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Acoustics in School Sport Halls and Its Implications for Physical Education

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Abstract

Due to the demanding acoustic conditions in physical education lessons and the related problems with health and academic success, the aim of this study was to examine the acoustic conditions of teaching in sport halls in Slovenia. Thirty-five sport halls were selected, reflecting four types of school sport halls grouped according to the period of their construction. The reverberation time was measured, and speech intelligibility was calculated by means of the Speech Transmission Index. Eighty-six per cent of the sport halls have poor or merely satisfactory speech intelligibility; statistically significant differences in acoustics were observed between different types of sport halls. The best acoustic conditions were found in the newer, multi-purpose sport halls, which allow three classes to be taught simultaneously; the worst conditions were observed in the older, single-class sport halls. The acoustics of the school sport halls should be improved, and the strain on the voice of the teachers should be reduced by means of a more suitable organisation of lessons and the use of information communication technology equipment.

Keywords: *gym; learning environment; noise; physical educators; speech intelligibility.*

Introduction

Strategies used for the improvement of the educational processes may focus on the didactic approaches or the teaching environment. Adequate teaching environments can ease communication, ensure a pleasant atmosphere and have beneficial influence on the health and capacities of both students and teachers. Elements affecting speaking and listening, which in terms of physics correspond to the transfer of sound in space, form an indispensable part of the teaching environment. Each sound carries certain information, which can be intelligible and useful, or not. If the information contains too much useless and incomprehensible content, it creates noise and distraction. *Noise* in the teaching environment is an undesired type of sound, which affects the audibility among the participants of the educational process.

The audibility of teachers and students is a vital part of academic excellence (Klatte, Bergstroem, & Lachmann, 2013; Woolner & Hall, 2010). Poor acoustic conditions cause disturbances and negative psycho-social behaviour of students (Crandell, Smaldino, & Flexer, 2005), whereas a decrease in noise improves students' attention span and increases their participation in lessons (Dockrell & Shield, 2012). Despite the above-mentioned facts, the acoustic conditions in the majority of classrooms are poor (Knecht, Nelson, Whitelaw, & Feth, 2002; Mikulski & Radosz, 2011) and can even endanger children's health (Holmes, Niskar, Kieszak, Rubin, & Brody, 2004; Niskar et al., 1998; Niskar et al., 2001; Walinder, Gunnarsson, Runeson, & Smedje, 2007).

The acoustic conditions in teaching are particularly demanding in sport halls. The number of participants in sport halls is large and sometimes several groups of people do different activities simultaneously. Sports activities are inherently loud because of the dribbling of balls, running, jumping, loud talking, sometimes cheering and shouting, using a whistle or other audible signs, or music (Bruck Marçal & Peres, 2011; Hadzi-Nikolova, Mirakovski, Zdravkovska, Angelovska, & Doneva, 2013; Lemoyne, Laurencelle, Lirette, & Trudeau, 2007; Palma, Mattos, Almeida, & Oliveira, 2009).

Speech is transferred from the teacher to the students as a combination of direct and reflected sound. Direct sound travels from the teacher and becomes reflected sound when it hits one or more obstacles or surfaces in the space. The prolongation of the reflected sound is known as *reverberation*. The position of students in a sport hall creates a distinctive combination of direct and reverberating sound, which students perceive. The distance between the teacher and the students defines the necessary amount of the acoustic energy of the direct and reverberating sound. Due to venue size, this distance is larger in sport halls than in normal classrooms. The energy of speech which students receive via direct and reverberating sound is more intense than the energy of speech they receive only via direct sound. Too much reverberating sound can also distort *speech intelligibility*. A sport hall is generally a noisy environment, because its large space is constructed from hard rebounding elements and its wall, floor and ceiling surfaces are mostly smooth in order to ensure long-term durability for use in various sports activities. These factors create long reverberation times, which can affect speech intelligibility and the level of noise in space.

The quality of acoustic conditions of space can be set by analysing the measured values of reverberation time. Some countries have set the highest possible values of reverberation times (e.g. Building Bulletin 93 (2003): school sport halls <1.5 seconds; ÖNORM B 2608 (2012): from 0.85 seconds for small sport halls to 1.94 seconds for large sport halls). Generally speaking, the longer the reverberation time, the poorer the acoustic quality of the space, although optimal reverberation time is influenced by several factors: the volume and geometry of space, the function of a sport hall (practicing, events) and the number of groups simultaneously using the hall. The acoustics of space can be described by means of various acoustic indexes extracted from the reverberation time (Radosz, 2013). The Speech Transmission Index (EN 60268-16:2003, 2003), which describes speech intelligibility, is widely used.

Normal speech occurs at a moderate level of 50-60 decibels (dB); the pain threshold is at approximately 130 dB (NIOSH, 1998). Larger and more frequent exposure to noise increases the risk of hearing loss. The unit of measurement dB(A) expresses the time-evaluated average of exposure to noise in an eight-hour working day, and dB(C) expresses the peak level of sound pressure. Hearing loss can occur due to a momentary exposure to extreme noise or due to regular (longer than one minute) exposure to noise at above 110 dB(C). Additionally, hearing loss can also occur as a result of long-term (daily or weekly) exposure to noise at above 85 dB(A). Experts advise against an unprotected exposure to noise greater than 100 dB(C) (NIOSH, 1998) for more than 15 minutes.

Studies on noise in sport halls have revealed that these spaces are extremely noisy. The background noise is frequently too loud (Ryan & Lucks Mendel, 2010); according to some guidelines it should not exceed 30-40 dB(A)(American Speech-Language-Hearing Association, American National Standards Institute, Building Bulletin 93, etc.). The total amount of noise that is created in the course of sports activities is even higher. The average level of noise during lessons is between 74 dB(A) and 101 dB(A), whereas the peak level is between 111 dB(C) and 135 dB(C) (Augustynska, Kaczmarska, Mikulski, & Radosz, 2010; Hadzi-Nikolova et al., 2013; Maffei, Iannace, & Masullo, 2011; Mirbod et al., 1994; Palma et al., 2009). As a result, increasing numbers of national and international regulations and guidelines recommend the limiting of noise and suggest or prescribe minimal levels of sound insulation between different areas in the sport hall and on its external walls (Palma et al., 2009). The optimal reverberation time and the highest level of noise emission, which is caused by the equipment in space are also recommended (Maffei et al., 2011). In Europe, Directive 2003/10ES (2008) sets 85 dB(A) as the upper exposure action value of daily noise.

