EVALUATION OF AUDIBLE TRAFFIC SIGNALS FOR PEDESTRIANS WITH VISUAL IMPAIRMENT

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SUMMARY

Audible signals are used at several road intersections across Canada to enable pedestrians with visual impairment to cross safely. The acoustic parameters can be quite different among the different signals used and this can be the source of particular difficulties for the users. A study was conducted to identify which signal is the easiest to localize, among 6 signals proposed, and which one is judged the safest. Two of the signals (cuckoo and peep-peep) are standardized by the Transportation Association of Canada, and the remaining signals are four variations of the melody signal proposed by the Institut Nazareth et Louis-Braille (Longueuil, QC). A group of 10 subjects with normal vision and 10 subjects with visual impairment participated. Objective sound localization measurements were made outside on a quiet street using a rotating chair as angular pointer. A questionnaire was also administered to obtain an individual appraisal of the 6 signals, and a rating system allowed judging the signals relative to each other. The results for the melody signals varied substantially with the fundamental frequency and harmonic richness of the musical sequence. Two of the melodies, with the lowest fundamental frequency and richest harmonic content, emerged as the best signals overall. Among the standardised signals, the cuckoo provided acceptable performance, but the peep-peep should be abandoned because of very poor subjective assessment.

SOMMAIRE

Des signaux sonores sont utilisés à certaines intersections routières au Canada pour assurer une traversée plus sécuritaire pour les piétons atteints de déficience visuelle. Les paramètres acoustiques peuvent être très différents d'un signal à l'autre et créer des difficultés pour les utilisateurs. Une étude a été menée afin d'identifier lequel, parmi 6 signaux sonores, est le plus facile à localiser, et celui qui est jugé le plus sécuritaire. Deux des signaux (cuckoo et peep-peep) sont normalisés par l'Association des transports du Canada et les autres sont quatre variantes du signal de mélodie proposé par l'Institut Nazareth et Louis-Braille (Longueuil, QC). Un groupe de 10 sujets avec vision normale et 10 sujets avec déficience visuelle ont participé à l'étude. Des mesures objectives de localisation sonore ont été réalisées à l'extérieur sur une rue calme à l'aide d'une chaise pivotante comme pointeur d'angle. Un questionnaire d'appréciation individuelle des 6 signaux devait aussi être complété, et un système permettait de coter les différents signaux entre eux. Les résultats pour les signaux de mélodie variaient sensiblement selon la fréquence fondamentale et la quantité d'harmoniques retenus dans la séquence musicale. Deux des mélodies, possédant la fréquence fondamentale la plus basse et les plus riches en harmoniques, se sont avérées les meilleurs signaux. Parmi les signaux normalisés, le cuckoo a produit un rendement acceptable, mais le peep-peep devrait être abandonné en raison d'un très faible rendement subjectif.

1. INTRODUCTION

For several years, specialists in Orientation and Mobility and blind pedestrians have been questioning the safety of audible traffic signal systems in place at road intersections in many Canadian cities (Hall et al., 1996). An attempt was made to standardize audible traffic signals in 1992 with the A6.80 standard by the Transportation Association of Canada. This standard suggests two audible traffic signals: a 'peep-peep' for crossing East-West and a 'cuckoo' for crossing North-South. The two signals do not seem to have unanimous approval. Many people report that the signals are too similar to environmental sounds, such as the song of birds, and are difficult to hear through the background noise or traffic.

Hall et al. (1996) made an extensive survey of the literature and the audible traffic signals used in many countries, and addressed various factors that audible signals must have to ensure safe crossing at road intersections, such as the acoustic characteristics. They also consulted potential pedestrian users from the City of Montreal about these different sounds. The safety of the user has been the single most important factor to consider. Sounds that could be easily confused with those commonly found in the environment were rejected. These included bird calls, such as cuckoo and peeping sounds. Buzzing and beeping sounds were also rejected since they closely resembled the warning signals on trucks moving in reverse direction. Having considered all these factors, melody signals were recommended. Czyzewski and Kostek (1996) as well as Tauchi et al. (1998) have recently considered this alternative for Poland and Japan, respectively. Hall et al. (1996) proposed the development of an audible traffic signal consisting of a four-note melody for the walking phase of the pedestrian crossing.

A study conducted by Ratelle et al. (1998) at a busy intersection in the east of Montreal (Sherbrooke and Fletcher streets) showed that pedestrians with visual impairment display good performances in crossing after only a few trials, and that they judge the melody system adequate in terms of mode of operation, choice of melody, and sound intensity. Following this study, Laroche (1998) was asked to verify the acoustic characteristics of the system generating the melody at this intersection. The principal objective was to verify the acoustic pressure level generated by the system in order to ensure optimal audibility of the melody in the background noise likely to happen at this location.

