Designing games for deaf children: first guidelines

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Abstract: According to the most recent deaf literature, playing with digital games shows positive effects on deaf children's specific skills. The goal of this paper is to present the first guidelines for the design of games for deaf children. Our review of deaf literature, briefly sketched in the paper, considers such abilities as well as deaf children's preferences most relevant for the design of digital games for them. Literature findings are then used to compile the guidelines, with accompanying usage examples. Guidelines and literature findings are correlated at the end of this paper.

Keywords: deaf people; deaf literature; special needs; guidelines; heuristics; design; evaluation; games; educational games.

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1 Introduction

In recent years, research in information and communication technologies paid increasing attention to the design of *electronic tools* (e-tools) for children. There is also a fair amount of work devoted to guidelines for designing e-tools for children (see e.g. Chiasson and Gutwin, 2005; Grammenos et al., 2000). Existing guidelines differentiate children according to their age or gender, and not according to other cognitive characteristics such as text comprehension skills, visual attention and memory abilities. However, these and other skills turn out to be crucial for designing e-tools usable and accessible for deaf individuals, according to deaf studies (see e.g. Marschark, 2000). For instance, the reading skills of deaf people are lagging behind compared to those of their hearing peers, whereas the visuo-perceptual skills of deaf people are generally regarded as equal to those of their hearing peers, when not more developed. Such differences call for guidelines for designing e-tools that are usable and accessible for deaf people, in general, and deaf children, in particular.

Moreover, recent studies show positive correlations between deaf children's cognitive skills and playing digital games. For instance, deaf children's improvement in memory skills seems to be directly related to the number of games they play (Bosworth and Dobkins, 2002; Marschark and Mayer, 1998). Playing action games was shown to

enhance all aspects of attention in deaf children (Wallander et al., 2001). Given the positive effects that digital games can have on deaf children and the need for guidelines for designing e-tools for them, we set ourselves on the tack of compiling the first guidelines for designing digital games that are usable and accessible for deaf children. That is the focus of our paper.

This paper is divided into two parts. The first part is an overview of findings concerning the characteristics and preferences of deaf people, and deaf children in particular, relevant for designing digital games for them. More specifically, the second section starts with an overview of field studies concerning relevant characteristics of deaf children from the deaf literature. It then continues with recent findings of a European project, TERENCE (TERENCE Consortium, 2013), that develops serious games for children, hearing and deaf, and for which the authors of this paper worked. The TERENCE team conducted field studies with hearing and deaf children, as well as contextual inquiries with their teachers, parents and experts of deafness, and in so doing the team learnt about characteristics and preferences of deaf children for digital games that are not emerging from the deaf literature.

Having so laid the groundwork, the guidelines for the design of games for deaf children unfold in the second part of the paper. The third section lists the guidelines, with example applications, that result from abstracting on the findings overviewed in the first part of the paper. The correlations between the guidelines and the findings are specified in a dedicated section, the fourth one. This paper ends recapping the main lessons learnt from the reported work and commenting on future work.

2 Characteristics and preferences of deaf children

We analyse what we know and we do not know from the literature about those characteristics and preferences of deaf individuals that are relevant for designing usable and accessible digital games for them.

Cognitive and behavioural characteristics of deaf children such as those necessary for comprehending texts are investigated in a number of field studies in the deaf literature. The major findings are reported in the first subsection below. Preferences and other characteristics of children necessary for playing digital games, such as their sensitivity to colours and illustration styles, were investigated in the running TERENCE project, and are briefly reported in the second subsection below.

2.1 Deaf studies

2.1.1 Introduction

In this section, we divide and report the findings in the deaf literature according to the main field of investigation: comprehension skills for texts; visual attention; focus and social interaction skills; memory.

Text comprehension skills are investigated across many deaf studies, possibly because the consequences of un-remediated low performances in reading tend to have a wider negative impact, e.g., on the social inclusion of deaf individuals, motivations to reading, performances in science curricula, usage of ICT tools and one's self-esteem.