Audibility is a vital part of the physical education (PE) teaching environment, as the effectiveness of the demonstration skills is better when combined with adequate explanation (description of a new movement, providing feedback information to participants). Listeners do not understand speech well when the total level of sound exceeds 69 dB(A) (Studebaker, Sherbecoe, McDaniel, & Gwaltney, 1999) meaning that students are unable to follow the teacher's instructions in such conditions. Speech intelligibility in noisy conditions is worse among children than among adults (Papso & Blood, 1989; Valente, Plevinsky, Franco, Heinrichs-Graham, & Lewis, 2012). The younger the children are, the less efficiently they hear in noisy conditions (Astolfi, Bottalico, & Barbato, 2012; Elliott, 1979; Jamieson, Kranjc, Yu, & Hodgetts, 2004) and the poorer their understanding is in reverberating conditions (Bradley & Sato, 2008; Johnson, 2000). With the increase in the distance from the source, the listeners find speech less intelligible (Leavitt & Flexer, 1991). Too heavy and too frequent exposure to noise can cause permanent hearing problems (Holmes et al., 2004; Niskar et al., 2001). Special conditions in a learning environment with clear communication are also required by students with attention deficit problems, learning difficulties, language problems (Cunningham, Nicol, Zecker, Bradlow, & Kraus, 2001), hearing difficulties (Bess, Dodd-Murphy, & Parker, 1998; Holmes et al., 2004; Niskaret al., 2001) and in children who are not taught in their mother tongue (Picard & Bradley, 2001).

Poor acoustics in space also creates problems for teachers' health. While students experience problems in hearing teachers due to the noisy environment and consequently, pay less attention in a large space, teachers experience problems in making themselves sufficiently loud in order to overcome the noise in the environment. Accordingly, problems with voice (Kovač, Leskošek, Hadžić, & Jurak, 2013; Simberg, Sala, Vehmas, & Laine, 2005; Smith, Kirchner, Taylor, Hoffman, & Lemke, 1998; Smith, Lemke, Taylor, Kirchner, & Hoffman, 1998) and hearing (Kovač et al., 2013; Lemoyne et al., 2007) are among the most common professional health problems in PE teachers. Due to the previously described acoustic working conditions, PE teachers are more prone to problems with their voice than other teachers (Jonsdottir, Boyle, Martin, & Sigurdardottir, 2002; Preciado, Perez, Calzada, & Preciado, 2005; Smith, Kirchneret al., 1998). Exposure to noise for longer periods of time also results in long-term effects in the form of increased fatigue during the day, increased psychological and emotional tension, feeling of nervousness and irritation, concentration difficulties, hoarseness and coughing (Augustynska et al., 2010). Additionally, problems with voice also affect the working capability and consequently the quality of life in the affected people (Ma & Yiu, 2001; Smith et al., 1996; Yiu, 2002) as well as considerable costs in health services (Smith, Lemke et al., 1998; Verdolini & Ramig, 2001). In this regard, Smith et al. (1998) report that approximately 20% of the teachers miss work due to voice problems, whereas in other professions only 4% of working people miss work due to this reason.

In relation to the presented topic, the purpose of this study was to examine specific acoustic conditions in sport halls in which PE teachers and students in Slovenia work.

Methods

Sample

For the purpose of this study, experts selected 35 school sport halls belonging to four different group types, which adequately represent various types of typical existing school sport halls in Slovenia (Jurak et al., 2012; see Table 1).

The groups of school sport halls have been designed according to the development of the construction of such facilities in Slovenia. The first school sport hall in Slovenia was built in 1874, and some similar sport halls had been constructed before the beginning of World War II. As only few such sport halls exist and some of them were damaged in the war, until the 1960s the teaching of PE in colder weather was mostly conducted in refurbished classrooms. An engineering advance in the construction of school sport halls was enabled by the introduction of the so-called self-imposed contribution in the 1960s and 1970s. From that time onwards, schools have generally not been built without sport halls. Over the years, standards in terms of the size of the training areas and their equipment have also risen (Jurak et al., 2012).

Table 1

Groups of school sport halls, where acoustics was measured

Abbreviation	Type of sport hall	Number of sport halls	Volume *mean* (m^3)	Age *mean* (years)
3-C	Sport hall for simultaneous use of three classes (3-section sport hall of dimension 42×23×7 m and more)	10	13,857	15.9
2-C	Sport hall for simultaneous use of two classes (2-section sport hall of approximate dimension 30×20×7 m)	9	4,772	18.2
1-C old	Old sport hall for use of one class (dimension 20-28 m in length and less than 20 m in width)	10	2,527	50.8
1-C spc	Small sport hall (less than 20 m in length) or a specialised sport hall (e.g. dancing, fitness, gymnastics) for use by one class	6	932	42.2

Type *1-Cold* represents the old school sport halls (mean age 51 years). The average area of these sport halls is 343 m^2, and the average volume is 2,527 m^3. The older ones of these sport halls have been renovated at least once, but these renovations occurred 20 or more years ago. All of these halls are rectangular with the exception of the ceiling; they are equipped with a polyurethane sport floor, wall-bars are mounted on one of the long sides of the hall, and basketball hoops are mounted on the end walls. The walls of the halls are not specially treated or protected. The gable roof of the building has a slope of up to 22°, and the ceiling has no special treatment.

Type *2-C* represents newer and larger school sport halls that allow the simultaneous practice of two classes with the average area of 671 m^2 and the average volume of 4,772 m^3. The average age of these sport halls is 18 years and they have never been renovated. All of these halls are rectangular with wooden sport floors. There is a suspended ceiling parallel to the floor surface, made of Heraklith wood wool panels. Wall bars are mounted on one of the long sides and the other walls are equipped with basketball hoops or other fixed or foldable sports equipment (goals, climbing holds, ropes, poles or ladders). These sport halls are also equipped with ceiling-suspended basketball systems.

