematization of that terminology could aid in the phenomenological analysis of music and also in the relation of certain sound results to certain systems of musical construction. As a case study, Bragança presents the synesthetic listening of a musical movement of the Turangalîla symphony, which he describes in his article [Bragança, 2010]. He also presents an incipient systematization of the terminology that was employed to synesthetically describe the movement and, those terms can be seen on Table 5.1. We highlighted the terms that can be related to visual stimulus, as some of them are going to be useful later in this chapter.

As it is still not the case that research in synesthesia has reached a level such as to present a fully fledged framework of intrinsic relations of audio and visuals, we stick to the use of the concepts of artistic synesthesia. Nonetheless, we still use some of the findings we have just presented.

5.2 Synesthesia Approach

Considering the comments from deaf and hard of hearing players in the questionnaire about their gaming experiences and the familiarity with the space-visual field that those players may have due to their use of sign languages, we consider it important to provide a, perhaps, friendlier assistive option in games, at least for those players. With this new alternative we propose, which we call the Synesthesia Approach, we tackle the problem of providing a visual, instead of textual, alternative to sounds whenever possible (see Figure 5.2).

We use the knowledge we obtained with the deaf and hard of hearing players opinions in the questionnaire (chapter 3), the results of the semiotic inspection of the use of sounds in FPS games (chapter 4) and a bit of creativity to propose a new assistive resource. From our knowledge that, for deaf players, the space-visual field is the native communication medium, we propose a process of representation of the audio stimuli with visual metaphors that are presented not in the game interface, but inside the game world. This alternative's benefits are twofold: players do not need to divide so constantly their attention between the game world and user interface as when reading closed captions and it is possible to easily convey the localization of sound sources.

This solution we are proposing is a projection of one whole sensory dimension (hearing) into another (visual). Thereby, not all information is represented in the receiving dimension. At the same time, another issue that can arise is the overload in

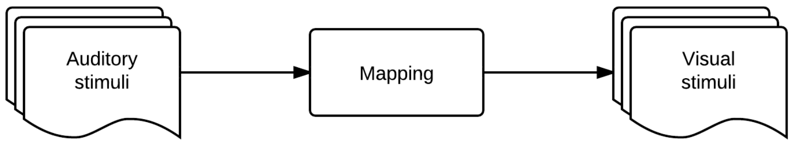


Figure 5.2: An overview of the process in the Synesthesia Approach.

the sensory perception for receiving all information from two different senses. An ideal solution would let players unable to hear to have the most similar game experience of players who can hear or, at least, provide them with exactly the same conditions of progressing or winning in the game. However, our approach does not encompass all the different usages of the sound.

Recalling from chapter 2, by using the IEZA framework, game audio is categorized in four domains, namely Interface, Effect, Zone and Affect (see Figure 2.3). As a reminder, we present a brief review on them:

- **Interface** - sounds that originate from the game interface.
- **Effect** - sounds from inside the game world that have a relation with the player activities.
- **Zone** - sounds from inside the game world to compose the game atmosphere.
- **Affect** - sound and music not present in the game world, used to "set the mood".

The scope of the Synesthesia Approach is limited to the presentation of the information conveyed through sounds in the **Effect domain**, which are frequently, according to [Huiberts, 2010], the most relevant sounds to gameplay, followed by sounds in the Interface domain. This restriction has been placed so that there was not an overload of visual information with not critically important sound information (Zone domain) and also because non-diegetic[5] sounds do not reside in a meaningful spot the game world, but rather originate from the game interface (Interface domain) or from no location at all (Affect domain). Beyond that, the Synesthesia Approach does not involve the representation of the information conveyed through speech, as that would require the creation of a different language, with a really complex structure to support the expressiveness of an oral language. Besides, there would be an even worse consequence: it would require game players to learn a new language to play the game. In games with rich worlds like FPSs usually have, most part of the sounds are tied to the player actions in the game world, belonging to the Effect domain. So, still with that

[5]As we described in chapter 2, in the context of game design, a feature is diegetic if it is part of the game narrative or non-diegetic if it is not.

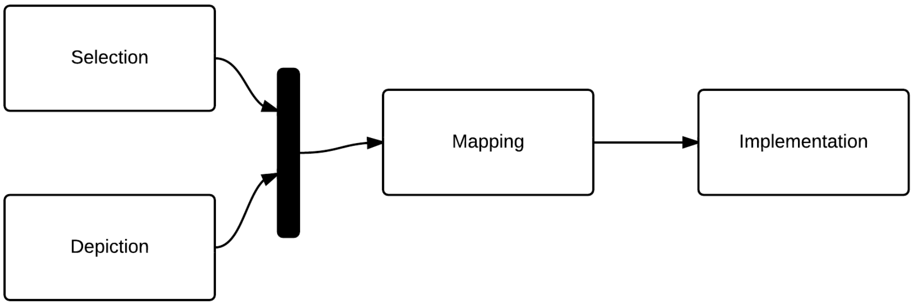


Figure 5.3: The topics that comprise the implementation of the synesthesia model. The first two topics can be investigated in parallel.

scope delimitation, for those games, most part of the sounds are represented by the Synesthesia Approach.

We now discuss a *model* for the usage of the Synesthesia Approach in the production of games. The need of a model arose from the existence of different ways to implement the Synesthesia Approach: it can vary from the use of a single visual metaphor for every applicable sound effect to a complete set of visual metaphors differentiating the characteristics of the sounds they represent.

5.2.1 The Synesthesia Model

The statement of the problem approached by the Synesthesia Model is " (i) to **select** what information from the game audio must be conveyed through visuals, (ii) to **depict** the sounds in visual metaphors, to decide (iii) how the information from sounds **map** to the visual metaphors and (iv) **implement** everything" (see Figure 5.3). When using the Synesthesia Approach in a game, its designers must answer these questions and thus create an instance of the model. We now present of the steps of the model, discussing the implementation possibilities for each one of them.

5.2.1.1 Selection

The first topic relates to the selection of sounds and sound features to be represented visually (i). The universe of game audio that is represented by the Synesthesia Approach has already been reduced to those from the Effect domain, except for the speech sounds. It must be further analyzed whether *all of those sounds* must be represented visually or if there is a *smaller subset of sounds* that convey more relevant information than others (see Figure 5.4).

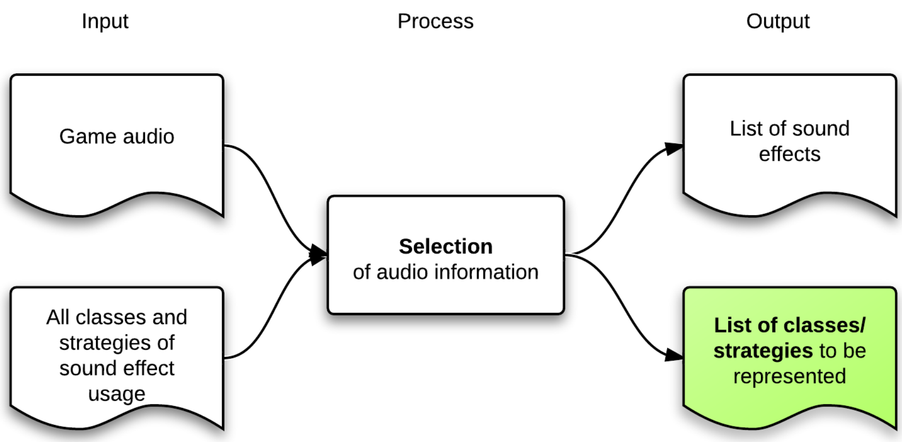


Figure 5.4: The **selection** process of the synesthesia model.

The principle pondering this decision is the cost / benefit ratio of presenting all the information conveyed through sounds in pursuit of an equivalent game experience for players who can not hear at the cost of possibly having an overwhelming amount of visual information, spoiling other aspects of gameplay. On the one hand, it may be considered even a matter of enabling the awareness of the presented information, the act of simply informing that a certain sound effect has been played or that there is music composing a scene, as it is commonly done with closed captions in TV and movies. On the other hand, it may also be possible that the presentation of information per se may not be relevant for them. To illustrate this point, one may ask: what benefit does reading in a movie the caption `[Bird sounds]` bring to the experience of a person who had no contact with the sound world? Unfortunately, we were not able to extract the opinion of deaf and hard of hearing players on this matter with the questionnaire and this is very interesting topic of further investigation, probably with a more in-depth method of data gathering like interviews. At any rate, we would expect their opinion to vary a lot in this matter, what could be affected by their experience with the sound world, reading skills and other aspects.

Another aspect regarding selection is which information from the selected game audio is represented. For this matter, we resort to the results we achieved on chapter 4. In the context of FPS games, we identified what characteristics of the sound effects are commonly used to convey information, i.e., the classes of audio signs. They are: (class 1) sound volume, (class 2) sound distribution, (class 3) timbre, (class 4) timing, (class 5) speech, (class 6) tempo, (class 7) music and (class 8) perceived frequency.

As we discussed before, the Synesthesia Approach does not represent the information conveyed through music and speech, so that leaves six classes to be represented. As was shown in chapter 4, the classes were used to convey information in very similar ways among FPS games (Table 4.3), although not with the same relevance. For instance, tempo was used in HL and MW2 to communicate the threat the player's character is under at a specific moment of the game, which is highly relevant, but XIII did not use tempo for that strategy. This demonstrates that in each game, the classes can be more or less important for communication and their visual representation in the Synesthesia Approach must reflect that design aspect. So, it is also a design decision to choose whether all the employed classes will be represented or only the most relevant ones. This decision is also tied to the same cost / benefit ratio of the selection of sounds.

Another option is to work in a higher level of communication, i.e., to use selected strategies for communication instead of the classes of sound usage. For instance, game designers could choose to represent with the Synesthesia Approach the strategy of enabling sound localization directly instead of representing the classes of audio signs that are used by the strategy (in this case, sound volume and sound distribution).

By the end of the selection process (i), the output of the decisions taken should be a list of the characteristics of the sound effects that is going to be represented by the visual metaphors, that will discussed in the next topic.

5.2.1.2 Depiction

The second topic comprises the design[6] decisions related to the visual metaphors to represent the information from sounds (ii) and the game design decisions on how they should integrate the game (see Figure 5.5).