Visual processing and especially visual attention constitute another body of research, spanning from attention to objects at the periphery of the visual field to its (re)orientation from one target to another. Several deaf studies analyse the capabilities of deaf individuals to maintain focused attention and to interact with others or the environment, which is relevant, for instance, for deciding about the game genre and feedback. Finally, we discuss memory skills of deaf children, relevant for our guidelines.

2.1.2 Text comprehension

The field of text comprehension is investigated by many deaf studies, also because becoming a successful reader is "one of the most significant barriers to learning and achievement for deaf young people throughout their school career and beyond into employment" (Traxler, 2000; Trezek et al., 2010). Reading has been recognised as a key concern in deaf education for over 30 years (Conrad, 1979), but despite research efforts and changes in placement and language approaches we are still waiting for a significant change in results (Easterbrooks, 2010; Hendar, 2009; Marschark et al., 2007).

Gibbs (1989) shows that deaf readers, like good hearing readers, use metacognitive strategies to monitor and maintain comprehension, but are less accurate in their meta-comprehension. This seems to also occur when a sign language is used, e.g. the studies reported in Dye et al. (2008b) and Gibbs (1989) purport that deaf children learn as much from reading as they do from signed instructions. The reasons of low performances in text comprehension seem, thus, to be multiple, varying from phonological coding and awareness to missing contextual knowledge, as we sketch below.

While hearing individuals read by converting printed letters into a phonological code that feeds into their auditory language system, deaf individuals use an alternate pathway, specific to reading, not used by hearing people.

Differences in visual processing in the deaf reader may result in different perceptual processes involved in reading as compared to those of hearing readers (see Section 2.1.3 and Azbel, 2004). Reading involves using the centre of the visual field to fixate the word for hearing children. Therefore, the fact that deaf children pay more attention to items in the periphery could partially cause confusion in the identification of letters and words (Banks et al., 1990).

In addition, deaf children tend to remember less in short-memory tasks (see Section 2.1.5 and Dye et al., 2008b) than their hearing peers. As shown in Campbell and Wright (1990), word recall by deaf individuals seems poorer for long words than for short words, as well as for abstract, ambiguous or unfamiliar words without surrounding contextual clues. Moreover, terms and words that do not confuse the child should be preferred, and attention should be paid to neighbouring words that influence where readers fixate their attention (Wallander et al., 2001).

The vocabulary of deaf children is usually considerably restricted in comparison with that of their hearing peers. For instance, a deaf student will not have heard many of the words that fill the classrooms and lecture rooms around them (Briggle, 2004). Due to their restricted vocabulary, their reading skills could be better when words have only a single meaning or when they are presented in context rather than in isolation.

Whether it depends on memory, visual processing or other factors, deaf individuals tend to have problems with comprehending a complex sentence, in particular, with tapping local cohesion in texts (Di Mascio et al., 2012; Trezek et al., 2010). Moreover,

deaf individuals tend to remember disconnected portions of texts rather than the whole picture, especially when the material is unfamiliar (Dye et al., 2008a; Gibbs, 1989). In that respect, they seem to benefit from self-paced reading windows, so that only small chunks of locally coherent texts are available, one at a time.

2.1.3 Visual attention

Several studies purport that visual ability in the deaf may be altered as a result of auditory deprivation. Deafness leads to changes not in all aspects of vision [e.g. there is difference neither in basic visual motion processing (Bosworth and Dobkins, 2002a) nor in the discrimination of shades of grey (Meadow, 1980)], but specifically in visual attention and alteration of attentional abilities.

