Vuvuzelas at South African soccer matches: risks for spectators' hearing

L. Ramma, L. Petersen, S. Singh

University of Cape Town, Groote Schuur Hospital, Old Main Bldg, F-45, Observatory, 7925, Cape Town, South Africa, *E-mail: Lebogang.Ramma@uct.ac.za*

ABSTRACT

South African Premier Soccer League (PSL) matches are known worldwide as some of the noisiest recreational events. Therefore, the objectives of this study were to i) measure noise levels during different PSL matches; ii) measure changes in auditory function after attending PSL matches; and iii)determine the factors that increase the risk of overexposure to noise during PSL matches. The study used a descriptive quantitative analytical pre- and post-exposure design. Participants (n=19 and n=10) attended two PSL matches. Each participant's auditory function was assessed using distortion product oto-acoustic emissions (DPOAEs) before and after attending a PSL match. Peak sound pressure (L_{Cpk}) and equivalent continuous (L_{Aeq}) levels as well as noise dose were measured during each match. Noise levels recorded during the poorly attended Match 1 were lesser than those of the well-attended Match 2. Participants attending Match 2 had statistically significant reduction in their DPOAE amplitudes after the match (p=0.003) than those attending Match 1. *Vuvuzela* blowers and participants seated within 1 m from them were most at risk of harm to their hearing with significant reduction in DPOAE amplitudes post the match (p=0.002 and p= 0.008, respectively). It was therefore concluded that noise levels at well-attended South African PSL matches pose a significant risk to spectators' auditory function as shown by reduced DPOAE amplitude post match attendance. Three risk factors for overexposure to noise during the match were identified: blowing the *vuvuzela*, close proximity to the individual blowing the *vuvuzela* as well as spectator turnout at the match.

Keywords: *Distortion product oto-acoustic emission, noise exposure, noise-induced hearing loss, soccer match, vuvuzela*

INTRODUCTION

The effects of exposure to loud noises on hearing have been known for centuries, with some of the earliest reports linking noise exposure to hearing loss dating back to the early 1800s (Fosboke 1831; Holt 1882). Much of what is currently known about the effects of exposure to noise on hearing is based on investigations of occupational noise, and less is known about the consequences of other sources of noise. The general public is being increasingly exposed to noise, suggesting that excessive noise exposure will continue to be a major public health concern in the 21st century (Passchier-Vermeer & Passchier 2000).

Modern hobbies such as sporting activities, rifle shooting, and use of personal stereos (under earphones) are known to expose individuals to high levels of noise that may have adverse effects on their hearing and quality of life. In South Africa, soccer matches, in particular, are under the spotlight as social events that expose the public to potentially harmful noise levels. The biggest contributor to noise levels in soccer stadiums across South Africa is the *vuvuzela*, a trumpet-like instrument that is often blown by fans during matches (Staff Writer 2009). The noise made by this instrument

has a broad frequency spectrum between frequencies 250 and 8,000Hz, with almost equal energy across all the frequencies (Swanepoel et al. 2010). A recent study by Swanepoel & Hall III (2010) provided the first empirical evidence linking the noise emitted by the *vuvuzela* during football matches to negative impact on auditory function of those exposed to it.

To minimize the health risks of noise to the workers, noise exposure is legislatively regulated in many occupational settings. Most agencies that regulate occupational noise exposure specify a Criterion Level, which is the maximum permissible exposure to accumulated noise, to be an 8-hour equivalent continuous noise level of 85 dBA (Nietzel et al. 2004). Therefore, any workplace that exposes employees to noise levels ≥85 dBA for 8 hours risks harm to their hearing (South African National Standards [SANS] 2004; International Organization for Standardization [ISO] 1990). Further, the exposure time must be halved for every additional 3 dB increase in the noise level (National Institute for Occupational Safety & Health, NIOSH 1998). For example, at 88 dBA, a safe exposure duration is 4 hours. In terms of the maximum permissible exposure to peak sound pressure, Directive 2003/10/EC of the European Parliament has set a occupational limits for peak sound pressure at 140 dBC for adults (Directive 2003/10/EC), while 120 dBC is the recommended limit for children (Passchier-Vermeer & Passchier 2000). According to Passchier-Vermeer & Passchier (2000), these Criterion Levels can be utilized for social noise exposure. Therefore, for an average soccer match of duration of 2 hours (including half-time interval), equivalent continuous noise levels must be below 91 dBA and peak sound pressure levels should be below 120 dBC to be considered safe for all spectators (adults and children).