The first issue is, inherently, subject to the artistic creativity of the game development team, not necessarily involving technical aspects. The question to be answered here is how a sound should be seen by players in the game, i.e., how are they going to be drawn in the game world. A guideline that certainly proceeds is that the art created to depict sounds must integrate harmonically with the game art as a whole, but yet be distinctive enough so that players can recognize it as what it is. That decision must be pondered by the compromise of how much the visual metaphors can vary and still be easily recognized as visual metaphors for sounds. In one extreme lies the intent of creating a large amount of variations, for each situation in which a sound is played, so

[6]We differentiate between design — as the creation of visual arts — and game design — as the creation of the game itself: game elements, mechanics, gameplay, levels, challenges etc.

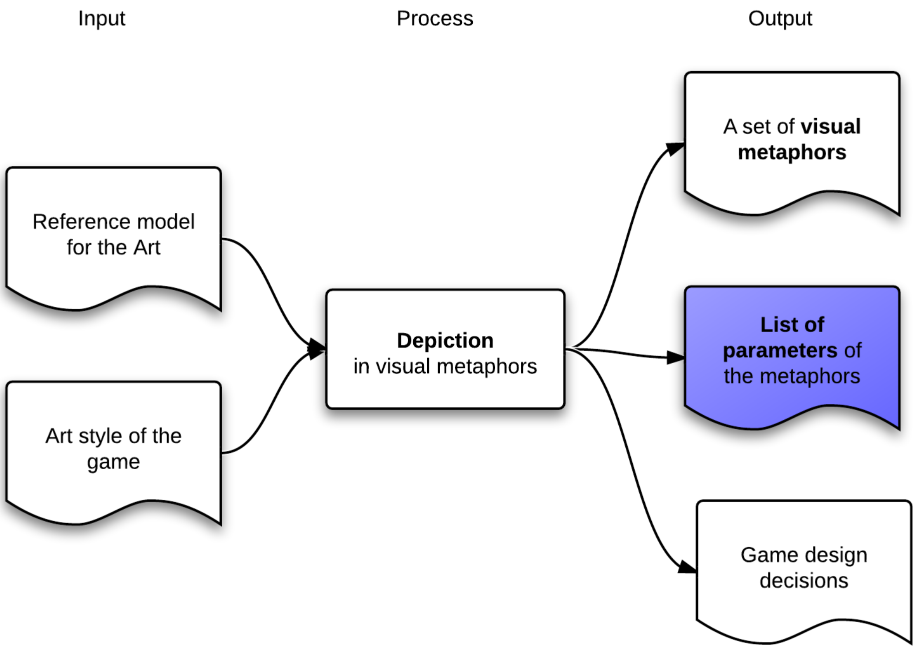


Figure 5.5: The **depiction** process of the synesthesia model.

every different sound would have its unique representation. However, this could lead to a cognitive overload and the visual effects from the synesthesia becoming less recognizable. In the other extreme is the use of a single visual effect to depict every sound. The latter option limits the amount of information that the visual effect conveys from the sounds they represent, as players would not be able to distinguish the different sounds.

The art style is also subject to discussion. Artists may use the physical explanations of sounds as reference for depicting them like sound waves; they may also resort to the theory of psychoacoustics, which deals with how sounds are perceived by people [Pfeiffer et al., 1996]; they can use reports through history about colored-hearing synesthetes that described their experiences [Marks, 1975]; or, they can use no references at all.

The second question regarding depiction comprises the game design aspects of how the visual metaphors should be presented to players. We further divide this issue in two: (a) where and how the visual metaphors are displayed, (b) whether the synesthesia approach is going to be part of the games diegesis or not.

It is a property of the Synesthesia Approach that the visual metaphors must be present inside the game world, originating from the sound sources, so players do not

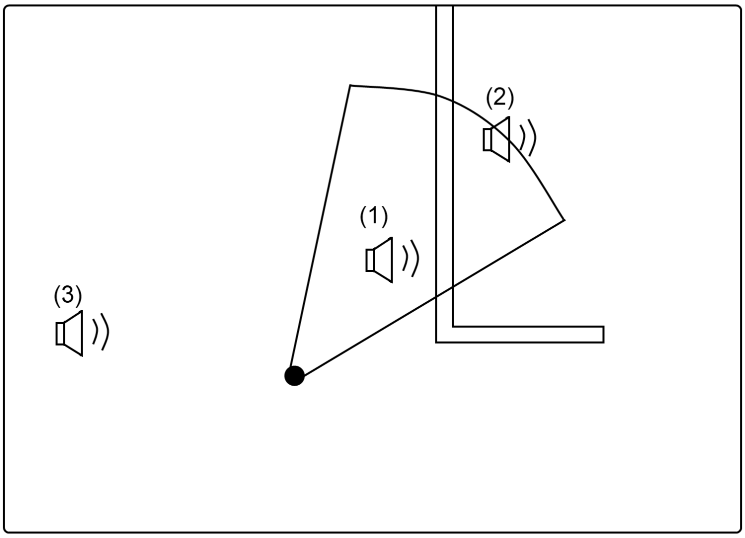


Figure 5.6: Possible locations of sound sources relative to the player's character in a first-person 3D game. Sound sources 1 and 2 are in the player's field of vision, but there is an obstacle between the character and sound source 2. Sound source 3 is outside the field of vision.

have to divide their attention between the game world and the game HUD[7]. However, as sounds can be heard independently of visual contact with the sound source (e.g., the footsteps from behind or in the other side of a wall), players need to be able to receive the information from sounds that are not in their field of vision but could still be heard.

In regard to (a), it must be decided how to depict sounds emitted from locations: that are visible to the players, that are invisible to players (e.g., behind a door), but still inside the players' field of vision and that are outside the field of vision (e.g., from behind players). For clarification, refer to Figure 5.6. A natural form of representation for "visible" sounds is to display their visual metaphors in the place where the sound originated, as previously said. For "invisible" sounds that are emitted somewhere in the player field of vision, a possibility is to make their visual metaphors visible even through walls or other obstacles. Another alternative that could also be used for sounds that are outside the field of vision would be a clever use of the HUD to show from which side the sound has been heard, very similarly to the blood screen effect in HL2 (see Figure 4.4).

We must also remember about the closed captioning system in Doom 3[CC] (see Figure 4.6), which uses a sound radar in the HUD to show the positions of the sound

[7]HUD is the acronym for Head Up Display, sometimes called game user interface. A typical HUD in FPS games displays information on the player's status like current health and ammunition.

effects sources relative to the player's character. That could also be an option for the Synesthesia Approach to somehow enable the localization of sound sources. However, that suffers from the problem of requiring the players' attention to be divided between the game world and interface.

There is also a risk pervading the game design decisions on the depiction of the visual metaphors. That could be the case if designers were able to deliver all the sound information so clearly, easily and effortlessly through the visual metaphors that the players would start to lose part of their enjoyment, by having less challenges. This is a particularly interesting issue in competitive multiplayer games, in which the use of an "unbalanced" Synesthesia Approach could even be considered cheating.

It must also be decided when the visual metaphors must be triggered, whether if it is when a selected sound effect is played, or when it is heard, as well as the moment the visual metaphors must fade away, whether instantly or until the end of the sound effect playback.

One last decision inherent to the depiction topic is whether to integrate the Synesthesia Approach as part of the game diegesis or just as an accessibility option. As we commented on chapter 4, the game XIII presents onomatopoeias of some sounds in the Effect domain. One of those sounds is the footsteps from enemies. They can be heard and their onomatopoeias seen even when behind walls and obstacles (see Figure 5.7) and, the game explains that the main character has some kind of sixth sense that makes him more alert of the surroundings than one normally is. In other words, they integrated an accessible feature inside the game narrative, i.e., as part of the game diegesis. The other alternative is to embed the Synesthesia Approach as a game option, much like is done with other accessibility settings.

Another output of the depiction process must be a list of parameters of the visual metaphors, which indicates how one effect can vary from another. Those parameters need to be configured according to some criteria. The process of defining these criteria is described as follows.

5.2.1.3 Mapping

The third component of the model addresses how the selected information from the game audio maps to the visual metaphors (iii) and is responsible for associating the selected information from game audio (i) and the visual metaphors (ii). It is called a mapping because it is, in fact, a matter of connecting, in a *consistent* and probably *meaningful* way, each characteristic from the audio (i.e., a class or an intention from a strategy) to a parameter of the visual metaphor (see Figure 5.8). As an example, the

Figure 5.7: The onomatopoeia for the sound of footsteps in the game XIII. They can be seen even from behind walls.

game designers may map the volume by which a sound effect is played to the size of the respective visual metaphor. Alternatively, the size of a visual metaphor could be set by the relevance in gameplay of the represented sound. To this effect, we suggest at least three reference models for mapping: game design, synesthesia (as a neurological condition) and a mix of both.

The first option is to use **game design criteria** to create a mapping that better prioritizes the more relevant sounds. Doom 3[CC], in its closed captioning system with the sound radar, presents a simple and consistent mapping of colors to identify the type of the sound source: green for friendly speech, white for environment sounds, yellow for sounds with unknown threat level, red for enemy sounds. Likewise, the colors of the visual metaphors could be set to represent the threat they represent for the player, e.g., red for sounds emitted from enemies, white for sounds emitted from friendly NPCs and so on.

Whether or not the research in synesthesia as a neurological condition will indeed be able to identify intrinsic relations between the auditory and visual stimuli, game designers can resort to the findings that have been done so far as a reasonable foundation for the mapping in the Synesthesia Approach. The second option is to use the **findings of synesthesia** as a neurological condition as a base for the mapping.