Visual attention is the ability to pay attention to and focus on items or things that are relevant to current goals while ignoring distractions that are not pertinent. Different studies examined the development of visual attention in different deaf subjects with different ages and access to sound. Bavelier et al. (2006) found that deaf individuals are better in certain aspects of visual perception, and specifically in allocating visual attention to the periphery of the visual field. Other studies (Proksch and Bavelier, 2002) show similar results, namely that deaf signers are more distracted by peripheral events and hearing individuals are more distracted by central events (Proksch and Bavelier, 2002). Specific tests show that deaf signers are better at identifying the direction of motion of stimuli at the edge of their visual field. Therefore, if the task requires them to pay attention to the centre of the visual field and there are distracting stimuli at the edge of the visual field, their performance is likely to be worse than for hearing subjects (Bavelier et al., 2006). However, Todmann and Cowdy (1993) purport that their ability to discriminate very small differences in direction of motion is altered and more deaf subjects discriminated gross differences in direction as leftwards vs. rightwards.

Worth of attention is also the study by Bosworth and Dobkins (2002a), where they report a fine-grained study concerning visual attention with hearing and deaf subjects. They used a direction of motion discrimination task in the periphery for investigating whether attention processes differ between deaf and hearing individuals. Their results are as follows: deaf individuals are better than hearing individuals in *orienting attention* from one location to another, and are more affected by the presence of distracters, i.e. they are less good in *selective attention*, whereas no difference was found in *divided attention*, i.e. the ability of processing multiple stimuli in the visual field.

Other studies differentiate deaf individuals by their age, and Grigonis and Narkevičienė (2010) assert that young deaf children have more difficulties for visual serial recall and take more time for recovering visual attention.

2.1.4 Focused attention and social interaction

A good deal of research investigations concerning the level of attention of deaf children report that the majority of them have problems related to focusing their attention (see e.g. Dye et al., 2008b). The problems of attention are demonstrated by means of tests like UFOV (Ball et al., 1988; Dye et al., 2009), backed up also by subjective ratings of teachers and parents. For instance, Meadow (1980) reports that few mothers declare that they have problems in eliciting and maintaining eye gaze and joint attention with their deaf children. Other studies have examined lower level visual skills

underpinning attention behaviour and the visuo-motor skills that may also influence action coordination (Werner and Strauss, 1941; Myklebust and Brutten, 1953). In order to get the attention of deaf children focused, calibrated feedback, e.g. vibration feedback or motion, may be used (Chiasson and Gutwin, 2005).

Reivich and Rothrock (1972), Quittner et al. (1994) and Quittner et al. (2004) reported that, according to teachers, deaf children tend to be more impulsive, easily grumpy and lack inhibition, probably because deaf individuals have less chances of learning social conventions than their peers. The analysis of the results of tests like CPTs, reported in Reivich and Rothrock (1972) and Quittner et al. (1994), shows that deaf children have problems in continuous performance tasks about vigilance, showing that deaf children are more impulsive and suffer from increased distractibility.

It is then not surprising that one of the first research studies conducted by Higginbotham and Baker (1981), and later confirmed by other researchers, concludes that deaf children devote less time to cooperative activities and significantly more time to solitary activities.

2.1.5 Memory

Memory is responsible for several game-related activities and is measured in different manners. *Short-term memory* is the ability of holding a small amount of information in mind in an active, readily available state for a short time. For instance, Macsweeney et al. (1996) and Marschark (1997) analysed relations between the use of short-term memory, memory codes and the reading ability of deaf children by means of tests on recall of pictures. The results show that reading ability is closely linked to the overall short-tem memory performances.

Short-term memory is generally considered lower for deaf subjects than for their hearing peers. However, the variations of stimulus and response conditions result in deaf individuals having better, equal or worse memory as compared to hearing subjects. Memory strategies and particularly memory codes may influence deaf children's recall performances. Deaf people are accredited to rely more heavily on visuo-spatial short-term memory codes. Marschark and Mayer (1998) found deficits in recall for linguistic stimuli, printed words and pictures but not in recall of non-linguistic stimuli such as unfamiliar faces and spatial arrays of lights. According to Todmann and Cowdy (1993) and Todmann and Seedhouse (1994), deaf children surpassed hearing children in short-term memory tasks for complex figures, except when the task involved serial recall. Deaf individuals may be at a disadvantage on linguistic tasks that involve serial recall. However, deaf people seem to be better in tasks that involve temporal order.