Type *3-C*are the largest school sport halls in Slovenia. These are the most cost- and user-optimal sport halls, in which three groups of students can work simultaneously. The average area of these halls is 1,272 m^2, with an average volume of 13,857 m^3. All but two of these sport halls in the sample have been built in the last twenty years (mean age 16 years). They are all rectangular with the exception of the upper face (gable roof with a slope of up to 18° with visible roof structure or flat roof with beacons that create a slightly uneven ceiling in combination with other installations), equipped with a wooden sport floor. One of the long sides is equipped with wall bars; on the other one, smaller stands are installed (the older halls have fixed, and the newer ones have telescopic stands). The other walls and the ceiling are equipped with fixed or folding sport equipment (goals, hoops, climbing holds, ropes, poles or ladders). All but the oldest two have wood-panelled walls, which are lined with Heraklith wood wool panels placed near the ceiling and on the ceiling. None of these sport halls has been renovated. In the newer ones, gym mats are installed on the wall bars and the front walls have safety protection padding.

Type *1-C spc* are the smallest sport halls. These are small, one-class gyms or training spaces, specifically designed to serve certain sports (e.g. fitness, gymnastics, dance). Their average surface area is 180 m^2, with 932 m^3 volume. Many of them were originally built as central training facilities but over the years schools have built newer school sport halls and these gyms became auxiliary training spaces at schools. These gyms are old (average age is 42 years). The older ones were renovated, but the renovations were made 15 or more years ago. All of these sport halls are rectangular, but the ratios of the sides (with the exception of the ceiling height) are quite diverse. The floor is covered with polyurethane or wooden sport floor and in gymnastic halls gym mats or gymnastic floor are installed on top of it. Usually, the wall bars are mounted on one side of the hall. The walls of the rooms are not padded, and the most prominent places are equipped with safety protection padding. They have ordinary ceilings without any lining.

Measuring Characteristics

All selected schools agreed to allow the acoustics in their sport halls to be measured, and they also provided documentation about the age of these halls. A laser measuring device was used to calculate the volume of each sport hall. Acoustic measurements were performed in empty sport halls. The external impulse method was applied according to the EN ISO 3382-2:2008 protocol (2008) at several places in each sport hall (three measurement points in all sport halls and two additional measurement points in group *3-C*). The first measurement point was located at the centre of the sport hall, the second one in the key of the basketball court, and the third one in one of the corners on the opposite side of the hall from the second measurement point. The additional two points for the sport hall type *3-C* were located in the key on the opposite side of the second measurement point and in the stands.

The reverberating time of sound was produced with a starting pistol. The received acoustics responses of each sport hall (sound signals) were registered with a Nor140 sound analyser (Norsonic, Norway). The sound file was transferred to a computer, where it was processed by DIRAC Room Acoustic Software (Bruel & Kjaer). The reverberation times of the individual measurement points were calculated across the entire frequency spectrum audible to the human ear. The measurements were performed once at each measurement point. A repeated measurement was conducted if the technician doubted its validity or if something influenced the measurement. In such cases, the repeated measurement was used in the analysis.

The measurements of the reverberation times in individual sport halls provided data about the time of the persistence of sound in the space after the sound activity was finished (e.g. how long the sound rebounded before it faded away entirely). This time was compared with the optimal reverberation time according to the characteristics of every sport hall. Referential values of the optimal reverberation time were calculated following DIN 18041 (2004). The elements for the calculation and setting of optimal reverberation time were the volume of the hall (in m^3) and the number of classes playing one or more sports simultaneously in the hall. This information was acquired from the PE teachers who teach in the observed halls.

The formula for calculating the optimal reverberation time for one class in a hall (Sport-1) was: optimal reverberation time for Sport-1 = $1.27 \times \log V - 2.49$ (sec). The formula for calculating optimal reverberation time for more classes in a hall (Sport-2) was: optimal reverberation time for Sport-2 = $0.95 \times \log V - 1.74$ (sec).

The DIN 18041 standard states that the acceptable deviation from the optimal reverberation time is ±20%. The standard for spaces with volumes above 8,500 m^3 and below 2,000 m^3 does not state a criterion or formula for calculation. For volumes above 8,500 m^3, the optimal time has been set as the maximal values for Sport-1 (2.5 sec) and for Sport-2 (2.0 sec) with an additional criterion regarding whether there was mainly one or several classes exercising simultaneously in the hall. For spaces with volumes of less than 2,000 m^3, an average value between Sport-1 and Sport-2 regardless of the number of classes exercising simultaneously has been set as the optimal reverberation time.

The acoustic conditions for teaching in individual sport halls have been evaluated according to two criteria.

- *Reverberation time* was measured (in 1/100 sec) at 500Hz and 2000Hz, as the area between these two frequencies represents the best audible frequencies for the human ear ("IEC 61672-3, Electroacoustics – Sound level meters", 2003). The measured reverberation time was compared with the optimal reverberation time of each individual space in order to find the quality of the acoustics of each sport hall.
- *The Speech Transmission Index (STI)*was calculated from the measured reverberation time of each individual space and the individual measured point in space. STI predicts the likelihood of the comprehension of syllables, words and sentences. Its levels are between 0 and 1. The higher the STI, the better the speech intelligibility in the observed space (see Table 2).

STI was calculated as the weighted sum of the modulation transfer indices (MTI), one for each octave frequency band from 125 Hz through 8 kHz (where each MTI value was derived from the modulation transfer index values over 14 different modulation frequencies), taking into account the auditory effects according to EN 60268-16 (2003).

Data Analysis

The data were analysed with the use of the SPSS Statistics 18.0 program. Simple descriptive statistics of variable distributions were calculated. χ^2 test and Cramer's V coefficient were used in order to test the differences in the acoustic variables according to the sport hall type. The correlation between the individual acoustic variables and the age of the sport halls was analysed with the Spearman coefficient range correlation ρ_s.

