Managing Sound Sensitivity in Autism Spectrum Disorder: New Technologies for Customized Intervention

by

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ABSTRACT

Many individuals diagnosed with autism experience auditory sensitivity – a condition that can cause irritation, pain, and, in some cases, profound fear. Efforts have been made to manage sound sensitivities in autism, but there is wide room for improvement. This thesis describes a new intervention that leverages the power of "Scratch" – an open-source software platform that can be used to build customizable games and visualizations. The intervention borrows principles from exposure therapy and uses Scratch to help individuals gradually habituate to sounds they might ordinarily find irritating, painful, or frightening.

Facets of the proposed intervention were evaluated in a laboratory experiment conducted on a non-clinical population. The intervention was also tested on three autistic individuals with histories of auditory hypersensitivity. One case study participant showed signs of complete remission of his auditory sensitivity issue, while another showed signs of gradual improvement. Future research designs are discussed that could evaluate these findings in greater detail.

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1. Introduction

Autism Spectrum Disorder (ASD) is a pervasive developmental disorder affecting as many as one in every 150 children in the United States [1]. It is characterized by a host of cognitive, social, and affective impairments, and its symptoms can range from mild to severe. Unusual perceptual abilities are also common in ASD; indeed, many individuals on the autism spectrum describe strange experiences or sensitivities in at least one sensory modality [2]. Sensitivity to sound, for example, is frequently reported by those with ASD diagnoses [3]. Temple Grandin, a researcher who is herself on the autism spectrum, has suffered from auditory sensitivity. She describes this disorder from a uniquely personal perspective, and writes:

> "Sudden loud noises hurt my ears - like a dentist's drill hitting a nerve… High-pitched continuous noise, such as bathroom vent fans or hair dryers, are annoying.
>
> I have two choices: 1) turn my ears on and get deluged with sound or 2) shut my ears off." [4]

Research suggests that Grandin's experiences are not unique, and are in fact shared by many autistic persons[1]. Sounds that most people would consider innocuous (or at most, mildly bothersome), may be extremely painful and frightening to people on the autism spectrum.

In serious cases, individuals with auditory sensitivity can develop phobic conditions, such that the mere possibility of hearing a painful sound can cause fear and anxiety [5]. To cope, these individuals develop strict routines to safeguard themselves from challenging acoustic environments. This, in turn, leads to increased isolation and an increased distance from natural, social communication. Autistic individuals are already at risk for restricted behaviors and communication impairments. Auditory sensitivity issues no doubt magnify this risk and, as such, they should be managed as best as possible. Unfortunately, there are few treatment options for individuals with this condition. And, of those that are available, many are costly, controversial, or simply ineffective. Clearly, more work needs to be done. In light of this problem, this thesis presents a new technological approach to manage sound sensitivities in ASD.

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[1] There is much debate over how to respectfully and sensitively refer to individuals who have an ASD diagnosis. Recently, Gernsbacher et al [59] took an empirical approach to this question and compared Google search results for the terms "autistics" and "person/s with autism." They found that 99% of the hits for the term "autistics" were from organizations led by autistic persons, whereas the first 100 Google hits for "person/s with autism" led to organizations run by nonautistic individuals. In light of these findings, I respectfully use the term "autistic person/s" throughout this thesis. However, I do so knowing that the most respectful designation may change with time. The way we refer to individuals diagnosed with autism may change as we learn more about the condition and as our sensitivities move with the spirit of the times.

1.1 Auditory Processing in ASD

Before the proposed intervention is described, it will be important to first review the literature on auditory processing in ASD. This is an important area to cover, because the unique auditory processing patterns observed in ASD may provide insight into auditory sensitivity issues.

1.1.1 Enhanced Perception of Sound

Research suggests that many individuals with ASD diagnoses have an enhanced perception of sound, especially for simple, low-level stimuli [4]. For instance, in research studies, people on the autism spectrum show exceptional performance on a host of auditory and musical perception tasks, including pure-tone recognition, chord-disembedding, and the detection of interval changes [6,7,8]. Compared to neurotypicals (that is, those without an ASD diagnosis), autistic individuals are about 500 times more likely to have absolute pitch [5]. Further, Khalfa et al. have observed an enhanced perception of loudness in eleven autistic children and adolescents [9], and incidents of hyperacusis – or the ability to hear sounds at extremely low volumes – were found in 18% of 199 autistic children examined by Rosenhall et al [12].

Musical savantism, while rare, may be yet another example of heightened auditory processing in ASD. Autistic individuals with musical savantism often show a virtuosic ability to encode and recall passages. With just one listen, they can often play back entire musical pieces, perfectly mimicking complex melodic, harmonic, and rhythmic structures [13]. Flawless recall of this sort may arise from any number of cognitive processes, and its neural underpinnings are not yet understood. However, enhanced auditory processing must be an important factor in the development of musical savantism; Heaton, for instance, argues that autistic musical savants invariably have absolute pitch abilities [8].

1.1.2 Impaired perception of sound

Interestingly, autistic individuals may show enhanced perception in some domains and yet show impaired perception in others. Indeed, both anecdotal reports and experimental research suggest that auditory perception can be highly impaired in ASD [3].

In general, the research on impaired audition in ASD suggests these disturbances stem from complex neurological deficits and not outer ear dysfunction [14,15]. Many studies have shown atypical central auditory processing in autistic individuals in the absence of peripheral hearing problems [16-20]. Hearing difficulties in this population are not simply the result of abnormal inner ear morphology. Instead, it seems that the problems stem from atypical top-down, neural control over inner ear structures.

For instance, among many reported deficits, autistic individuals often have trouble distinguishing sound in the presence of background noise [21-23], a process that involves top-down, neurological control over inner ear functioning. Findings reported by Khalfa et al. [24] showed that children and adolescents with ASD diagnoses failed to engage midbrain auditory filtering mechanisms (namely, medullary olivarchochlear-mediated efferents to the inner ear) when one ear was stimulated with distracting noise.

In addition to filtering out salient sound from background noise, autistic individuals may also have difficulty processing certain complex sounds. Research using auditory event related potentials (ERPs) reveals atypical neural responses to certain categories of complex sounds. Lepisto et al., [25] for instance, found atypical ERPs in response to sounds that change in both pitch and vowel formants, and Samson et al. [26] found abnormal ERPs for sounds containing spectral and temporal dips.

Imaging studies also provide insight into impaired auditory perception in autism. Morphometric imaging studies on individuals diagnosed with ASD reveal maldevelopment of the temporal lobes, a cortical area that contains the primary auditory cortex and other regions thought to subserve auditory processing [27]. Diffusion Tensor Imaging, a technique used to measure white matter connectivity between different brain regions, has also been used in ASD studies. Findings from these studies revealed reduced white matter connectivity between the posterior corpus callosum and regions in the auditory cortex [28].

A PET study by Boddaert et al. [29] showed reduced activation in left temporal regions during processing of complex speech sounds, and an fMRI study by Gomot et al. [16] revealed atypical processing of unexpected auditory stimuli. Taken together, these imaging studies, and the previously discussed ERP studies, suggest a variety of auditory processing abnormalities in autism.

1.1.3 Conflicting Patterns

In general, one can only begin to understand auditory processing in ASD by recognizing its complexity and its paradoxical properties. In some situations, individuals with ASD show remarkably enhanced abilities to process sound. And yet, in other situations, extreme hearing deficits are common. Further, autistic individuals may shift between being hyper- or hypo-responsive to certain sounds. Sometimes, these patterns seem to depend less on the sound itself and more on the context in which the sound occurs. Hans Asperger observed this phenomenon over sixty years ago and noted that, in ASD:

> "There is hypersensitivity too against noise. Yet the same children who are distinctly hypersensitive to noise in particular situations, in other situations may appear to be hyposensitive. They may appear to be switched off even to loud noises." [30]

These contradictory patterns are confounded further by the fact that ASD, by definition, is a spectrum-based disorder and every autistic individual may therefore present his/her own unique constellation of auditory processing abilities and deficits.

Abnormal auditory processing may not cause auditory sensitivity, per se, but it seems likely that these two conditions are related. Heightened perception of sound could no doubt be painful in certain acoustic environments, while deficits in hearing, especially with regard to filtering out background noise, could also create discomfort. More research should be done to further elucidate the relationship between auditory processing and auditory sensitivity. Also, an enhanced understanding of these relationships could inspire new technologies to help manage sound sensitivity in autism.

1.2. Current Interventions for Auditory Sensitivity

1.2.1 Sound Isolators

Unfortunately, auditory sensitivity in ASD is often improperly managed or it is ignored entirely. The most common intervention is simple sound isolation, and it usually involves fitting an individual with bulky, industrial-sized ear muffs (see fig 1). This technique, while crude, has some important short-term benefits. Incoming sounds are reduced to very low decibel levels, creating a buffer between the individual and the sounds s/he finds threatening or painful. For serious conditions that need immediate intervention, this approach is the best alternative available. Yet, over time, it can pose significant problems.

Figure 1 – "Outdoor kids" ear muffs, such as the ones shown here, are frequently used to manage sound sensitivities in ASD.

For instance, there is evidence that habitual use of these devices may actually exacerbate sound sensitivities over time[31]. If the ears are not appropriately challenged, and are instead routinely shielded from challenging environmental sounds, sensitivity thresholds might go down. Also, these sound-isolators have fairly nonspecific, broadband sound-attenuating characteristics (see fig 2). As a result, they tend to muffle many kinds of sounds, across a wide continuum of frequencies. Bothersome, environmental sounds are attenuated, but so are important speech sounds. This presents a barrier to linguistic communication, and can engender social isolation.

1.2.2 Auditory Integration Therapies

Sound-isolators merely manage auditory sensitivity, and they make no attempts to treat the underlying condition. In an effort to completely cure auditory sensitivities, some individuals undergo a treatment called Auditory Integration Therapy (AIT). Typical AIT treatments involve multiple half hour sessions, in which patients are exposed to customized, frequency-filtered music [32]. According to practitioners of this therapy, the

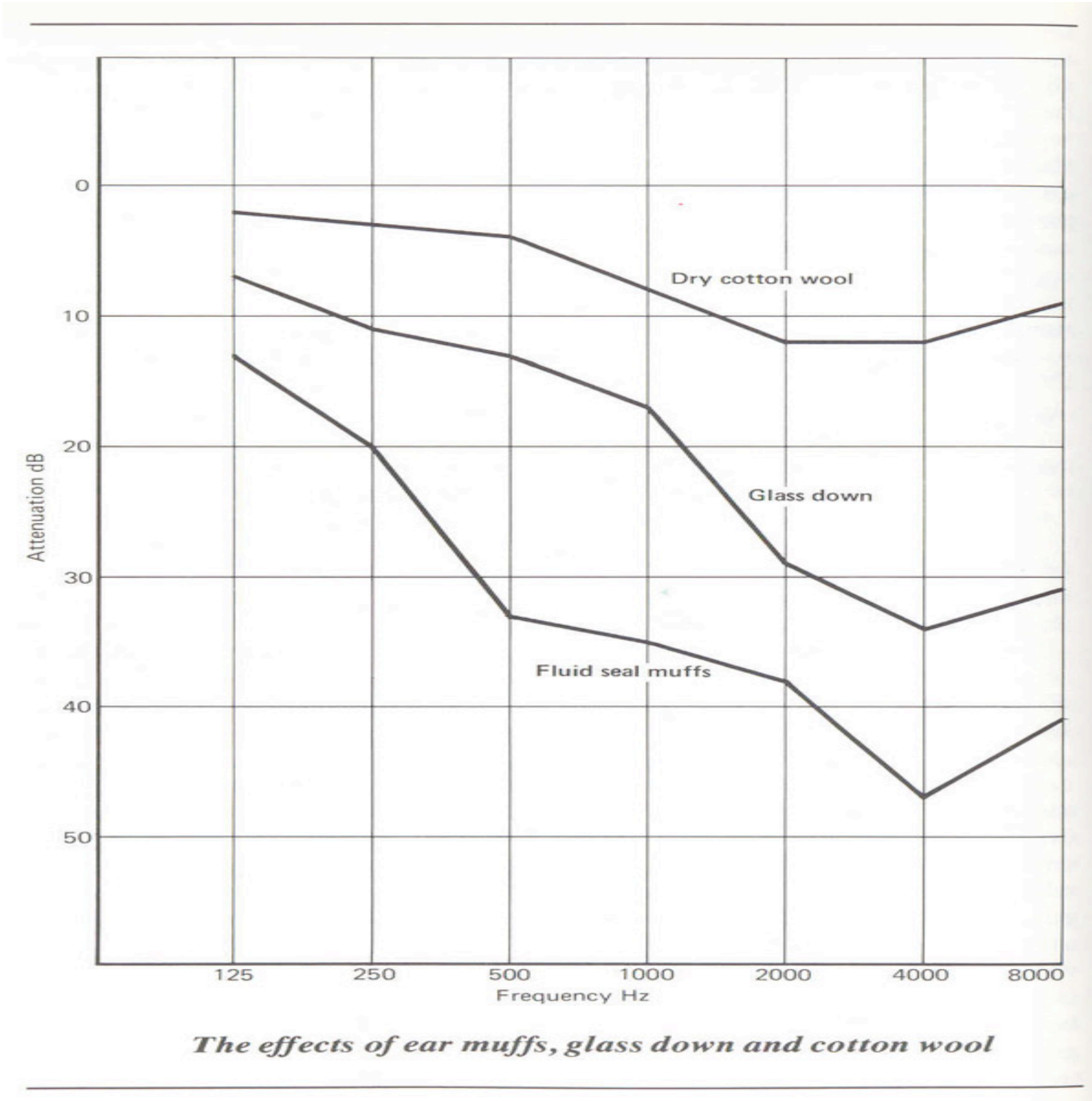

Fig 2. *Frequency response of various sound canceling materials, including a brand of fluid seal ear muffs. Graph courtesy of http://www.decimin.com/Technical%20Information.html.*

music is specifically designed to re-train the ears, causing an individual to lose sound sensitivities after multiple treatment sessions. Unfortunately, the therapy lacks a clear theoretical basis, and its therapeutic efficacy is questionable. Despite enthusiasm from its many impassioned supporters, AIT methods (and the related Tomatis approach), have not yet stood up to critical, independent peer-review [32-34].

