Developing sounds and metrics for a smart bicycle bell

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ABSTRACT

A bicycle bell is an important safety add-on and is used by the vast majority of bicycle users. The relationship between sound design, safety performance, and personal choice has become a significant issue now that it is possible to implement almost any sound in a bicycle bell. In this paper we describe the development of new sounds for a smart bicycle bell, the adoption of localizability as a key safety measure, and the measurement of key variables such as Urgency and Pleasantness for sounds intended for different hazard situations and terrains, as well as how these variables affect the 'Coolness' and suitability of the sounds as bicycle bells.

1. INTRODUCTION

The advent of smart vehicles is potentially a boon to safety. In addition to their relative silence, both the sensing of other vehicles and the sending out of signals indicating one's presence can be a great deal more sophisticated and complex than previously [1], [2], [3]. The bicycle bell itself now has much more potential to warn and alert in different ways (possibly in different terrains) because it is no longer dependent on old technology such a hitting a bell or squeezing air through a horn.

Due to the traditional shape of bicycle bells and the method of activating them, bells and horns produce characteristic sounds which have become heavily associated with bicycles and, it can be assumed, appropriate action such as looking for a bicycle and getting out of the way. More recently, new types of bell have emerged on to the market which can be activated in different ways and the introduction of digital sound files into bells has meant that new sounds are appearing on the devices and hence onto the roads. Similarly to what has happened in other domains where alarms and alerting signals are used (healthcare, transport, chemical and oil processing, aviation) it is technically possible now to use almost any sound as an alarm and therefore also a bicycle bell. It is therefore important to know how these sounds will be perceived by both riders and pedestrians, as well as how they will interact with t heir environments.

The purchase of bicycle bells, and what motivates riders to buy particular bells rather than others, is a topic of some interest. For example, there seems to be a general belief that 'louder is better'. Horns are available for purchase which can have a maximum volume of 140dB. This is very loud indeed. Of interest here is whether the continual striving for louder and louder bicycle bells is the most ergonomic and effective way to ensure appropriate behavior on the part of the hearer, which is to note the presence of the bicycle and to get out of its way. Evidence from other areas suggests that simply making alarm sounds louder and louder does not achieve the required behavior, but leads to other problems instead [4]. Bicycle bells are also sold on the basis of aesthetic, particularly with ringing bells. Some of the more expensive of this type make very aesthetically pleasing, lingering ringing sounds. Other types of bells which are popular make what might be considered rather low-key sounds which might be used on a trail or a similar environment; these sounds tend to be operated rather differently, in that they can be turned on and then left on until the cyclist turns them off again. With the increase in range of possible bicycle bell sounds comes the opportunity to tailor sounds both to the needs and tastes of the user, and to the environment.

In this paper we describe the process of developing and testing sounds intended for possible use in a digital bicycle bell. Key features of this project center around the new issues which arise when it is suddenly possible to use any sound as a bicycle bell; what features of a bicycle bell should be used as indicators of its safety; and how to develop bicycle bells for different types of terrain which have different soundscapes.

The remit of the complete project is to develop a smart bell which is attached to the handlebar or other suitable position on a bicycle. The bell will produce a number of sounds which the user can access via an app, which are then loaded into the smart bell. The bell should have sounds intended for three different uses: 'Friendly', which might be used in the suburbs or a relatively quiet, sedate riding environment; 'Emergency', which might be used in a city or busy environment, or when collision is likely or imminent; and 'Ambient', where the sound is intended to play continually when turned on, until it is turned off again. These ambient sounds would be used in a woodland-type environment, on a trail and so on. In this paper we focus only on the sounds, not on the design of the smart bell itself.

2. SOUND TYPES

Similar to other areas where alarms and sounds for safety are used, a paradigm shift has occurred in the last few years whereby the restrictions as to what sorts of sounds can be used have now completely been lifted because sounds can now be produced digitally. Therefore the bells and horns traditionally in use are no longer the only sounds which can be used. However, we would expect riders and pedestrians, being used to horns and bells, to have interesting, possibly conservative, views on the potential use of other types of sounds as bicycle bells. In this study we carry out a survey on different classes of sounds as potential bicycle bell sounds, asking participants for their views on important aesthetic and acceptability questions about those sounds.