Results

The optimum reverberation times according to the volume ranged between 1.7 and 2.2 seconds (see Figure 3), while some also extended to 7 seconds (see Figure 1). Apparently, the actual reverberation times were also sometimes very long in smaller sport halls (types*1-C old* and *1-C spc*). There was a high correlation found (ro = 0.73) between the measured reverberation times at 500 Hz and 2000 Hz, but in most sport halls the reverberation times at 500 Hz were slightly longer than at 2000 Hz (see Figure 1).

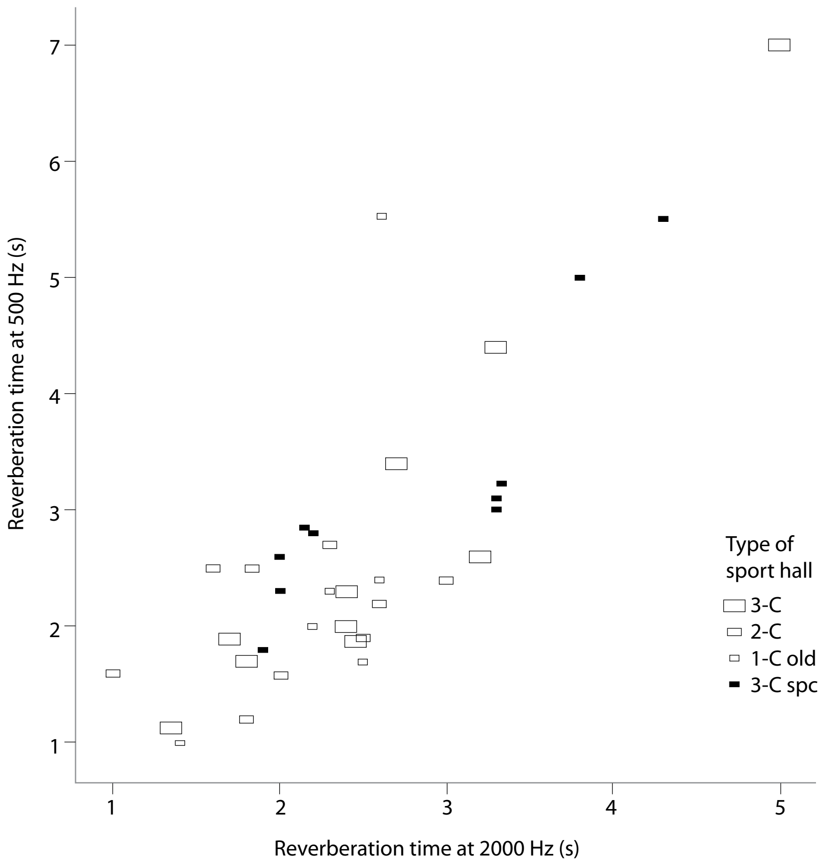

Figure 1. Distribution of reverberation time at 500 Hz and 2000 Hz according to the type of sport hall

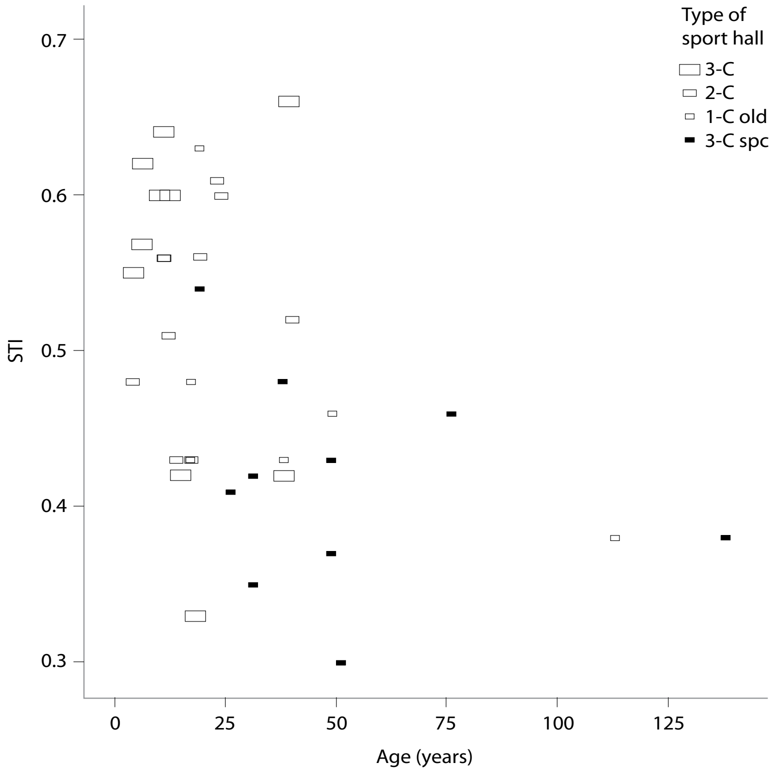

Figure 2. Distribution of STI according to the age and type of sport hall

STI values ranged from 0.30 up to 0.66 (see Figure 2). According to the previously detected long reverberation times, it was expected that the smaller sport halls (types *1-Cold* and *1-C spc*), which are also generally older (see Figure 3), would be among those with lower indexes.

Table 2

Speech intelligibility of sport halls according to STI

STI value	Speech intelligibility	No. of all sport halls	No. of 3-C	No. of 2-C	No. of 1-C old	No. of 1-C spc
0.00 - 0.30	bad	1	0	0	1	0
0.30 - 0.45	poor	14	3	2	6	3
0.45 - 0.60	fair	15	4	6	3	2
0.60 - 0.75	good	5	3	1	0	1
0.75 - 1.00	excellent	0	0	0	0	0

A comparison of the evaluations of speech intelligibility in groups according to STI (see Table2) indicates that not a single hall achieved an “excellent” mark, as the highest recorded STI was 0.66. The majority of sport halls (over 80%) is placed in the groups “fair” and “poor” (Mean=0.49±0.10).

