Using Sound to Represent Positional Accuracy of Address Locations

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Abstract: Uncertainty data are often ignored by spatial data users for reasons that include difficulty of representation and comprehension. This study evaluated the benefits of a sonification extension to ArcGIS which represented the positional accuracy of address locations using piano notes. The approach was assessed by 49 survey participants via a computer based task and subsequent discussion. Two factors that influenced successful interpretation were the proportion of values requiring detection and the presentation method. Knowledge of the data source also appeared relevant. Future studies will examine applications to climate scenarios and visualisations of future landscapes, as well as other aspects of sound.

Keywords: positional accuracy, sound, sonification, tone, ArcGIS

INTRODUCTION

All spatial data have some uncertainty concerning their positional accuracy. However, even when information on the level of accuracy exists and is potentially important in terms of fitness for use, it is widely recognised that it can be ignored by users of the data. Several studies have investigated the reasons for this situation and how it can be addressed (Agumya & Hunter, 2002; van Oort & Bregt, 2005). One aspect is the technical challenges of representing uncertainty alongside other attributes of the data, but there is also a need for research to evaluate how the outputs of different techniques are understood by users (Hunter & Goodchild, 1996; MacEachren et al., 2005). This paper seeks to contribute to the literature on these two topics by presenting a sonic technique to represent positional accuracy in Ordnance Survey's MasterMap® Address Layer 2 data and assessing the ability of experienced spatial data users to correctly interpret it.

The representation of uncertainty in spatial data has been widely discussed in the research literature and visual methods such as colour, blurring or multiple maps are most common (Appleton et al., 2004; Ehlschlaeger et al., 1997; MacEachren et al., 2005). However, these methods can obscure underlying data or limit the amount of information shown. There has been extensive work on tools for visualising spatial data dynamically, resulting in many novel methods of exploratory analysis including interactive visualisation (Dykes et al., 2005) and more recently development of the newer field of geovisual analytics (Andrienko et al., 2007). The vast majority of these displays, however, only employ visual stimuli, and displays are reaching higher levels of complexity, sometimes pushing the limits of visual comprehension (Tukey, 1990).

The use of other senses has been suggested as a sensible complement to visual displays. Haptic (touch) maps have advantages for comprehension and can be combined with visual displays relatively easily, but require significant investment of time and money to implement (Golledge et al., 2005). The hardware to utilise sound (sound card and headphones/speakers) is cheaper and more readily available, and consequently has been more widely utilised in research, but much still remains to be understood in order to make the most effective use of sonic techniques (Pauletto & Hunt, 2009).

The Use of Sound

A number of studies have examined, from both theoretical and practical perspectives, how sound can be used as a supplement to visual stimuli. Krygier (1994) outlines two different ways of utilising sound – using real sounds (such as traffic noise to represent a city or bird song for the country) or abstract sounds, where the sound utilised (e.g. piano notes) represents a different variable. The use, impact and manipulation of real sounds is quite well covered in the sonic methods, music and arts literature (e.g. Jazel, 2005), but the use of abstract sounds has received less attention. Kryiger outlines nine different aspects of sound that could be altered to represent spatial data, including location, loudness, pitch, register, timbre, duration, rate of change, order and attack/decay. Using one of these aspects to represent a set of spatial data is certainly possible, and there have been experiments with multiple sound variables for exploration of multivariate data (Flowers et al., 1996) but these have a much higher level of complexity. Gaver (1989) highlights the fact that sound is a transient phenomena, in that it is very good for representing dynamic, changing phenomena (usually, but not exclusively temporally), but can have limitations when representing a large amount of data over an extensive area, particularly if the data are very variable.