One of the key elements of this project was to identify the likely safety performance of each of the sounds. The required behavior on the part of the pedestrian (and possibly car driver) on hearing a bicycle bell is to get out of the way and to let the bicycle pass without incident. Of some importance may be knowing that the object making the sounds is a bicycle (rather than a car, motorcycle or other vehicle) as this will also influence behavior. The required behavior has often been assumed to be a function of the 'louder is better' logic. Of course, a louder bicycle bell will be heard over a larger area, as louder sounds will carry further. The inverse square law demonstrates that, at least in an uncluttered environment, the power of a sound will decrease by 6dB with every doubling of distance. Thus a sound that records 80dB at a distance of 1 meter will still travel some way in most environments before it becomes inaudible (probably masked by ambient noise). In emergency situations the pedestrian would have to be fairly close to the cyclist for getting out of the way immediately to be important, so there may be a ceiling to how loud bicycle bells actually need to be in practice. Very loud sounds will startle, and will not necessarily produce the required behavior. The auditory human factors literature shows many examples where alarms are turned off when they are heard, because they are too loud, diverting the operator from the problem at hand [4]. Of course, a pedestrian has no choice if a very loud sound is heard so must respond in some way.

A key action that a listener needs to perform in order to get out of the way of a bicycle quickly is to discern the direction from which it is coming. Therefore localizability might be an important metric of future bicycle bells. There is no correlation between a sound's loudness and its localizability; rather, the localizability of sound depends on other features related to its harmonic content, particularly spectral spread and to some extent the sheer number of harmonics present in a sound [5], [6]. In our exploration of the effectiveness of new bicycle bell designs we therefore investigate their localizability, using a paradigm used in the development and benchmarking of medical alarms [7], [8]. We use this test as a laboratory-based baseline measure of localizability which already has provenance in the research literature. It was used to gauge the relative localizability of different bell sounds in a controlled environment, using randomization and counterbalancing of both bells and speakers. The study is not intended as a simulation, which would be portrayed more realistically by perhaps using a pedestrian simulation task with a bicycle approaching the pedestrian from in front or behind, or even a field test in a cycling environment such as a road or a trail. In these settings the pedestrian would also use visual cues to localize a bicycle.

2.1 Experimental Design and Sounds

The experiment was a 4 (Sound type) x 2 (Urgency level) design. Eight sounds were developed, some designed specifically for this study and some taken from existing bicycle bells and other sound libraries. In each of the four categories of sound, one was a 'Friendly' sound and one was 'Emergency'. The four categories of sound were 'Abstract', 'Control', 'Music', and 'Natural'. The 'Abstract'sounds were sounds made from series' of pulses, the Friendly sound with a soft tone and downward pitch glide, the 'Emergency' with a rougher tone and an upward pitch glide. The 'Control' condition used two bells already on the market, one very loud ('Emergency') and the other a more gentle bell sound ('Friendly'). Two short musical segments were used (the 'Music' condition), one consisting a gentle vibraphone glissando ('Friendly') and the other a brass fanfare for the 'Emergency' sound. Finally two natural sounds were used, a woodpecker sound ('Friendly') and a roaring bear sound('Emergency').

2.2 Localizability Method

2.2.1. Participants

37 participants took part in the study. 24 identified as female, 13 as male. The average age of the participants was 28 years. Some were students of Psychology at Plymouth University, and others were members of the public recruited through the university. None had uncorrected hearing loss.

2.2.2. Procedure

A set of eight relatively inexpensive and small speakers was arranged in a straight line behind the participant, with the participant facing away from the speakers. They were spaced 40cm apart and placed on tripods at a height of 140cm. The entire speaker array subtended a total angle of approximately 120 degrees. Each of the eight sounds was played eight times, once from each speaker (randomized), and the participant was required to identify which of the speakers had sounded by clicking on the correct speaker as indicated in a layout mimicking the speakers' positions on a tablet placed in front of them. They were given eight seconds to respond, after which they were timed out and their response recorded as incorrect. There was an interval of 2 seconds between each trial. There were 64 trials in all and the procedure lasted approximately 15 minutes.