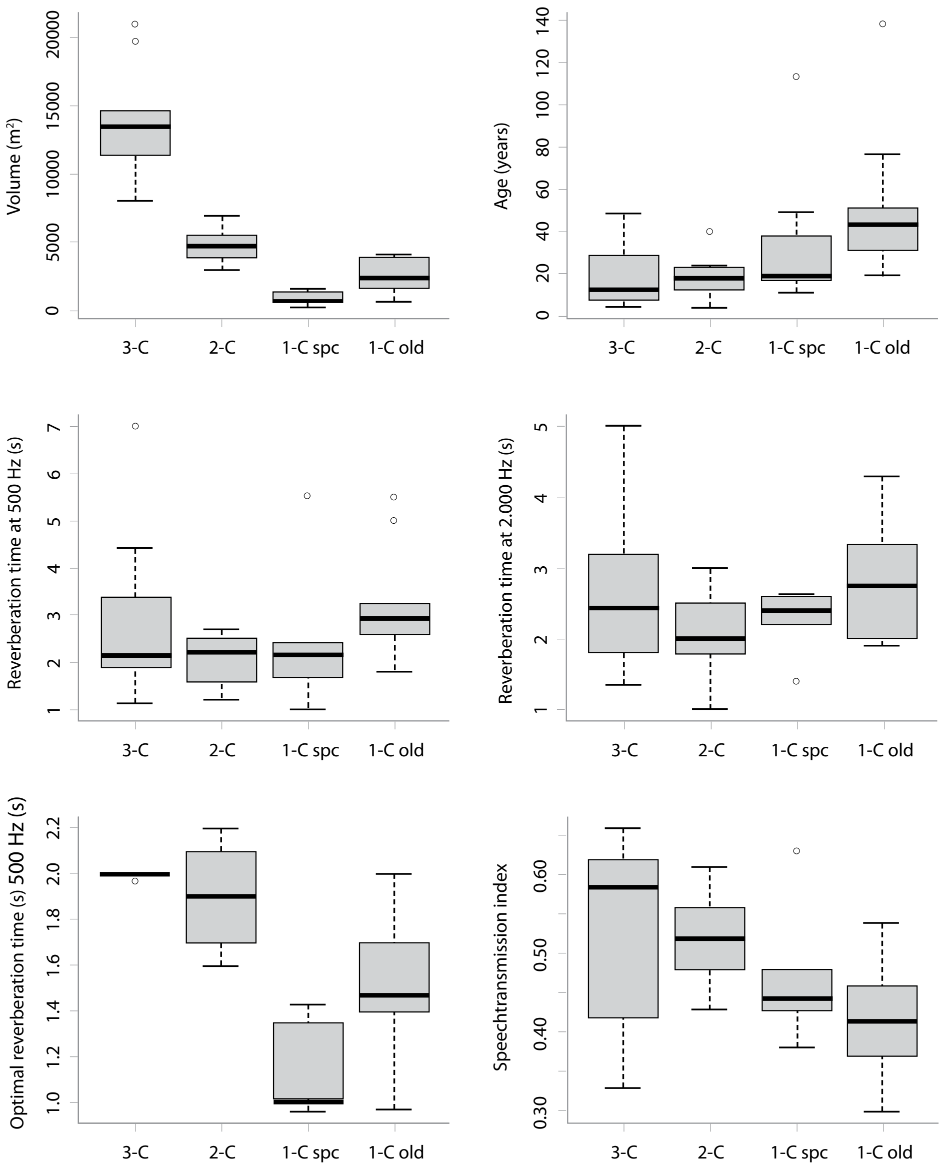

Figure 3. Differences in the acoustic conditions according to the type of sport hall

Statistically significant differences in STI (χ^2=9.924; p=0.019) were observed between the types of sport halls. Therefore, the mean values of the acoustic conditions according to the sport hall type are presented in Figure 3. It can be seen that the sport halls in which three classes can exercise simultaneously (*3-C*) are much larger in volume in comparison with other halls; consequently, the optimal reverberation times in those halls are longer. Nevertheless, the measured reverberation times at 500 and 2000 Hz in such halls were on average no longer than were the reverberation times in the other groups of sport halls, thus allowing better speech intelligibility. It is clear how STI decreases by individual types of sport halls, so that it is the highest in sport halls type *3-C* and the lowest in the halls type *1-Cold*. This trend coincides with the average age of the individual types of sport halls. Further analysis revealed statistically significant correlations between the age of halls and the STI (Spearman ρ_s=0.49, p=0.003; see Figure 2),where the measured reverberation time was at 500 Hz (ρ_s =-0.42, p=0.013), whereas the measured reverberation time at 2000 Hz bordered on statistical significance (ρ_s =-0.32, p=0.057).

Discussion

This study adds to the knowledge about the acoustic teaching/learning conditions in sport halls. The research revealed that the acoustic conditions in Slovenian school sport halls are poor, which makes it more difficult for pedagogic processes to be conveyed and consequently causes problems for PE teachers who identify voice disorders as their second most important professional health problem (Kovač et al., 2013). Differences in acoustics exist between the individual groups of sport halls. The best acoustic responses have been found in large multi-purpose sport halls, which can be used by three classes simultaneously, whereas the worst results were seen in the old sport halls where only one class can exercise at a time. It has been revealed that the acoustics of the sport halls is related to their age.

When examining acoustics as an important factor of the learning environment in PE or any other sports activity, the following factors of this environment can be defined: the speaker (teacher, coach, student), the background noise (shouting, rebounding of balls, dragging of shoes and floor, whistle, music, ventilation), the acoustic conditions of the space (applied finishing of walls, floors and ceilings, geometric proportions of halls, shapes of ceilings, etc.) and the listeners (students). All of the above factors affect the efficiency and successfulness of teaching. The findings have shown that the improvement in the learning success in PE can be achieved by means of such practice in which the teacher provides individual feedback information to participants (Silverman, Tyson, & Krampitz, 1992), thus consequently increasing practice time as less time is spent on lesson organisation (Evertson & Harris, 1992; Siedentop, 2002). Teachers can influence background noise by applying appropriate organisation techniques and the audibility with the use of teaching equipment; however, they cannot influence the acoustic conditions, which affect students' learning capacities and the teaching ability of a teacher. These conditions depend on the construction characteristics of a sport hall. Therefore, teachers can influence these conditions only indirectly by striving to achieve suitable acoustic characteristics at the time of the construction of the hall or by improving them at the time of renovation.