Contrary to short-term memory, *long-term memory* can store a seemingly unlimited amount of information for a long time span. Studies such as Grigonis and Narkevičienė (2010) on serial recall of deaf children in elementary schools show that deaf children did not exhibit an advantage over hearing subjects in immediate recall task performances, but the groups of deaf children performed worse in long-term storage of visual material – deaf individuals used to forget more than hearing subjects.

Short-term memory is also different from *working memory* in that this refers to structures and processes used for temporarily storing and manipulating data. Some, but not all, deaf children have lower working-memory spans than hearing children (Nunes et al., 2010). However, Marschark and Mayer (1998) administered question games and

showed that deaf students with experience of playing games performed as well as hearing peers, but, among the inexperienced participants, hearing children performed better than deaf children. Children's performances were directly related to the number of games they play: the more games they play, the better their performance in working memory tasks become when retested (Bosworth and Dobkins, 2002; Marschark and Mayer, 1998). This means that deaf children's working memory can improve by playing adequate games.

2.2 The TERENCE studies

2.2.1 Introduction

TERENCE is a collaborative project funded by the EC under the ICT Call 5 FP7- ICT-2009-5 and that develops the first adaptive learning system with stories and reading interventions in the form of smart games, all designed within a stimulation plan for text comprehension. The system is meant to be accessible and usable by all children in primary schools, in particular, hearing and deaf children that have deep text comprehension problems. In particular, we concentrate on children in the age range of seven to ten, when poor comprehenders tend to start lagging behind their peers at school.

Given such an aim, the TERENCE system is developed following the Evidence-Based Design (EBD) and the User-Centred Design (UCD; see Slegers and Gennari, 2010). For producing a pedagogically effective system, EBD stresses the need for basing the system design on empirical evidence, also gathered from *domain experts*, namely diagnosis or stimulation plan experts for poor text comprehension or deaf children. For producing a usable system, UCD places the users at the centre of the design process and iteratively designs the system starting with the analysis of the context of use and revising prototypes of the system through evaluation studies.

Within the TERENCE project, we conducted several field studies and contextual inquiries, firstly, for analysing the context of use, and, secondly, for evaluating the usability of prototypes of the TERENCE system. More specifically, we ran game-like field studies with children, hearing and deaf, from UK and Italy. We also ran contextual inquiries, such as diaries with parents and teachers, and structured interviews with domain experts.

The studies for the context of use analysis involved 592 seven- to ten-year-olds across UK and Italy, 70 of which were deaf. Usability studies involved 174 seven- to 16-year-olds, 38 of which were deaf. For more details on all such studies, we refer the reader to Melonio (2013).

In the following, we report the main findings of the TERENCE studies, clustered in the same fields we used for the deaf literature reported above.

2.2.2 Text comprehension

According to the TERENCE domain experts, deaf children's problems with text comprehension are concerned with tapping global coherence as well as local cohesion, complex periods and, in particular, coreference. For some deaf individuals, decoding and phonology can be problematic. That said, informative texts should use unambiguous and familiar words or the surrounding words should help disambiguate the unknown word.

As for preferences, teachers say that deaf children seem to prefer reading short texts. Deaf children say that they like adventure, fantasy or comics books with detailed and colourful illustrations. In fact, teachers and parents confirm, if pictures or games are used, the deaf child is more stimulated to perform reading tasks.

Deaf children tackle difficult reading tasks with the help of parents, older relatives or teachers.

A comprehensive survey of the reading skills of deaf individuals is offered in the conclusions to Slegers and Gennari (2010).

2.2.3 Focused attention and social interaction

According to domain experts and teachers alike, deaf children tend to have diminished attention time – "after a bit they are bored". The deaf child is distracted more easily and should always be called to his/her attention with signs. When deaf children are reading books, the teacher often has to recall the attention of the children and point to where they were reading.

Deaf children are more alert to being treated differently, and suffer from it. For instance, it often happens that teachers give deaf children that are older than eight stories that are meant for a young child, due to the lack of textual material that is adequate to their reading skills. This creates discomfort in the deaf child. In the case of older deaf children, the more they are exposed to failure the more frustration-prone and irritable they grow.