2.3. Localizability Results

Chance performance in this task is 12.5% as there are eight speakers. A one-sample t test confirmed that performance was above chance ($t = 990.42$, $p < 0.001$). Table 1 shows the percentage correct responses for each of the sounds.

	Abstract	Musical	Natural	Control	Overall
Friendly	47.86	49.18	42.23	42.61	45.47
	(22.08)	(17.82)	(20.06)	(21.25)	(20.38)
Emergency	45.03	49.66	37.98	33.45	41.53
	(23.40)	(20.30)	(20.32)	(19.33)	(21.41)
Overall	46.44	49.42	40.11	38.03	43.50
	(22.22)	(18.97)	(20.16)	(20.69)	(20.96)

Table 1: Percentage correct speaker identifications for each of the 8 sounds (sd in brackets)

A 4 x 2 ANOVA revealed a significant effect for Sound type ($F(3,108) = 5.65$, $p < 0.01$, BF 9.298), a nonsignificant (but close to significant) effect for Urgency (F (1,36) = 3.99, p = 0.053, BF = 0.447), and no interaction between the two.

2.3. Survey Method

2.3.1 Participants

82 participants took part in the survey. 57 identified as female, 23 as male and 2 as non-binary. The mean age was 21.8 years of age and all participants were members of the School of Psychology, University of Plymouth.

2.3.2. Procedure

The same eight sounds were used as in the Localizability study. A survey was set up on *Qualtrics* (2022). *Qualtrics* is a free on-line survey-making tool enabling the user to present questions and obtain responses from online participants. After logging in to the study and confirming their consent, participants heard each of the sounds, presented in a different random order for each participant. They were asked to rate on a 1-9 Likert scale with 1 = 'not at all' and 9 = 'very much' the answer to each of the following questions:

How urgent do you perceive this sound to be?
How pleasant do you find this sound?
How 'cool 'or fun do you find this sound to be?
To what extent would you expect to hear this sound coming from a bicycle?

2.4. Survey Results

	Abstract	Musical	Natural	Control	Overall
Friendly	6.85 (1.89)	2.72 (1.88)	5.23 (2.15)	5.25 (2.23)	5.06 (2.52)
Emergency	7.41 (1.69)	4.77 (2.07)	6.51 (2.16)	7.72 (1.77)	6.60 (2.24)
Overall	7.13 (1.81)	3.74 (2.22)	5.87 (2.24)	6.49 (2.36)	5.81 (2.51)

Table 2; Urgency ratings

	Abstract	Musical	Natural	Control	Overall
Friendly	2.65 (1.62)	6.68 (1.92)	3.83 (1.89)	5.05 (2.09)	4.55 (2.40)
Emergency	2.26 (1.51)	4.52 (2.18)	2.76 (1.82)	2.30 (1.84)	2.96 (2.06)
Overall	2.45 (1.58)	5.60 (2.32)	3.29 (1.93)	3.68 (2.40)	3.76 (2.38)

Table 3: Pleasantness ratings

	Abstract	Musical	Natural	Control	Overall
Friendly	3.32 (2.11)	5.71 (2.03)	4.16 (1.86)	3.93 (1.74)	4.28 (2.12)
Emergency	3.49 (2.21)	4.99 (2.11)	3.34 (2.29)	2.27 (1.63)	3.52 (2.28)
Overall	3.40 (2.16)	5.35 (2.10)	3.75 (2.12)	3.10 (1.88)	3.90 (2.24)

Table 4: 'Coolness' ratings

	Abstract	Musical	Natural	Control	Overall
Friendly	2.46 (1.76)	2.10 (1.61)	2.30 (1.73)	8.18 (1.57)	3.76 (3.05)
Emergency	2.10 (1.42)	2.15 (1.54)	1.30 (1.03)	2.88 (2.00)	2.11 (1.63)
Overall	2.28 (1.58)	2.12 (1.57)	1.80 (1.50)	5.53 (3.21)	2.93 (2.58)