1.2.3 Exposure Therapy

For individuals with specific sound sensitivities, exposure therapy may be a useful intervention. The technique has many variants, but the general principle involves gradually re-introducing an offending stimulus at progressively closer ranges until habituation occurs.

Recently, Koegel and colleagues [5] used exposure therapy to treat sound sensitivities in several children diagnosed with autism. As is commonly reported in ASD, the children in this study had problems with certain, specific types of sounds. One child, for instance, could not stand to hear blenders or vacuums, while another child was extremely averse to the sounds of certain electronic toys.

For each child, a typical exemplar of the problematic sound was chosen and used throughout the intervention. Over the course of several weeks, this target sound was gradually brought closer and closer to the child. Independent raters evaluated the children's responses to the sounds at each step and determined whether the child appeared comfortable. The sound was moved closer if the child showed sustained comfort during two to four consecutive 3-minute intervals. Eventually, the sound source did not disturb the child, even when it was placed in the same room and turned on at a normal volume. This comfort level was maintained at follow-up for all children, and for two of the children, exposure to the single target sound generalized to other, similar types of sounds.

The results are intriguing and the authors suggest that these children may have suffered from phonophobia – an intense, persistent fear of specific sounds. Exposure therapy is designed to treat fear and anxiety, not pain, and the fact that the children responded as well as they did suggests that their sound sensitivities could have been phobic in nature.[2] Furthermore, it is interesting to note that, compared to neurotypicals, individuals diagnosed with ASD may be more likely to develop phobias [35]. Based on results for a multisite study, Baron et al. estimate that about one-third of children with ASD meet the DSM-IV criteria for specific phobias [36]. Given this possible baseline prevalence for specific phobias, and given the results from the Koegel et al. study, it seems that some auditory sensitivities in ASD could be phobic in nature and may therefore be treatable with exposure-based protocols. Unfortunately, the procedure described by Koegel et al. was lengthy (14-24 weeks) and required clinician or researcher oversight. Many parents or caregivers of autistic individuals do not have the time or the financial means to pursue this kind of intervention. Computer-assisted exposure therapy may offer yet another a solution, and this approach will be the focus of this thesis.

1.3 Computer-assisted Exposure Therapy

With clinician guidance, exposure therapy is a remarkably efficacious treatment for individuals with specific phobias. *In vivo* exposure methods, which use direct (as opposed to imagined) confrontation of the feared stimulus, can generate long-term treatment gains in up to 90% of patients [37-39]. Positive therapeutic outcomes can be achieved even in the absence of direct clinician oversight. Computer-delivered exposure treatments have already been used for many types of phobias, and promising results have been achieved [37]. These methods typically involve an automated delivery of exposure hierarchies

[2] It is important to note, however, that phobias often originate from genuinely painful experiences. Extremely painful experiences with sound, such as those described by Temple Grandin (see pg 14), could understandably lead to phobic conditions.

based on patient feedback. For example, Coldwell et al [40] used a computerized system to automate exposure methods for individuals with dental injection phobias. To prepare individuals for the dental injections, the system automatically presented video clips of others receiving dental injections. It also systematically selected scripts for the dental hygienist to follow while working with the patient.

Sometimes, however, it may be difficult to adequately represent the feared stimulus in a clinic or in a movie clip. For instance, acrophobia (fear of heights) is not particularly amenable to traditional clinic-based exposure treatments. Videos of heights or still images of cliffs are sometimes not sufficiently evocative for the patient, and the clinician may not be able or willing to find a high stairwell, elevator, or roof to take the patient. Some investigators have used virtual reality to counter this problem. For instance, Rothbaum et al. [41] have used virtual reality to create simulations of high bridges and precipices, and the approach has helped acrophobics gradually get used to the sensation of being in elevated heights. Virtual reality has also been used to treat agoraphobia, fear of flying, and PTSD, and many studies show that the approach can be at least as effective as more traditional, clinician-delivered exposure methods [42-44].

To date, no research has been done to see if auditory sensitivity can be treated with computer-assisted, exposure-based approaches. Yet, when one considers the gamut of specific phobias, phonophobia might be one of the best candidates for computer-assisted exposure therapy. For acrophobia or fear of flying, a complex virtual world must be created to represent the feared situation. On the contrary, if the auditory sensitivity involves fear of the sound itself, and not something specific to the visual attributes of the sound source or the context in which it occurs, then computer-assisted approaches could be fairly easy to develop; visuals of the sound source might not be necessary and, instead, work could be focused on finding the most appropriate audio files. Of course, a sound played through headphones or external speakers will never sound exactly the same as it is heard in real life. But, successful exposure therapy treatments do not necessarily require perfectly realistic training stimuli. Most of the therapy is conducted while the feared stimulus is at a distance and, in fact, a close-range, extremely realistic version of the stimulus should not be presented until the therapy is complete. One form of exposure therapy, termed “imaginal therapy,” is based on creating increasingly vivid encounters with the feared item or situation in one’s mind’s eye; a physical replica or approximation of the stimulus is never used, and yet success rates are still fairly high [37,45]. Therefore, it stands to reason that auditory desensitization could occur even in the absence of perfectly realistic audio-playback. For these reasons, computer-assisted, exposure-based treatments for phonophobia may be effective, easy to construct and inexpensive to distribute.

2. The Proposed Intervention

This thesis presents a new technological intervention for individuals with hypersensitivity to sound and ASD. The intervention incorporates techniques from exposure therapy, and it uses new computer technology to automate and augment this approach. Currently, the intervention is targeted for individuals with sensitivities to specific sounds, as opposed to individuals with problems simply related to loudness, sudden noises, or acoustically crowded environments.

In the proposed framework, free customizable software called "Scratch" is used to help individuals gradually get used to sounds they might ordinarily find frightening or bothersome. Simple video games or visualizations are created to engage the patient whilst simultaneously introducing problem sounds in a gradual, hierarchical fashion. Before this framework is described in more detail, it will be useful to first educate the readers about Scratch and how it can be used.

2.1 Scratch

Scratch is a media-rich programming environment developed by the Lifelong Kindergarten group at the MIT Media Lab (see http://scratch.mit.edu/). It was conceived as a way to introduce programming skills and technological fluency to young children. Instead of writing code from a command line or an external text file, Scratch commands are constructed using a building block metaphor. Lines of code are built by combining various blocks together, and different commands and data types are positioned so that they can only fit together in syntactically-correct formats (see fig 3).

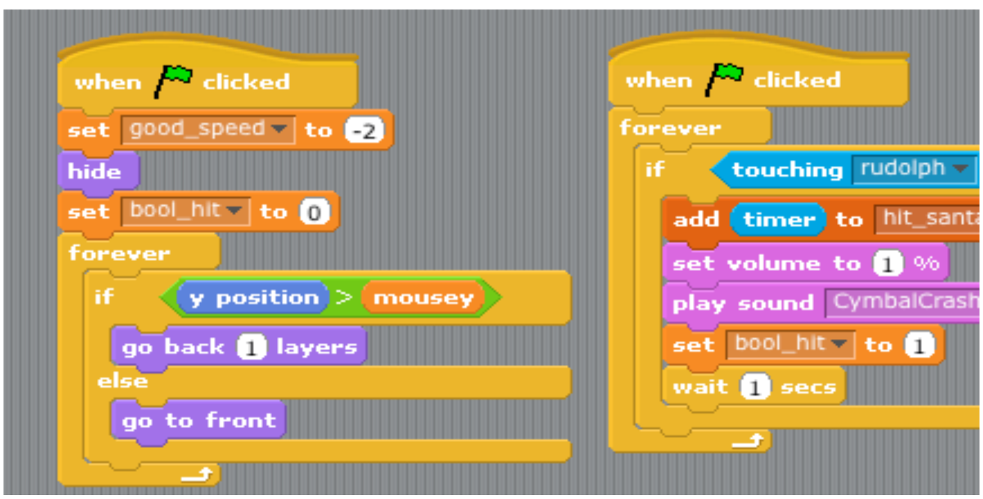

Fig 3. *A screenshot of the Scratch programming blocks.*

Thus, syntax errors do not plague the beginning user, allowing users to quickly generate programs that run effectively.

In addition to its ease of use, Scratch is also noteworthy for its ability to integrate and manipulate media content, including sound files and picture files. Users can easily incorporate pictures and sounds into their projects, making it very easy to create customized video games, animations, or puzzles.

Scratch also supports the idea of “deep shareability” [46]. This term, coined by Scratch designers, refers to the software’s ability to be shared, exported, and re-designed across many different types of devices (including desktops, laptops, and various handheld devices). Whenever a Scratch project is created, it can easily be uploaded to the Scratch website, where it can then be viewed by anyone. The programming scripts and media content from any project are downloadable, making it extremely simple for anyone to build new projects based on work that has already been done. Scratch’s ease of use, its customizable content, and its “deep shareability” were all designed to help engage young kids who might not ordinarily take interest in a programming language. Yet, these features may also be relevant to other domains that were not initially considered by the Scratch developers. This thesis, for example, describes how Scratch’s unique features may be applied to auditory desensitization interventions for individuals with ASD.

2.2 Overarching Framework

The proposed intervention draws heavily on the Scratch programming environment, and it follows the algorithm depicted in figure 4. Specific details of this approach are discussed at length in the case studies, and this section will provide a basic overview.

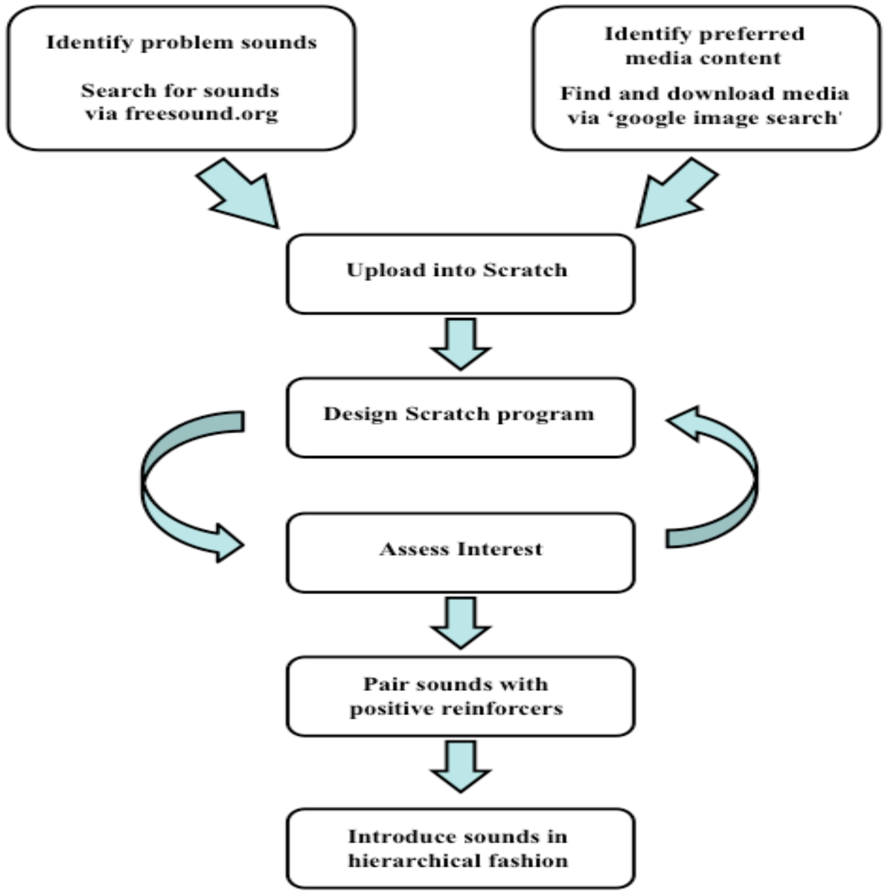

Fig 4. *An algorithmic depiction of the proposed intervention*

First, specific target sounds are collected from the web and are uploaded into Scratch. A Scratch project is created that focuses on the unique abilities and interests of the individual. The program should be engaging enough to hold an individual's interest over repeated uses; it cannot just be temporarily intriguing, and then get boring or tiresome after one or two sessions. After an appropriate project is designed (be it a simple visualization, or a more complex, skill-driven game), problem sounds are incorporated as sound effects.

When incorporating problem sounds into the Scratch environment, careful consideration is given to the volume of the sounds. The proposed intervention follows a changing criterion design (see [47]), and the volume is raised in a step-wise fashion; exposure increases are not made dynamically within sessions, and are instead adjusted prior to the start of any given session. The duration of the sounds is fixed throughout the intervention and does not increase gradually. This decision is motivated primarily by the fact that most of the freely available sound files are not terribly long in length and are therefore not amenable to gradual adjustments in duration. In the future, work should be done to examine the effect of increasing exposure in the form of increased duration, as well as increased sound pressure levels.

Careful attention is paid to make sure the individual is comfortable with each volume increase. If the individual willingly plays the game and appears at ease with the current sound level, the volume is gradually increased in the next session. If the individual appears stressed or uncomfortable with the sound level, the volume is decreased to the level that was tolerated previously. In the intervention's current manifestation, only the volume of the sound is changed. Other acoustic parameters, such as sound duration or timbre, are not systematically altered.