In the beginning of the chapter, we presented some findings and suggestions from researchers on that matter [Marks, 1975; Ward et al., 2006; Head, 2006; Bragança,

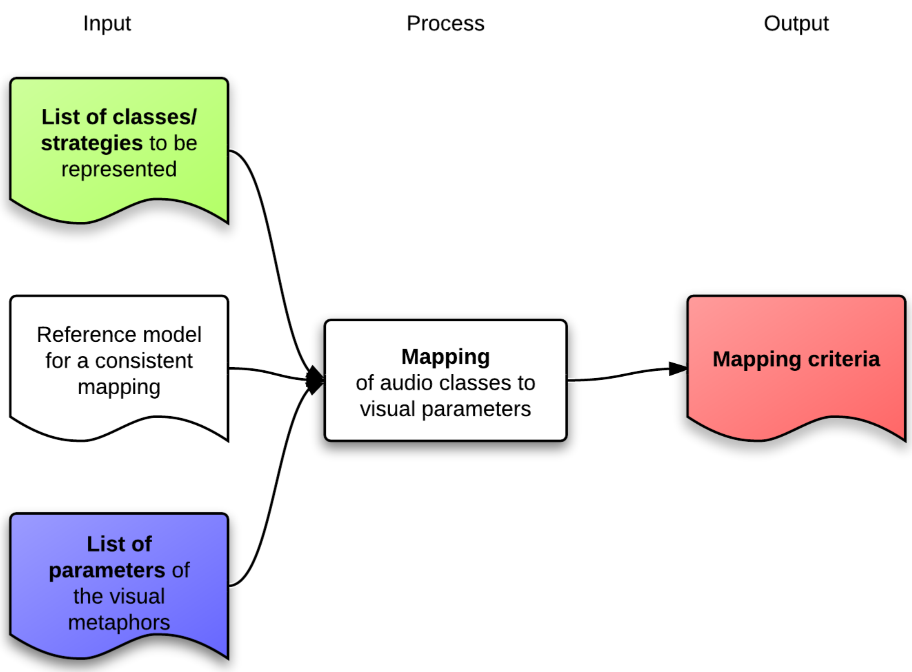


Figure 5.8: The **mapping** process of the synesthesia model.

2010]. In a mapping based on them, sound effects with higher pitches could be represented with lighter colors; higher volumes could lead to bigger sizes; the type of sound could influence their behavior, (order/chaos, movement type); different timbres could map to different chroma (gray to colorful); faster paces could set faster movements and so on.

The use of a reference model based on game design knowledge or on synesthesia as a condition differs in that, whilst the former alternative enables more easily the representation of strategies, which have a less abstract level of communication, the latter is better suited to represent the classes, which convey more detailed information.

The third alternative is to use **both references**, as using both may bring the benefits from each. For example, the opaqueness (vs. translucency) of the visual metaphors could be set by their relevance to game play and their sizes could be set by the volume of sounds. Thus, the use of the synesthesia mapping would enable the representation of more detailed information through visual parameters and the use of game design criteria would enable a prioritization of the represented sounds.

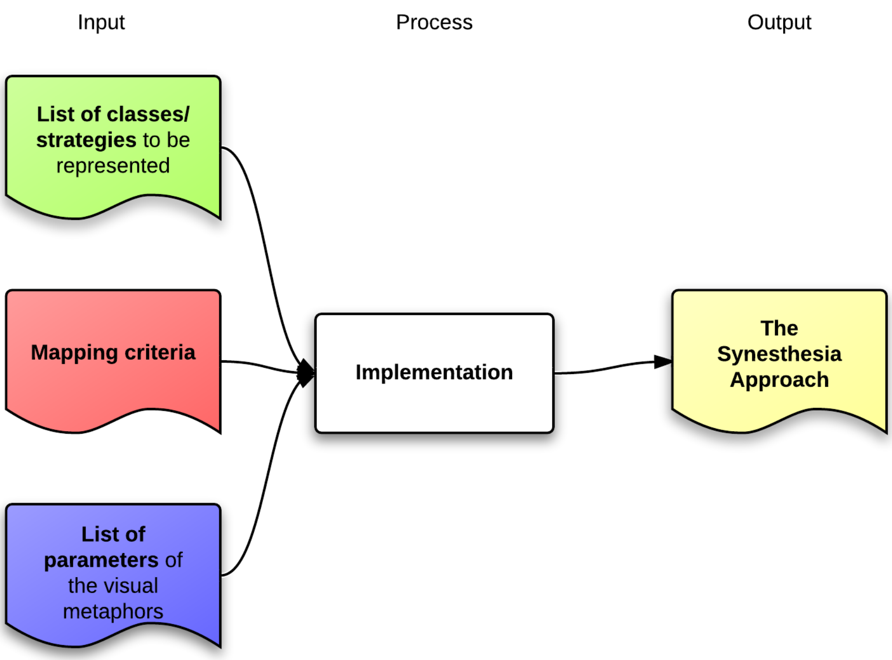


Figure 5.9: The **implementation** process of the synesthesia model.

5.2.1.4 Implementation

The implementation (iv) process takes place once in possession of the outputs from the three other topics, mainly the list of classes or strategies from sounds that are going to be represented, the set of visual metaphors and the mapping criteria that links the first two. It comprises the task of actually inserting the Synesthesia Approach in the game (see Figure 5.9).

We do not present the specific details of the implementation to be done, since this is a conceptual model and also because each game and game engine presents a different architecture, rendering this an unfeasible task in our context. However, it is relevant to discuss the process that should guide the implementation.

Implementing the visual metaphors should be done in such a way that exposes configurable parameters to be set by game designers for each selected sound effect in the game. Game designers must, then, configure those parameters accordingly for each selected sound effect, considering the mapping criteria. This is a very time consuming task that can impact the game production time so, a lot of effort has to be put on the sense of easing and parallelizing the process.

A decision must be made about the target object of the Synesthesia Approach: is the visual metaphor attached to sound effects (i.e., the same sound, in different contexts, has the same visual representation) or to the sound effects playback instances (i.e., each time a sound is played, its visual representation can be influenced by the context within the game in which it is being played)? In the latter case, there would be even more work to be done, as every use of a sound effect would have different representations.

So far, the Synesthesia Approach might have an associated cost that is very high to implement, rendering it hardly suitable to be considered by the game industry, which so frequently works under tight budgets and limited time constraints and is primarily driven by the games graphics, gameplay and artificial intelligence [Novak, 2008]. In this sense, a more practical approach should be a lot less costly in terms of production. In the next section, we propose an automated version of the Synesthesia Approach.

5.3 Algorithmic Synesthesia Approach

As the complexity of games grow, the higher the number of sound effects and, consequently, the less practical it is to invest time and effort in providing an accessible approach for hearing impaired players. However, part of the most cumbersome task of the implementation of the Synesthesia Approach can be automated.

The aim of the Algorithmic Synesthesia Approach (ASA) is to make the implementation (Figure 5.9) of the Synesthesia Approach feasible within the constraints of the game industry reality by automating, as much as possible and desirable, the activities of configuring the visual metaphors parameters according to the mapping criteria.

Sagiv et al. [2009] define *algorithmic synesthesia* as the use of sound or image that share a computational resource to produce multimedia content. The ASA is based on that concept, considering the sound effects in a game the data sources for both the sound playback and the generation of visual metaphors. In other words, the ASA proposal is to automatically extract information from the selected game audio to configure the visual metaphors' parameters.

To illustrate, let us consider an instance of the Synesthesia Model that uses a mapping of sound effect pitches to set the colors of the correspondent visual metaphor. If a pitch to color mapping table is provided and there is an algorithm capable of extracting pitches from sounds, the task of implementing the Synesthesia Approach can be largely automated. Fortunately, algorithms like that do exist and can even be executed in real-time in nowadays gaming hardware.

In the field of sound analysis, common computational problems try to segment, analyze, recognize, understand and interpret features from sound signals [Roads, 1996]. Game audio files can be digitally represented by digital signals (e.g., WAVE, MP3) or symbolically (e.g., MIDI format). As in nowadays mainstream games the most common representation format is digital [Novak, 2008], we resorted to the use of the techniques from the digital signal processing (DSP) area. Nonetheless, in case of implementing the ASA for games with symbolic representation of sounds, there are also analog techniques to those mentioned in this chapter, most of them being a lot simpler than those for digital signals [Tzanetakis and Cook, 2000].

5.3.1 Digital Signal Processing Algorithms

For illustration of the ASA, we present suggestions on the use of DSP techniques to automatically extract information from the game audio sources.

5.3.1.1 Pitch Detection

Pitch is a perceptual feature of sounds that closely relates to their frequency, but is not equivalent to it, as it is subject to the cognitive processes of sound perception [Roads, 1996; McLeod, 2008].

Some types of sounds have their pitches more easily recognizable than others, e.g., the identification of the pitch of a guitar note is much more distinguishable than the pitch of low rumblings. A pitch detection algorithm focuses on sounds composed of a melody of one note at a time (monophonic), and can provide accurate results with more than 90% success in case of purer signals.

The statement of the pitch detection problem is to estimate the fundamental pitch of a signal, which is equivalent to finding the frequency that a human listener would consider the same pitch present in the signal [Roads, 1996]. There are a wide variety of pitch detection algorithms. They use different approaches for the problem (e.g., time-domain, frequency-domain, autocorrelation), each one being more accurate at different types of sounds, but none robust enough to produce 100% detection success as of now.

For sounds that are composed of more than one melodic voice (i.e., polyphonic), pitch detection algorithms do not provide very accurate results. That is actually another problem in sound analysis, which is called the polyphonic pitch detection problem and has not been as much researched as the monophonic version has. This would render the use of pitch detection very limited in the context of the ASA, as only a small part of the game audio would be fit for the algorithms. It turns out that, depending on the usage of the pitches extracted from the game audio, the accuracy of the algorithms is less important than their precision[8]. For example, game designers may intend to use the pitches to configure the set of colors of the visual metaphors with the purpose of making each metaphor distinguishable and recognizable as their sound sources are (Strategy 2, among others), it is more important that the extracted pitches are consistent between different detections (so the same sounds always have the same metaphor) than correct, as the players would eventually learn the association of each visual representation to its sound emission event.

5.3.1.2 Rhythm Detection

The detection of the rhythm of digital signals rests on the detection of events, i.e., identifying the presence of milestones in the stream of audio samples and their duration [Roads, 1996]. Based on that, a measure of the signal tempo can be calculated. For digital signal inputs of monophonic sounds with a metronome reference beat (e.g., a very periodic sound with distinguishable beats), the results of the rhythm detection are reliable and robust. For polyphonic sounds, some proposed algorithms have also showed results of detection similar to the performance of human listeners [Scheirer, 1998; Goto and Muraoka, 1996].

In case game designers use tempo (class 5) to convey information to players through sounds, the automatic extraction of the tempo of sound effects can automate the configuration of the corresponding visual metaphors. For example, supposing the sound of footsteps, which clearly can be assigned a tempo measure according to the speed of walking, has a visual metaphor that is an animation of moving particles, a real-time rhythm detection could dynamically set the speed of the particle movement according to the current tempo of the sound effect.