The findings from this study revealed that sports practice is carried out in poor acoustic conditions. The majority of the sport halls from the observed sample achieved poor or merely fair conditions according to the STI criteria. The actual measured reverberation times in the studied sport halls were much longer than the optimal times (see Figure 1 and 3); as a result, speech intelligibility in these sport halls is generally unsatisfactory (see Table 2). According to the STI valuation, this implies that students in these sport halls understand only half of all syllables, less than a quarter of words and less than a tenth of sentences. The measured acoustic characteristics differ according to the types of sport halls (see Figure 3) and their age (see Figure 2). The best acoustic characteristics were found in large multi-purpose sport halls, which allow simultaneous use by three classes and which are generally also newer, whereas the worst conditions were found in the old multi-purpose sport halls, which can be used by only one class at a time. However, the largest range of values was observed in the large multi-purpose sport halls as this group comprised halls with both the best and the worst acoustic conditions (reverberation time of 7 seconds). This indicates that less attention has been paid to the adequate acoustic treatment of space in the oldest ones of the *3-C* type sport halls.

The extremely poor acoustics of the small sport halls is also worth mentioning; these halls are mainly intended for the realisation of PE lessons in the first three-year primary school period and partly also in the second three-year period in Slovenia. In these sport halls, PE is taught by a generalist teacher with lesser organisational knowledge (Kovač, Strel, & Jurak, 2008), and the number of pupils in a group can reach 28, according to the Regulation on teaching standards in primary school (2010). With younger pupils, with whom lessons are carried out in large groups and within limited space, discipline is also more problematic (Lemoyne et al., 2007). As a result, it is not unusual to find that the quality of the pupils' motor knowledge in the first three-year-period is to a great extent related to the quality of material conditions which schools have available for the realisation of PE lessons (Štemberger, 2003).

In addition to the volume of the room, reverberation time depends on the construction solutions and materials used in its completion. These factors are associated with the period of the construction of the sport hall; therefore, differences between the types of sport halls were expected. From the description of the individual types of sport halls, we can conclude that the oldest sport halls have the hardest parallel surfaces (bare walls, polyurethane floor and the rough ceiling). Slightly newer, small gyms were also built according to the same principles. Due to their specific use, they are usually equipped with additional equipment (e.g. safety wall protection, gym mats on the floor), which improves their acoustic conditions. Common characteristics of the sport halls from the last two generations (types *3-C* and *2-C*), which affect the acoustic conditions, are wooden sport floors and covering (ceiling covering of type *2-C* and mostly wall covering of type *3-C*). The key difference of these two types of sport halls, of course, is the volume, because the newest generation of school sport halls (*3-C*) is almost three times larger, which extends the optimal reverberation time. Moreover, in the latest generation of halls, we can find larger covering surfaces (sometimes wood panelling on all walls with gym mats on wall bars). The acoustic conditions in these sport halls are also affected by slightly more diverse shapes of space (visible elements of the roof structure and ceilings that are not parallel to the ground, space occupied by stands).

In more than half of all sport halls (57%), the measured reverberation time at 500 Hz is lower than at 2000 Hz. In spaces without acoustic treatment, the trend is usually reversed, since the reverberation time decreases with increased frequency due to the properties of absorbing materials. As such a relationship between the reverberation times exists independently of the type of the sport hall (with different acoustic conditions), a question arises regarding what affects it. A more detailed analysis has shown that only few of such sport halls experienced some acoustic treatment (i.e. Heraklith wood wool panel ceilings). Many sport halls in which the reverberation time at 500 Hz was lower than at 2000 Hz showed uneven reverberation times between 100 Hz and 4000 Hz (i.e. reverberation time of 2.3 seconds at 100 Hz, 1.7 seconds at 500 Hz, 2.5 seconds at 1600 Hz, 1.9 seconds at 4000 Hz) (Jurak et al., 2012). More thorough analyses should be done to investigate this question.

In order to improve the acoustic characteristics of Slovenian sport halls, it has to be understood that the problem is much lesser in the newly built facilities and greater in the existing sport halls. In the past, an adequate network of school sport halls was built; their average age is 32 years (Jurak et al., 2012). The largest group consists of small sport halls with an average age of 34 years. The findings of this study on the acoustic appropriateness of individual groups of sport halls therefore indicate that there is a need for the acoustic modernisation of sport halls in Slovenia. Case studies of possible modernisations (Jurak et al., 2012) show that the installation of various acoustic panels and absorbers could ensure adequate acoustic conditions. Such installations need to be durable and suitably placed in an aesthetically pleasing way and in an appropriate location (collisions of participants, balls and other equipment) in order to allow the appropriate usage of the hall.

The second possibility for improving acoustic conditions in sport halls is to carry out a more suitable organisation of lessons and the use of information communication technology (ICT) during the lessons. Some authors prefer technical accessories, such as voice amplifiers for teachers or earpieces for students (Ryan, 2009) in order to improve audibility. It is the opinion of the authors of this study that the use of the voice amplifiers or loudspeakers would only cause more problems, as the level of noise would be increased. Earpieces for students are less suitable for the types of movement that are part of the PE curriculum, and in some cases could also be dangerous (i.e. collision of the ball with the head). The authors see the solution in the organisation of work, i.e. in having the teacher carefully plan the realisation of the lessons. At the same time, the number and specific factors of students have to be considered, as well as equipment that will be used, the surface available and the activities of the other classes that will be carried out in the sport hall simultaneously.