In addition to the theoretical discussions, there have been a number of practical implementations using abstract sounds. One of the most common applications of sound with spatial data has been for maps or navigational aids for people with visual impairments, such as Zhao et al. (2008) who developed iSonic which is a geographical data exploration tool for the blind. The on-screen map data were split into a 3x3 matrix, which was sonified and accessed by the user through a numeric keypad with values 1 to 9. When the user selected a number, the data in that quadrant was read out and each quadrant could then be zoomed in to, and the process repeated. This illustrates some of the limits on the amount of information that can be represented using sound, but the in-depth case studies with seven blind participants suggested that the interface was effective. Two other examples using abstract sounds are Fisher (1994) and Veregin et al. (1993) who used sound in conjunction with GIS in a relatively basic way. They were both constrained by the technology available at the time, as both spatial data handling and computerised sound technology were in their infancy. Fisher sonified the reliability information at a pixel level in a land cover classification and Veregin worked on soil map units and their data quality.

More recent examples have employed a variety of data sets and begun to report some user testing. Gluck (2000) experimented with using different aspects of sound to show levels of environmental risk in the counties of New York State, by using notes with variable pitch and tempo as well as combinations of notes in the form of chords. He found that using sound and vision on a complementary basis was most successful and gave greater information and understanding than either sense separately. Jeong & Gluck (2003) compared haptic, sonic and combined display methods in a series of user evaluations (n=51) and found that haptic alone was most effective, however, users preferred haptic and sonic combined even though their performance was lower. The sound utilised involved variations in volume of a clip of music, and this abstract nature could mean that these results have a limited wider applicability.

MacVeigh & Jacobson (2007) used real sounds to represent three different land uses (sea, land and harbour) which participants in their experimental found very easy to understand. They also suggested a sonification extension to an industry standard GIS (e.g. ESRI's ArcGIS) could be created which would allow greater use and easier evaluation of sonification techniques. This type of research has been rare to date and comparison of studies is complicated by a lack of consistent terminologies and different research frameworks (Frauenberger & Stockman, 2009).

This paper follows on from the suggestion of MacVeigh & Jacobson (2007) by developing a sonification extension of ArcGIS. It then reports on the experience of using this tool in a survey of spatial data users where the aim was to assess the influence of different visual and sonic methods on their ability to correctly identify the level of positional accuracy in a set of address data. The following section introduces the data and techniques used, before describing the nature of the experimental design.

DATA & METHODS

A number of possible application areas were considered including change detection (identifying alterations over time or differences between two sets of data) and address matching (finding the spatial locations, such as National Grid co-ordinates, of text postal addresses). The latter was chosen because it is a common task in GIS analysis and there was a widely used UK data set (Ordnance Survey MasterMap® Address Layer 2, hereafter AL2). This data set provides a list of postal addresses with associated spatial co-ordinates and allows users to geocode their own address data through text matching procedures. It also includes a set of status flags for positional accuracy of addresses to indicate how accurate the spatial co-ordinates are (known as PQA in the data set). Telephone interviews with Ordnance Survey Account Managers and Pre and Post Sales staff also suggested that often these status flags are not properly considered when the data are used by external organisations. The reasons given for this situation varied, but included the users not being aware that the status flags existed or of their relevance, as well as difficulties in representing the accuracy information in a meaningful way.

An ArcScript (custom extension to ArcGIS) was created to allow visual and sonic representation of the positional accuracy within the AL2 data. The AL2 status flags took the form of five ordered classes, namely: Surveyed (most accurate), Approximate, Postcode Unit Mean, Estimate and Postcode Sector Mean (least accurate) (see Ordnance Survey, 2009 for details and data examples). Given the categorical nature of the information it was decided that variations in pitch (i.e. different notes) would be an appropriate sonic variable to employ. The specific instrument chosen was a piano because it is a common instrument which the vast majority of people recognise and the notes have a very clear order to them (low to high). In an initial pilot study the majority of participants said that five different notes were difficult to discriminate between and relate to the status flag categories. The five classes were therefore reduced to three by combining Postcode Sector Mean with Estimate and Approximate with Postcode Unit Mean (see Table 1). These three categories were represented using the piano notes C_4, G_4 and E_5, based on the CEG triad split over two octaves (see Figure 1). A triad was chosen because these are sets of notes which sound harmonious together (Burrus, 2009) and CEG was the favoured option in the pilot study. The highest note (E_5) represented the most accurate level and the lowest note (C_4) represented the least accurate.