There is generally limited research evidence that realistically estimates the extent of noise-induced hearing loss (NIHL) from non-occupational noise exposure and thus the risk of NIHL (Nietzel et al. 2004). Therefore, this study aims to i) measure noise levels during different South African Premiere Soccer League (PSL) games; ii) measure changes in auditory functions after attending a PSL match; and iii) determine the factors that increase the risk of overexposure to noise during PSL matches.

METHODS

A descriptive analytical pre- and post- exposure design using quantitative methods of data collection was chosen for this study. Ethical clearance was first obtained from the University of Cape Town (UCT), Faculty of Health Sciences Human Research Ethics Committee, to conduct the study (REC REF: 373/2009). Permission was then obtained from the relevant stadium management authorities. Invitations for volunteers to participate in the study were posted on notice boards at UCT's Faculty of Health Sciences campus. Only individuals with normal outer ear appearance, middle ear function and normal hearing thresholds were selected for this study. Written informed consent was obtained from the volunteers once they had been provided with information about the study and agreed to participate.

Study population

Participants were provided with free match tickets and transportation to and from the stadium. Participants attended soccer matches in Cape Town, between different PSL teams. The first match was in November 2009 at a 40,000-seat capacity stadium (half-full) in Cape Town. There were 19 participants (3 females and 16 males) who attended this match (Group 1) and their ages ranged from 18 to 45 years (median age of 22 years). The second match was in March 2010 at a 52,000-seat capacity stadium (sold out match). Only 10 of the original participants attended this second match. This group (Group 2) comprised 10 males with ages ranging from 19 to 32 years (median age of 20 years).

Data collection

Pre-match assessment

At least 2 hours before the commencement of each match, the participants had an otoscopic examination (to rule out outer ear abnormalities), tympanometry (to ascertain middle ear function), and bilateral pure tone (air and bone conduction) audiometry testing in a sound treated audiometric booth at the following frequencies: 250; 500; 1,000; 2,000; 3,000; 4,000; 6,000 and 8,000 Hz (using GSI 61 2-channel diagnostic audiometer) to rule out peripheral hearing loss.

Integrity of the outer hair cells of the cochlea was assessed bilaterally via distortion product oto-acoustic emissions (DPOAEs) using GSI Audera system. To improve reliability of DPOAE assessment, each DPOAE amplitude measurement was done twice without removing the probe from the ear, and whenever there was some variability, the best response (i.e. response with the highest amplitude) was used. Only responses that were 3 dB or high above the noise floor were used for analysis.

Match one (Group 1)

Participants were assigned seats across the stadium stand, from extreme left (facing the soccer pitch) to the extreme right and at different levels from the lowest (closest to the pitch) to the highest level. None of the participants blew the *vuvuzela*.

During the match, one participant who was seated in the middle of the stand wore a personal noise dosimeter (Noise-Pro) with the microphone affixed to his/her shoulder to measure the noise dose at ear level. The dosimeter recording began as soon as the participant entered the stadium and ended as soon as he/she exited the stadium.

In addition, a survey of noise levels was conducted during the match using a Brüel and Kjæar Integrating Sound Level Meter Type 2239A. Equivalent continuous noise level (L_{Aeq}) measurements were determined using the A-weighted (dBA) frequency network of the sound level meter. A-weighting is useful for assessing the noise risk to hearing because it de-emphasizes the low and very high frequencies which pose less of a risk to hearing and it also approximates the ears' response to moderate level sounds (NIOSH 1998). Peak noise levels were measured using the C-weighting scale which captures and emphasizes all frequencies.

Therefore, the following recordings were obtained: Peak level (L_{Cpk}), which reflected the highest instantaneous sound level detected by the sound level meter; and equivalent continuous noise level (L_{Aeq}), which captured the true equivalent sound measured over the recording time (about 2 hours for each match) (NIOSH 1998). Noise dose (D), which represents the amount of actual exposure relative to the amount of allowable exposure, and for which a dose of 100 % and above represents noise exposure that is hazardous (NIOSH 1998), was also measured during the match.