2.3 Specific Aims

In addition to its overarching therapeutic goal – that is, reducing auditory sensitivity in individuals diagnosed with ASD -, the proposed intervention is also built to meet the following specific aims: (1) it should be useful for most any individual on the autistic spectrum, regardless of cognitive, verbal, or motor abilities; (2) it should be intrinsically engaging, inducing patients to willingly participate in the therapy; (3) it should be inexpensive to use; and (4) it should be humane and should not introduce any unwanted stress or side effects. The following sections describe these aims in greater detail and elucidate the manner in which they can be achieved. The sections that follow also describe how these aims combine to strengthen the therapeutic potential of the intervention as a whole.

2.3.1 Serving the Whole Spectrum

As mentioned before, autism is, by definition, a spectrum-based disorder. Each individual with ASD has his/her own unique pattern of abilities and deficits and it is very difficult to make any generalizations about this population. When treating individuals with auditory sensitivity, it is therefore useful to consider approaches that can work with many different kinds of individuals. For this reason, an exposure-based approach is especially useful. Exposure therapy can be tried with almost any individual, regardless of age, verbal ability, or comorbid diagnosis, and studies suggest that it can be used successfully with many different individuals on the autism spectrum [48,49].

Also, Scratch can be easily adapted to suit many different ability levels. Individuals without verbal abilities and with motor control difficulties can still use Scratch and find it engaging. Many different kinds of projects can be made in Scratch, and the online web repository has numerous examples. Scratch users have made complex games of skill that require lightning fast reflexes, but they have also created interesting event-driven games that proceed at the player's own pace. There are also many different Scratch projects that do not follow a game trajectory, per se, and would instead be most aptly described as an animation or a visualization. What's more, since Scratch files are posted online, it's fairly easy to find an already existing Scratch file and re-design it to suit any particular individual's skill set (see http://scratch.mit.edu/tags/view/remix). Many computer interventions in autism are not useful for individuals at the low-functioning level. With Scratch, it should be possible to engage many types of individuals, even those that are typically ill-suited for most computer-based interventions.

2.3.2 Engaging

Although exposure-based therapies are often explicitly designed to be low-stress interventions, they are rarely designed to be intentionally fun or engaging. Oftentimes, therapists will use rewards or incentives to motivate patients to move farther up in an exposure hierarchy, but the process is rarely designed to be fun. In the proposed intervention, exposure to the target sound is couched within an entertaining context. Ideally, individuals will be intrinsically motivated to play with the "Scratch" project, and this motivation will help them gradually increase their comfort levels with the target sound.

Of course, it would be nearly impossible to conceive of a single game, or even a suite of games, that could possibly appeal to any person, regardless of whether they have a diagnosis of ASD. As such, the customization features within "Scratch" are extremely important tools. Many different games or visualizations can be created, and these can be customized to appeal to any given individual's specific interest.

Individuals with ASD often have restricted and idiosyncratic interests. With Scratch, any image of any object or situation can be imported into a game or visualization. This feature can help personalize the project and provide further incentive for engagement. When an individual is interacting with their interest of choice, they may feel more relaxed and therefore more willing to expose themselves to challenging sounds.

2.3.3 Inexpensive

With the exception of a computer, all of the tools involved in the proposed intervention can be acquired at no cost. No external hardware is needed, and all the recommended software is open source. Indeed, one of the best features of Scratch is its price - as of this writing, it is entirely free to run, download, and modify.

To run the intervention properly, specific audio files must be uploaded into Scratch. In order for the desensitization process to generalize outside the Scratch environment, convincing audio files must be used. However, one no longer needs to access expensive sound effects libraries to find high quality audio samples of real-world sounds. Sites such as freesound.org, sound-effects-library.com, and wavecentral.com all have fairly extensive repositories of free sound effects. Recently, researchers compiled a list of free sound library databases that allow users to scour the web for free audio files (see [50]). Many of these sites also offer extensive search filters, allowing users to base their queries on description, channel number (i.e., stereo vs. mono), length, sampling rate (e.g., 44.1kHz, 48kHz), or file type (e.g., .wav or .mp3).

Also, any content that needs to be loaded into Scratch can be modified either within Scratch or with free image or sound editing software. For audio, Audacity is a powerful free tool that allows users to edit an audio file's length and apply many different DSP tools (such as EQ, normalization, and compression). Recently, Gimp has emerged as a free alternative to Photoshop, and it is a great free tool to process images for use in Scratch.

2.3.4 Humane

Exposure therapy is remarkably efficacious, and it is also considerably humane. Unless intense, massed exposures are employed (a technique sometimes referred to as 'flooding'), the treatment follows a gradual pace, prompting minimal fear or anxiety. In fact, typical approaches ensure that an offending stimulus is removed or moved back if it causes anxiety for the patient. Perhaps the core tenet of exposure therapy is the idea that patients need to experience the target stimulus in a relaxed state, *without* anxiety. While some techniques actively encourage deep-breathing and relaxation techniques (systematic desensitization, for example) to achieve this state, most forms of exposure therapy simply do not allow an individual to progress unless s/he is sufficiently calm.

Individuals with ASD often have chronic stress conditions, and it is important to consider interventions that do not exacerbate already elevated stress levels. All too often, clinical interventions give as they take; that is, as something gets cured, a new problem is simultaneously introduced. This is especially true with psychopharmacological treatments that introduce side effects which must then be treated with additional drugs which may introduce yet additional problems. The proposed intervention does not require adjunct psychopharmacological treatment and it is unlikely to introduce any significant new stressors or other psychological problems.

2.4 Methods of Evaluation

The proposed intervention was explored with three case studies and one laboratory study. The laboratory study was conducted with neurotypical participants and was used to investigate how problem sounds should be embedded within Scratch. The case studies examined the entire protocol of the proposed intervention and were done with three individuals diagnosed with ASD. All case study participants had limited verbal abilities, were unable to live independently, and were over 18 years of age.

3. Uncomfortable Loudness Level Study

Incorporating target sounds into a Scratch program would be trivial if the sounds were simply played at random. However, random exposures in the program might be distracting and counter-productive. It may be more effective to couple the offending sounds to positive elements in the Scratch program, such that gradual habituation is paired with positive reinforcement. For example, consider a Scratch program that involves a simple racing game. If the goal is to win the race, the game could play offending sounds whenever the player presses the accelerator. In this way, achievement in the game would be linked to exposure to the sound. Ideally, players would be motivated to expose themselves to the sound. A primary goal would therefore be to include intrinsic rewards within the game that encourage individuals to expose themselves to the sound. With a video game or a visualization, there are a variety of ways to provide positive reinforcement, such as score keeping, playing pleasant sounds, or animating interesting graphical sequences (see Appendix B for more examples).

Pairing the unpleasant sounds with pleasant images or animations relates, in some ways, to tactics employed in systematic desensitization – a type of exposure therapy that, as described earlier, combines progressive exposure with relaxation strategies. As part of systematic desensitization therapy, therapists try to help patients remove their negative associations with a feared stimulus. To do this, they encourage patients to breathe deeply and think of happy situations when the target stimulus is encountered. A well-engineered game could help make these associations explicit by directly pairing the feared stimulus with naturally rewarding and happy elements of the program.

It would be interesting to know whether there is truly value in directly pairing aversive sounds with rewarding elements of a media experience. Unfortunately, a direct examination of this idea with a large cohort of autistic individuals is beyond the scope of this thesis. However, elements of this hypothesis were investigated using a small cohort (n = 16) of neurotypical, non-phobic individuals. In the study, responses to aversive sounds were examined before and after a short session with a video game. In the game, an aversive sound was either: (a) paired directly with a rewarding element in the game-play (a condition hereafter referred to as 'paired') or (b) played at random intervals during the game (a condition hereafter referred to as 'randomized').

For this experiment, we hypothesized that individuals in the paired condition would show greater habituation to the aversive sound than individuals in the random condition. In addition, this study was done as a pilot to explore a modified version of the uncomfortable loudness level (UCL) test – a behavioral method used to evaluate tolerance to sound.

3.1 Method

3.1.1 Participants

Nine women and eleven men (aged 18-30) from the MIT community participated in exchange for a $10 gift certificate. They were told they would be rating some sounds and playing video games, but a connection between these tasks was never alluded to or mentioned (the recruitment flyer used in this study is included in Appendix A). Participants gave informed consent according to the guidelines of the MIT Committee on the Use of Humans as Experimental Subjects. Participants were excluded if they did not complete the study, or if they reached the highest threshold for every sound on an initial auditory threshold test. Two participants were also excluded from the final analyses because they were affiliated with our research lab group and they indicated that they were non-naïve to the experimental hypothesis. With these individuals excluded, the total cohort included 16 participants (7 women and 9 men).

3.1.2 Materials

Six 16-bit, stereo audio files were chosen from Soundjay.com's online archive of free sounds. Using Audacity software, sounds were edited to be exactly 5 seconds long, and each clip was normalized to remove DC offset and to set the maximum gain to -3dB. All the clips were continuous waveforms, with no pauses or breaks. Pro Tools LE software was used to perform a 1ms linear amplitude fade at the start and end of each clip. This was done to eliminate possible discontinuities in the waveform when the sounds were looped together.

To prevent hearing damage, and to conform to the guidelines suggested by OSHA (Occupational Safety and Health Administration), the maximum volume of the sounds in the headphones never exceeded 80dB. Sound level measurements were taken using a Radio Shack digital sound level meter, such that the microphone was placed directly inside the earcups of a pair of Bose Noise Cancelling headphones. A C-weighted filter was used to approximate the Fletcher-Munson equal-loudness contours perceived in human audition.

The sound clips featured real-world sounds, and they ranged from being fairly innocuous (e.g., people talking at normal volumes, or the sound of kids playing) to sounds that are generally thought to be aversive (e.g., an electric drill, an alarm clock, and an aerosol can). The data collected in the experiment confirmed these categorizations; the drill, the aerosol can, and the electric drill received the lowest average UCL ratings, while the human sounds were rated more favorably. The sound of a handsaw fell somewhere in between. Creating a uniform distribution of pleasant and unpleasant sounds was not integral to this experiment, however. But, to eliminate fatigue, care was taken to ensure that the sounds varied in pleasantness somewhat, so that participants wouldn't only be exposed to bothersome sounds throughout the experiment.

When entering the lab, participants were told they would participate in an auditory study, and that their data would be used to develop new treatments for ASD. They were also told the experiment had three phases: first, they would rate some sounds on a computer; second, they would take a break to play a short video game; and third, they would complete another round of sound ratings on the computer.

For each sound, participants were told to turn up a volume knob until the sound was "just at the point where it is no longer comfortable." This procedure is based on a UCL methodology developed by Hawkins et al. (for a review, see [51]). The approach has several variants, but the basic idea is often employed by audiologists to ensure that hearing aids, or other assisted-listening devices, do not amplify sounds beyond comfortable levels. This method was chosen as a model because we wanted to examine a behavioral method of sound appraisal that might work with individuals with ASD and sound sensitivity and who might be non-speaking and/or have limited use of language. The approach gives individuals full control over their exposure to the problem sound and, so long as the instructions are clear and understood, there is little risk of pain or anxiety. Participants were instructed to press the spacebar as soon as the volume reached a level that was no longer comfortable.

The experiment was done in a semi-soundproofed lab room, and the participants were instructed to wear Bose active noise-canceling headphones. To control the sound level, participants turned a potentiometer that was connected to an Arduino Diecimilla microcontroller (see fig 5).

The potentiometer had no markings, and participants were therefore unable to note exactly how far they turned the knob for each sound. There was also no visual feedback on the computer screen to indicate knob position or changes in volume. This helped restrict UCL judgments strictly to the auditory channel. It also prevented participants

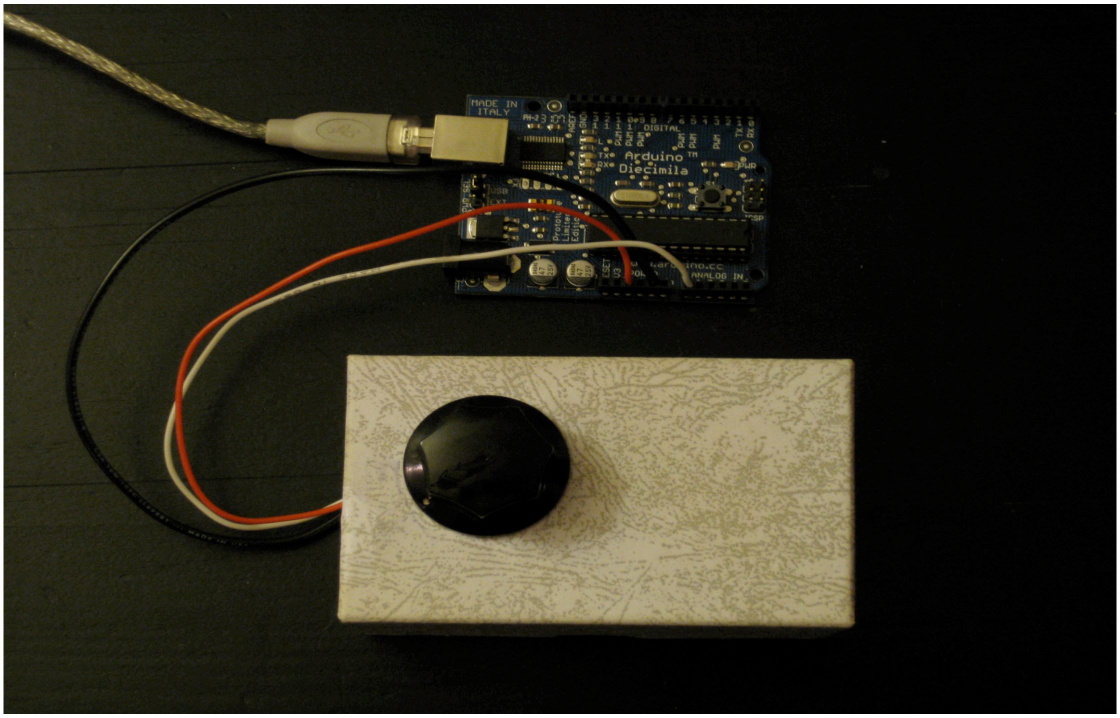

Fig 5. *A potentiometer and an Arduino Diecimilla microcontroller were used to record the UCL measurements.*

from assigning a specific level for each sound and then sticking to these levels merely for the sake of consistency. Also, the knob was chosen because we wanted to test an interface that might eventually be used in studies with autistic participants. For individuals with motor control issues – a common problem in ASD -, a knob interface may be easier to control than a mouse or a keyboard. The UCL level meter went from 0 to 160, and this distance corresponded to a range of 0- to 75-dB.