2.2.4 Memory

According to teachers, in agreement with domain experts, deaf children tend to better recall images than texts alone compared to their hearing peers. In particular, since their first impact is with the physical aspect of a person, they tend to remember this better. Often, they refer to a person by signing physical characteristics of the person, e.g. the curly girl.

2.2.5 Game devices, avatars and genres

The field studies with children in TERENCE gave valuable information for the design of digital games for them, mainly concerning the attitude of deaf children towards illustrated books and digital games, and their preferences.

In general, deaf children are very enthusiastic about using new technology, such as tablets. They tend to use the computer mostly for playing and sometimes for research on the internet or chatting with friends.

Deaf children generally prefer playing games with human-like avatars. More in general, they tend to prefer

- playing with mobile devices (e.g. Nintendo DS or tablets);
- console games (when the age increases the use of non-photorealistic consoles decreases and the use of photorealistic consoles increases);
- games involving movement (they often refer to the usage of a balance board), action games like Mario Kart and brain teasing games;
- playing by themselves, alone and in the same place.

Male deaf children are fairly sensitive to points and challenges: "it's really great to get high scores on challenging shooting games". They also like sport games such as FIFA 12 and shooting or war games such as Call of Duty: Black Ops.

Deaf children like adventure, fantasy or comics books with many vivid illustrations and are more picky about and alert to discrepancies between a text and its illustration than their hearing peers.

In general, they seem not to care about reading instructions; deaf children seem to read them only if they appear before the start of the activity or in a dedicated portion of the screen, without other distracters.

3 Guidelines

In this section, we compile the first guidelines for designing digital games that are accessible and usable for deaf children, and that arise from the research in deafness reported above. We cluster the guidelines into five main areas for the design of digital games, according to the findings we have in the surveyed studies: words; other characteristics and position of textual elements; choices and interaction; feedback; game devices, avatars and genres.

3.1 Words

According to the literature review, unfamiliar or ambiguous words, without contextual clues, are problematic for deaf children, and words that have not been specifically introduced to the student cannot be easily lip-read (when the carrier language allows for this) Moreover, if deaf readers have an alteration in their visual selective attention, they could have problems in identifying the letters of a word and in creating representations that preserve both the correct letters and their correct spatial arrangements. Therefore, texts should prefer *familiar and unambiguous words*, *paying attention to neighbouring words that influence where the reader will fixate their attention [GL 3.1.1]*. If unfamiliar, ambiguous or abstract words are used, *then their meaning should be easily inferred from the surrounding context [GL 3.1.2]*.

GL 3.1.2 example	
Wrong	*Correct*
The rocket went to the **asteroid**.	The rocket landed on the **asteroid that was floating in space and was surrounded by light stardust.**

As explained in the above literature review, word length matters to the point that the length of words for pictures may affect the serial recall of pictures. Therefore, *words should not be too long, in particular, for key information such as instructions [GL 3.1.3]*.

3.2 Other characteristics and position of text

Reading problems, attention and memory issues constrain how texts should be positioned for playing games. This is particularly true for instructions for games.

Firstly, any key textual information, like instructions, should use short and simple sentences, without complex or distant referential expressions [GL 3.2.1].

GL 3.2.1 example	
Wrong	*Correct*
Mathias and Lucas were the best friends of Ben and Sophie […] One day Ben and Sophie visited the biggest swimming pool in town with their Mum and **their best friends.**	Mathias and Lucas were the best friends of Ben and Sophie […] One day Ben and Sophie visited the biggest swimming pool in town with their Mum, **Mathias and Lucas.**

Moreover, given the visual attention orienting and selective skills of deaf learners, games should *use visual clues or animations for directing the attention of the child on relevant textual information [GL 3.2.2]*.