Initial Five Classes of Status Flag	Reduced Three Classes of Status Flag
Surveyed (most accurate)	Surveyed (most accurate)
Approximate	Postcode Unit Mean
Postcode Unit Mean	Postcode Unit Mean
Estimate	Estimate (least accurate)
Postcode Sector Mean (least accurate)	Estimate (least accurate)

Table 1. Positional Accuracy status flags 5 original classes (left) and how they were reduced to 3 classes (right).

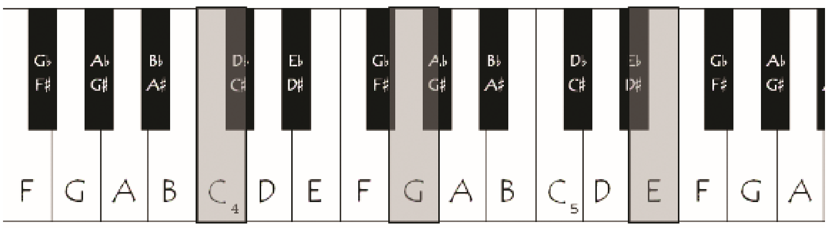

Figure 1. Piano keys with C_4, G_4 and E_5 highlighted.

The ArcScript tool utilised Ordnance Survey MasterMap® Topography and AL2 data for two terraced streets in the city of Norwich, UK. The AL2 positional accuracy data were linked with the Topography data using the associated TOIDs (topographic identifiers). Figure 2 shows an example screenshot of the display, with the shading of the building polygons providing a visual representation of address positional accuracy. A sound legend (in the top right-hand corner) was also provided to link specific notes to particular categories. These notes were played as the user moved the mouse cursor over each building (without needing to click on polygons), allowing them to either query a specific building or scan an area of data to get an overall impression[1].