5.3.1.3 Segmentation

The segmentation of digital signals consists on identifying moments of abrupt changes in the signal [Tzanetakis and Cook, 2000], e.g., a sound effect of the explosion of a bomb could have two segments: the part of the burning fuse and the part of the bomb exploding.

The results of the segmentation algorithms are the timestamps at with segments start and they can be used to convey information of timing (class 4), but also to enable the use of a different visual metaphor for each segment in the sound. Using the

[8] We use the terms accuracy and precision to indicate, respectively, how close a detected pitch is to its reference value and the rate at which the application of the pitch detection algorithm to the same input signal provides the same results.

exploding bomb example, game designers may want to create different representations for each part so that they could enable the inference of a change in the game state - the imminence of explosion. The HL2 scanner robots (explained in section 4.2.1) are examples that could benefit from the segmentation algorithm to dynamically set a visual metaphor property to indicate the imminence of an attack.

5.3.2 Implementation

The DSP techniques usage presented before serves to illustrate how the ASA can be used to automate part of the Synesthesia Approach. It is not our intention to provide a complete list of how to use those techniques, as each instance of the Synesthesia Model may map different characteristics of the sound to different parameters of the visual representations.

As stated in chapter 2, the available gaming hardware is capable of not only playing digital audio with great quality, but also of applying DSP techniques in real time[9] [Huiberts, 2010]. However, if the overhead of using the "extra" algorithms in real-time is considered high, a possibility is to execute them during the production of the game and store metadata with the extracted information for each sound. During runtime, the only overhead of the ASA would be the same of the Synesthesia Approach, which is the display and control of the visual metaphors.

Considering the time constraints in game production, we advocate the use of existing digital signal processing libraries. Examples of free, open-sourced libraries are MARSYAS[10] and Tartini[11].

MARSYAS (Music Analysis Retrieval and Synthesis for Audio Signal) is a framework for audio analysis, synthesis and retrieval of information that has been used in different contexts in the academy [Tzanetakis and Cook, 1999]. Although it was crafted with the main purpose of supporting the high level task of Music Information Retrieval, it provides access to the building blocks that can be combined to perform other tasks, either simple or complex. So, as it provides efficient DSP algorithms for sound analysis, it can be used to support the ASA.

Tartini is a software for supporting sound (in the form of digital signals) composition, playback and analysis [McLeod, 2008]. It provides a user interface for aiding

[9] In fact, when we created a modification of the game Half-Life 2 (in chapter 6), we identified the use of DSP techniques in the game, which is relatively old (launched in 2004).

[10] MARSYAS can be downloaded here: `http://marsyas.info/`. Last access on 03/31/2012.

[11] Tartini can be downloaded here: `http://miracle.otago.ac.nz/tartini/download.html`. Last access on 03/31/2012.

users in those tasks and, as it is open-sourced and freely distributed, pieces of code from the DSP algorithms can be extracted or used just like MARSYAS.

Both libraries support either online (real-time) and offline (pre-executed) signal analysis. The benefits of using existing libraries comprise the time saved for not having to implement the DSP algorithms and the use of already tested and reliable implementations. As a downside, the game producers may have less control over the game's source code and the dependence on third-parties to develop the algorithms can be considered a risk in the game production.

One concern that might arise with the use of the ASA in the production of games is the reliance on the mapping done by the algorithms to configure the visual metaphors, which is, at some level, the transference of the responsibility of art creation to the synesthesia algorithm. In this case, a semi-automated mode of the Synesthesia Approach can be used: the ASA algorithms are executed offline to *suggest* the configuration of the visual metaphors, which would be later subject to designers' adjustments and fine-tuning.

5.4 Chapter Summary

In this chapter, we presented a new approach of assistive resource that tackles the game accessibility for hearing impaired players and is based on the concept of synesthesia.

Although our synesthesia proposal does not encompass all the game audio domains and, consequently, is not able to substitute text based approaches for game accessibility like subtitles, we believe it still brings benefits to gameplay. One of the premises advocated by the Synesthesia Approach is to enable sound localization without making visual contact with the sound source, as can be done using the information from the sound distribution and volume, but not with closed captions. Some games do provide a radar that depicts relative positions of the sounds to the main character, but that kind of solution may require that players dedicate too much of their attention to the HUD to receive that information. Another benefit is the reduction in the amount of necessary text, as it may be possible to use the Synesthesia Approach without the closed captions.

The applicability of the Synesthesia Approach has yet to be further investigated. We believe that, as FPS games so frequently have rich game worlds with relevant use of sounds, our proposal could have its best fit with the genre. However, other types of games that share those characteristics with the FPS may also be able to benefit from the Synesthesia Approach.

In the next chapter, we present an experiment of application of the Synesthesia Approach in a game and its evaluation as an assistive resource.

Chapter 6

Experiment and Evaluation

In this chapter we take a first step in the direction of validating the Synesthesia Approach. We report the development of an experiment with the synesthesia model in the game Half-Life 2 and a preliminary evaluation of the experiment with users.

Our objectives comprise developing a proof-of-concept of the Synesthesia Approach with the intention of illustrating what has been proposed and also of validating our proposal as a valid assistive resource for deaf and hard of hearing players.

6.1 A Modification in Half-Life 2

We used the game HL2 as a test-bed to implement the Synesthesia Approach. The game was chosen for several reasons: for being an FPS and already having been used as a case study in this dissertation, for presenting well accepted assistive resources for hearing impaired players (subtitles and closed captions) and also because it enables the creation of modifications to implement new features in the game or even to create entirely different games, as part of its source code is officially available for modding[1] [Machado et al., 2011]. We do not present the technicalities of the development of the modification, focusing, instead, on the concepts of the Synesthesia Approach.

Our instantiation of the Synesthesia Approach was done in a very simplistic way due to time the constraints of this dissertation and we have kindly baptized it the **U**ltra-**n**aive-**dread**fully-**s**imple-1-**w**eek-**imp**lementation, or UNDreadSWImp. We created a semi-automated Synesthesia Approach. The decisions of the synesthesia model we made are presented in the following section.

[1] *Modding* is the act of modifying existing games by the gaming community [Novak, 2008].

6.1.1 UNDreadSWImp: The Synesthesia Model Instantiation

Recalling from Figure 5.3 in chapter 5, the synesthesia model is comprised of the selection of audio information, its visual depiction, the definition of a mapping criteria of audio to visual information and the implementation of the system. We briefly cover how we approached these topics to implement the Synesthesia Approach in HL2. It must be noted that our decisions towards the instantiation of the model do not reflect solely on game design decisions. Rather, they were a lot more influenced by the feasibility of the Synesthesia Approach implementation considering our time constraints.

6.1.1.1 Selection

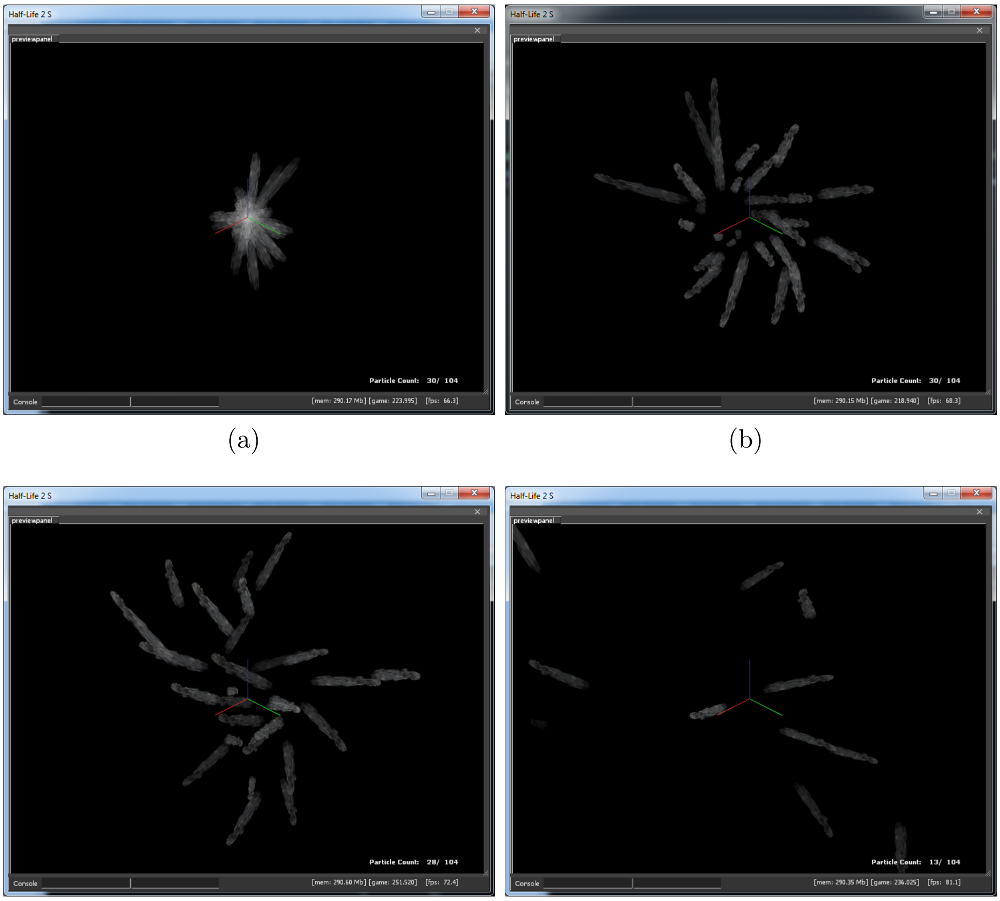
As the game audio in HL2 is not categorized according to the IEZA model, it was not possible to select only the audio in the Effect domain. We were able to separate the sound files in music, voiceovers, soundscapes (environment sounds) and general sound effects. The UNDreadSWImp picked the sound effects related to voiceovers and general sound effects only. Despite the content of speech is not represented by the Synesthesia Approach, it is still desirable to indicate the presence of a dialog and maybe its interlocutors — hence, we included the sounds files which contained voices, but did not try to represent them according to its content.

The audio information selected was a mix of strategies of communication and classes of sound features usage:

- <u>enabling sound localization</u> (strategy 1),
- <u>sound volume</u> (class 1),
- <u>timing</u> (class 4) and
- <u>tempo</u> (class 6).