Deaf children may have problems with longer fixation and tend to have slower text comprehension time. Several studies assert that signed instructions are not better comprehended than written instructions. In general, it is better if limited amounts of information are made available at one time. Therefore, *relevant information* such as instructions *should occur in a separate dedicated part of the screen, in small chunks [GL 3.2.3]*. Given the attentional abilities of deaf children, relevant information should also come *without other distracters if not for (re)orienting the attention towards key points [GL 3.2.4]*.

3.3 Choices and interaction

According to the literature review of this paper on attention, young children have more difficulties for serial recall and take more time for recovering attention. This means that *young children may need fewer choices in games [GL 3.3.1]*. More in general, *using the same items in the same position and order in the interface should aid the recall of deaf children [GL 3.3.2]*.

On the screen, there should not be distracting stimuli for the peripheral visual field because deaf individuals are more distracted by peripheral events. *On the edge of the screen, the interface should have objects and motion stimuli that do not distract the children from their main playing task [GL 3.3.3]*.

GL 3.3.3 example	
Wrong	*Correct*
	

Deaf children often fail to respond with gestures or signs when their eyes are attracted by the objects in motion, due to their difficulty with divided attention. While hearing children can listen and answer simultaneously within the game, deaf children must interact with one task at a time. Therefore, the *game should be composed of a single interaction task or use a single communication channel at a time, e.g. the game should propose reading and a visual task, such as moving or finding objects, at separate moments [GL 3.3.4]*.

3.4 Feedback

In general, children are impatient and need immediate feedback: they expect to see the results of their actions immediately; if nothing happens after their input, children may repeat their action until something does occur. In general, a child should not be left idle in front of the screen for too long a time without any stimulus or feedback. This is particularly true for deaf individuals. Deaf children have problems at focusing attention for too long a time in a reading task or demanding playing activity. However, they seem better than hearing ones in orienting spatial attention, especially at reorienting it. Deaf subjects tend to discriminate gross differences in direction as leftwards vs. rightwards. Therefore, games for deaf children could use *vibration feedback or motion of objects for (re)directing the attention [GL 3.4.1]* of the deaf player towards specific targets, e.g. the correct or wrong resolution of a game. However, one must be careful where to place the animation on the screen because it might adversely affect their attention focus. Since deaf children are more impulsive, *the type and timing of feedback must be carefully calibrated on the target deaf child [GL 3.4.2]* so as not to be frustrating or irritating.

3.5 Game devices, avatars and genres

According to the above literature review, possibly due to difficulties in communicating and socially interacting with nearby peers, *deaf children prefer single-player games [GL 3.5.1]*. In the TERENCE studies with deaf and hearing children, we observed that all our children's preferences were for playing with mobile devices and console games. All of them prefer doing specific activities always in the same place. In particular, the majority of deaf children prefer *playing with consoles by themselves*: whereas *seven- to nine-year-old children prefer non-photorealistic consoles, nine- to 11-year-old ones prefer photorealistic ones [GL 3.5.2]*.

Moreover, deaf children tend to prefer *games with movement* (e.g. balance board of WII or kinect of XBOX)*, action games and sometimes brain-teasing games [GL 3.5.3]*. Male deaf children are fairly sensitive to points as well as challenges and like sport, shooting and war games. Therefore, games *for male children should have many progressive challenges, extrinsic rewards, sport and adventure elements [GL 3.5.4]*.

Deaf children suffer from increased distractibility and have different attention needs according to the literature. Moreover, they are easily irritated and prone to frustration. Therefore, the *timing of games should be carefully calibrated on the target deaf players, in particular, if reading is involved [GL 3.5.5]*. Notice that deaf children perceive immediately when they are treated like younger children, i.e. if the illustrations in a book are for a younger kid they may refuse to read the book. The older they grow, the more impatient they become. Thus, *the game genre should be calibrated on the age of the target player, e.g. the genre of texts and pictures should be age-appropriate [GL 3.5.6]*.

Several studies show that children who played action digital games showed enhanced performance on all aspects of attention. Moreover, from our TERENCE usability experiments with deaf and hearing children, it turns out that playing video games takes a large part of the deaf children's day, and is preferred over other daily activities (e.g. TV, reading). So *the training with games like action games may be used to enhance deaf children's skills, in particular, for improving their performance in problem-solving strategies [GL 3.5.7]*, possibly enhancing their working memory.