Accordingly, teachers should carry out the majority of the explanations at the beginning of the lesson, when the noise level in the sport hall is the lowest. Students should be seated in a semicircle, so that they are all positioned at the same distance from the teacher, and the voice is transferred from above down. When the teacher has to provide additional explanations during the lesson, a signal which has previously been agreed on should be used (clapping, whistle, word) to stop the activity of students, then the students should gather around the teacher in order to receive short and clear additional information or lesson explanation. The technique of the teacher's speech is also crucial: words should be spoken clearly and at an appropriate pace. The students' attention should also be caught with non-verbal body communication. When providing explanations, some charts (contents or organisational) could be used, describing the technical execution of the movement or giving additional information. In such a way, the time of information transfer will be much shorter, and the teachers will avoid excessive talking.

Teachers can also reduce the strain on their voice with the adequate use of ICT. The modern fully-equipped sport hall should allow the teacher to easily organise the presentation of the visual information (Jurak & Kovač, 2011). Active planning enables the installation of LCD screens on sport hall walls, which can be connected with a computer, internet and a motion-activated rotating camera that can be fixed on the ceiling. With this relatively simple solution, teachers can set up a system for forwarding contents and visual feedback information to the participants, among many other things (e.g. demonstration of correct warm-up for the afternoon participants, demonstration of correct set-up and removal of equipment in a sport hall). Certain contents could also be presented as e-material in an internet classroom.

As the voice of the teacher is a source of sound and, as such, a vital element of audibility, teachers should also train and look after their own voice (Bruck Marçal & Peres, 2011; Simberg et al., 2005; Yiu, 2002). Additionally, educational institutions should also equip students (i.e. future teachers) with the relevant knowledge about the professional use of voice.

There are limitations to the present study and care should be taken if the results are generalized across different countries, since there could be differences in types of school sport halls and their acoustic treatment. Another limiting factor of this study is that the school sport halls were not randomly selected but included based on the expert knowledge as representatives of certain types of school sport halls.

Conclusion

The improvement of the acoustic conditions in sport halls requires acoustic changes to space and adequate teaching methods. Better acoustic conditions in sport halls can be achieved by accepting a standard of the acoustic conditions in the sport halls and by modernising and constructing new sport halls in accordance with this standard. According to the findings in this study and comparison with some international standards, the authors suggest that the standard for STI in Slovenian sport halls should be above 0.6. This standard could also be defined according to the optimal reverberation time depending on the volume of the sport hall; nevertheless, the STI also includes some other acoustic criteria and thus better describes the acoustic conditions in the sport hall. Adequate teaching methods can be ensured with increased teachers' competencies (education and in-service teacher training) and with the installation of suitable ICT equipment in sport halls, which will allow teachers to prepare and present visual information more easily. In accordance with this, further studies on the efficiency of various organisations of PE lessons on the students' understanding of the subject matter taught in sport halls with different acoustic conditions are strongly encouraged.

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Akustika u školskim dvoranama i njezine implikacije na nastavu tjelesnoga odgoja

Sažetak

Zbog zahtjevnih akustičkih uvjeta u kojima se odvija nastava tjelesnoga odgoja, problemima po zdravlje i uspjeh učenika koje takvi uvjeti uzrokuju, cilj je ovoga rada bio istražiti akustičke uvjete u školskim dvoranama u kojima se u Sloveniji odvija nastava tjelesnoga odgoja. Odabrano je trideset i pet školskih dvorana koje su odražavale četiri tipa sportskih dvorana izgrađenih u različito vrijeme. Mjereno je vrijeme odjeka te je s pomoću Indeksa prijenosa govora izračunata vrijednost razumljivosti govora. Razumljivost govora loša je ili jedva zadovoljavajuća u osamdeset i šest posto sportskih dvorana. Pronađene su statistički značajne razlike u akustici prostora koji pripadaju različitim tipovima dvorana. Najbolje akustičke uvjete imaju višenamjenske sportske dvorane koje pružaju mogućnost simultanoga rada s trima skupinama učenika. Najlošije uvjete imaju starije sportske dvorane u kojima se u jednom vremenskom razdoblju može održavati nastava samo s jednom skupinom učenika. Potrebno je unaprijediti akustiku školskih sportskih dvorana, a napor koji trpi glas nastavnika umanjiti s pomoću primjerene organizacije nastave i opreme koju nude informacijsko-komunikacijske tehnologije.

Ključne riječi: *buka; dvorana; nastavnici tjelesnog odgoja; okolina u kojoj se odvija nastava; razumljivost govora.*

Uvod

Strategije za unaprjeđenje obrazovnih procesa temelje se na didaktičkim pristupima ili okolini u kojima se nastava odvija. Primjerene okoline mogu olakšati komunikaciju, osigurati ugodnu atmosferu i imati pozitivan utjecaj na zdravlje i sposobnosti učenika i nastavnika. Čimbenici koji utječu na aktivnosti govorenja i slušanja, tj. na aktivnosti prenošenja zvuka u prostoru, čine neophodan dio okoline u kojoj se nastava održava. Svaki zvuk nosi određenu informaciju koja može, ali i ne mora biti razumljiva i korisna. Ako informacija sadrži previše beskorisnoga i nerazumljivoga sadržaja, ona stvara buku te odvraća pažnju učenika. *Buka* predstavlja nepoželjnu vrstu zvuka u okolini u kojoj se odvija nastava jer ima negativan učinak na čujnost među sudionicima obrazovnoga procesa.

Čujnost nastavnika i učenika ključan je dio akademske izvrsnosti (Klatte, Bergstroem, i Lachmann, 2013; WoolneriHall, 2010). Loši akustički uvjeti u učeniku uzrokuju nemir i negativno psiho-socijalno ponašanje (Crandell, Smaldino, i Flexer, 2005), a u uvjetima smanjene razine buke pospješuje se pažnja učenika i njihovo sudjelovanje u nastavi (Dockrell i Shield, 2012). Usprkos prethodno navedenim činjenicama, akustički su uvjeti u većini učionica loši (Knecht, Nelson, Whitelaw, i Feth, 2002; Mikulski i Radosz, 2011), pa čak mogu i naštetiti zdravlju djece (Holmes, Niskar, Kieszak, Rubin, i Brody, 2004; Niskar i sur., 1998; Niskar i sur., 2001; Walinder, Gunnarsson, Runeson, i Smedje, 2007).