6.1.1.2 Depiction

In the depiction process, the design related question of how to depict the sounds was approached by the development of a tiny experiment in which a group of three people with some basic knowledge of art were asked to draw a depiction of sounds in different situations, e.g., a moving car, a shot from a pistol, people walking and talking etc. Based on the drawings and on a later discussion with the experiment participants, a single metaphor was selected, which was comprised of small particles with tails emanating from the sound sources, moving concentrically farther and dissipating after some time (see Figure 6.1). The configurable parameters of the metaphor are:



(a) (b) (c) (d)

Figure 6.1: The chosen visual metaphor to represent sounds over time.

- the colors of the particles,
- their sizes,
- the rate and time at which they appear and
- their movement speed.

The use of a single metaphor for all the represented sounds (despite the variable parameters) should allow the synesthesia metaphors to be easily recognizable by the players.

As of the game design decisions, the visualization of the sounds are done inside the game world, in the 3D position of the sound sources. Sounds that have their sources positioned inside the field of vision but which are visually blocked by an obstacle are depicted the same way the "visible" sounds but only the sounds of weapons and enemies can be seen through obstacles. The sounds emitted outside the players' field of vision were not depicted by UNDreadSWImp. This is not in line with the model, but was done that way as it was a preliminary implementation.

The synesthesia approach was implemented as an assistive option accessible through the game options, not being part of the game diegesis as in the game XIII (explained in chapter 5). That enabled us to evaluate the game with and without UNDreadSWImp, and in combination with the other accessible features of subtitles and closed captions.

6.1.1.3 Mapping

The definition of the mapping criteria considered mostly the findings of the synesthesia as a neurological condition. In UNDreadSWImp, the information from audio was mapped to parameters of the visual metaphor such as follows:

- enabling sound localization → position of the visual metaphor in the game world;
- sound volume → particles sizes;
- timing → the moment in which the particles are spawned;
- tempo → the rate at which particles are spawned and their movement speed;

As can be noted, the colors of the particles were not set by any information from the sounds in this first experiment. Thus, all the particles in UNDreadSWImp were displayed in white. One possibility would be to use a pitch detection algorithm to identify the pitches from the sounds and set the particles colors according to a lookup table. That could enable players to distinguish between different "sounds" so as to achieve the communication strategies 2 (characterizing game elements) and 3 (communicating threat).

6.1.1.4 Implementation

The visual metaphor was created as a particle effect, which is a technique in computer graphics to create various visual effects [Novak, 2008]. We used the HL2 modding tool for creating particle effects[2] to create the visual metaphor for sounds with the exposed parameters of configuration (see Figure 6.2).

In the game code, we identified the function calls for playing sounds by the sound engine and injected code to display the particle effect appropriately configured

[2]An overview of the particle editor can be viewed on `https://developer.valvesoftware.com/wiki/Particle_Editor`. Last access on 03/31/2012.

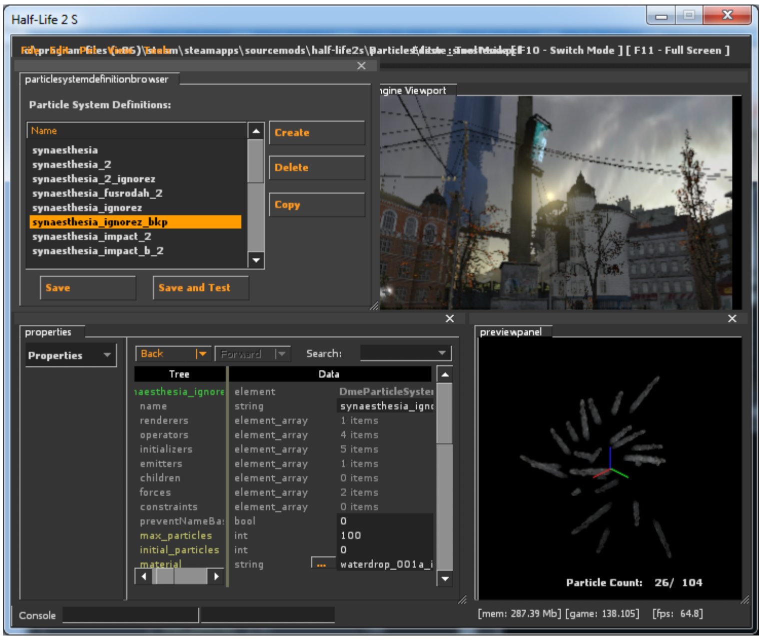


Figure 6.2: The particle editor included in the modding tools of HL2.

according to the information of the sound emission whenever a selected sound was played.

All of the mapping could be automated thanks to the presence of **metadata** related to the **sound effects** and to the **sound emissions**.

In HL2, each sound effect file has an associated *soundscript file* containing parameters of its playback. For instance, the soundscript contains information about whether the sound file is a voiceover or a general sound effect, the relative frequency in which it should be played, the sound level in decibels (measure of intensity) differentiating, for instance, a whisper from an explosion (something like the emission volume) and the channel of the sound, indicating, roughly, the type of the sound effect (some channels are always used for voice, some for weapon sounds, some for environment sounds, etc.).

The sound level information was used to set the size of the visual metaphor, in that higher levels of <u>sound volume</u> (class 1) implied in bigger particle sizes.

The information from the sound channels was used to identify the sounds that should be visible through obstacles, which were those from the channels body (CHAN_BODY), weapon (CHAN_WEAPON) and item (CHAN_ITEM), which we considered more relevant to gameplay.

The position of the visual metaphors was retrieved inside the sound playback functions, by referencing the game objects[3] that triggered the sound emission. This enabled players to do <u>sound localization</u> (strategy 1) through the visual metaphors

[3]The terminology used for game objects in the game is *entities*.

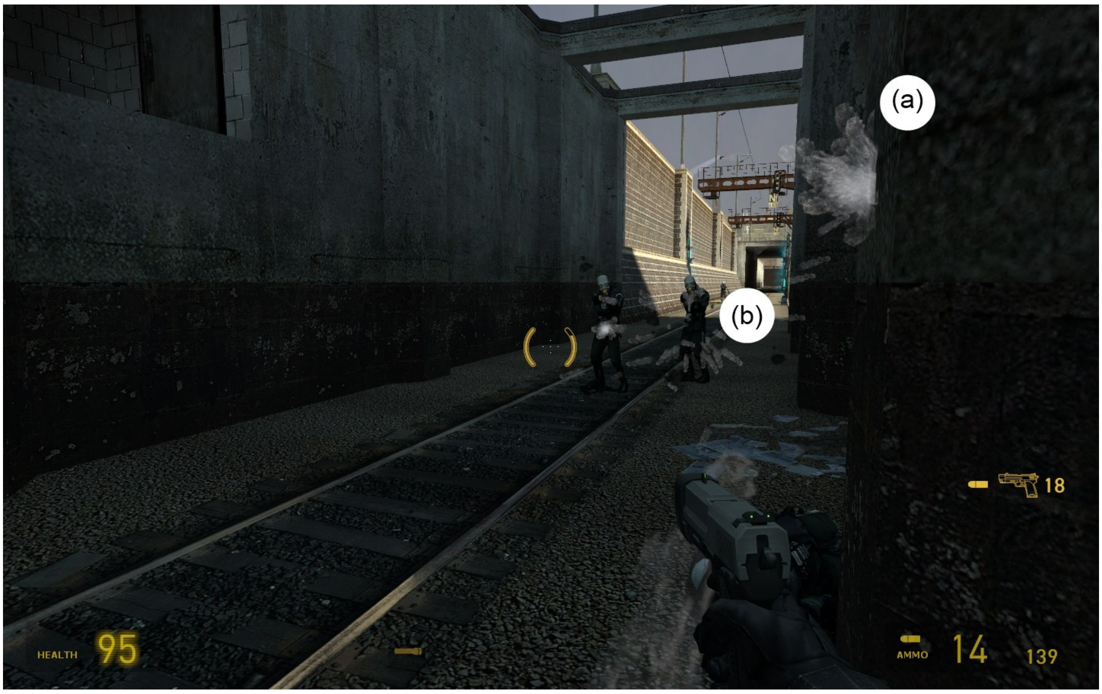


Figure 6.3: A battle scene from the HL2 mod showing the visual metaphors for sounds. (a) is the visual effect displayed to represent the sound of a bullet hit on the wall and (b) is the visual effect of the sound of a gunshot.

inside their field of vision. Additionally, the perceived volume (class 1) of the sound effect is also somehow represented by the relative size of the visual metaphor in the game screen, as it is positioned in 3D space and, gets smaller with higher distances.

For repetitive sounds like those of footsteps, the resulting effect was that the higher the pace of the repetition of the sound, the higher the rate of spawned particles from the particle effect, which gave a representation of tempo (class 6). As the game plays repeatedly the same sound effect instead of providing sound effects with repeated content, both tempo and timing (class 4) were automatically represented visually as the display of the visual metaphor was tied to (every) sound playback function. Figures 6.3 and 6.4 show how the game looks like when the sound is being visually represented.

An issue with UNDreadSWImp is that we were not able to isolate sounds of the Effect domain from those of the Interface, as that would require checking individual sound files for inclusion in the Synesthesia Approach or not and that was out of our scope for a first experiment. Consequently, the interface sounds, e.g., the sound emitted when the ammunition gets low, were also visually represented as if originating from the main character's position.

The next steps in the development of the modification to create a more accessible HL2 for hard of hearing users are to properly select only the sounds in the Effect

Figure 6.4: A screen from the HL2 mod showing the sounds made by the footsteps of an enemy before the player makes visual contact with it.

domain, to integrate a DSP library for automating the mapping of sound pitches to the colors of the particles and the indication of sounds outside the players field of vision in the HUD.

Despite the simplified instantiation of the UNDreadSWImp, we believe that it illustrates a considerable portion of the Synesthesia Approach and is sufficient to perform a preliminary evaluation to gather information on the acceptance among players and its effectiveness, which is the subject of the next section.

6.2 Evaluation of the Experiment

We conducted a preliminary evaluation of our implementation of the Synesthesia Approach with three objectives: (i) to **inquire on the acceptance** of the Synesthesia Approach for deaf and hearing players, (ii) to **evaluate our implementation** of the Synesthesia Approach and (iii) to start an **investigation on the evaluation of the model** we proposed.