Table 5 Expectation ratings

2.5. Discussion

The key finding from the localizability study is that all of the sounds were considerably more localizable than by chance. Extrapolating from this, we can infer that the mere presence of a bicycle bell helps the hearer to identify that a bicycle is approaching. Our data showed that within this context (the speakers in a straight line, 40cm apart) performance varied from just under 50% to just above 30%. In other studies ([7], [8]) we have found performance to be considerably higher, but this is because in those studies the speakers were set out in a circle (thus covering 360 degrees) and were further apart both in distance and in angle. Using the percentage performance, and the angle subtended by each of the speakers (about 15 degrees apart if placed in a circle), we can calculate the angle at which performance would likely reach 100%, and also cite this performance as a metric indicating how much more accurate localization would be with or without a sound. This equates to a figure of about 12 times better than chance for the best-performing sounds and 8 times better than chance for the least well performing sounds. This may translate into a meaningful measure in practical settings. In practical settings, pedestrians will also have other cues such as visual cues, prompts from colleagues and so on.

The reason why different types or classes of sounds might be more or less localizable than one another is because of differences in harmonic richness and spectral spread, not because they are different types of sounds *per se.* We found that the Music and the Abstract sounds were easier to localize than the Natural and the Control sounds. The harmonic content of the former two sets of sounds was much more within our control than the latter, which meant that we were able to imbue greater localizability (through the adding of many harmonics over a large spectral range) into the design of those sounds than the other two sound pairs, for which we used already-existing sounds. Our finding that the Control sounds were the least localizable suggests that the localizability of those sounds may not have not been a key concern in their design and implementation, though in this study we tested recordings of those sounds played through the experimental speakers, rather than through the original devices used to produce those sounds. A follow-up study using the actual sounding devices would shed further light on this topic.

The survey served as a check on the Urgency and Pleasantness (translating to 'Friendliness') measures, as well as providing some feedback on the kind of reception these different types of sounds might have if released in a product. Of course, many of these sounds had been heard for the first time in the context of bicycle use and, if used in the product, it would be expected that familiarity and liking ratings would change with exposure and complexity [9]. Most importantly, the ratings confirmed that the Emergency sounds received higher Urgency ratings than the Friendly sounds for all four categories. They also confirmed that the Friendly sounds were perceived as more Pleasant than the Emergency sounds. In both cases, this serves as a validity check and is useful for design purposes, as we see the influence of design choices on the perception of these features of the sounds.

We added 'Coolness' of the sounds to the rating scales because it is thought to be an important influence in purchasing intentions [10]. Having some sounds which are 'cool', 'fun', or 'quirky' is seen to have a positive impact on people's purchasing decisions. Here, we see that the Music sounds, which in this case were short musical 'stingers', were seen as the most cool, and the Emergency Control sound was seen as the least cool. Natural animal sounds and Music were rated as cooler sounds than both the already existing sounds, and the abstract alarm-type sounds.

Finally, it is not surprising that none of the sounds scored high on expectation except for the Friendly Control bell, which was a typical ringing bicycle bell. Not even the Emergency Control sound, the very loud horn, scored high on this measure. All of the sounds produced low scores, but the Natural sounds scored the lowest. Of course, if such sounds were used in smart bells as a matter of course, the suitability judgments would change quite dramatically.

The methodologies used suggest that the localizability test is a useful benchmarking technique with which to compare different bell sounds. The data obtained from the test allows bells to be compared on relative localizability, a measure which will be useful in demonstrating an important safety feature of bicycle bells. In the real world, other aspects (such as visual cues, expectations, other pedestrians, the cyclist themselves) will also contribute to the localizability of a bicycle. The survey shows that different bell sounds produce different aesthetic responses, which will also have an influence on where the sounds are used. For example, a pleasant sound may be used on a trail or in a quiet environment, whereas an urgent bell may be used in a city environment, or where impact between the bicycle and another object is imminent. The numbers obtained from the survey suggest that further improvements can be made to the bells in order to maximize their intended impact and aesthetic.
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3. ACKNOWLEDGEMENT

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