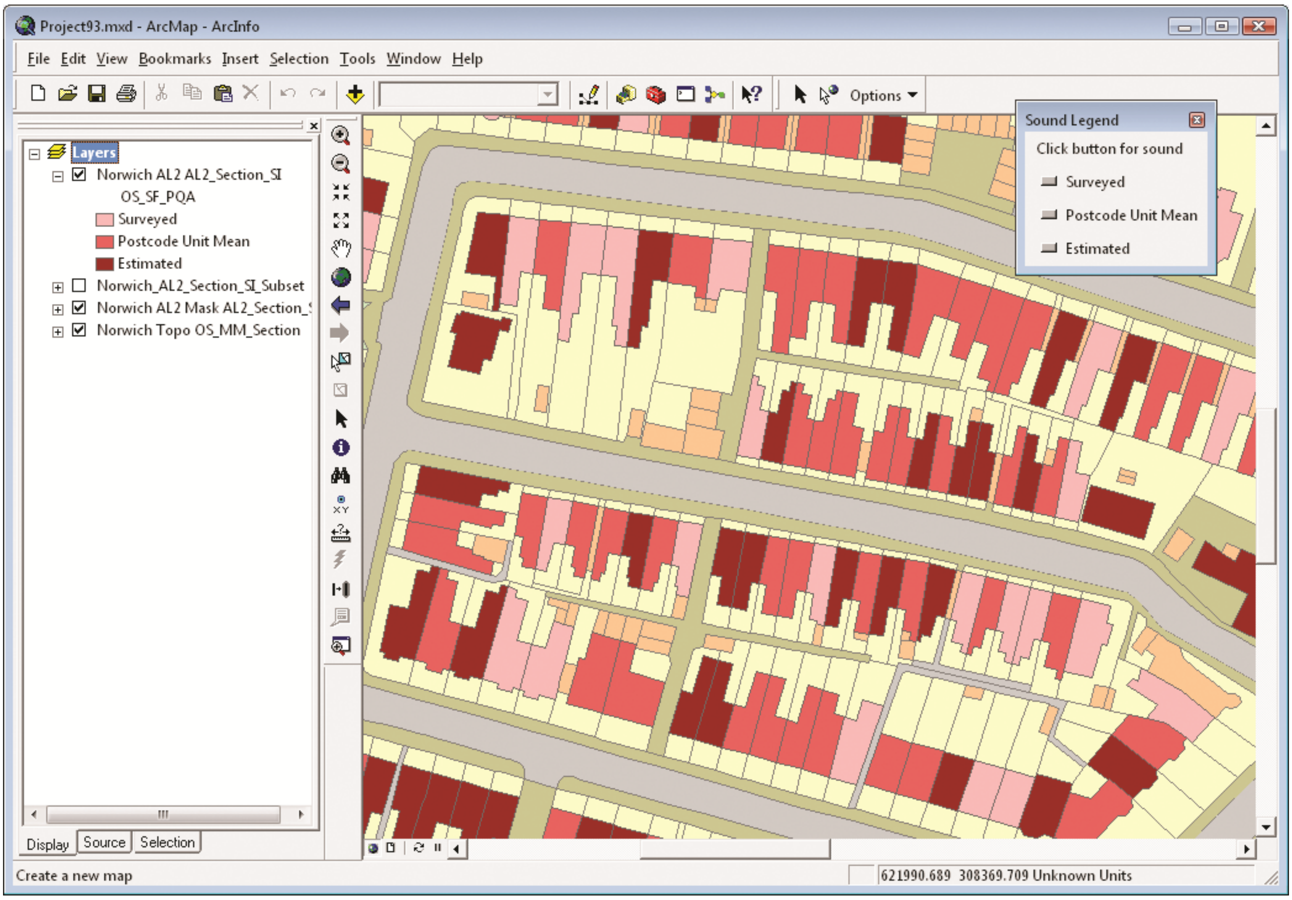

Figure 2. Screen shot of ArcMap showing the positional accuracy classes represented visually and with the sound legend in the top right-hand corner. *ArcMap Interface © ESRI 2010, Ordnance Survey. © Crown Copyright. All rights reserved.*

During the survey of users the data were presented using four different methods in the order shown in Table 2. The Topography layer was always depicted in order to provide baseline spatial reference. In the sonic only method (hereafter Sonic) the Topography polygons were shaded according to feature class categories and the AL2 Positional Accuracy was represented using sound (see Figure 3). Visual only (Visual) showed the building polygons with different shadings to represent their AL2 Positional Accuracy. The third method (VS Same) used both sound and visual methods to show positional accuracy in a complementary manner, while the fourth (VS Different) used sound to represent AL2 Positional Accuracy and a visual shading to depict fabricated “Council Tax band” (local property value) information.

1 The source code, demonstration data and a video showing implementation of this technique can be downloaded from http://www.nickbearman.me.uk/go/bearman_lovett_2010/.

Presentation Method	Abbreviation	Visual Data	Sonic Data
Sonic only (see Figure 3)	Sonic	Topography feature classes	AL2 Positional Accuracy
Visual only	Visual	AL2 Positional Accuracy	None
Visual and Sonic representing the same variable (see Figure 2)	VS Same	AL2 Positional Accuracy	AL2 Positional Accuracy
Visual and Sonic representing different variables	VS Different	Council Tax bands	AL2 Positional Accuracy

Table 2. The four different presentation methods (in the order they were shown to survey participants) and which data were represented visually or sonically.