All experimental trials were controlled using Max/Msp – a graphical programming language developed by Miller Puckette and now distributed by Cycling '74. Using the Arduino controller, movements of the knob were set to control sound level volumes within the Max/Msp environment.

3.1.3 Phase I

In the first phase of the experiment, each sound was rated four times. All six sounds were presented in random order. After each sound was rated, there was an inter-trial interval of seven seconds. After 24 trials, each participant was given a 5-minute break. During this time, the experimenter saved the data and identified the sound that, on average, received the lowest UCL rating. This sound was selected as the target sound to be used in the second phase of the experiment.

3.1.4 Phase II

In the second phase, participants played a game called 'Santa Smash.' The game was designed using Scratch and Photoshop. In 'Santa Smash,' players use the mouse controller to move their character (an ice-skating Rudolph the Red-nosed Reindeer) around a lake of ice. The objective is to knock imposter Santas off the ice while avoiding any collisions with the real Santa Claus. Imposter Santas look just like the real Santa, except their hats are not colored red (see fig 6).

Before playing the game, participants were shown a quick demonstration and then, without their knowledge, they were randomly assigned to either the paired or the randomized condition. In the paired condition, the target sound was played for .5 seconds each time a participant successfully ran into an imposter Santa. For players in the paired condition, the game ended after 200 successful hits (or 200 exposures to the sound). Timing statistics were recorded for players in the paired condition, such that a log was made of when the target sound was played. Participants in the randomized condition

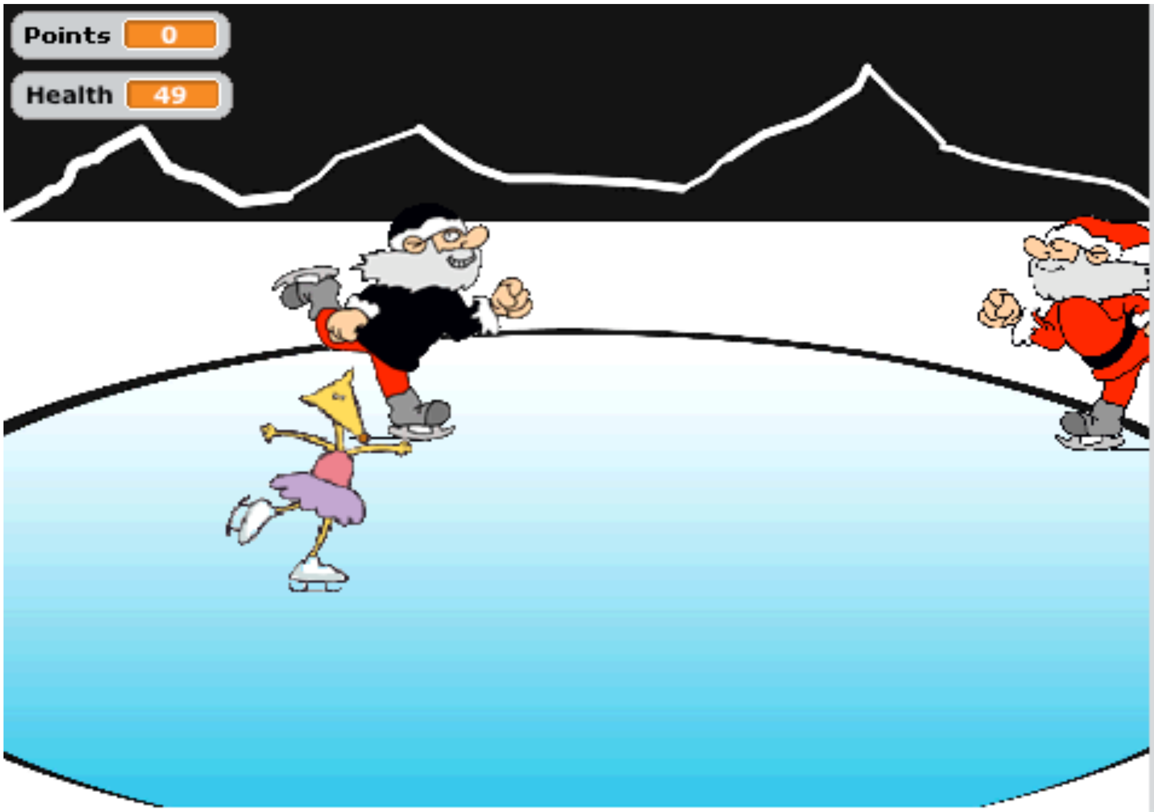

Fig 6. *A screenshot of the Santa Smash game. This image shows the main character successfully knocking into one of the imposter Santas.*

heard the target sound for .5 seconds each time as well, but the timing of this sound was not controlled by their actions in the game-play. Instead, the log from the most recent paired session was uploaded into the game and was used to orchestrate the playback of the target sound. Since the timing of hits in each game is highly variable from player to player, the soundtrack of one player's game would rarely, if ever, align with the actions and events in another player's game. An analysis was done to confirm the legitimacy of this method, and it showed that the target in the randomized condition never perfectly matched the players' actions.

Also, for players in the randomized group, the game did not necessarily end after 200 hits were recorded. Rather, it ended as soon as the log file finished playing the target sound. This was done to ensure that the target sound was heard the same number of times by all participants, regardless of whether they were assigned to the paired or randomized condition. The amount of exposures could have a significant effect on habituation, and it was therefore important to precisely control this variable. The average playing time for both groups was 8 minutes and 35 seconds.

3.1.5 Phase III

In phase three, the sound order was re-randomized, and players repeated the same task as in phase I. After completing their 2nd round of ratings, participants filled out a debriefing questionnaire. They reported their age, and they were asked to describe the purpose of the whole experiment. They were encouraged to guess if they were unsure.

3.2 Results

UCL measures were obtained for the target sound for each participant, both before and after the video game (see fig 7). A mixed model, two-way ANOVA was applied to the data, with time (pretest vs. posttest) as the within-subjects variable, and group (paired vs. randomized) as the between-subjects variable. In this, and all subsequent analyses, the alpha level was set to .05. The ANOVA revealed a main effect for time [$F(1, 14) = 5.772$, $p = .031$], but not for group [$F(1, 14) = 1.870$, $p = .193$]. The interaction effect between time and group approached significance [$F(1, 14) = 3.599$, $p = .079$], but did not reach an alpha value of .05.

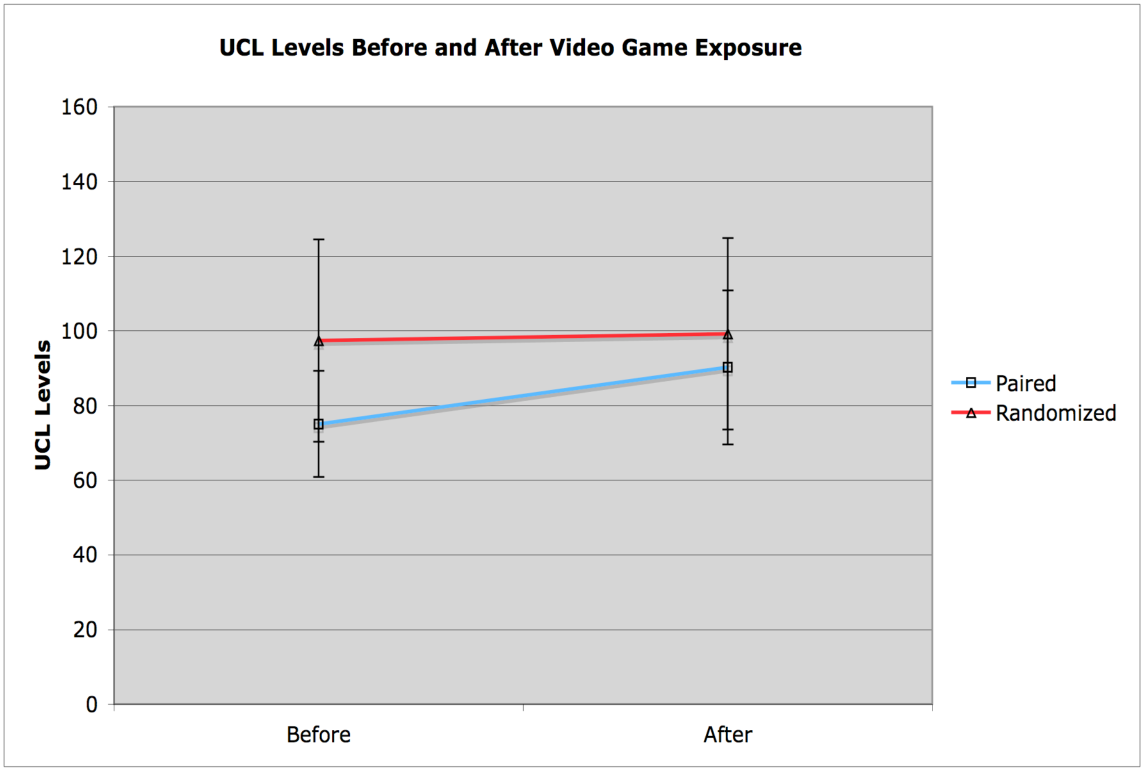

Fig 7. *A graph of mean UCLs from participants in both conditions. Greater UCL values indicate greater tolerance for the target sound. The scale on the y-axis is unit-less and reflects sound meter levels in the Max/Msp program.*

The group by time interaction was examined further using a simple main effects analysis. For individuals in the paired condition, there was a significant change in the UCL of the target sound [$F(1, 14) = 9.24$, $p = .009$]. In support of our hypothesis, the change was in the positive direction; that is, individuals in the paired condition showed higher UCLs after playing the video game. For individuals in the randomized condition, there was no significant difference between pre- and post-test UCL measures of the target sound [$F(1,14) = .13$, $p = .726$].

An examination of the target sound data showed that, while the electric drill was the target sound for six individuals in the paired condition, it was only used once in the randomized condition. In the randomized condition, by contrast, the aerosol sound predominated and was selected for five individuals (see fig 8).

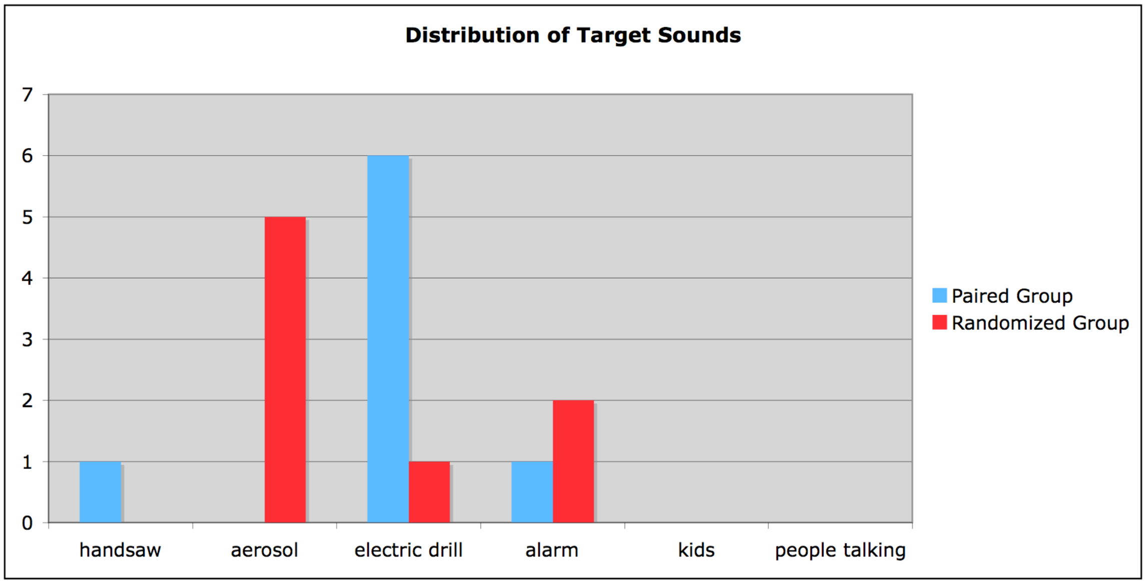

Fig 8. *The graph above shows the types of sounds selected for participants in both the paired and the randomized groups. The human sounds were never rated poorly in the UCL pre-tests and were therefore never included as target sounds.*

The pre-test phase was the same for every individual, regardless of their subsequent group assignment, and any differences in target sounds between the two groups must have reflected the natural variability of the individuals in the experimental cohort. The pre-test mean of the paired group ($M = 75.03$) was lower than that of the randomized group ($M = 97.41$), and a two-tailed, unpaired t-test [$t(14) = 1.93$, $p > .07$) showed that the difference approached, but did not attain, significance.