Match two (Group 2)

This group of 10 participants was divided into two groups of five, with each group having one individual who blew the *vuvuzela*. Two members of each group were seated within 1 m from the *vuvuzela* blower (one on each side of the *vuvuzela* blower), and the other two members of the group were seated more than a meter (at least two rows of seats behind the *vuvuzela* blower) away from the *vuvuzela* blower. For ethical reasons, no one was made to sit immediately in front of the *vuvuzela* blower. The person blowing the *vuvuzela* was requested to blow the *vuvuzela* in a manner that is consistent with the way the *vuvuzela* is usually used during a football match (e.g. when a goal is scored, when their favourite team was "attacking", etc.).

The person blowing the *vuvuzela* for each sub-group wore a personal noise dosimeter during the match set up as described above. An additional member of the group, who was not blowing the *vuvuzela* and seated at least over 1 m from the *vuvuzela* blower, also wore a personal noise dosimeter to facilitate comparison. The dosimeter recording began when the participants entered the stadium and was ended when they exited the stadium. In addition, noise levels were surveyed as described for Group 1. Finally, 1/3 octave analysis of the *vuvuzela* noise was performed using *Norsonic Nor131 Class 1* sound level meter to determine its spectral characteristics.

Post-match assessment

Within an hour after the match, DPOAE measurements were obtained from all participants by the same researcher who conducted the pre-match assessments.

Data analysis

Peak level (L_{Cpk}), continuous equivalent noise level (L_{Aeq}), and noise dose were tabulated. DPOAE amplitudes for the pre- and post-match conditions were compared using Wilcoxon Signed Ranks test for repeated measures on a single sample.

RESULTS

The *vuvuzela* was found to emit broad-spectrum noise comprising frequencies across the range of human hearing (20 Hz–20 kHz) with maximum peaks between 1 and 3 kHz. Figure 1 reflects the results of 1/3 octave analysis (A-preweighted) of the *vuvuzela* noise.

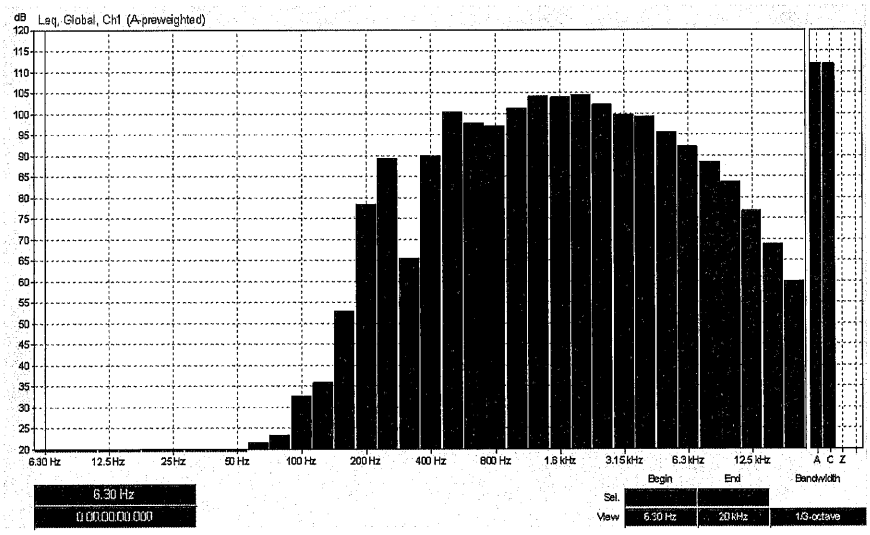

Figure 1: Frequency spectrum of *vuvuzela* noise (A-preweighted)

LC_{pk}, LA_{eq}, noise dose, as well as the duration of exposure to noise (i.e. actual noise exposure) during the two soccer matches are presented in Table 1. Permissible exposure time (SANS 10083:2004), which indicates the duration of noise exposure at a given level that is considered "safe", were also included for comparison.

Table 1: Noise levels and percentage dose during the match for three participants

	Match 1 *vuvuzela* non-blower	**Match 2 *vuvuzela* blower**	**Match 2 *vuvuzela* non-blower**
Peak Level (LCpk)) dBC	115.7	134.5	132.0
Equivalent noise level (LAeq) dBA	85.3	98.9	92.7
Percentage dose (%)	26	684	171
Actual time of exposure (minutes)	125	130	130
Permissible exposure time	8 hours	19 minutes	76 minutes

As seen in Table 1, noise levels during Match 1 were lower than those of Match 2. Further, the two participants in Group 2 who blew the *vuvuzela* had higher equivalent noise exposure levels and consequently higher noise dosage than the participants who did not blow the *vuvuzela*. All the participants attending Match 2 were exposed to a noise level of 92.7 dBA for a period that exceeded the permissible duration at that level.