Analysis of the data collected in March 1998 highlighted several elements that needed further consideration (Laroche, 1998). The audible traffic signal generated by the studied system had several shortcomings. The level did not seem equivalent on both sides of the intersection. A 9 dB difference was noted between the average level generated at the Northeast corner and the one generated at the Southeast corner. Moreover, each note of the melody did not seem to be sufficiently rich in harmonics to ensure good sound localization, based on accepted knowledge (Laroche, 1994; Canévet, 1998). Good sound localization of the audible traffic signal can be critical to blind pedestrians to maintain proper alignment during crossing. Actually, each note of the tested melody signal had only the fundamental frequency and one harmonic (the third), and the level of this harmonic was at least 6 dB softer than the fundamental. Finally, the rise and fall times of 10 ms for each note could be briefer to facilitate localization (Rakerd and Hartmann, 1986).

The aim of the present study was to collect further information on the contribution of different acoustic parameters (frequency spectrum, rise/fall time) of the audible traffic signals necessary to ensure a sufficiently accurate sound localization and pedestrian safety. Six different audible traffic signals that are presently used or could be used to facilitate crossings of road intersections by pedestrians with visual impairment were assessed. The final goal was to identify the signal(s) that display(s) the best results in terms of sound localization performance and that the participants judged to be acceptable.

2. METHODOLOGY

2.1 Audible traffic signals

The following audible signals were tested in this project:

Signal 1 — This is the 'cuckoo' proposed in the Canadian standard on audible traffic signals for blind pedestrians (Transportation Association of Canada, 1992). The signal consists of a sequence of two complex sounds, the first having a duration of 70 ms and being of higher pitch (fundamental frequency F_0 @ 1100 Hz), and the second having a duration of 140 ms and being of lower pitch (F_0 @ 900 Hz). Each sound contains harmonics of the fundamental up to approximately 8000 Hz. The level of the harmonics decreases at a rate of about 6 dB per harmonic. There is a pause of about 200 ms between the two sounds. The signal is repeated every 1.5 seconds.

Signal 2 — This is the 'peep-peep' proposed in the Canadian standard on audible traffic signals for blind pedestrians (Transportation Association of Canada, 1992). The signal, of a duration of 140 ms and repeated every 1.0 second, sounds like a bird chirp and consists mainly of a downward frequency sweep between 4200 Hz and 1900 Hz, for the fundamental, and between 8400 Hz and 3800 Hz, for the second harmonic.

Signal 3 — This is the original melody recommended by the Institut Nazareth et Louis-Braille of Longueuil, Quebec (Hall et al., 1996). It consists of a sequence of 4 notes, each lasting 300 ms (with rise/fall times of 10 ms), without pauses between notes. Spectral analysis indicated a fundamental frequency of about 1325 Hz, 1125 Hz, 1000 Hz and 900 Hz for notes 1 through 4, respectively, and the presence of the third harmonic component for each note at a level at least 6 dB lower than the fundamental. Each 4-note melody sequence lasts for 1.2 seconds and can repeated without pause to generate a signal of any desired length.

Signal 4 — This is similar to signal 3, except that all the possible harmonic components are included for each note up to 8000 Hz. The level of the harmonics decreases at a rate of 3 dB per successive harmonic. Signal 4 has the same pitch as signal 3, but has a different timbre reflecting a richer harmonic content.

Signal 5 — This is similar to signal 4, except that the fundamental frequency is decreased by a factor 2. Therefore, this is signal 4 played one octave lower.

Signal 6 — This is similar to signal 5, except that the duration of each note is decreased to 250 ms and a pause of 50 ms is introduced between notes. The rise/fall times of each note are decreased to 1 ms. Compared to signal 5, there is a more definite temporal separation between notes.

2.2 Experimental subjects

Recruitment of the subjects started after approval of the project by the Ethics committee for research with human subjects at the University of Ottawa. Subjects had to meet the following hearing criteria: (1) audiometric thresholds better than 15 dB HL from 500 to 8000 Hz, (2) normal external auditory canals, (3) normal tympanograms, and (4) no history of otologic problems.

Sixteen blind subjects and ten subjects with no visual problems were invited to participate. Six blind subjects were eliminated because they did not meet the screening criteria. Thus, a total of 20 subjects (10 subjects with normal vision and 10 blind subjects) completed the experimental procedure. The average age was 25 years for the group of normal subjects, and 41 years for the group of blind subjects. Among the blind subjects, half were blind from birth and half developed blindness after birth. One blind subject did not complete the entire experimental procedure.