3.3 Conclusions

The simple effects analysis confirmed our hypothesis and showed that UCL levels of the target sound increased for individuals in the paired condition, but not for individuals in the randomized condition. The experiment also showed that the target sounds were unequally distributed between the groups, with the electric drill predominating in the paired group and the aerosol can predominating in the randomized group. With a higher sample of experimental participants, this difference should diminish. However, in the context of this experiment, these differences should be taken into consideration when making conclusions about the data. For instance, it could be that habituation depends more on the type of the target sound than on the method of delivery. For instance, the drill sound may be more amenable to habituation than the other sounds. If this sound predominated in both groups, both the paired and randomized participants may have shown increased UCLs. With greater numbers of subjects, the type of target sound could be used as covariate in the analysis and its influence can be properly assessed. Alternatively, the experiment could be re-run, such that individuals in both groups are given the same target sound. Even though the distribution of the electric drill sound and the aerosol sound was not even across the two groups, the raw data showed that both groups tended to dislike both sounds. Therefore, in future studies, one of these sounds could be chosen as the sole target to be used for both the paired and randomized groups.

Overall, this experiment suggests that tolerance to aversive sounds can change when these sounds are embedded within a video game. The data also lends some support to the notion that these sounds should not be introduced randomly, but should instead be aligned with positive elements of the game-play.

4. CASE STUDY 1: JH

4.1 Background

JH is a 26-yr old male with a longstanding diagnosis of ASD. He was administered the CARS (Childhood Autism Rating Scale) in 1993 and received a score of 40, placing him in the "severely autistic" range. When the test was re-administered in 1997, his diagnosis was updated to "moderately autistic." JH's score on the Stanford-Binet Intelligence Scale places him in the "mentally retarded" classification of intellectual functioning. JH does not live independently and has limited verbal abilities. He is skilled in areas of visual perception and enjoys making arts and crafts (especially beaded jewelry). JH has sensitive hearing and can become irritated if an environment is too noisy.

Coughing sounds have been a consistent problem for JH. When he hears a cough, he can become upset, frustrated, and anxious. Although JH does not have significant verbal abilities, he can clearly express his displeasure. When he hears a cough, he might cover his ears and leave the room. He may also make nonverbal utterances or screams that reflect a distressed state. In extreme situations, coughing sounds may prompt a full-blown meltdown. According to his family, JH has had significant problems with coughing sounds for at least the past ten years. JH also expresses anxiety by repeating a mantra of three phrases: “nice and easy,” “relax,” and “that’s alright.” When anxious, he will often say each of these phrases and wait for another person to consolingly repeat them after him. In times of severe stress, JH may repeat these phrases *ad nauseum* for several hours. JH’s family has observed all these behaviors to occur in response to coughing sounds.

It is interesting to consider the human coughing sound more deeply. Coughing is characterized by two phases: first, the expiratory muscles contract against a closed glottis. Then, after a significant build-up in pressure, the glottis opens suddenly, causing a fast and violent expiration [52]. The human cough comes in many varieties; some are loose, some are dry, some are followed by long expiratory wheezes, while others are short and staccato. There are noticeable differences in the acoustic and dynamic properties of coughing, depending on the how it originates. Different disease states (e.g., ashma, acute and chronic bronchitis, or tracheobronchial collapse syndrome) are associated with different acoustic profiles, both in terms of the overall spectral energy and the number of expiratory phases [53]. Experimentally-induced coughs in healthy subjects also show considerable variety between individuals. A study by Doherty et al showed that these individual differences persisted within and between days, suggesting a unique cough signature pattern for each person [54].

Unfortunately, it is hard to know whether JH has issues with some types of cough, but not others. According to his family, practically any coughing style could pose a problem. However, they have observed that loud and chronic coughs affect JH the most. For instance, while JH responds negatively to most any cough heard in his household, he has the most difficulty with his father's loud coughing style. He also has difficulty when coughs continue, unabated, throughout the day, as when someone has an acute upper respiratory infection. His behavioral expressions of anxiety and irritation also increase dramatically with each additional cough heard. He will often reach a point where the mere hint of an impending cough can cause extreme anxiety. For example, he might plug his ears or scream even if someone just starts to cough, but stifles it immediately.

Interestingly, JH never seems to mind his own cough. Even if he has an extreme fit of coughing, he does not show any of the behavioral indications of anxiety or fear. Presumably, JH can feel a cough coming on, and the resulting sound is not surprising when it comes from him. Thus, the element of surprise may play a factor in JH's aversion to coughing sounds.

In the future, it would be extremely interesting to tease out these possibilities in a controlled, experimental setting. One could directly compare JH's response to different types of coughing. It would be interesting to know whether coughing sounds are problematic because of what they signify (that is, disease or the expulsion of sputum), how they sound (e.g., spectral or dynamic patterns), or some combination of the two. Experimentally manipulating the source of the cough or its spectral features could yield some answers. Also, controlling the timing of the cough sound could be interesting, to see whether coughs that come as a surprise are more troublesome than those that can be predicted.

4. 2 Materials and Procedure

Since we could not determine whether one class of coughing was particularly aversive to JH, several different exemplars were chosen as desensitization stimuli. Eight coughing sounds were chosen from the archives at www.freesound.org. The coughing sounds posted on www.freesound.org all vary in quality and length, but an effort was made to select realistic, high-quality sounds that were around 1-3 seconds on average. After the sounds were selected, they were imported into Audacity and were trimmed to be exactly 2.5 seconds in length. Next, they were normalized, such that the maximum amplitude for each sound file was set to -3dB. All sound files were therefore similar to each other in terms of length and absolute sound pressure level.

Sketches for the Scratch program were created based on discussions with JH's family members. Prior to this intervention, JH had never shown an interest in a computer, despite his family's numerous attempts to get him to engage with the technology. On multiple occasions, JH was given animated storybooks and other programs. But, even when these programs featured some of JH's favorite TV characters (such as Arthur or some of the Sesame Street characters), they never seemed to capture his attention.

JH has some issues with motor skills, and fast or complex keypresses on a computer may pose a challenge for him. Our first Scratch design was therefore created with two goals in mind: (1) to help inspire JH to take interest in a computer as a user-interface and

(2) to provide a project that could be controlled with simple and limited keypress commands.

According to his family, JH has an extreme fascination for babies. A simple baby slide-show was created in Scratch to appeal to this interest. 15 different baby pictures were taken from a Google image search and uploaded into Scratch. Pictures were selected on the basis of quality and relevance, but no strict inclusion criteria were imposed.

When the slideshow begins, one of the baby pictures is randomly selected to appear off to the right side of the screen. In three seconds, this picture glides to the center of the screen. Once centered, the picture slowly moves up and down and side to side in small, random trajectories. After 7 seconds, the picture slides off the screen to the right. The screen remains black until the spacebar is pressed, at which point a new picture slides into the screen and the cycle begins anew (for a screenshot, see fig 9).

A counter in the upper right corner records each time a new picture appears on the screen. Importantly, no sound files were incorporated in this preliminary Scratch program. It was important to first ascertain whether JH liked the program on its own, independently of its relation to the target sound.

4.3 Results

JH's mother downloaded and installed the Scratch software with no difficulty. The baby slideshow was sent to her over e-mail, and she successfully loaded it into Scratch.

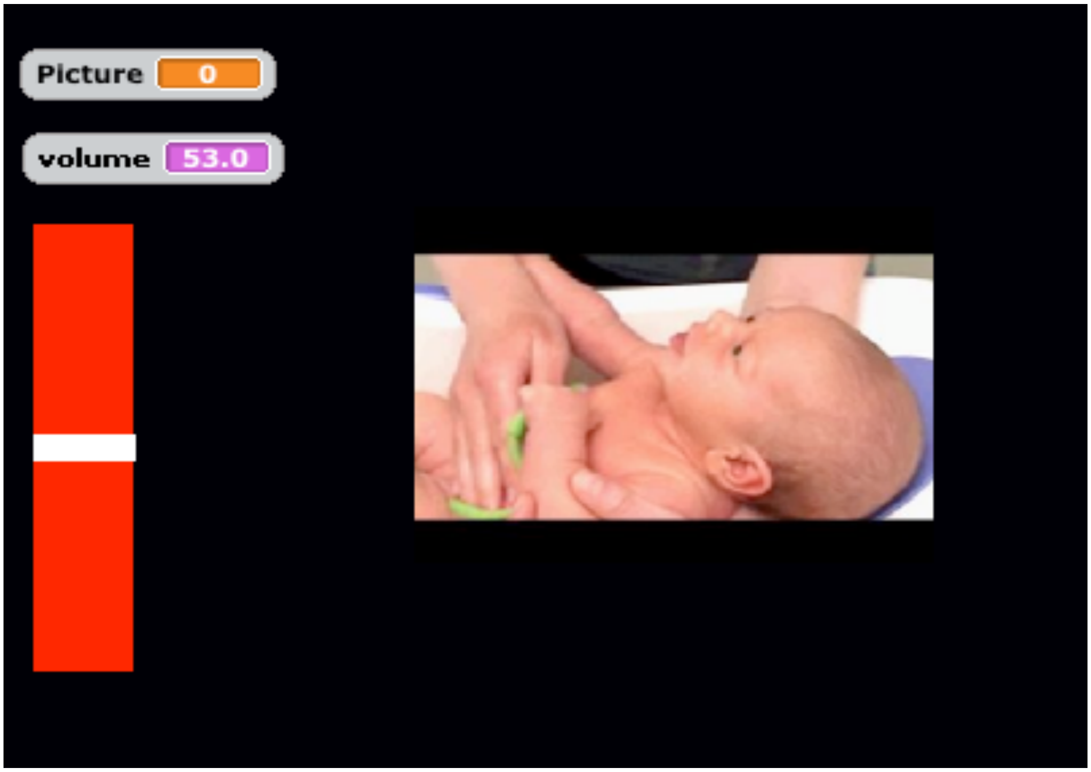

Fig 9. *A screenshot of the baby slideshow used in JH's intervention. The meter on the left controls the volume, and the picture counter keeps track of exposures. The sound controls were included on subsequent updates of the program and were not used during the initial phase of the experiment.*

While the program worked well on her computer, JH did not seem intrigued. JH's mother first suggested that the pictures be larger. This was a simple problem to solve and involved telling JH's mother how to switch from Scratch's normal view size to 'presentation' mode size. In presentation mode, the Scratch project fills the entire computer screen, not simply a small box somewhere in the middle of the monitor. When JH was shown the pictures of the babies in the full-screen mode, his interest seems to have been piqued. His mom noted that his "face lit up when he saw the first screen" and he moved close to the computer screen. Still, JH did not seem to want to watch many of the pictures and his interest faded quickly.

Given this response, JH's mother suggested using slightly more evocative stimuli. Upon reflection, she noted that, while JH enjoys babies, he might be most drawn to images that portray actual childbirth. JH is always especially excited and intrigued during birth scenes in TV hospital dramas such as ER. Accordingly, the Scratch project was re-designed to feature birth scenes as well as pictures of babies. Using the Google image search feature, different birth scenes were gathered and uploaded into Scratch. Most of the scenes involved pictures of a doctor holding a newborn, just as it emerges from the mother's womb.

JH saw this newly updated Scratch project, and immediately expressed interest. JH watched the first 4 pictures with his mother pressing the spacebar and then he began pressing the spacebar himself. He watched 50 pictures, at which point his mother asked if he was finished. He said 'yes', and the program was stopped. Since each picture appears on the screen for ten seconds, it would have taken JH a little over 8 minutes to view all 50 pictures if he pressed the spacebar immediately each time.

These results are noteworthy for several reasons. First, prior to seeing the 2nd Scratch project, JH had never shown much interest in the computer. It now seems that he is perfectly capable of interacting with the machine, provided it displays content that interests him. Also, these results attest to the value of customizing of Scratch projects. A slideshow of babies, while close to his domain of interest, may not be sufficient to engage his attention. JH's response to the slideshow was considerably different when the pictures included actual birth images. When comparing this project with the previous one, his mother observed the following:

He seems to be more interested in the shots of the babies with the nurse or birth/action shots vs. just the babies, but he seems to like them as well, he just seemed a little more attentive to the hospital shots.

His mother also noted that, of the baby images that weren't set in a hospital or a birth scene, JH seemed to prefer those that seemed "unhappy and not posed for a cutesy greeting card."

While JH seemed intrigued by the new Scratch project, we wanted to assess whether this interest could be maintained over time. In the next session, JH was given the same project and was again shown how to use the spacebar. He immediately took ownership of the computer and indicated that he wanted to look at the pictures by himself. He looked at pictures 76 times and then indicated that he was done.

In another session, JH looked at only 13 pictures and then quit. His parents suggested that the project should include more content. At this point, there were 11 different pictures, only four of which included hospital birth scenes. It was highly possible that JH was simply growing bored with the small number of pictures.

A new Scratch project was created to include new birth scenes. While it is fairly easy to find 5-7 birth scenes from a Google image search, the results quickly dwindle after this number. Still, a new project was made to include 15 pictures, 7 of which were birth scenes and 8 of which were new baby pictures. The new baby pictures were not artfully photographed or artificially posed as one might see in a greeting card. Instead, the new baby pictures showed neutral or unhappy expressions.

JH's parents also suggested creating a new Scratch project with family photos. In the past, JH has enjoyed looking at family photo albums. Accordingly, 15 family photos were uploaded into a new Scratch slideshow program. JH's sister created this new project in a few minutes, simply by re-mixing one of the already existing baby projects. With Scratch, exchanging different pictures is extremely simple, and merely involves deleting the old pictures and uploading new ones with a few mouse clicks. Scratch's user interface is designed to allow users to customize the content without having to write a single line of code.