The results of auditory function, as assessed with DPOAEs, are displayed in Figures 2a and 2b. The results displayed in Figures 2a and 2b show the average DPOAE amplitudes for the left ear only (right ear results showed the same pattern). Participants in Group 1 did not demonstrate significant reduction (p=0.060) in their OAE amplitude (auditory function) post-exposure to the noise at the match (Figure 2a).

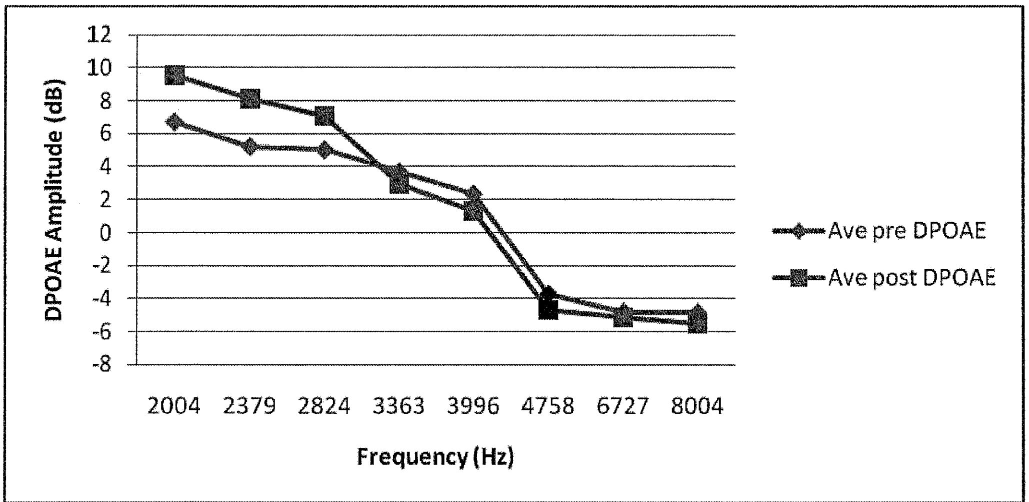

Figure 2a: Average left ear pre- and post-match DPOAE amplitude for Group 1 (n=19)

Participants in Group 2 exhibited significant (p=0.003) reduction in DPOAE amplitude (auditory function) post the match as depicted in Figure 2b. However, when the *vuvuzela* blowers were excluded from this group, the change in DPOAE amplitude post-noise exposure at the match in this group was not significant (p=0.117).

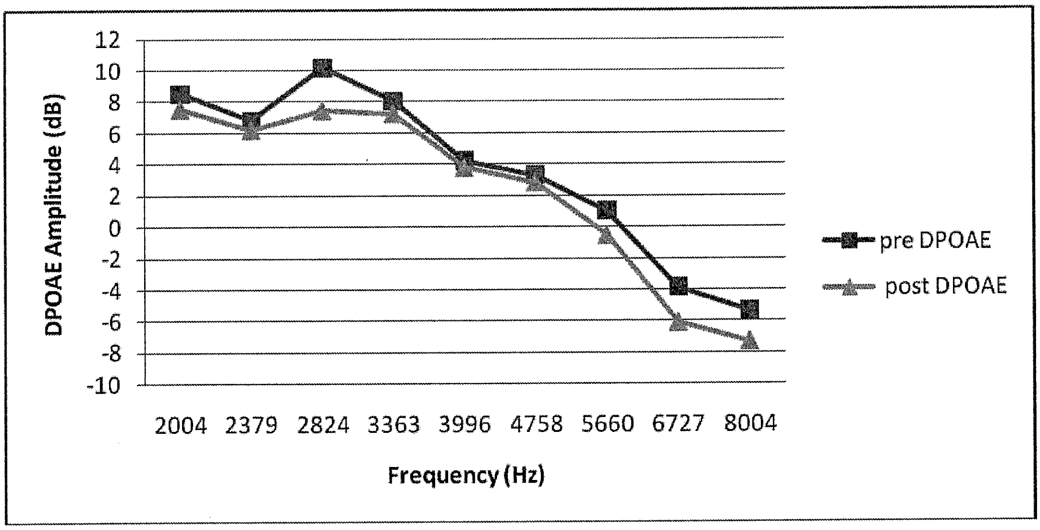

Figure 2b: Average left ear pre- and post-match DPOAE amplitude for Group 2 (*n*=10)

The members of Group 2 fell into three categories, viz., *vuvuzela* blowers, within 1m from the *vuvuzela*, and >1 m from the *vuvuzela*. Average changes in DPOAE amplitudes (pre vs. post) for the three groups are displayed in Figure 3.