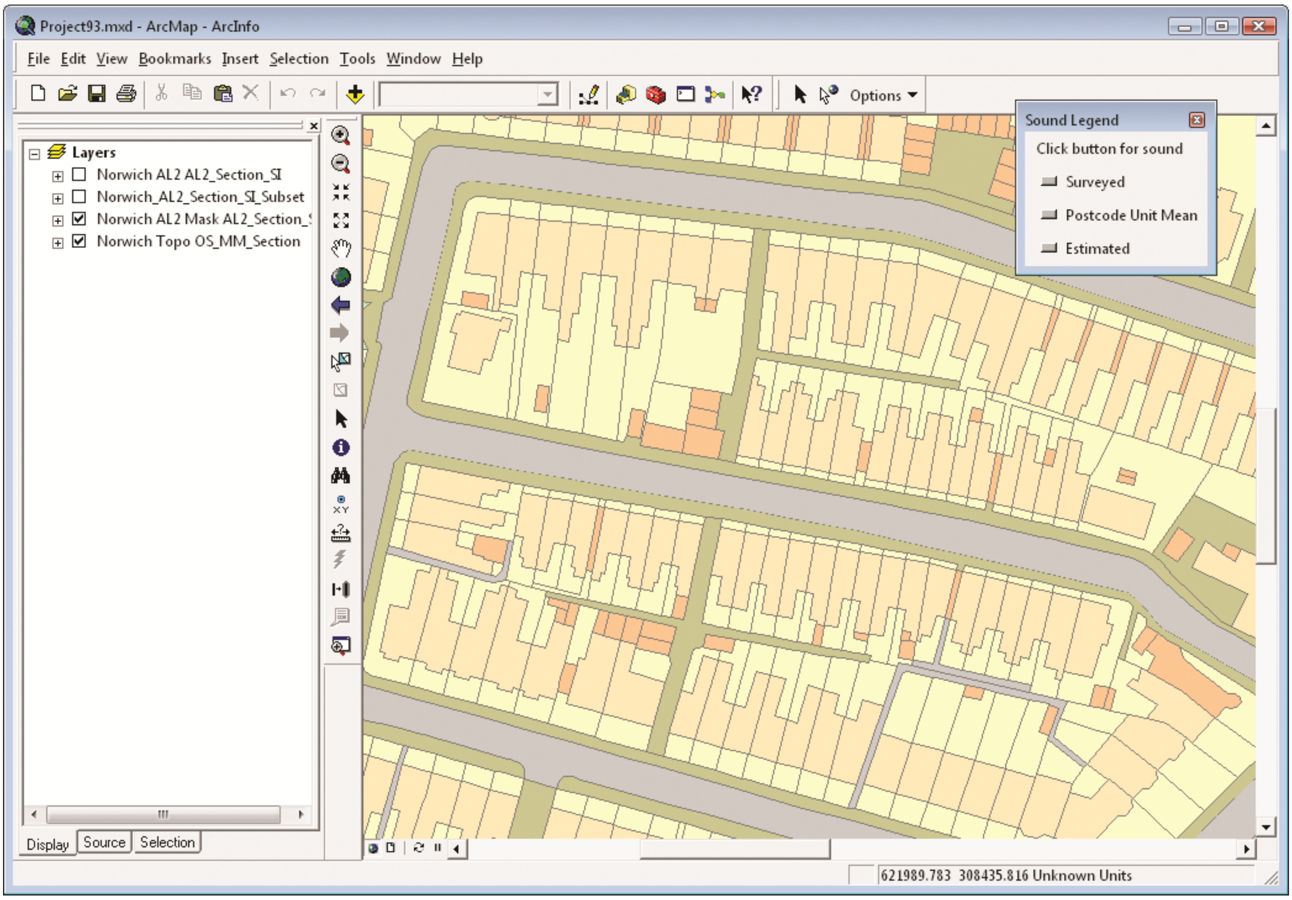

Figure 3. Screen shot of ArcMap showing the sonic only representation method. *ArcMap Interface © ESRI 2010, Ordnance Survey. © Crown Copyright. All rights reserved.*

For each presentation method, the survey participants were asked to identify the proportion of Surveyed values (i.e. the most accurate), from options of 25%, 50% or 75%. A stratified random method was used to assign the status flag values to the building polygons. This meant that for each presentation method approximately a third of participants had each proportion of Surveyed values represented. The task of identifying the proportion of Surveyed values was chosen because it combined a question that was not too easy or hard with the need to interpret sound in a way that visual representations are often employed.

As well as the main computer-based task, during the survey other background questions were asked concerning musical skills, learning preference and experience with AL2 data. The evaluations were performed in small groups (4 to 6 people, though not able to see what each other were doing) and were followed by a discussion session (20 – 30 minutes) where the participants were asked their opinions on the experiment, highlighting aspects that did or did not work well and suggesting any possible improvements.