The walking methods and mobility abilities of the subjects were not taken into account at the time of recruitment. Moreover, use of a guide dog and cane were not considered during the experimentation. Finally, familiarity with the existing audible traffic signals (e.g. 'cuckoo' and 'peep-peep') was not a part of the selection criteria. It would have been very difficult to recruit blind subjects meeting all these criteria. Also, there is no evidence in the literature that a familiar sound is easier to localize than a new sound. Finally, the objective was to identify the easiest audible traffic signals to localize by the subjects as a whole, and not to compare the inter-subject performance or mobility.

2.3 Experimental set-up

The experiment took place in the middle of a dead-end street in the Municipality of Hull, Quebec. No obstacles (houses, cars or others) were present under 15 metres of the experimental set-up, as to eliminate any reflection of the sound waves, except for those due to the paved road (asphalt). The subject sat on a rotating chair placed over a vinyl carpet having a 1.15-meter radius and lying on the pavement. The carpet was graduated in 1-degree steps, from 0 to 360°. The chair was equipped with a pointer attached to the backrest. The pointer was suspended vertically down to a distance of about 3 cm from the carpet. The device was used to facilitate the reading of the angular data on the carpet (Figure 1).

The audible traffic signals were presented with a loudspeaker (JBL Pro3) mounted on a tripod, itself mounted on a cart. The loudspeaker was plugged to an amplifier (SCS 2150A), itself plugged to a portable computer (Toshiba T6600C). The centre of the loudspeaker was 2.25 metres above the ground. The horizontal distance between the loudspeaker and the centre of the rotating chair was 8.63 metres (Figure 1). Once seated, the subject's head was about 1.12 metre above the ground.

The frequency response of the loudspeaker system, measured at one metre in front of the speaker, is uniform at ± 5 dB between 100 Hz and 10000 Hz. This response is larger in bandwidth and more uniform than the typical commercial speakers used for generating the audible traffic signals for pedestrians. Within the scope of this study, we preferred to use a high-fidelity loudspeaker in order to obtain results that are as much as possible independent from the spectral characteristics of a particular speaker.

The frequency response of the entire experimental set-up from the electric signal at the input of the loudspeaker amplifier to the sound pressure at the position of the subject's head, the subject being absent, is illustrated in Figure 2. This

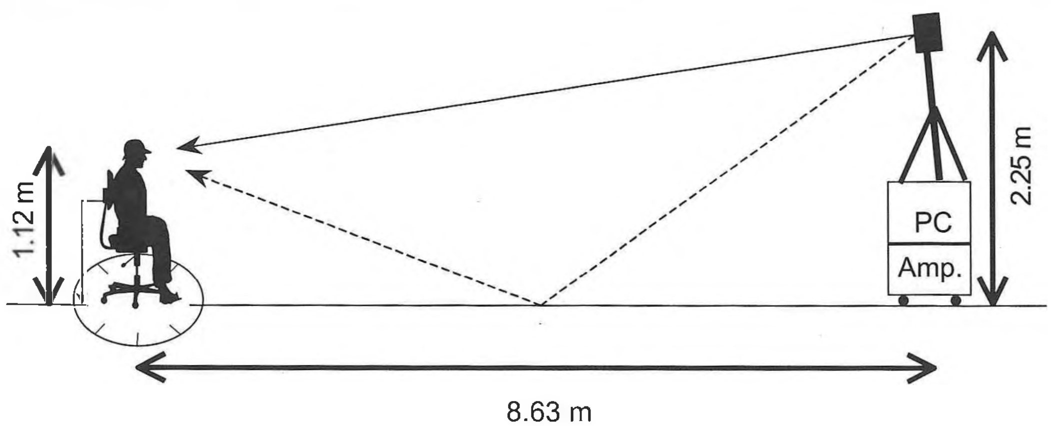

Figure 1. Schematic Diagram of the experiment set-up. The direct wave is shown with a solid line and the wave reflected from the road is shown with a dashed line.