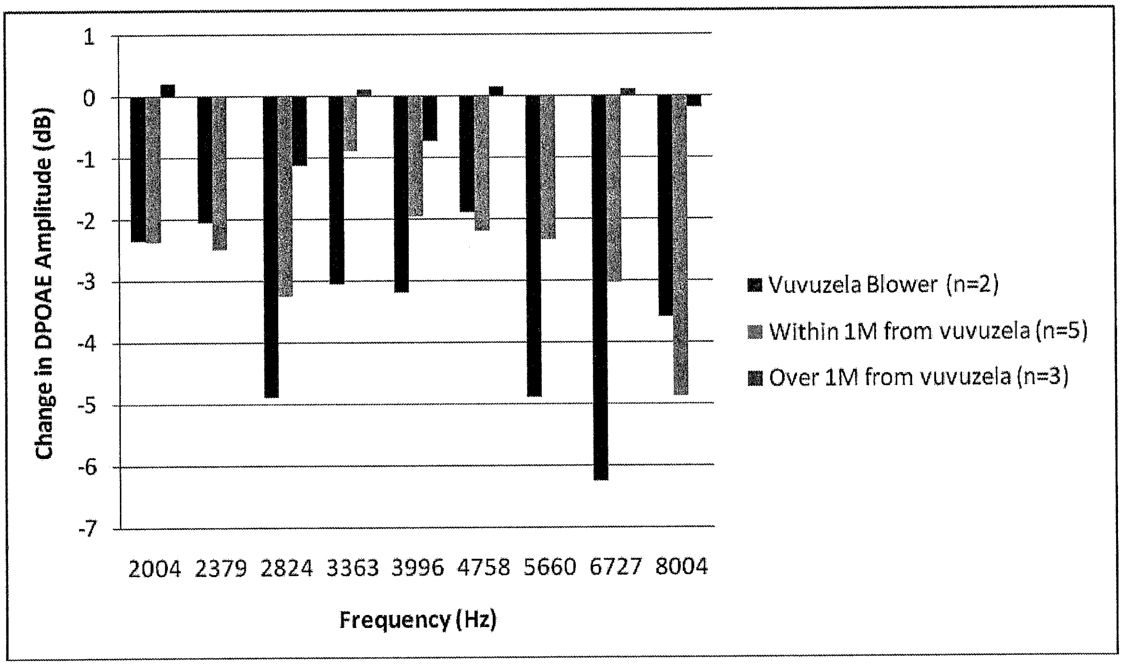

Figure 3: Change in left ear DPOAE amplitude as a function of proximity to the *vuvuzela* blower

After the match, *Vuvuzela* blowers had the largest reduction (p=0.002) in DPOAE amplitude relative to the other two groups. Participants seated within 1 m of the *vuvuzela* blower displayed the second largest reduction (p=0.008). The group seated over 1 m from the *vuvuzela* blower demonstrated a non-significant reduction in DPOAE (p=0.238). In general, the largest reduction in DPOAE amplitude occurred in the higher frequencies (5,660–8,004 Hz) when compared to the low frequencies (i.e. frequencies < 5,660 Hz) for all groups of participants.

DISCUSSION AND CONCLUSION

Exposure to loud noises, whether in an occupational or social setting, has known health effects, including NIHL (Nietzel et al. 2004). This study revealed that the intensity of noise that spectators are exposed to during well-attended ("full house") South African PSL soccer matches is high enough to affect their auditory function as manifested by reduced DPOAE amplitudes after the match. These findings are consistent with those of Swanepoel & Hall III (2010).