A total of 49 participants completed the survey, consisting of 19 staff from Ordnance Survey, 23 from the University of East Anglia and seven from local authorities. All the participants had at least a basic knowledge of GIS, spatial data and ArcGIS and used these on a regular basis, although experience with AL2 varied. Headphones with adjustable volume were used to provide the auditory stimuli.

RESULTS & DISCUSSION

Nearly all participants (46 out of 49) identified the correct proportion of Surveyed values in at least two of the four presentation methods. Figure 4 shows how the mean answer for participants (based on correct = 1, not correct = 0) varied by the proportion included and presentation method, which were the two main influencing factors. VS Same and Visual methods (see Table 2 for abbreviations) performed best, while Sonic and VS Different had lower correct frequencies. Participants said they were comfortable with the Visual method as it was familiar to them and with the VS Same method because the sounds confirmed the information acquired visually which made them feel more confident about the proportion they chose. Many respondents said that the Sonic only presentation was hard to use, mainly because it was difficult to get an overall sense of the data when scanning the cursor over the map display. VS Different was also described as challenging, primarily because of the need to separate what was seen from that heard (i.e. the two sources of information could be in conflict with each other).

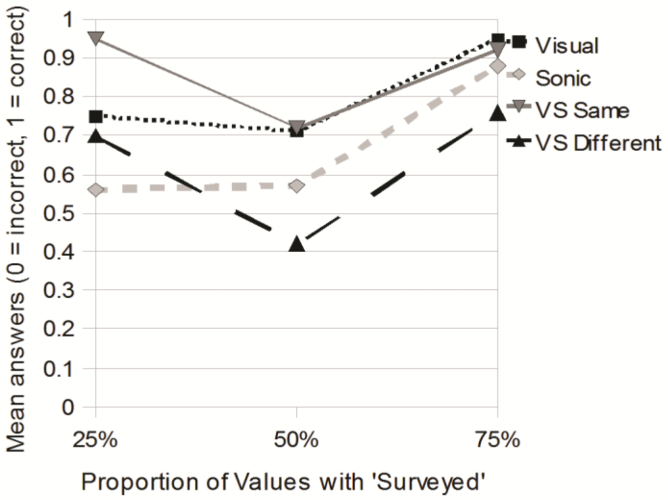

Figure 4. Variations in correct answers by proportion of Surveyed values and presentation method.

The second broad trend was for more correct answers with 25% and 75% proportions of Surveyed values and fewer with a 50% proportion. The exception to this was the Sonic only presentation method, which performed as badly with 25% as it did with 50%. This may have occurred because the nature of the user interface made it fairly straightforward to find particular sounds when they were common, but more difficult when they were sparse, leading participants to overestimate the proportion. Both proportion ($p < 0.005$) and presentation method ($p < 0.05$) had a significant influence on whether a participant identified the correct proportion of Surveyed values. Participants were also asked to select the easiest and hardest presentation methods to use, with 59% choosing Visual only as the easiest and 51% specifying Sonic only as the hardest, broadly consistent with the trends in Figure 4.

A logistic regression analysis was undertaken in SPSS to examine how combinations of different variables influenced the probability of a correct answer. Data for the three respondents who got all or all but one of the proportions incorrect were excluded from this analysis as it was found that they biased the outcome. In a forward stepwise analysis only the proportion of Surveyed values and presentation method made a significant improvement to model fit at the 0.05 level (Table 3) and the coefficients for these variables showed similar trends to those already discussed.

Factors added to Model	**-2 Log Likelihood**	**Cox & Snell R^2**
Proportion of Surveyed	182.01	0.043
Presentation Method	168.579	0.11
Address Knowledge	167.319	0.116

Table 3. Factors added to the Logistic Regression Model and their impact on model fit.