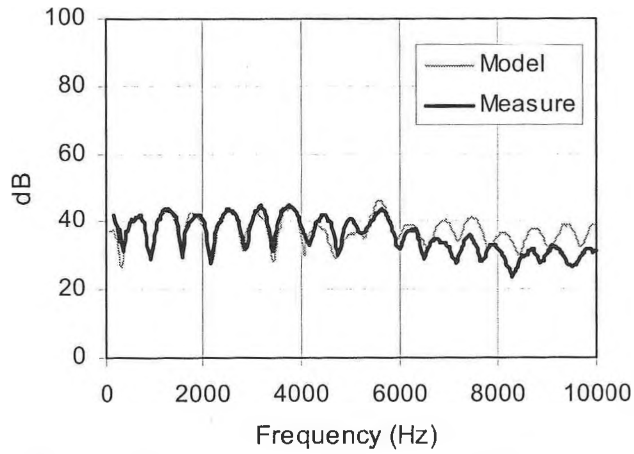

Figure 2: Frequency response of the experimental set-up measured at the subject's position. The model response is the spectrum of a direct wave with reflected wave delayed by 1.6 ms. The reflection coefficient on the road is 0.65 up to 4000 Hz and 0.40 beyond 4000Hz. The electroacoustic response of the loudspeaker is included in the model.

response consists of a series of resonance peaks and troughs with a frequency spacing of about 625 Hz between adjacent peaks or troughs. The level difference between the resonance peaks and troughs is around 14 dB up to 4000 Hz and 7-8 dB beyond this frequency.

Figure 2 also shows that the measured frequency response corresponds closely to the spectrum of a direct wave and a reflected wave of smaller amplitude arriving later at the measurement point. The 625 Hz frequency spacing indicates that the reflected wave is late by 1.6 ms, which is exactly the anticipated delay of the reflection on the asphalt pavement given our experimental set-up. Moreover, the level difference between the resonance peaks and troughs indicates that the reflection coefficient on the pavement is around 0.65 up to 4000 Hz and 0.40 beyond this frequency. In Figure 2, the frequency response of the loudspeaker system has been incorporated to the model to enhance the correspondence between the measurements and the model. On the other hand, the atmospheric attenuation effect was not incorporated, which could explain the slight gap between the measurements and the model beyond 7000 Hz.

During the experiment, the sound pressure level of the audible traffic signals was set to a comfortable level of 65 dB(C) at the subject's location. Measurements were made with an Alcan SLS95 sound level meter. The surrounding environmental noise level was about 50 dB(A), which allowed a sufficiently high signal-to-noise ratio in the frequency bands of each audible traffic signal to ensure good audibility (Tran Quoc and Hétu, 1996).

2.4 Experimental procedure

The subject was blindfolded to eliminate any visual cues. Each signal was presented through a fixed source, but was received by the subject from 12 different starting chair rotations spaced 30° apart in a random order. Between each presentation, the subject was disoriented by slowly rotating the chair, while ensuring that she/he did not become dizzy, and positioned at one of the selected starting angles. The subject then listened to the audible traffic signal, and had to turn the chair in direction of the perceived fixed sound source, stopping the rotation when confident that she/he was well oriented. The total duration of each traffic signal was fixed at 6 seconds. The subject was allowed to start the rotation during the signal presentation. The pointer attached to the back of the chair allowed the reading of the angle at which the subject had stopped. The graduated carpet was positioned in such a way that the 0-degree angle corresponded to an orientation of the subject directly in front of the speaker (no angular error). The sign and size of any localization error was noted from this reference. For instance, if the subject stopped at position 5° (too much to the left), the researcher recorded a value of +5°. If the subject stopped instead at 357° (too much to the right), a value of -3° was recorded.

Finally, the subjects were asked to assess the audible traffic signals. A short questionnaire was completed for each traffic signal to allow identification of the signals that were perceived as acceptable or effective to ensure safe crossings at road intersections. This questionnaire was based on the one devised by Ratelle et al. (1998). A relative appraisal of the localizability of signals was also made by asking the subjects to position each signal on a graded scale, while cross-comparing them (Figure 3).

Figure 3: Tactile scale used by the subjects to indicate their level of confidence in judging the localization of the signals.

3. RESULTS

3.1 Localization of audible traffic signals

For each subject and signal, we characterized the performance in sound localization based on the method proposed by Rakerd and Hartmann (1986). This method involves the calculation of three distinct measures of localization error.

Constant error — It is the simple average of the 12 individual measurements of error for each subject for a given signal.

For this calculation, we keep the sign of the error, i.e. whether the subject responded on the left (+) or right (-) of the true speaker position. Thus, the constant error indicates if there is a tendency to respond in a preferential manner on either side of the loudspeaker.

Variable error — It is the standard deviation of the 12 individual measurements of error for each subject for a given signal. The variable error indicates the precision or consistency of the subject's responses once the lateral bias introduced by the constant error is eliminated

Total error — It is the root-mean-square average of the 12 individual measurements of error for each subject for a given signal. The total error indicates the global error of localization without taking into account the sign of the error of individual measurements.

A subject who would make large errors of localization, but whose responses would be symmetrically distributed on the left and right of the speaker, would have a zero constant error and a high variable error. A subject who would have a clear tendency to respond on one particular side of the speaker, but who would be very consistent in his/her responses, would have a large constant error and a small variable error. In both cases, the total error would be large.