The frequency spectrum of the *vuvuzela* noise was found to be similar to that of common industrial noise (i.e. it has a broad spectrum) (Henderson & Hamernik 1986). Due to the acoustic resonant characteristics of the outer ear which tends to amplify sounds in the 2,000–3,000 Hz region (creating a band-pass filter centered at about 3,200 Hz), broad-spectrum noises such as the *vuvuzela* noise typically cause more threshold shift in the 3,000–6,000 Hz region in humans (Royster 1996). This shift is typically observed as a "notch" within this frequency range in the audiograms of individuals with NIHL (McBride & Williams 1995). It was therefore expected that the effect of the noise would be more evident in frequencies higher than the center frequency of the *vuvuzela* noise, with the largest reduction in DPOAE amplitudes in this high frequency region, which was observed in this study.

It was also found that noise exposure is not uniform across matches as evidenced by the substantial differences in noise levels between the two matches. Noise levels for Match 1 were within safe limits. However, the intensity of noise during Match 2 clearly exceeded the SANS 1003:2004 safe exposure level (SANS 2004), confirming the concern that some soccer matches expose spectators to unsafe noise levels. Peak sound pressure levels ($L_C pk$) for both matches were safe for adult ears, but peak sound pressure levels in Match 2 exceeded the recommended limit for children.

In conclusion, the findings of this study confirmed that some PSL matches expose spectators to unsafe noise levels as evidenced by a reduction in DPOAE amplitudes post-match attendance. It was established that the biggest risk factors for overexposure to noise during matches are blowing the *vuvuzela*, close proximity (<1 m) to the *vuvuzela* blower and high spectator turnout at a match.

While the limitations of using DPOAEs to document auditory function is well understood, the use of this test is more sensitive to changes in the auditory function than most available audiometric measures, and hence able to detect a cochlear damage sooner than it can be detected using standard audiologic tests (Marshall et al. 2001).

The authors are also aware of the limitations of using a simple energy-based metric such as A-weighted sounds (dBA) to predict the risk of hearing loss from noise exposure, especially when considering that exposure to the same A-weighted sounds may differ in the potential for causing hearing loss in different individuals.

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Noise induced hearing loss in the entertainment sector

E. Toppila[1], H. Koskinen[1], A. Savolainen[2], R. Pääkkönen[1], E. Airo[1], P. Olkinuora[1], I. Pyykkö[3]

[1] FIOH – Finnish Institute of Occupational Health, Topeliuksenkatu 41, 00250 Helsinki, esko.toppila@ttl

[2] YLE, aslak.savolainen@yle.fi

[3] Tampere University, ilmari.pyykko@pshp.fi

INTRODUCTION

In 2003 the European Union introduced the new noise directive (EC 2003). One of the new requirements in the directive was that all member countries must develop a code of conduct for music and entertainment sector. The European Agency for Safety and Health at Work (2005) has published recommendations for the entertainment sector. In these recommendations it is identified that noise reduction can be obtained by organisational measures, through technical and architectural measures and by using hearing protection. For practice rooms a size of 17 m^3 is recommended. Good acoustic design and proper absorption are recommended to reduce the sound levels.

In Finland the code of conduct is intended to be used as a checklist by labour inspectors. It does not provide any practical solutions, how to achieve the goal, but it provides an overall view of the requirements and possibilities. Also the Health and Safety Executive (HSE) provides a similar overall view in their webpage (HSE 2007). The instructions are given by the type of music: concert halls and theatres, amplified music, studios, schools and colleges, pubs and clubs and marching bands. Also the needs of different worker groups, like technicians and freelancers, are identified in a similar way to the Finnish code of conduct.

The Finnish code of conduct divides the workers into 12 groups based on their work tasks and type of employment (Table 1). To make things even worse one worker may belong to several groups. For example many of the music teachers act as part-time musicians.

Table 1: Division of the workers based on employment type and character of work and examples of workers belonging to each group

Employment	Performers	Teachers	Technical staff	Service work
Regular	Theatre/opera musicians, actors	Regular teacher	Theatre technical staff	Waiters, safety officers
Odd job	Restaurant musician, actors	Part time teacher	Constructors of outdoor event	Waiters, safety officers
Own company	Restaurant musician		Constructors of outdoor event	

The major problem with the code of conduct is that it does not provide a practical solution. As a consequence there is a confusion in the music and entertainment sector, how to implement the conduct in the field. A second problem was found that research is needed before any implementation can be made. This paper describes the research made in Finland to implement the code of conduct.