Deaf children tend to tackle difficult reading tasks with the help of their parents, older relatives or teachers. Deaf children tend to prefer customisable human-like avatars that guide them through games. Thus, games should feature *collaborative customisable*

human-like avatars, guiding players through difficult game tasks [GL 3.5.8]. Deaf children like adventure, fantasy or comics books with many vivid illustrations, and are picky about and alert to discrepancies between a text and its illustration. Therefore, *illustrations should be informative and highly coherent with textual information. More in general, graphical elements should be vivid and coherent with the game genre [GL3.5.9]*.

4 Relations between guidelines and deaf study findings

The above guidelines are rooted in the studies from the literature reported in the opening to the paper. Next, we present a list of recap tables (Tables 1–4) for each of the fields of the above literature review (Section 2): text characteristics; visual attention; focused attention and social interaction; memory; game devices, avatars and genre. The bottom of each table also lists the relevant bibliographical references from the literature review. Each row of a table corresponds to an area of the guidelines, and reports the related guidelines with their identifiers in the last column.

Table 1 Text comprehension

Characteristics	*Area*	*GL #*
Word recall by deaf seems poor for long words, as well as for abstract, ambiguous or unfamiliar words without surrounding contextual clues.	Word	3.1 3.2.2
Deaf children's vocabulary skills are better when words have only a single meaning or when they are presented in context.		3.2.3
Unfamiliar words, or words not specifically introduced to the student cannot be easily lip-read – whenever feasible.		
Reading involves using the centre of visual field to fixate the word for hearing children. Therefore, the fact that deaf children pay more attention to items in the periphery could partially cause confusion in the identification of letters and words.		
Some deaf individuals have problems with decoding and phonology.		
Deaf individuals seem to have problems with complex sentences, in particular, with local cohesion.	Sentence	3.2.1
Deaf children are likely to have problems with tapping global coherence as well as local cohesion.	Entire text	3.2
Deaf students tend to remember disconnected portions of the text rather than the whole picture, especially when the material is unfamiliar.		
Deaf readers seem to benefit from a 'windowed reading', whereby only limited amounts of a locally coherent text are made available at any one time.		
Several studies assert that signed instructions are not better comprehended than written instructions.		
Deaf children prefer reading short texts and books with vivid pictures. If the teacher uses pictures or games, the deaf child is more stimulated to perform reading tasks.	Preferences	3.5.8 3.5.9
(Bavelier et al., 2006; Proksch and Bavelier, 2002; Dye et al., 2009; Campbell and Wright, 1990; Grigonis and Narkevičienė, 2010; Dye et al., 2008a; Trezek et al., 2010; Marschark, 2000, 2001; Banks et al., 1990; Di Mascio et al., 2012)		

Table 2 Visual attention

Characteristics	*Area*	*GL #*
Deaf individuals seem better in certain aspects of visual perception and specifically at allocating visual attention to the periphery of the visual field. Deaf signers seem to be more distracted by peripheral events and hearing individuals are more distracted by central events.	Visual attention to peripheral events	3.2.2 3.2.3 3.2.4 3.3.3
Young children have more difficulties for serial recall and take more time for recovering attention.	Serial recall and attention recovery	3.3.1 3.3.2
Deaf individuals are better than hearing individuals in orienting visual attention from one location to another.	Orienting visual attention	3.2.3 3.2.4
Deaf individuals are more affected by the presence of distractors, i.e. they are less good in selective attention.	Selective visual attention	3.3
In deaf individuals, the ability to discriminate very small differences in direction of motion is altered and more deaf subjects discriminated gross differences in direction as leftwards vs. rightwards.	Discrimination of small/ gross differences	3.3.3 3.3.4
(Bavelier et al., 2006; Proksch and Bavelier, 2002; Smith et al., 1998; Dye et al., 2010; Bosworth and Dobkins, 2002b; Dye et al., 2009; Todmann and Cowdy, 1993; Grigonis and Narkevičienė, 2010; Dye et al., 2008a; Bosworth and Dobkins, 2002a; Fine et al., 2005)		