The sound localization results are summarised in Table 1. For each of the three error measures, we present the localization performance for the two groups of subjects and each signal. The performance calculated over all subjects is also presented. For each signal, the reported error value is the simple average of the error (constant, variable or total) of all the subjects of a same group.

The constant error ranges between -6.2° (right side) and 9.0° (left side) across subjects. This indicates that some subjects have a clear tendency to respond on a preferential side. However, when we calculate the mean over all the subjects of a same group (Table 1), the positive and negative errors cancel out and the constant error oscillates around 0°. For the subjects with normal vision, it is -0.3° on average over the six signals. For the blind subjects, the constant error is slightly positive (towards the left) for each signal and 2.0° over the six signals. The constant error over the total subject pool and signals is 0.79°. A repeated measures (2 factors) ANOVA statistical analysis shows that there is no group or signal effect for the measure of the constant error and no group-by-signal cross effect ($p>0.05$).

Table I: Sound localization results by subject group and signal. Mean (standard deviation)

Constant error (degrees)								
Group	n	Signal 1	Signal 2	Signal 3	Signal 4	Signal 5	Signal 6	Ave.
Normal	10	+0.18 (3.4)	-1.0 (4.5)	-0.92 (5.1)	+0.40 (3.9)	-0.27 (3.6)	-0.19 (3.7)	-0.30
Blind	9	+2.6 (5.0)	+2.1 (5.0)	+2.2 (5.3)	+2.3 (5.8)	+0.57 (4.1)	+2.4 (4.9)	+2.0
Total	19	+1.3 (4.3)	+0.45 (4.9)	+0.54 (5.3)	+1.3 (4.8)	+0.13 (3.8)	+1.0 (4.4)	+0.79

Variable error (degrees)								
Group	n	Signal 1	Signal 2	Signal 3	Signal 4	Signal 5	Signal 6	Ave.
Normal	10	4.7 (2.8)	3.7 (0.5)	5.2 (1.5)	3.8 (1.6)	3.7 (0.9)	3.8 (2.3)	4.1
Blind	9	3.7 (1.6)	4.0 (1.4)	4.7 (2.2)	4.0 (1.8)	3.5 (1.4)	3.8 (1.7)	4.0
Total	19	4.2 (2.3)	3.8 (1.0)	5.0 (1.8)	3.9 (1.7)	3.6 (1.1)	3.8 (2.0)	4.0

Total error (degrees)								
Group	n	Signal 1	Signal 2	Signal 3	Signal 4	Signal 5	Signal 6	Ave.
Normal	10	5.6 (2.8)	5.5 (1.7)	6.9 (2.5)	5.1 (2.2)	4.9 (1.4)	5.1 (2.4)	5.5
Blind	9	6.1 (3.0)	5.9 (3.3)	6.9 (3.1)	6.4 (3.9)	4.9 (2.5)	5.9 (3.3)	6.0
Total	19	5.9 (2.8)	5.7 (2.5)	6.9 (2.7)	5.7 (3.1)	4.9 (1.9)	5.5 (2.8)	5.8

The variable error is similar for the subjects with normal vision and the blind subjects, or approximately 4.0° on average over all signals. Over all subjects, the variable error varies as a function of signal between 3.6° (signal 5) and 5.0° (signal 3). A repeated measures (2 factors) ANOVA shows that there is no group effect ($p>0.05$), but that there is a significant difference between signals ($p=0.02$). There is no group-by-signal cross effect ($p>0.05$). A Fisher PLSD type post-hoc analysis shows that, with a confidence criterion of 95%, signal 3 is significantly different (larger error) from signals 2, 4, 5, and 6.

The total error is slightly less for subjects with normal vision than for blind subjects, that is 5.5° versus 6.0° in average for the six signals. Over all subjects, the error also varies as a function of signals between 4.9° (signal 5) and 6.9° (signal 3). A repeated measures (2 factors) ANOVA shows that there is no group effect ($p>0.05$), but that there is a significant difference between signals ($p=0.04$). There is no group-by-signal cross effect ($p>0.05$). A Fisher PLSD type post-hoc analysis shows that, with a confidence criterion of 95%, signal 3 is significantly different (larger error) from signals 2, 4, 5, and 6.

3.2 Subjective appraisal of audible traffic signals

For each subject and signal, we have quantified the results of the subjective appraisal. We derived two measures of the level of appreciation of the signals by the subjects.

Individual appraisal — It is a measure calculated from the short questionnaire about sound quality, intensity level, ease of localization, and the level of safety brought by each signal. Each of the 4 questions counts for 25%. The maximal value of 100% corresponds to a signal that would be judged very appropriate or very appreciated in all regards. The subjects had to judge every signal individually.