The evaluation was conducted as a test with users in a controlled environment. Altogether, we conducted tests with six people divided in two groups: three deaf and three hearing players. The tests with the second group were performed both to evaluate the use of the assistive resources for hearing players in hearing limiting conditions (i.e., having to play games without sounds for some reason) and to simulate players that lost hearing degrees in a middle age (i.e., after having learned the oral language). A pilot-test was conducted with a hearing user to validate the test methodology.

6.2.1 Methodology

The methodology of the evaluation was based on the user test methodology described in Barbosa and da Silva [2010], which is comprised of the explanation of the test to users, the filling out of a consent form, the application of a pre-test questionnaire, observation and recording of the software by the user and an post-test interview. The material used for the evaluation is available at Appendix A.

The consent form is required by law in Brazil when conducting experiments which involve human participation. By giving their consent, users agreed to participate anonymously and voluntarily in the evaluation and also permitted the recording in video format of the interviews and the capturing of the computer screen.

The pre-test questionnaire aimed at identifying users' profiles according to their gaming experience and information regarding their hearing loss (just in case of deaf users).

Before playing, the users were taught the controls and characteristics of the game. They were instructed to ask for help anytime it was necessary. They were also shown three 10 second video clips, each one illustrating an assistive resource of the game: subtitles, closed captions and synesthesia.

The step in which the users use the software was divided in two parts. In the first, they were asked to play a little bit so that they could learn the game mechanics, controls and its atmosphere. During this part of the game, there are no battles, so players only need to find their way to progress in the game. In the second part, users were expected to interact with all aspects of the game and the evaluators started taking notes and observing the interaction. Each of those parts was further divided in three configurations, in this order: (a) with sounds and subtitles (Conf1), (b) without sounds, with subtitles and closed captions (Conf2), (c) without sound, with subtitles, closed captions and synesthesia (Conf3). The transitions of one configuration to another were done by the evaluators by interrupting the user to announce the new configuration and effectively changing the game settings. In the second part of the test, during each transition, we also conducted a quick interview related to the configuration that had just been played, so that users and evaluators would be less susceptible to forgetting what had happened during that part (see Figure 6.5).

The portion of the game that was played by the users were excerpts from the

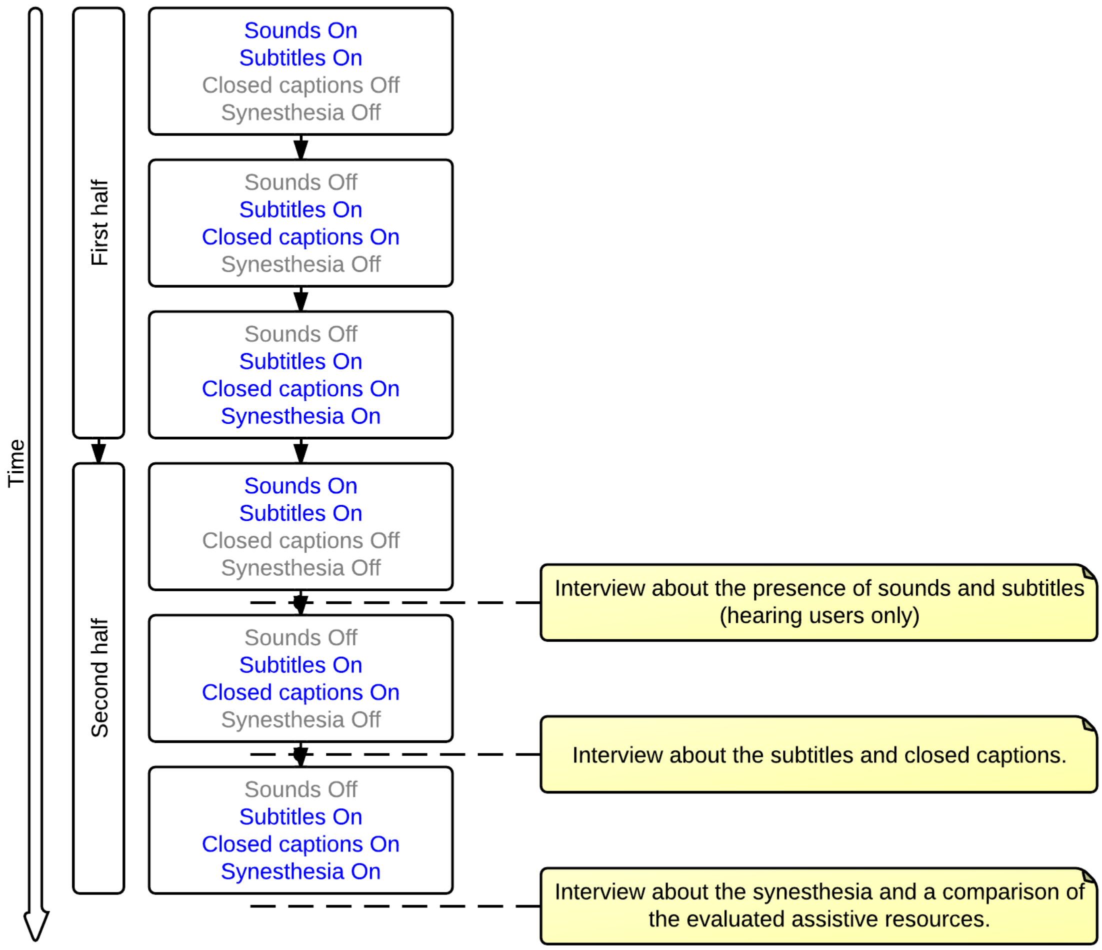


Figure 6.5: User test evaluation: division in two parts and configurations used in each one.

first three chapters: "Point Insertion", "A Red Letter Day" and "Route Kanal". As the first two chapters do not contain typical battles of FPS games in which players must shoot and avoid enemies, they were used in the first part of the test, in which players were told to play just to be introduced to the game. In the beginning of the third chapter, the players' character actually gets its first weapon and engages in real battles, in which he must attack and/or avoid enemies. That chapter contains several battle scenes followed by calmness, but only the first three were picked so that the test would not be too long. Each of those battle scenes were played using one of the configurations cited before. When playing the excerpts of the game with sounds turned on, the hearing users were asked to use the headphones we provided, properly worn with the channels (left and right) in the correct side, so they were able to capture the distribution of the audio.

The tests with deaf users were accompanied by a Libras interpreter, who ensured the realization of our communication with the users. The consent form was first read by the deaf users and then was interpreted in Libras. The questionnaire was responded by the participants themselves in digital form and only when deaf users had doubts did the interpreter intervene to enable the communication. We also translated the majority of the texts in the game HL2 to Brazilian Portuguese, so that players would not have to be able to read the subtitles and captions in Portuguese from Portugal or English (which are some of the available languages in the game).

The test participants were not told who were the authors of the assistive resources, so that they would not be afraid of criticizing them.

The results of the test were based on the analysis of the observation of the gaming experience of the users and on their opinions on the use of the three assistive resources under consideration provided in the post-test interviews.

6.2.2 Users Profile

As previously said, users were divided in groups composed of three deaf users (D1, D2 and D3) and three hearing users (H1, H2 and H3). All participants were between 18 to 30 years old. All of them were men and had finished high school and started/finished higher education, except for D1, who had recently entered technical school. None of them had ever played HL2, but D2 and H2 had played the predecessor game (Half-Life).

About game experiences, three participants (D2, H2, H3) marked the FPS genre as one of their favorites. Five participants (all except for D3) were already familiar with the game controls used in HL2 (through other games that use the same scheme). None of them had ever played a game with closed captions. When inquired about how proficient they considered themselves as game players, only D2 answered advanced, H1 answered basic and all the others answered intermediate. However, we later reconsidered their responses after observing their interaction with the game. D3 was shifted from intermediate to basic and H2 promoted from intermediate to advanced. Coincidentally, with those changes, we had one participant with each level of skill (basic, advanced and intermediate) in each group (deaf and hearing).

All the deaf participants had profound hearing loss that happened before being 2 years, which meant they were prelingual deaf. All of them had studied in both specialized and regular/inclusive schools and were skilled at Libras, having started learning it before the age of 7 (D1, D3) or after the age of 16 (D2). Two of them (D2, D3) were skilled at orofacial reading. When asked about their proficiency in reading in Portuguese, D2 declared having no difficulties, D1 declared having some difficulties and D3 declared having much difficulty.

6.2.3 Results

During the tests, we focused our attention on trying to detect some situations, which were: (a) if and how the users managed to identify of the presence of sounds, (b) if and how the users accomplished to localize sounds, (c) if it was possible to identify the interlocutors in dialogs.

During the played portion of the game, users had to identify (a) and localize (b) certain sounds to progress in the game or to avoid critical conditions. The first situation in which this was necessary was in the beginning of the game, when the character is requested to follow an NPC (non-playable character) through a corridor by the voice coming from the character's side: "You, citizen! Come with me". In a later situation, players must identify and localize an NPC that appears in the roof of a small building and periodically calls: "Hey, Gordon (the main character's name)". In both situations, the game does not progress until the player identifies and localizes the voices. In the test, both events occurred when users were playing with configuration Conf1 (sound and subtitles).

Two deaf users (D2, D3) noticed the subtitle, but spent some time to find — visually — the first talking NPC. The other players found it quickly either because the NPC was being seen when he appeared (and started talking) or because the position of the NPC was inferred through strategy 1 sound localization. In the second event, one hearing (H1) and two deaf users (D1, D3) had trouble localizing the NPC, which was in a position that was less visible than in the first situation. After some time inspecting visually (about 1 minute), H1 and D3 found the NPC. As user D1 could not find the source of the subtitle "Hey, Gordon!" after 4 minutes, he was offered help to indicate what he needed to do in order to progress in the game, which was looking in the direction of the NPC to start a conversation. In contrast, H2 and H3 looked almost immediately in the direction where the NPC voice was coming from, suggesting the use of strategy 1 (sound localization) again.

Still in the same configuration (Conf1), another situation worth mentioning was the passage of a train that could run over the main character, if it was not detected in time. Hearing users were alerted by the sound of the train horn but, as the subtitles do not represent sound effects, deaf users could only notice the train once it appeared and thus had less chances to avoid having the character being hit. In fact, D2 narrowly escaped it and D3 had the character hit by the train.