Table 3 Focused attention and social interaction

Characteristics	*Area*	*GL #*
The majority of deaf children have problems in focusing their attention. When deaf children are reading books, the teacher often has to recall the attention of the children and indicate the point where they were reading. Deaf children tend to have diminished attention time (after a bit, they are bored).	Focused attention	3.2.2 3.2.3 3.2.4 3.4 3.5.3 3.5.5
Few mothers declare that they have problems in eliciting and maintaining eye gaze and joint attention with their deaf children.	Eye gaze and joint attention	3.2.4 3.4
Deaf children tend to be more impulsive and lack inhibition and suffer from increased distractibility. They are more alert of being treated differently and suffer from it. The older they become, the more frustration prone they grow.	Impulsivity and lack of inhibition	3.4 3.5.4 3.5.5 3.5.6
Calibrated use of vibration feedback or motion for deaf children may be used to get their attention focused.	Vibration feedback or motion	3.4
Several studies show that children who play action video games show an enhanced performance on all aspects of attention.	Playing games – effects	3.5.6 3.5.7
Deaf children devote less time to cooperative activities and significantly more time to solitary activities.	Preference for cooperative activities	3.5.1 3.5.2
(Quittner et al., 2004; 8; Hertzog, 2011; Buckley et al., 2010; TERENCE Consortium, 2013; Meadow, 1980; Quittner et al.,1994; Reivich and Rothrock, 1972; Higginbotham and Baker, 1981; Di Mascio et al., 2012)		

Table 4 Memory

Characteristics	*Area*	*GL #*
Reading ability is closely linked to overall short-term memory performance. This seems lower for deaf individuals, so is long-term memory.	Short- and long-term memory performances	3.1.3 3.2.1
Deaf children surpass hearing children in short-term memory tasks for complex figures, except when the task involved serial recall. Deaf people are accredited to rely more heavily on visuo-spatial short-term memory codes. For instance, deaf subjects have deficits in recall for linguistic stimuli, printed words and pictures, but not in recall of non-linguistic stimuli such as unfamiliar faces and spatial arrays of lights. Deaf children tend to better recall images than texts alone. In particular, since their first impact is with the physical aspect of a person, they tend to remember this better; often, they refer to a person by signing physical characteristics of the person, e.g. the curly girl.	Visuo-spatial short-term memory	3.3 3.5.2 3.5.3 3.5.4 3.5.9
Deaf individuals may be at a disadvantage on linguistic tasks that involve serial recall, but they seem to be better in tasks that involve temporal order.	Memory for temporal order tasks	3.5.5
Children's performance in memory tasks seems directly related to the number of games they play: the more games they play, the better their performance in memory tasks when retested.	Playing games – effects	3.5
(Bosworth and Dobkins, 2002b; Marschark and Mayer, 1998; Todmann and Seedhouse, 1994; Macsweeney et al., 1996; Todmann and Cowdy, 1993; Grigonis and Narkevičienė, 2010; Nunes et al., 2010; Di Mascio et al., 2012; Proksch and Bavelier, 2002; Smith et al., 1998)		

5 Conclusions

This paper presents guidelines for the design of digital games for deaf children. Positive effects that playing games has on the deaf child's visual and memory abilities are already reported in the deaf literature. Such abilities as well as other characteristics or preferences of deaf children are listed in the literature overview in the first part of this paper. The major findings about deaf individuals are picked up for compiling our guidelines, and the relations between the guidelines and the literature are pinpointed in the closure to the paper. A preliminary shorter version of the guidelines was published in Melonio and Gennari (2013). Such guidelines were applied in the design of incrementally revised prototypes of the TERENCE system (Cofini et al., 2012). Future work foresees the usage of the guidelines for conducting co-design studies of games with deaf children as participants (see Melonio, 2013).

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