Relative appraisal — It is a measure calculated from the 0 to 100% scale in Figure 3. It relates to the level of localization confidence brought by each signal. The subjects had to judge the signals by comparing them with each other.

The results of the subjective appraisal evaluations are summarised in Table II. For each measure, we show the degree of appreciation of each audible traffic signal for each group of subjects. We also show the degree of appreciation of the signals over all the subjects.

The individual appraisal level of the signals is quite similar for both groups of subjects. Over the total subject pool, the individual appraisal score varies as a function of signals between 61% (signals 2 and 3) and 81% (signal 6). The average individual appraisal level is 72%. A repeated measures (2 factors) ANOVA revealed that there is no group effect ($p>0.05$), but that there is a very significant difference between signals ($p=0.0001$). There is no group-by-signal cross effect ($p>0.05$). A Fisher PLSD type post-hoc analysis shows that, with a confidence criterion of 95%, signals 2 and 3 are significantly different (lower appraisal score) from signals 1, 4, 5, and 6. Within those two signal categories, there are no significant differences.

The relative appraisal score varies within a very narrow range between 53% (signal 4) and 63% (signal 5) for sub-

Table II: Subjective appraisal results by subject group and signal. Mean (standard deviation)

Individual appraisal (%)								
Group	n	Signal 1	Signal 2	Signal 3	Signal 4	Signal 5	Signal 6	Ave.
Normal	10	73 (20)	67 (13)	54 (13)	75 (12)	77 (13)	79 (13)	71
Blind	10	77 (20)	55 (17)	68 (14)	79 (13)	82 (15)	84 (13)	74
Total	20	75 (20)	61 (16)	61 (15)	77 (12)	79 (14)	81 (13)	72

Relative appraisal (%)								
Group	n	Signal 1	Signal 2	Signal 3	Signal 4	Signal 5	Signal 6	Ave.
Normal	10	59 (25)	54 (25)	57 (22)	53 (33)	63 (22)	58 (26)	57
Blind	10	64 (39)	32 (29)	30 (19)	56 (32)	72 (25)	75 (19)	55
Total	20	62 (32)	43 (29)	44 (24)	54 (31)	67 (24)	66 (24)	56

jects with normal vision. For blind subjects, on the other hand, this level varies over a larger range between 30% (signal 3) and 75% (signal 6). The average relative appraisal level over all the signals is similar for both groups, namely 55-57%. A repeated measures (2 factors) ANOVA revealed that there is no group effect ($p>0.05$), but that there is a very significant difference between signals ($p=0.006$) and a barely significant group-by-signal cross effect ($p=0.049$). A Fisher PLSD type post-hoc analysis made with the total pool of subjects shows that, with a confidence criterion of 95%, signals 2 and 3 are significantly different (lower appraisal score) from signals 1, 5, and 6. Signal 4 is not significantly different from any other signal. A post-hoc analysis made with the blind subjects only shows the same results, except for signal 4, which is also different from signal 3. With the subjects with normal vision, there is no significant difference between the six signals.

4. DISCUSSION

4.1 Choice of optimal audible traffic signal

The principal aim of this study was to determine which audible traffic signal would be the most appropriate to facilitate crossings at road intersections by blind pedestrians. The factors studied for the choice of signal were the ease of localization of the sound, as measured by an objective test (Section 3.1), and the subjective appraisal of the signals by the normal vision and blind subjects participating in this experiment (Section 3.2).

Sound localization performance was analyzed using three different measures. For the constant error, we noted important variations from one subject to the other, but on the whole, there were no significant differences between the different signals or between the two groups of subjects. Over all the subjects, the constant error for each signal is near 0°. This is consistent with our expectations, given the right-left symmetry of the experimental set-up.

For the two other error measures, the variable error and the total error, we noted some significant statistical differences between signals. On the other hand, there were no significant differences between the two groups of subjects. The statistical ranking of the signals being the same for both types of error, we retained the results of the total error. This error indicates the global localization error. In Figure 4, the total error is drawn along a vertical axis and the statistical clusters are identified. It is clear that localization performance with the melody signals (signals 3, 4, 5, and 6) varies widely according to the acoustic characteristics of the signals, as defined in Section 2.1. The two bird call signals from the Canadian standard (signals 1 and 2) show very similar performance near the average performance across signals (5.8° error).