Once several Scratch projects were customized for JH, the target sounds were incorporated into the programs. Each Scratch project was updated to include a sound control meter and a numerical indicator on the left side of the screen (see fig 9). When the spacebar is pressed and a baby picture appears onscreen, one of the coughing sounds begins playing immediately. The sound is chosen at random and, once it has been played, there is a short pause before the next clip is played. For each picture, three different coughing sounds are played, and there is a pause between each that lasts .5 seconds After the third sound plays, the audio is turned off until the baby picture disappears off the screen and the spacebar is pressed again.

Before starting the actual intervention, a test was run to make sure JH's family could control the sound coming out of the Scratch program. The family was told to check the sound controls when JH was not in the vicinity of the computer. This precaution was taken in case the controls were not working and the sound was played at full volume. If this happened, and JH was nearby, he might immediately associate this startling sound with Scratch or the computer and become averse to using it. JH's family opened the file and found the sound controls to be extremely easy and reliable.

JH's father was instructed to start the intervention and he was told to use the program that featured family photos. As per our instructions, the volume was set to the lowest point above zero, so that the sounds were just barely audible. JH looked at 4 family pictures and then said “no thank you,” indicating that he did not want to watch anymore. JH’s father switched to the baby program and set the volume to the same level that was used for the family photo program. When he saw the baby pictures, JH reportedly smiled and flapped his hands. He watched 14 pictures and controlled the presentation by pressing the spacebar himself.

In the next session, we told JH’s father to increase the volume slightly and closely monitor’s JH’s response. Perhaps mis-interpreting our instructions, JH’s father turned the volume up halfway, a significant increase from the previous level. Nonetheless, without any prompting, JH looked at 16 pictures on his own and controlled the spacebar himself; the high volume did not seem to bother him. In this session, JH heard the coughing sounds 52 times (4 times in the family photo program and 48 times in the baby program).

In the next session, the sound was turned up to ¾ of the total volume. JH watched 19 baby pictures on his own, and then watched 10 family photo pictures with the volume set to the same level. JH therefore heard the coughing sounds 87 times and the session lasted about five to ten minutes.

A week passed before JH’s family had time to do another session. Despite this break from the intervention, JH’s progress did not seem affected. In the next session, the sound was turned up to the maximum level and JH watched 15 pictures on his own.

The sound from the computer speakers was reportedly realistic enough to confuse JH’s mother and make her think that a stranger was coughing in the other room. However, clearly the sound coming out of the two PC speakers cannot be directly compared to the sound of a real person coughing. To determine the therapeutic potential

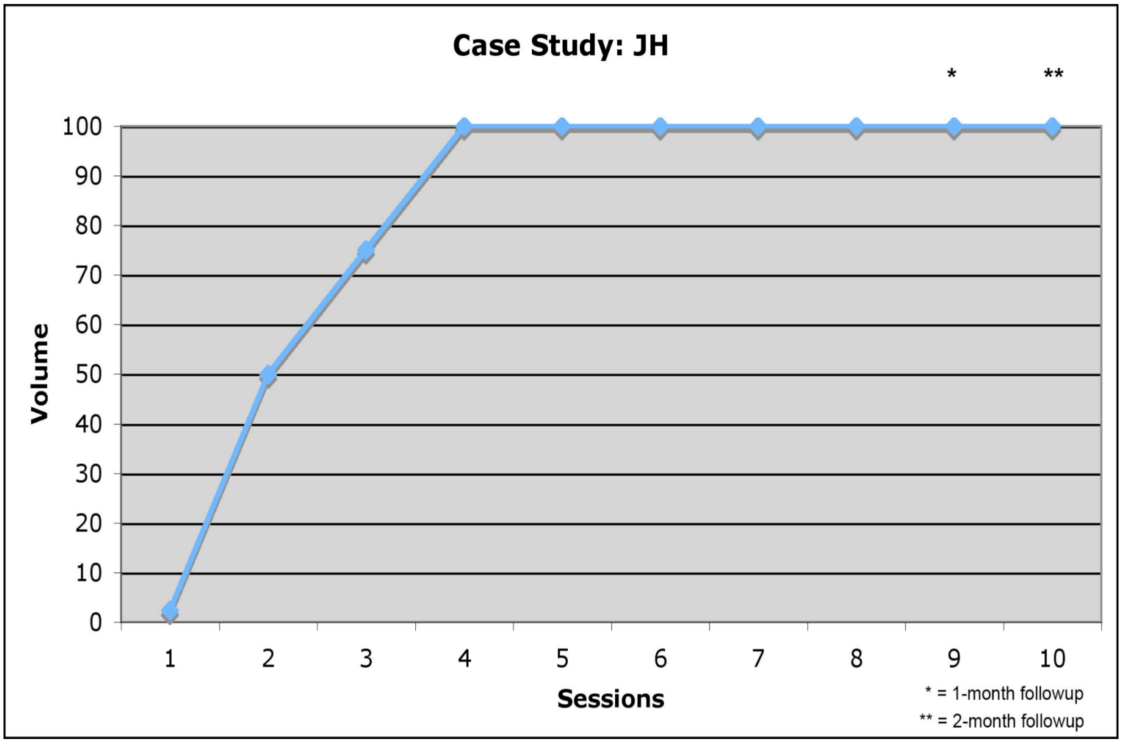

Fig 10. *A graph representing JH's progress throughout the intervention and during the 1- and 2-month follow-ups.*

of this intervention, JH's response to real coughing sounds must be observed. Thus, after the intervention, JH's parents were instructed to observe JH whenever someone could be heard coughing. Over the course of four days, JH's father purposely and accidentally coughed while in close proximity to JH. According to his father, JH reacted only once during this period and in general did not seem to react positively or negatively to the sound of his coughing. None of the coughing sounds included in the Scratch program were from JH's father. It is therefore possible that exposure to the exemplars in Scratch generalized to a new stimulus.

After these initial sessions, JH was not exposed to the program until a follow-up session was scheduled a month later. In this session, the target sound was exactly as loud as it was one month earlier. JH was reportedly unperturbed by the sound and happily proceeded with the program until he decided he wanted to stop. The next day, while his father worked on his laptop, JH said, “babies” and indicated that he wanted to start the Scratch program. This is an excellent result, given that, prior to the intervention, JH would not interact with a computer even when his parents prompted him to do so. Also, even after a month of not doing the program, JH’s father continued to notice a drastic improvement in his son’s response to coughing sounds. He wrote, “I would estimate that [JH] is reacting to less than 10% of coughs he has heard vs. close to 100% prior to your program.”

A second follow-up was done one month later, and the same results were achieved; JH did not seem bothered by the sound and seemed quite happy to interact with the program. Also, JH’s father continued to notice a significant improvement in his son’s response to coughing sounds.

4.4 Conclusion

The data collected from this study, while encouraging, are by no means definitive. Even though JH has had problems with coughing for most of his life, he has reportedly had a couple short periods of spontaneous remission. These periods have been extremely rare and his family believes it would be a strange coincidence for JH to have another one at precisely the time the intervention began. Nonetheless, it is important to consider this possibility. Also, JH’s response to coughing outside the intervention has only been reported anecdotally; precise before- and after-treatment measures were not obtained.

5. Case Study 2: CC

5.1 Background

CC is a 22 year-old female with an ASD diagnosis and sound sensitivity issues. She was originally diagnosed with pervasive developmental disorder, but this diagnosis was changed to ASD when she was five. In her most recent evaluation, at age 13, she received a score of 27 on the CARS, and she scored a test composite of 32-40 on the Stanford-Binet test. These scores should be interpreted with caution, however, because CC tends to be uncooperative during evaluations and her performance can be extremely hard to evaluate. At other times, CC can be quite sociable; her mother notes that she loves to make jokes and make people laugh. Currently, CC does not live independently and instead stays at home with her family. CC uses some language, but not in a conversational sense; instead, she tends to mostly use routinized phrases.

Prior to this intervention, CC has never had treatment for her sound sensitivities. While sound sensitivities have always been a problem for CC, they have never caused her enough agitation to merit aggressive intervention on the part of her parents. To date, CC's sound sensitivities have been managed by simply removing the offending object, or by providing ample warning about when a challenging sound will be heard. For example, CC does not like the sound of the coffee grinder, but she is able to tolerate it if her mother tells her exactly when the sound will occur.

Unfortunately, CC's sound sensitivities have gotten worse over the last few years and she has started having trouble with two sounds that often come without warning: the sound people make when they clear their throats and the sound people make when they sneeze. CC's response to sneezing is especially intriguing in that it seems to teeter from significant aversion to significant fascination. At times, CC will appear shocked and frightened if she hears someone sneeze. A sneeze may even cause her to run frantically out of the room. Also, if someone shows signs they are about to sneeze, CC will run over and clutch the person, almost in a desperate attempt to stop the sound at its source. And yet, at other times, sneezes seem to fascinate CC and she appears to actively seek out the sound.

The "ahem" sound people make when clearing their throats can be symptomatic of an underlying physical condition (e.g., from vocal cord swelling or an upper respiratory infection), or it can simply be made to draw another person's attention. Occasionally, the sound becomes a habit and is made without intention and without a person's knowledge.

Regardless of the cause, CC finds the sound extremely irritating. Her response to this type of sound is much more consistently negative than her response to sneezing. When someone clears their throat, CC will usually show visible signs of irritation and may yell, "Are you OK?" in a voice that her mother described as 'highly agitated and somewhat sarcastic.'[3] Given that CC shows consistent, aversive responses when people clear their throats, this sound was chosen as the first target sound in the intervention.

5.2 Materials and Procedure

CC has used a computer before, and enjoys playing with the Living Book series – a software program that allows kids to interact with animated stories. CC also loves Disney princesses, and she has a particular fondness for the characters in Cinderella and Sleeping Beauty. She also enjoys contemporary female pop/country singers such as Norah Jones, Faith Hill, and Shania Twain.

Based on this information, a Scratch program was created in the spirit of the Living Book series, but that featured the female characters from Cinderella and Sleeping Beauty and the songs of famous female pop/country stars. In the program, each Disney character moves about the screen and sings when clicked with the mouse. Mp3s of the Disney songs were initially difficult to obtain, so the Disney characters instead sang clips from songs by Norah Jones, Faith Hill, and Shania Twain. Although the target sound was not originally introduced into the program, the design was built around the need to eventually incorporate the sound of someone clearing one's throat. To accommodate this sound, to

[3] Individuals diagnosed with ASD often have difficulties expressing emotion in speech by way of prosody [60], and sometimes they may use seemingly angry or agitated tones of voice without intention. However, CC's mother notes that her daughter's response to "ahem" sounds seems to clearly suggest irritation.

have it make sense within the context of the program, and to have it align with rewarding elements, each Disney princess was programmed to visibly clear her throat immediately prior to singing (see figure 11 for a description of this animation).

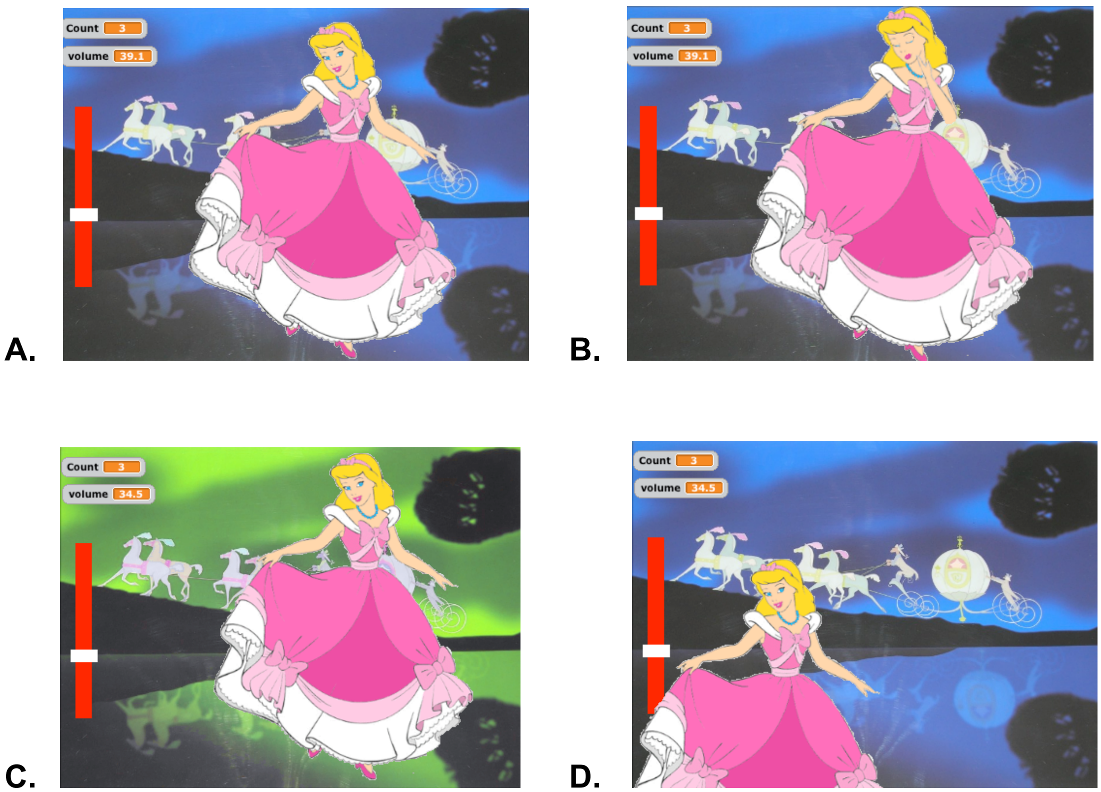

Fig 11. *A depiction of the Disney Scratch program. When the game starts, a Disney princess appears on the screen (panel A). As soon as the princess is clicked, she clears her throat (panel B) and then starts singing and moving about the screen (panels C and D).*

CC tried the program, and enjoyed it, but there were a few problems. First, CC tended to click the mouse button repeatedly, even after the character started to animate, and this excessive input caused the Scratch program to crash. Second, CC's mother felt that the program would be more effective if the Disney characters were actually singing songs from the movies. She identified some YouTube clips that featured the songs, and the audio from these clips was streamed and incorporated into the Scratch program. The program was also changed so that excessive mouse clicks would not cause it to crash.