During the first battle (Conf1), the player must only flee while avoiding being hit by the enemies' shots. A few seconds before it begins, a hectic music starts playing. When a hearing user (H3) was asked about what he thought of the relation of the music and the situation in which it was played, he considered the music hindered his capabilities of distinguishing the sounds, as he could not listen separately to the sounds of shots. After playing without sounds (Conf2), he then changed his opinion stating that the presence of the music in battles *"[...] brings a tension, creates an atmosphere to the game"*. Moreover, he stated that playing without sounds also made him tense, but that was due to not knowing what was happening, as *"the sound helps to know when you must be more alert"*. About playing without sounds, H1 and H2 considered the game to be more monotonous and less pleasant, respectively, but not worse.

After the first battle and a time of calmness, the sounds were turned off, the closed captions were turned on and the subtitles kept on (Conf2). All users stated they made use of the closed captions, specially to perceive the beginning of the battle, but they said they were not able to read all the texts. One observation they made about the closed captions was that they do not aid in the localization (b) of the sounds, but just indicate its presence and help detect what is happening in the game. What helped them more in battle was the blood screen effect (all users quickly grasped the mechanism to indicate the direction from which the character took a shot). D2 told that the fact that the closed captions are coded in different ways helped him know when to stop shooting an enemy, as they informed with different formats when enemies were hit, but still alive and when they died. Some users (H1, H3, D3) complained about having to divide their attention between the game and reading texts. D3 pointed out that captions were better than subtitles because the closed captions contained only short phrases, whereas the subtitles contained long ones.

After the second battle and another short time of calmness, the third battle begun, with sounds kept off, subtitles and closed captions kept on and the synesthesia turned on (Conf3). By using the synesthesia, all users were able to localize enemies, even when they were farther, or in darker places, or behind walls. Another benefit of the synesthesia cited by H3 was that it enabled the identification of who was speaking in dialogs with more than one NPC, as the subtitles do not indicate the origin of the voices it transcribes (c). As downsides, the users cited the high amount of visual information at times and the false alarms of threat triggered by the effects of the sounds emitted from the own character (his footsteps, shots and all the Interface sounds), which were confused with legitimate hostile attack attempts. The user D2 compared the synesthesia to the closed captions as one provided information to for the localization of sounds and the other to distinguish the type of sound. Another difference cited by D2 between them was that the synesthesia had no benefits when the sounds occurred outside the player field of view, whereas the closed caption could still be read.

When asked to choose the best combination of assistive resource for playing HL2 (the hearing users were asked to consider a situation in that they could not use the game audio), only three users (D1, H1, H3) would use subtitles in their combinations, four users (D1, D2, H1, H3) would include closed captions and five users (D1, D2, D3, H1, H2) would include synesthesia. Of the five users that would include synesthesia, four users (D1, D2, D3, H1) had combinations that also included the closed captions. The reasons H3 gave for not including synesthesia was that sometimes the visual effects emitted in the character's position overwhelmed his vision of the game world and also that the synesthesia should enable the identification of the types of sounds being represented (from the character, from enemies and from the scenario).

6.2.4 Discussion

Some of the potential communication breakdowns that were detected in the HL2 semiotic inspection (see chapter 4) did occur in the test, most of them being related to the lack of representation of sound information by subtitles and closed captions that could enable its localization. In the configuration in which hearing users were receiving sounds and subtitles and deaf users were receiving only the subtitles, the negative impact on losing the auditory stimuli was very clearly identified.

In the deaf users group, the person who showed the most positive feedback on the use of closed captions (D2) responded in the questionnaire to have no difficulties with reading and writing in Portuguese. In contrast, D3, who declared to have much difficulty to read, emphatically criticized the use of subtitles as there was too many texts, composed of long phrases. This observation is not enough to confirm our point that text based approaches may not benefit all hearing impaired players, but is, in any case, in line with it.

Our implementation of synesthesia, although very simplistic, provided assistance in the communication of sound positions inside the players' field of vision and did that in such a way that did not require the players' attention to be divided between the game action and the reading of texts in the HUD.

Finally, when asked how they preferred to play the game using a combination of the presented assistive resources most users indicated the acceptance of synesthesia. Furthermore, the fact that the synesthesia and closed captions were frequently (4 out of 5) included together in the combination may suggest that each resource complements the other, i.e., they may benefit from each other's characteristics. In fact, some users suggested using different colors to make the "sounds" distinguishable.

6.3 Chapter Summary

In this chapter, we presented an experiment of implementing the Synesthesia Approach in the game HL2 and a later evaluation of the experiment with users. The synesthesia model was instantiated in a very simplistic way, with the purposes of illustrating some of the concepts of the approach presented in this dissertation. An evaluation of existing and new assistive resources was conducted as a test with users in controlled environment.

We believe the results of the evaluation provided strong hints on the potential benefits of the Synesthesia Approach, as even a very simplistic implementation could complement the other assistive resources and was well accepted among the users. However, a broader evaluation of the approach still has to be conducted with clear metrics related to users performance, with a higher number of users with different profiles. Furthermore, an improvement of features in the UNDreadSWImp could be done considering the participants of the test comments and our own findings, as well as other experiments should be implemented with other games and genres.

Chapter 7

Conclusions

This chapter presents a review of the research contributions of this dissertation.

7.1 Summary of Results

In this dissertation we addressed game accessibility for hearing impaired people. Most works in the literature basically cite the use of the transcriptions of the game audio (in the form of subtitles and closed captions) as the only assistive resource for players who cannot hear. However, as presented in Chapter 1 and 2, besides losing the information conveyed by the auditory stimuli in games, deaf and hard of hearing people may have difficulties with the acquisition of the oral language, rendering the use of texts a not so appealing assistive resource for them. Furthermore, the familiarity with the space-visual field due to their use of a sign language is rarely mentioned and considered in the literature.

By applying an online exploratory questionnaire about gaming experience that was responded by 111 people with some degree of hearing loss (Chapter 3), we found that games that relied on a lot of text reading, or that had complicated rules or that made very relevant use of audio were more rejected than accepted and FPS was the most rejected genre. The participants' suggestions to improve game accessibility included a variety of other approaches, indicating that text based solutions may not benefit all hearing impaired players equally.

Motivated by those findings, we investigated how audio was used as a medium for communication in FPS games (Chapter 4). The Semiotic Inspection Method (SIM), grounded on Semiotics Engineering, was used as methodology to both evaluate the accessibility of games and to determine the strategies of communication through audio in those games. SIM was applied to the games Half-Life 2 (HL2) as a case study and to other two FPS games for triangulation. The result was the identification of a consistent set of classes of use of sound features and another set of strategies of communication through audio by use of the classes. These findings contribute to game design knowledge, as it presents a systematic view of how audio was used in different FPS games so the classes and strategies could be used in the design of new games; or, the findings can be used as an epistemic tool to aid in the design of accessible communication strategies in games, as we did ourselves in Chapter 5.

The identification of classes of signs in the context of audio enabled the use of SIM without any changes to evaluate the accessibility of games for people with hearing impairment. Thus, that was a contribution for that other people may use the method (already knowing the classes and strategies) and also for Semiotics Engineering and Human-Computer Interaction, once it illustrates the applicability of the method in a new context.

Beside the not so appropriate use of text replacements for sounds as an assistive resource (Chapters 1, 2 and 3), it was found in the evaluation of HL2 (Chapter 4) that the game's closed captioning system fails to convey all the relevant information from audio to players in alternative forms. We proposed the Synesthesia Approach for assistive resource (Chapter 5), which is based on the use of visual metaphors for sounds, instead of text. The approach makes use of the findings regarding the communication strategies to select what information from audio must be depicted visually. An implementation model for using the approach in games was presented, which describes the decisions and compromises pervading the use of the new resource. An alternative, more feasible version in terms of production costs, was also presented: the Algorithmic Synesthesia Approach, which comprehends the use of signal processing algorithms to extract information from the game sounds and automate the configuration of the visual metaphors.

After the proposal of the new assistive resource, we created an experiment by modifying HL2 to implement the Synesthesia Approach in the game (Chapter 6). A very simple instantiation of the synesthesia model was implemented in order to illustrate some of the concepts of the proposal. The modified game was subject to a preliminary evaluation with users in a controlled environment. Three profound deaf and three hearing users participated in the test and played the game for some time, using different combinations of the game's assistive options: subtitles, closed captions and the implemented version of the Synesthesia Approach. The data collected with the test comprised our observation of their gaming experiences and the users opinions on the assistive resources. Results pointed to a general acceptance of the synesthesia approach and also showed some of its benefits under the perspective of deaf and hearing gamers, like the enabling of sound localization and the less attention required by not presenting the information from sounds on the screen space.

7.2 Future Work

In this section, we describe possible avenues for further work.

a. Further investigation on accessibility issues for deaf and hard of hearing players could be made with a **bigger and more representative sample**. The results could, then, be used to properly determine intervening and non-intervening variables in the gaming experiences of the population of hearing impaired players, which, in turn, could enable characterizing game accessibility needs and preferences according to their characteristics.

b. The application of **SIM to games of other genres**, with both objectives of evaluating those games' accessibility and also of identifying their communication strategies through audio. Parallels between the strategies identified for each genre could be traced in search of a more complete characterization the use of audio to convey information in games.

c. **Other experiments** with the Synesthesia and Algorithmic Synesthesia Approaches could be made so as to proper illustrate the concepts of the proposals. New games or the modification of existing ones could be used for this purpose. An investigation of the adequacy (and need) of the Synesthesia Approach in other game genres could be conducted.

d. **A more complete evaluation** of the current implementation of the Synesthesia Approach in HL2 could be done by broadening the number and profile of users and by defining more clear metrics to assess the quality of the instance and the model of the synesthesia proposal.

e. The creation and distribution of a **middleware aimed at integrating the Synesthesia Approach to existing and new games at a low production cost**, which could be called the Synesthesia Framework. By cutting production costs of the Synesthesia Approach, we believe the probability of the game industry including it as accessibility option would increase.