In Figure 4, the melody signals that are easier to localize (least error) are the ones with a low fundamental frequency and rich in harmonic content (signals 5 and 6). In contrast, the melody signal with a high fundamental and poor in harmonic content (signal 3) is the least easy to localize. The intermediate melody (signal 4), with a high fundamental but rich in harmonics, ranks between these two extremes. Within the scope of this study, we did not note any localization improvement when the rise/fall times of each note of signal 5 are shortened and when pauses between notes are inserted (signal 6). These modifications have even brought a slight decrease in localization (though not statistically significant).

In Figure 4, we also show the individual and relative appraisal scores for each signal along a vertical axis and identify the

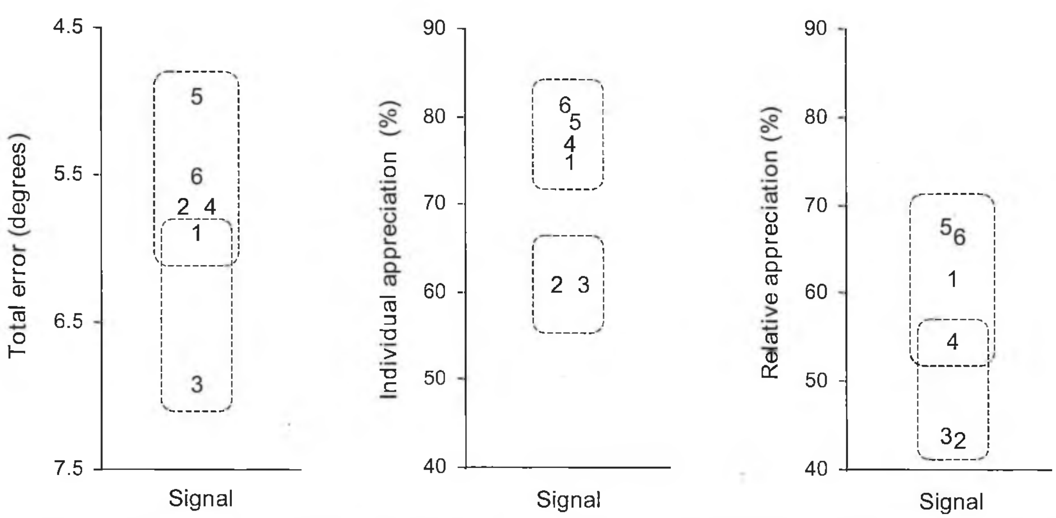

Figure 4: Summary of results for the total localization error and the two measures of subjective appreciation. Results are based on the total of the subjects. The statistical clusters are based on Fisher PLSD post-hoc analyses with a 95% confidence criterion.

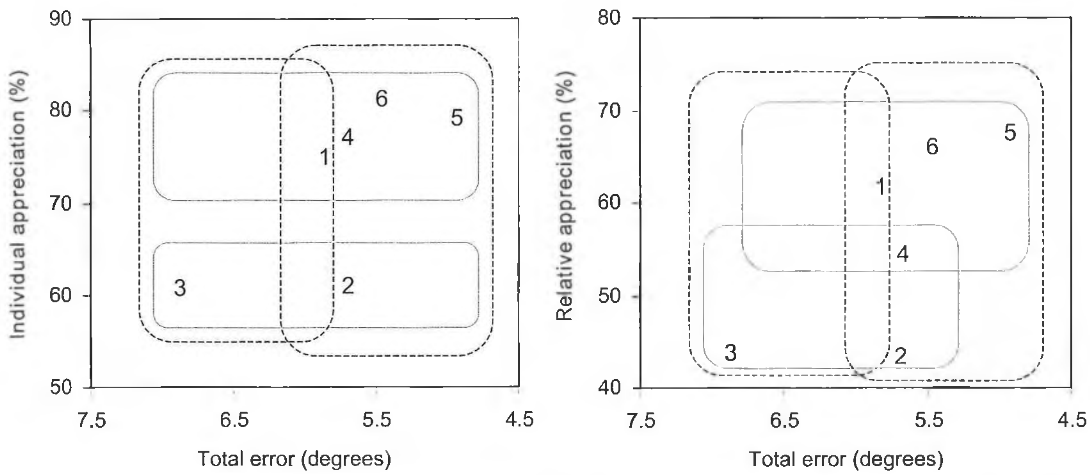

Figure 5: Summary of the results of individual and relative appreciation as a function of the total error of localization. Results are based on the total of the subjects in the experiment. The statistical clusters are based on Fisher PLSD post-hoc analyses with a 95% confidence criterion. The rectangles in solid line are the subjective appreciation statistical clusters. The rectangles in dashed line are the total localization error statistical clusters.

statistical clusters. In both cases, we presented results related to the total of all subjects since there was no group effect for these measures. There was also no group-by-signal cross effect for individual appraisal. For relative appraisal, there was a barely significant group-by-signal cross effect. However, for this measure, the statistical clusters among signals realised with all the subjects were largely dependent on the results from the blind subjects.