Unlike JH's program (describe in chapter 4), which could essentially be played forever, CC's program ended after 21 exposures of the sound. This limit was implemented to ensure that CC did not get fatigued with the program too soon. For the intervention to work, it is important to ensure that participants do not lose interest in the program too early. To prevent this possibility, a ceiling was therefore imposed on the number of times the program could be run in a given session. This change was also imposed to ensure that the parents would also not get too exhausted with the program. CC's mother was therefore instructed to let her child play the program for as long as she liked or until she reached the end (whichever came first).

In the first session, CC reportedly enjoyed the program and reached the end with no difficulty. Next, target sounds were introduced into the game to occur exactly at the moment when each character appears to clear her throat. Five "ahem" sounds were taken from www.freesound.org, while another three were recorded directly into Scratch by members of the MIT community. Half of the sounds were from females, while another half were from males. Each sound clip was between 1 and 3 seconds long, and each file was normalized using the procedure described in chapter 4.

5.3 Results

CC's mother tested the new version of the program, made sure the sound controls were working properly, and then set the volume to its lowest possible level above zero. CC enjoyed the game and played it through to its completion in every session, even as the volume of the target sound was gradually increased (see figure 12).

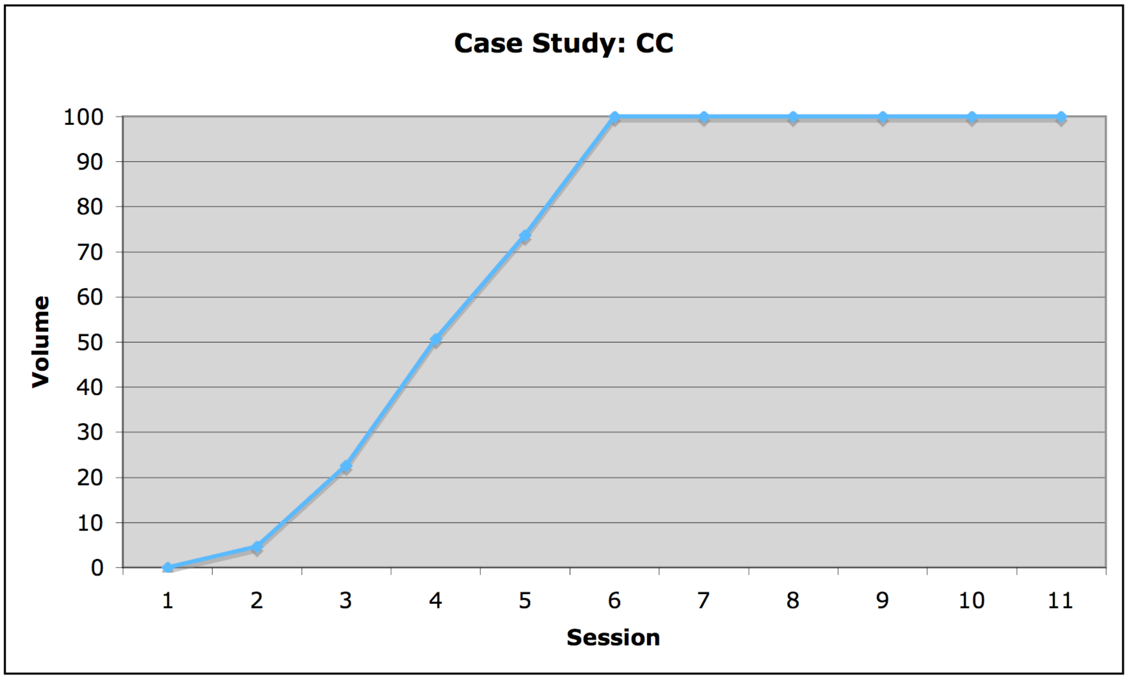

Fig 12. *A graph representing CC's progress throughout the first set of sessions.*

The target sound was turned up gradually over the course of five sessions, and by the sixth session, the volume was at its maximum. CC continued working with the program at this maximum volume for five additional sessions. Throughout all these sessions, CC reportedly never lost interest in the program and she seemed to enjoy it immensely.

Yet, despite the progress she made in the game, CC still showed aggravation when she heard her mother clear her throat. Her tolerance of sounds in the game was not generalizing to this real-world sound. It is possible that the Scratch sounds were not realistic enough for CC, and that the audio from the computer speakers lacked the fidelity to accurately replicate a real-world 'ahem' sound. To explore this further, one exemplar of the target sound was chosen and it was played for CC in two different contexts: (1) live and in the real world, and (2) pre-recorded and played through the computer speakers.

CC's mother was told to record herself clearing her throat so that the sound could be played back through computer speakers. A microphone was mailed to CC's mother, and she was told how to record 'ahem' sounds directly into the Scratch project. Recording new sounds into Scratch is quite easy, and CC's mother had no difficulty with this task. As the sounds were being recorded, CC heard them live and in person. She expressed irritation exactly as she had many times before. Interestingly, as soon as CC's mother played back the recordings, CC again expressed irritation and said, 'Are you OK?' Her response was exactly the same as when she heard the same sounds in the real-world. The computer audio clips were played back four times, and CC made the same response each time. Given these results, it seems that Scratch recordings are clearly capable of engaging CC's sound sensitivities. Her response to her mother's throat clearing sound seemed consistent; CC showed the same reactions regardless of whether the same came from the real-world or from computer speakers.

CC's Scratch project was redesigned to include "ahem" sounds from her mother. All elements of the program remained the same, except that four of the old target sounds were replaced by four new sounds recorded by CC's mother. The new sounds seemed to bother CC, and she did not tolerate the program well; she was less enthused and wanted to finish early. The volume was reduced to 4.6% - a level that is barely audible – and CC completed all trials of the program. However, when the volume was increased to 9.2% CC again wanted to stop early. In the next session, the volume was reduced to 6.9% and

CC willingly completed all the trials. These results seemed to suggest that CC was having some trouble tolerating the new ‘ahem’ sounds her mother recorded.

After a consultation with CC’s mother, a decision was made to update the Scratch program with new material. We hoped that CC would have renewed interest in the content of the program and that this might help her tolerate the sound. We also adjusted the sound meter in the program, so that the sound could be increased at extremely small intervals. Based on input from CC’s mother, the program was changed to include new songs and new Disney characters. CC’s mother was able to tell us exactly which parts of which songs should be included in the program, and the level of customization was even more refined than before. Since Scratch is based on object-oriented principles, the program was easily updated in a few hours.

With these new changes in place, the intervention proceeded as it did during the first set of sessions. CC seemed delighted with the new changes and, according to her mother, she was extremely happy to begin the new sessions. To help CC gradually habituate to the new sound stimuli, an extremely gradual pace was set. The previous results indicate that CC may have had trouble at the area where the sound just starts to become audible. Accordingly, the next 10 sessions were set to increase at extremely small intervals. As of this writing, CC has successfully completed another 10 sessions, and the volume level is now at 23.5% of the total possible volume. At this level, the sound is audible, but slightly below the volume that would typically be heard in real life. CC’s mother has observed some progress and notes the following:

I've noticed some change in her reaction when I clear my throat. When she says, "Are you okay?" she says it in a normal, pleasant tone rather than loudly or with an irritated inflection that was common in the past. Also, there seems to me more instances in which she doesn't react at all.

These results are promising, especially at this stage in the intervention. Hopefully, by the time the volume is near its maximum, CC will have completely habituated to the 'ahem' sound.

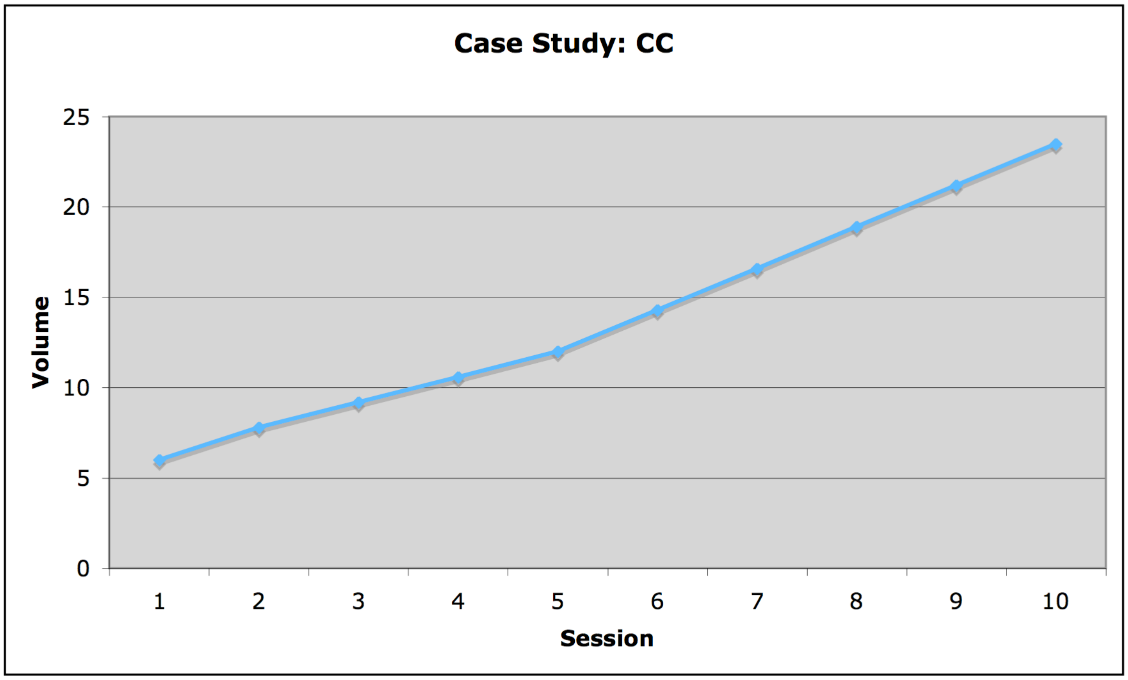

Fig 13. *CC showed aversive reactions to the new sound stimuli, so her first ten sessions were set to proceed at a gradual pace. At this pace, CC enjoyed each session and always played the program to its completion.*

5.4 Conclusion

Unfortunately, it is too early to establish whether CC will continue to proceed at such a promising pace. It is also too soon to know whether CC's increased tolerance to 'ahem' sounds within the Scratch program will generalize to other, similar sounds she hears in the real world. While it seems as though CC is now better able to tolerate the sound her mother makes, more exhaustive data needs to be collected to verify these anecdotal observations. Fortunately, CC and her mother still seem to enjoy the program and are eager to continue the intervention.

Even though this case study is still ongoing, it has already revealed some important aspects of the proposed intervention. Most notably, this case study illustrates the power of customizing therapeutic interventions, rather than applying a one-case-fits-all approach. It also reveals the importance of letting family members direct the process of customization. CC's mother clearly has an intimate understanding of the kinds of media that interest her child. In fact, she even knows which phrases of which songs are most loved by her daughter, and this knowledge was used to make extremely customized media programs.

This case study also showcases some of the benefits of using Scratch for this type of intervention. CC's mother does not claim to have an in-depth technical background, and yet she was able to use the Scratch interface with remarkable ease. She installed the problem without any problems, and she had no difficultly recording new sounds and uploading them into the Scratch program.

6. Case Study 3: BL

6.1 Background

BL is a 20-year old male, who was diagnosed with ASD at age three. BL lives with his parents in a rural part of the country. His neighbors have a farm with roosters and sheep, and the sounds from these animals can be challenging for BL. While many find the crow of a rooster a bit grating (especially early in the morning), BL finds it extremely difficult to endure at any time of day. When he hears the sound of a rooster, he puts his hands over his ears and expresses his discomfort with loud verbal utterances. The sound influences his quality of life, and can disrupt his ability to play outside; for instance, his mother has observed him attempting to ride a bike whilst simultaneously cupping his hands over his ears to muffle the rooster sounds.

BL has always had sound sensitivity issues, and these were addressed with AIT when he was young. His mother found the experience extremely distressing both for herself and for her child. BL cried miserably during every session and strongly resisted the treatment. Worse still, BL did not seem to gain any benefit from the costly and traumatic AIT sessions.

BL has many interests, but his mother notes that his greatest love may be Herbie the Lovebug – an anthropomorphic Volkswagen Beatle featured in several Disney movies. His mother also notes that BL enjoys simple puzzle games on the computer, including ones that involving finding items or re-arranging scrambled images to create a complete picture.

6.2 Materials and Procedure

Two Herbie-themed puzzle games were created for BL. One of the games requires the player to find the real Herbie vehicle amongst an increasing number of distracter vehicles (that is, vehicles that look similar to Herbie, but have slightly different markings). When the correct vehicle is found and clicked, it grows in size and drives across the screen in a frenetic fashion. The other game is a scrambled puzzle game that requires players to piece together a coherent image of different scrambled images of Herbie (see fig 11)**.** BL played both games and seemed to prefer the game in which he had to search for Herbie on the screen. However, his mother noted that the game was perhaps too easy, and

Fig 11. *Screenshots of two Herbie-themed games created for BL with Scratch software.*

should be made more challenging. The game was changed to make the distracters resemble Herbie more closely and the number of levels was increased significantly (from 10 to 50). With these new changes in place, BL seemed more engaged with the game and, while it was challenging, he was still able to complete all the levels.