Within each of the survey locations (Ordnance Survey, UEA and local authorities) there appeared to be a trend that indicted higher knowledge of the AL2 data set resulted in an increased likelihood of a correct answer. However, as an overall effect in the regression model this did not provide a significant improvement (see Table 3). In part this may be because including this variable resulted in some combinations of attributes with low counts (<3) so a larger sample might have altered this interpretation. Similarly, it should be recognised that participant specific attributes (e.g. AL2 knowledge, survey location etc.) were duplicated when the data were analysed by categories such as presentation method, and it would require the use of statistical techniques such as multi-level modelling to properly separate out these aspects of the data set structure. However, this refinement is most unlikely to alter the general interpretation above.

The free text answers from the survey indicated that some participants found the sonification very useful and that it added considerably to their interpretation of the data, while others said the sound was very difficult to understand and when combined with vision, distracted them from the visual interpretation. Sonic and VS Different methods were considered harder to use than Visual and VS Same. Sonic only had a relatively low success rate and seems unlikely to have much applicability with this type of interface.

The discussions after each evaluation session provided further qualitative information and gave participants a chance to suggest changes and improvements to the technique. Preferences for the types of sounds used were subjective and are likely to vary depending on the data set and the analysis taking place. A wider range of audio clips coupled with user choice could allow easier differentiation of sounds and potential for representing a larger number of variables. Possibilities include different piano notes and instruments or completely different environmental or animal sounds. Colour-blind users were highlighted as a group who might find the sonification useful; however a larger sample size is required to effectively evaluate this possibility.

Reflection & Future Work

Estimating the proportion of a data set may seem unusual to many GIS users, as a more common way of calculating these values would be via statistics. However, the method provided a means of comparing visual and auditory stimuli methods and is common in other fields, such as histopathology. This is in the context of looking at stained cells when testing for cancer, and when using a reference card (to compare proportions to) humans perform very well (accurate to within 5%) (Cross 1998, 2001). However, estimating proportions without a reference card (such as in this study) has a wide range of success rates, and there has been very limited research in this area, despite its relevant significance in both the cartography/GIS and histopathology fields (Cross 2010, pers. comm.).

The task chosen may limit the wider applicability of the results but there are few existing evaluations of this type so there is little comparative data and very few examples of previous successful evaluations to base the method on. It is obviously possible for the AL2 positional accuracy to be represented visually, negating the need for sonification. However, the study sought to determine if sonification could work and add to understanding so the task needed to be easy enough to ensure that most participant could answer at least some questions correctly and avoid a situation where there were widespread incorrect answers. Overall, the research demonstrates how a sonification tool can be added to an industry standard GIS and the results suggest that at least some spatial data users find such a technique a useful complement to visual representation. Upon reflection, the majority of participants answered the tasks questions correctly, so perhaps the difficultly level could have been increased. Possible future options include more complex tasks (such as clustering exercises) and other comparisons of presentation methods, utilising both sound and vision. These could include different types of sounds, such as other musical instruments, non-musical abstract sounds or potentially even real sounds depending on the data being sonified. Another possibility would be to generate sounds representing the overall data quality of the map, potentially using a 3-note chord with the volume of each note proportional to the amount of data with that quality. Such an approach would help negate the issue of the users finding it difficult to get an 'overview' of the map from sound alone, but such a sonic signal might be complex for some people to interpret.

This research has also highlighted specific characteristics that influence the ability of users to interpret sound to make proportion judgements. The proportion of the data the user is interested in and the presentation method are the two factors that appear to have the most impact on whether a person will be able to understand the information correctly. Knowledge of the data set being sonified also appears to have some impact, but is not so clearly apparent with the available data. These issues will be explored further in ongoing research which is evaluating the use of sound to represent uncertainty in UK climate scenario data and virtual reality visualisations of future landscapes.

ACKNOWLEDGEMENTS

This study has been conducted as part of ESRC/NERC PhD Studentship No. ES/F012454/1 with additional financial support from Ordnance Survey. The authors would like to thank all the participants in the survey and the Ordnance Survey for their support, particularly Jenny Harding and Glen Hart for their advice, cooperation with data and assistance with arranging the evaluation sessions. Helpful comments from the journal editor and reviewers are also appreciated.

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