It is obvious from Figure 4 that signal 2 (standardized 'peep-peep') and signal 3 (the original melody signal) are significantly less appreciated than other signals. Moreover, these two signals get only 61% in the individual appraisal questionnaire, which means that the subjects' impression is generally neutral. Signals 1 (standardized 'cuckoo') and signal 4 get an individual appraisal score of 75 to 77%, whereas signals 5 and 6 get a score from 79 to 81%. For the latter two signals, this means that they are appreciated or judged to be appropriate by the subjects. It should be noted that, among the two groups of subjects, it is the blind subjects that particularly appreciated signals 5 and 6, at a score of 82 to 84% (Table II).

Finally, we have drawn in Figure 5 the results of individual (or relative) appraisal as a function of the total localization error, and identified two-dimensional statistical clusters of signals. The best signals are found in the upper right corner. The plot of the individual appraisal as a function of total error indicates that the best signals are the melody signals 4, 5, and 6. The plot of relative appraisal as a function of total error indicates that the best signals are melody signals 5 and 6. Overall, signals 5 and 6 thus seem to be the two best choices to facilitate crossings at road intersections by blind pedestrians. Both signals have a low fundamental frequency and are rich in harmonic content. The lack of statistical difference between the two signals indicates that the introduction of a short pause between notes and a shorter rise/fall time for signal 6 did not further improve the design of the melody. Thus, we recommend the use of signal 5. This signal is easier to generate and is more similar to the original concept of a melody signal proposed by Hall et al. (1996) and Ratelle et al. (1998) than signal 6.

4.2 Practical considerations

The results of the preceding sections highlight that the use of melody signal 5 would be associated with better localization performances as well as a subjective appraisal superior to the one associated with signal 3, the original melody. We can now estimate how the 2° difference between the total error associated with signal 5 (4.9°) and signal 3 (6.9°) would translate in everyday life, when a blind pedestrian crosses a road at an intersection?

We calculated the lateral deviation at the end of a typical crossing given an angular localization (alignment) error at the start of the crossing. The basic formula below is used:

$$D = L \times \tan \theta$$

where D is the lateral deviation (m) at the end of the crossing in reference to the central line of the corridor, L is the length of the intersection (m) and θ is the angular error (°) at the start of the crossing. We assume that the pedestrian starts in the centre of the pedestrian corridor and that the traffic device emitting the audible signal is aligned with the centre of the corridor. The pedestrian corridor is assumed to be 3 m wide.

Taking a typical 4-lane intersection with a narrow median (about 20 metres long), an alignment error of 4.9° (signal 5) will result in a crossing 0.2 m outside the lateral boundary of the pedestrian corridor, i.e. at a deviation of 1.7 m from the corridor's central axis. If the error is rather on the order of 6.9° (signal 3), the deviation from the central axis of the corridor will then reach almost 2.4 m, that is almost 1 metre outside the lateral boundary of the corridor. So the larger the localization error, the greater the likelihood of a crossing far exceeding the lateral boundaries of the pedestrian corridor and the higher the risks of accident.

In interpreting these results we have to keep in mind that in practice the pedestrian may be able to compensate for his/her starting alignment error while walking along the crossing and hearing the signal. Still, signal 3 was more difficult to localize and even the compensation made by the pedestrians could be insufficient to ensure a crossing inside the pedestrian's corridor. Moreover, audible traffic signals typically last only during the walking phase of the crossing and not during the clearing phase, which means the pedestrian is often left to complete the crossing without any audible sound. This concept of compensation while crossing is under study in a separate set of experiments.

5. CONCLUSIONS

This study demonstrated that the melody signals are not necessarily easier to localize or judged to be more acceptable than the standardized audible traffic signals based on bird calls by the Transportation Association of Canada. In fact, the original melody signal generated a localization performance statistically inferior to the standard 'peep-peep' and a subjective appraisal score statistically inferior to the standard 'cuckoo'. However, two of the melodies designed in this study offered a superior localization performance and subjective appraisal score than all the other signals, those of Canadian standard included. The proposed signal contains the same four notes as the original melody, but each note is played one octave lower in frequency and is much richer in harmonics.

Hence, the concept of a melody signal should be retained as an audible traffic signal for blind pedestrians, but the choice of the acoustic characteristics of the signal plays a major role in determining the ease of localization in space and the level of subjective appraisal of the sound. The standardized 'peep-peep' signal should be abandoned due to poor subjective appraisal. The standardized 'cuckoo' is found to be adequate.

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