Another interesting path for further work that is worth special mention is the **implementation of the Synesthesia Approach in real life**, instead of inside game worlds. Through the use of specialized equipment (e.g., LCD glasses, microphones and processing hardware) that could somehow translate audio to visual stimuli, deaf and hard of hearing people could receive part of the audio information circulating around them. That could bring benefits in a lot of real life situations, as knowing when a car is buzzing, when the doorbell or telephone is ringing, when music is being played etc. Of course, a much more robust translation of stimuli dimensions must be created and the challenges are much greater. We hope to have given a small step in the direction of making this technology possible, at least by throwing out this idea for future research.

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Appendix A

Questionnaire Material

A.1 Questionnaire Release Message

Hi,

My name is Flávio Roberto and I am working with Glívia Barbosa in a research about the use of Orkut and of Digital Games (computer, consoles, cellphones and other) by people with hearing impairment (any degree of deafness).

Glívia and I are master students in the Department of Computer Science in the Federal University of Minas Gerais (DCC/UFMG) and we would like you to participate in this research by answering a questionnaire.

Answering that questionnaire is quick and easy. You must click in the link (address) below to start. That link does not contain virus.

http://qplprod.grude.ufmg.br/experiencia_em_jogos_e_redes_sociais/

If you have doubts, you can send an email to me (flavioro@dcc.ufmg.br) or to Glívia (gliviaangelica@dcc.ufmg.br).

A.2 Questionnaire Agreement Term

Questionnaire: Experience in Orkut and Digital Games

This questionnaire is for researching information about the experience of people with hearing impairments in the use of Orkut and Digital Games (computer, consoles, cellphones and other).

Your answers will help us to find important information about the participation of deaf people in social networks (Orkut, Facebook and other) and computer games.

This information will also be important for us to know how to improve social networks and games and to facilitate the use of these systems for deaf people.

Your participation is anonymous (you don't need to write your name) and voluntary (by your own will, to collaborate). Filling in this questionnaire takes around 15 minutes.

Thanks for your participation!

Responsible researchers:

Flávio Coutinho (DCC/UFMG)

Glívia Barbosa (DCC/UFMG)

Luiz Chaimowicz (DCC/UFMG)

Raquel Prates (DCC/UFMG)

Elidéa Bernardino (FALE/UFMG)

If you want to know more about the research, send an email to Flávio Roberto (flavioro@dcc.ufmg.br) and Glívia Barbosa (gliviaangelica@dcc.ufmg.br).

Click the button below to answer the questionnaire.

Help us disclose this research.

A.3 Questionnaire

Questionnaire: Experience in Orkut and Digital Games

Goal

The goal of this questionnaire is to obtain information about the experience of users with hearing impairments in the use of Orkut and Digital Games.

Your answers will help us to find important information about the participation of deaf people in social networks (Orkut, Facebook and other) and computer games. This information will also be important for us to know how to improve social networks and games and to facilitate the use of these systems for deaf people.

Your participation is anonymous (you don't need to write your name) and voluntary (by your own will, to collaborate). Filling in this questionnaire takes around 15 minutes.

Respondent Profile [All the "Profile" questions are mandatory]

1. Are you part of the Deaf Community? (have deaf friends, communicate in Libras)?
    a. Yes
    b. No
    c. I don't know
2. Your degree of deafness is?
    a. Mild
    b. Moderate
    c. Severe
    d. Profound
    e. I don't know
3. How would you rather communicate?
    a. Just Libras
    b. Verbalization/oralization and lip-reading
    c. Verbalization/oralization and lip-reading and Libras
    d. Libras and Portuguese
    e. Another way
4. If another way, which way? [Open question]
5. What is your scholarship level?
    a. Incomplete basic (old 1st grade until 8th grade)
    b. Complete basic (old 1st grade until 8th grade)
    c. Incomplete high school
    d. Complete high school
    e. Incomplete college
    f. Complete college
    g. Incomplete post-graduation
    h. Complete post-graduation

6. You studied at
   a. Special school (deaf people only)
   b. Inclusive school (hearing and deaf students together)
   c. Special and inclusive school
7. How frequently do you use a computer?
   a. Everyday
   b. 4 to 6 days a week
   c. 1 to 3 days a week
   d. Less than once a week
8. In which state do you live in?
9. Do you play (nowadays) or have ever played (some time ago) computer or video games?
   a. Yes
   b. No

Game Experience

1. How many times do/did you play computer or video games? (Choose only one option)
   a. Everyday
   b. 4 to 6 days a week
   c. 1 to 3 days a week
   d. Less than once a week
2. Which games do you like? (write as many as you remember) [Open question]
3. Which games don't you like? (write as many as you remember) [Open question]
4. Have you ever played one of those games with other people? (Choose only one option)
   Yes
   No
5. Which games did you play with other people(multiplayer)? [Open question]

6. Where do/did you usually play (You can choose more than one)

    a. Mobile

    b. Computer

    c. Social network (Orkut, Facebook, Kongregate, etc)

    d. Video game (Wii, Xbox, PlayStation, Super Nintendo, Mega Drive, Master System, etc)

    e. Portable console (Game Boy, PSP, Nintendo DS, etc)

    f. Other

7. Have you had difficulties to play due to deafness? (Choose only one option)

    a. Yes

    b. No

    c. I don' remember

8. Which problems did you have? [Open question]

Movies and TV

1. Do subtitles help in understanding movies and TV programs? (Choose only one option)

    a. Yes

    b. No.

    c. So so, as there are some difficult words.

    d. I don't watch TV.

    e. I don't know what subtitles are.

2. What makes subtitles not good? [Open question]

3. Do closed captions (the subtitles that appear when you click on closed caption on the TV) help in understanding movies and TV programs? (Choose only one option)

    a. Yes

    b. No.

    c. I don't watch TV.

    d. I don't know what closed captions are.

4. What makes closed captions not good? [Open question]

5. What would you like that digital games had so they get better for deaf people?
   [Open question]

   In the next step of this research there will be interviews with some Orkut users and game players. Would you be willing to participate on the interview?

   a. Yes

   b. No

If you do accept, please, provide us with (this data will be used only for the research):

Name:
City where you live:
Email:

Appendix B

User Test Material

B.1 Pre-test Questionnaire

Half-Life 2 pre-test questionnaire

Profile

1. Sex:
    a. Male
    b. Female
2. What is your age?
    a. 18 to 20 years
    b. 21 to 25 years
    c. 26 to 30 years
    d. 31 to 35 years
    e. 36 to 40 years
    f. 41 to 45 years
    g. 46 to 50 years
    h. above 50 years
3. What is your scholarship?
    a. Basic (1st to 8th grade - complete ou incomplete)
    b. High school (1st to 3rd grade - complete ou incomplete)
    c. University

d. Post-graduation

Only for people with some degree of hearin loss

1. You studied at:
    a. Special school (for only deaf people)
    b. Regular school (together with hearing students)
    c. Special school and regular school
    d. I don't remember
2. Do you know your degree of hearing loss?
    a. Mild
    b. Moderate
    c. Severe
    d. Profound
    e. I don't know
3. Can you speak in Libras?
    a. Yes
    b. No
4. Do you remember when you started to learn Libras?
    a. While a child (until 7 years)
    b. While teenager (10 to 15 years)
    c. While adult (after 16 years)
    d. I don't remember
5. Can you do lip-reading?
    a. Yes
    b. No
6. When did you loose your ability to hear?
    a. Before 2 years old
    b. Between 3 and 5 years old
    c. Between 5 and 7 years old
    d. After 7 years old

e. I don't remember, but it was when I was a child

f. I don't know

7. In relation to Portuguese reading, how do you consider yourself?

 a. I read with a lot of difficulty

 b. I read with some difficulty

 c. I read without difficulty

Use of digital games

1. Have you ever played Half-Life 2?

 a. Never

 b. Some times

 c. I played it until the end

2. Which types of games have you played? (You can choose more than one)

 a. FPS (Counter Strike, Doom, Call of Duty, Medal of Honor, etc.)

 b. Platform (Sonic, Mario, Metroid, etc.)

 c. Soccer and sports games

 d. Racing games

 e. Musical games (Guitar Hero, Rock Band, etc.)

 f. Strategy (Age of Empires, Warcraft, Starcraft, etc.)

 g. Adventure

 h. RPG (Zelda, Final Fantasy, Ragnarök, etc.)

 i. Puzzle (Tetris, Angry Birds, etc.)

 j. Fighting

 k. Mobile games

 l. Simulation (flight simulation, etc.)

 m. Digital games of board games (chess, solitaire, etc.)

 n. Other:

3. Which of the following platforms do you usually play nowadays? (You can choose more than one)

 a. Computer

   b. Mobile
   c. Tablets
   d. Video games (PS3, XBox 360, Wii, etc.)
   e. Portable consoles (Game Boy, PSP, Nintendo DS, etc.)

4. Are you familiar with W A S D and mouse controls to play?
   a. Yes
   b. No
   c. I don't know

5. Have you ever played games with Subtitles?
   a. Yes
   b. No
   c. I don't know

6. Have you ever played games with Closed Caption?
   a. Yes
   b. No
   c. I don't know

7. How frequently do you play?
   a. Everyday
   b. Once to three times a week
   c. Once to three times a month
   d. Less than once per month

8. What type of player do you consider yourself?
   a. Advanced
   b. Intermediate
   c. Basic

B.2 Consent

Title: Evaluation of the accessibility resources of the game Half-Life 2

The goal of this test is to evaluate the accessibility resources for players with deafness or without access to the music and sound effects of the game Half-Life 2.

We ask the participants to play Half-Life 2 for some time. While playing, the computer screen will be recorded in a video to be analyzed later. By the end of the gaming activities, an interview will be done about what you thought about the accessibility resources. This interview will be recorded with a digital camera or a voice recorder.

The videos and sound files that we record during the test will be used for study only and, neither your name or you recordings with your voice or face will be disclosed. The anonymity of the evaluation participants is guaranteed, being that they only people that will know their names are the researchers responsible for this test and their names will appear only in this consent, if the volunteers agree to participate.

If you choose not to participate in this research

You are free to decide, at any time, if you want to participate or not of this research. Your decision won't affect your student life or your relationship with the evaluators, teachers or the institution behind this.

Compensation

The participation in the research is voluntary and no remuneration will be offered to the participants.

Consent (voluntary agreement)

The aforementioned document describing the benefits, risks and procedures of the research was read and explained. I had the opportunity to make questions about the research, that were nicely answered. I agree to participate as a voluntary.