Eight different rooster sounds were incorporated into the game and one sound was chosen at random and played whenever BL successfully clicked on the correct vehicle. If all the levels are passed and the game is completed, the rooster sounds get played 50 times. The rooster sounds were taken from www.freesound.org, and were on average between 2-3 seconds in length. The sound files were normalized using the same procedures described in chapter 4.

When BL was away from the computer, his mother tested the sound control and reported that it was working properly. Unfortunately, during BL's first exposure session, the sound controls failed to work and the cars failed to animate properly. Efforts were taken to diagnose and fix the problem, and BL's mother was sent a compressed version of the program in the hopes that it might be less of a burden on her computer's CPU. When the problems persisted, a visit was made to BL's residence and the program was inspected first-hand. The program was tested multiple times and seemed to work perfectly on BL's mother's laptop. A recommendation was made to only launch Scratch when all other programs were closed, and a Macintosh laptop was loaned to BL's mother as a backup in case the problem returned.

6.3 Materials and Procedure

Once Scratch was again working properly on her laptop, BL's mother had her son play the game with the rooster sounds on at the lowest possible volume above zero. BL played the game through to its completion, and his mother reported that he enjoyed the experience. However, she also noted that BL made car sound effects whenever Herbie started to move across the screen, possibly in an attempt to drown out the rooster sounds.

It took almost two months to arrive at this stage in the intervention, and it was becoming clear that BL's mother was perhaps too busy to do the protocol according to our specifications. She was reminded that she could quit the experiment at anytime but that the intervention required her to run the program with her son consistently, leaving no more than a two-day break between each session. In the next session, the volume was turned up 20% and BL found the sound too distressing to continue. Prior to the start of the intervention, and several times throughout the correspondence, specific instructions were given to turn off the sound if BL appeared agitated and to report back to the researchers. Nonetheless, BL's mother, perhaps in a good-natured attempt to expedite the process, did four more sessions with her son that day, all of which were at relatively low volume levels. BL appeared to tolerate the game when the sound meter was at 4.6% of the maximum volume, but not when it was one increment above that (6.9%). After this session, BL's mother was again instructed to follow the specific protocol and was told to do another session with the volume at a low, comfortable level. Unfortunately, several weeks passed without any new updates from BL's mother and a decision was therefore made to terminate the study.

6.3 Conclusions

This case study, while abbreviated, was important for several reasons. For one, it clearly demonstrated the potential for computer-delivered audio clips to replicate real-world responses to aversive sounds. This study also illustrates the need to test exposure games on multiple platforms prior to starting an intervention. In an initial interview, BL's mother mentioned that some of the computer games her son used to enjoy had crashed on occasions. Like many individuals with ASD, BL likes routines and can get upset when faced with unexpected dilemmas. The fact that the Herbie game crashed several times may have worried BL's mother and may have contributed to her sporadic engagement with the intervention.

Finally, this study reiterates the fact that many parents of children with ASD live busy, complicated lives and, for some, daily therapeutic sessions may be difficult to complete.

7. Conclusions and Future Directions

Auditory sensitivity in autism is a complicated problem, and it is unlikely to be solved with one simple treatment approach. However, the intervention described in this thesis could be a useful tool for managing sound sensitivities in autism, and further work should be done to examine its full potential. Preliminary data collected in this thesis support the notion that some auditory sensitivities can be managed with the proposed intervention. While JH's outcome could only be measured anecdotally, his parents' observations are striking. According to their reports, JH has shown an almost full remission of his sensitivity to coughing sounds. As of this writing, the data from CC is also promising. She is progressively nicely through the treatment and her mother notes that she may be showing less sensitivity to her target sound. However, data is still being collected from

CC and a complete analysis of her treatment outcome cannot be presented. The case of BL remains unfinished. Unfortunately, his family dropped out of the study before any conclusions could be drawn about his progress with the intervention. Nonetheless, much can be learned from all the case studies presented in this thesis, and while only one was run to its completion, all of them offer intriguing insight into the many facets of the proposed intervention.

The UCL study (described in section 3) offers quantitative data to support the claim that problem sounds should be paired with positive elements of a media program. Based on these findings, and the results from the case studies, we conclude that this approach should be followed in the future. Further work in this area should at least consider the importance of how a target sound is delivered within a media context.

7.1 Specific Aims Revisited

In section 2.3, four specific aims for the intervention were described. In this section, these aims will be revisited and examined in light of the data collected from this thesis.

7.1.1 Specific Aim 1

One of the most important aims of this intervention is to provide a treatment option that can fit the needs of any individual on the ASD, regardless of any pre-existing cognitive issues, motor impairments, or language deficits. Auditory sensitivity can afflict any individual with ASD and so treatment approaches should be adaptable to fit the needs of many different individuals. All the case study participants described in thesis had significant language and cognitive deficits. While no formal evaluation was done to assess their motor control abilities, all three individuals seemed to have some difficulty with fine motor controls. The Scratch programs were easily adapted to meet the needs of these individuals. The games and visualizations did not impose any significant burdens on motor control or cognitive functioning. All participants were able to play the programs that were presented to them.

But, this intervention cannot work without the active participation of the autistic person's parent or caregiver, and so it is not enough to design the treatment solely with the autistic individuals in mind; the constraints of the parents must also be taken into account. The parents of JH and CC were excited to try the intervention and they did not feel burdened by the time commitments required for this intervention. However, many parents of autistic children experience extreme amounts of stress, and the extra time required to set up and run this intervention may be too much for some individuals. Also, the case of CC shows that some trial and error can be involved in finding the proper target sound. Her case study shows that a significant number of sessions may sometimes be needed for this intervention. Thus, while we believe that the intervention is suitable for any autistic individual, more work should be done to streamline the intervention and make it less of a time commitment for parents/caregivers.

7.1.2 Specific Aim 2

Another aim for this intervention was to make it intrinsically engaging, such that participants would willingly expose themselves to the treatment. Scratch was used to serve this aim, and it allowed us to create highly customized media programs for each case study participant. In all cases, a program was created that engaged the participant's interest. This was especially remarkable for JH, since he had never expressed interest in using a computer prior to his participation in this study. Occasionally, the program needed to be updated or modified during the intervention to prevent it from becoming old or boring, but these updates were easy to create and were completed in as little as a few hours.

Customized programs that engage autistic individuals could have many different uses beyond the intervention proposed in this thesis. Computerized interventions to help autistic persons learn how to type or read could benefit from the customizability built into the Scratch platform. Many individuals diagnosed with ASD have restricted interests and may not enjoy trying new things unless their interest is represented. While it is certainly not recommended to encourage restricted interests, it is important to recognize their power to motivate and engage. Customized programs could cater to these interests in order to attract the individual's attention and participation.

7.1.3 Specific Aim 3

Three different software tools were used in this intervention: (1) Scratch Software; (2) Audacity (a sound editor); and (3) Gimp (an image editor). These programs are freely available on the Internet and were chosen to make the intervention as inexpensive as possible (the goal outlined in specific aim 3). CC's mother needed a $10 microphone to record herself clearing her throat, but all the other sounds for the other case studies were downloaded for free at www.freesound.org.

Developing the programs for each participant was fairly simple, but proficiency with audio and image editing tools was required. Customizing the Scratch programs required a specific skill set that might not be freely available to most parents or caregivers. To avoid this problem in the future, free online tutorials could be created to teach parents/caregivers how to customize Scratch programs with free image and sound editors. The Scratch community has already starting building tutorials like this and they are actively compiling them on a new website (http://learnscratch.org).

7.1.4 Specific Aim 4

Finally, the proposed intervention aimed to be humane. Interventions like AIT can cause significant stress for autistic persons because the treatment sessions are sometimes imposed without the consent of the individual (consider, for example, the AIT experience described by BL's mother in section 6.1.). By contrast, the methods described in the proposed intervention are never forcibly administered. The case studies suggest that the intervention engaged the participants and did not cause any significant or enduring stress. CC and BL both expressed aversive reactions to the target sounds at some points during their sessions, but these moments were fleeting and, for the most part, their parents followed our protocol and turned off the volume as soon as their child showed any stress or disinterest. Overall, the results suggest that this approach is a humane and low stress way to manage sound sensitivity issues.

7.2 Future Directions

More work should be done to evaluate the therapeutic efficacy of this intervention. The case studies presented here, while intriguing and informative, are not sufficient to draw definitive conclusions about the efficacy of the proposed treatment methods. A larger sample of participants should be recruited, and controlled pre- and post-tests should be conducted to precisely determine the effects of the treatment. It is important to measure each participant's reaction to the target sound both before and after the intervention takes place. Also, these pre- and post-tests measures should not be based on anecdotal observations, but should rather be based on quantifiable ratings. These ratings could be obtained with UCL measures (as described in section 3.1), or they could be obtained from independent raters trained to observe and record each participant's reaction to real-world sounds. A pre- and post-test involving this latter method would be perhaps the best approach, since it would offer a high degree of ecological validity.

With a large number of participants, three treatment groups could be created: (1) a group that is gradually exposed to a target sound using the methods outlined in this thesis; (2) a group that receives no treatment; and (3) a group that is gradually exposed to a neutral sound. The third group would serve as a technology control, to control for any placebo effects that might come simply from playing with a customized Scratch program.

Alternatively, if a large between-group comparison cannot be run, a single-case design could be conducted on a larger number of case study participants. For individuals that are averse to several different sounds, a multiple baseline across stimulus approach could be used. This approach, described by Barlow, Knock and Hersen [55], has been used to successfully examine exposure-based treatments for phobias in small numbers of patients, and it can be a powerful way to assess behavioral interventions [56,57].

It will also be important to examine the generalizability of the treatment. JH's response to recorded coughs seems to have generalized to real-world coughs. JH now appears much more relaxed when he hears another person coughing near him. By contrast, CC's progress did not initially transfer to a real world situation. After her first series of sessions, she was able to tolerate ‘ahem’ sounds at full volume in her Scratch program, and yet she was still quite irritated whenever she heard her mother clear her throat. Further research should be done to determine why JH showed immediate generalization and CC did not.

More work should also be done to see how different treatment approaches might affect different types of auditory sensitivity. Various subtypes of auditory sensitivity may be present, in any combination, in any given individual with autism. For instance, anecdotal evidence suggests that some individuals are sensitive to all loud sounds, while others are only averse to certain specific sounds (such as a particular type of blender sound) [2]. Others, by contrast, may only grow distressed in acoustically crowded environments. It is important to consider how different intervention techniques might differentially affect different types of sound sensitivity issues.

To date, auditory sensitivity in ASD has been a sorely neglected area of research. The currently available intervention techniques are substandard and should be replaced with new methods. More research should also be done to examine possible causes of auditory sensitivity in ASD. New findings uncovered from this research would be extremely valuable and could lead to new therapeutic advances.

Auditory sensitivity can be a difficult burden to bear, and many individuals with ASD describe how it can significantly impair their quality of life. Temple Grandin notes that, for her, “the sound of the school bell ringing was like a dentist drill in my ear [58].” Far from hyperbole, these remarks offer insight into the severe pain that certain sounds can cause autistic persons. New interventions are drastically needed to manage this problem, and this thesis presents an option that merits further investigation.

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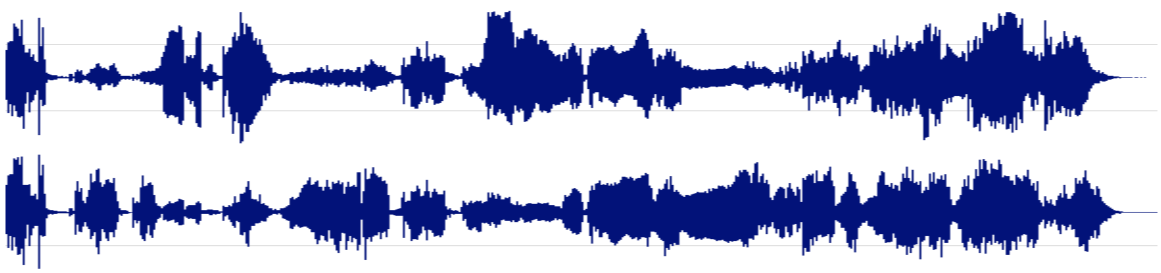
Appendix

A. Recruitment Flyer

Rate Sounds and Play Video Games!



Earn A $10 Gift Card For Your Participation

Participate in an auditory study at the MIT Media Lab. The study will take no longer than 1 hour, and you will be compensated for your participation. For more information, please contact Rob Morris at rmorris@media.mit.edu.

This study has been approved by the MIT Committee on the Use of Humans as Experimental Subjects (COUHES).

B. Sound Placement Examples

Numerous games and programs were piloted for this thesis. While only a few were used in the actual studies, some of the other ideas are presented below:

Program	Sound Placement
Racing game	Target sounds play whenever the car accelerates or successfully passes an opponent.
UFO game	Players control an alien spacecraft and beam up enemies. The tractor beam plays the target sound and the power of the tractor beam matches the volume of the sound.
Search game	Target sounds play whenever an item is successfully found. This could be a "Where's Waldo?" type of game, or a game where objects must be clicked and dragged to reveal hidden items.
Puzzle game	Target sounds play each time a puzzle piece is successfully positioned. This could be a simple jigsaw puzzle game or a more complex scrambled jumble game.
Other games	Any time points are earned, the target sound plays as a sound effect. This approach could fit almost any game that uses sound effects to reward game performance.
Animated Story	Target sounds play whenever characters animate.
Slide Show	Keypresses cue new pictures and target sounds play each time a new picture appears on the screen.