Akustički uvjeti u kojima se izvodi nastava osobito su zahtjevni u dvoranama u kojima se odvija nastava tjelesnoga odgoja. U dvoranama istodobno radi velik broj učenika, a ponekad različite skupine učenika u isto vrijeme izvode različite aktivnosti. Sportske su aktivnosti po prirodi glasne zbog driblanja lopti, trčanja, skakanja, glasnog govorenja, povremenog navijanja i vikanja, uporabe zviždaljke i ostalih zvukovnih znakova, kao i puštanja glazbe (Bruck Marçal i Peres, 2011; Hadzi-Nikolova, Mirakovski, Zdravkovska, Angelovska, i Doneva, 2013; Lemoyne, Laurencelle, Lirette, i Trudeau, 2007; Palma, Mattos, Almeida, i Oliveira, 2009).

Govor je kombinacija izravnoga i reflektiranoga zvuka koji putuje od nastavnika do učenika. Izravan zvuk polazi od nastavnika i postaje reflektirani zvuk kad udari u jednu ili više prepreka i površina u prostoru. Produžetak reflektiranoga zvuka naziva se *odjekom* (engl. *reverberation*). Položaj učenika u sportskoj dvorani uvjetuje percepciju određene kombinacije izravnog i reflektiranog zvuka. Udaljenost između nastavnika i učenika uvjetuje potrebnu količinu akustičke energije izravnoga i reflektirajućega zvuka. Zbog veličine prostorije ta je udaljenost veća u sportskim dvoranama nego u učionicama. Energija govora koja dolazi do učenika putem izravnog i reflektirajućeg zvuka intenzivnija je od energije govora koju proizvodi samo izravan zvuk. Previše reflektirajućega zvuka može pogoršati *razumljivost govora* (engl. *speech intelligibility*). Sportska je dvorana uglavnom bučna sredina jer je njezin velik prostor sazdan od tvrdih materijala od kojih se zvuk odbija, a površine zidova, poda i stropa uglavnom su glatke kako bi se dugotrajno mogle koristiti za različite sportove i aktivnosti. Ti čimbenici povećavaju vrijeme odjeka, što narušava razumljivost govora i povećava razinu buke u prostoru.

Kvaliteta akustičkih uvjeta prostora može se odrediti mjerenjem i analizom vrijednosti vremena odjeka. Neke su zemlje postavile najviše moguće standarde vremena odjeka (npr. Building Bulletin 93 (2003): školske sportske dvorane <1,5 sekundi; ÖNORMB 2608 (2012): od 0,85 sekundi za male sportske dvorane do 1,94 sekundi za velike sportske dvorane). Općenito gledano, što je dulje vrijeme odjeka to je lošija akustička kvaliteta prostora, iako na vrijeme odjeka utječe nekoliko čimbenika: razina i geometrija prostora, funkcija sportske dvorane (vježbanje, događaji) i broj skupina koje istodobno koriste dvoranu. Prostorna akustika može se opisati s pomoću različitih akustičkih indeksa koji se izračunavaju na temelju vremena odjeka (Radosz, 2013). Često se koristi Indeks prijenosa govora (EN 60268-16:2003, 2003) kojim se opisuje razumljivost govora.

Normalan je govor jačine 50-60 decibela (dB), a razina bola je na oko 130 dB (NIOSH, 1998). Intenzivnija i češća izloženost zvuku povećava rizik od gubitka sluha. Jedinica mjere dB(A) izražava prosječno vrijeme izloženosti buci tijekom osmosatnog radnog dana, a dB(C) izražava razinu vrhunca tlaka zraka. Do gubitka sluha može doći zbog trenutne izloženosti izrazitoj buci ili uslijed redovite (u trajanju duljem od jedne minute) izloženosti buci jačine veće od 110 dB(C). Gubitak sluha također može biti posljedica dugoročne (dnevne ili tjedne) izloženosti buci jačine veće od 85 dB(A). Stručnjaci upozoravaju na to da treba izbjegavati izloženost zvuku jačine veće od 100 dB(C) u trajanju duljem od 15 minuta ako se osoba ne koristi primjerenom zaštitom od buke (NIOSH, 1998).

Izučavanja buke u sportskim dvoranama pokazala su da su ti prostori iznimno bučni. Pozadinski je zvuk nerijetko preglasan (Ryan i Lucks Mendel, 2010), a prema nekim smjernicama ne bi trebao prijeći 30 – 40 dB(A) (American Speech-Language-Hearing Association, American National Standards Institute, Building Bulletin 93itd.). Još je veća ukupna količina buke koja se stvara tijekom izvođenja različitih sportskih aktivnosti. Prosječna razina buke koja se proizvodi tijekom nastave kreće se između 74 dB(A) i 101 dB(A), a razina njezina vrhunca doseže između 111 dB(C) i 135 dB(C) (Augustynska, Kaczmarska, Mikulski, i Radosz, 2010; Hadzi-Nikolova i sur., 2013; Maffei, Iannace, i Masullo, 2011; Mirbod i sur., 1994; Palma i sur., 2009). Zbog toga se u sve većem broju nacionalnih i međunarodnih propisa i smjernica savjetuje smanjivanje razine buke te se predlažu ili propisuju minimalne razine zvučne izolacije koje treba postaviti između različitih prostora u sportskim dvoranama i na njihovim vanjskim zidovima (Palma i sur., 2009). Postoje također preporuke o optimalnom vremenu odjeka i najvišoj dopuštenoj razini buke koju uzrokuje uporaba opreme u zadanom prostoru (Maffei i sur., 2011). U Europi je najviša preporučena razina aktivne dnevne izloženosti buci 85 dB(A) (Directive 2003/10ES, 2008).

Čujnost predstavlja ključan čimbenik u okolini u kojoj se odvija nastava tjelesnog odgoja, s obzirom na to da je učinkovitost demonstracijskih vještina nastavnika bolja kad je udružena s primjerenim objašnjenjem (opis novoga pokreta, pružanje povratne informacije učenicima). Ako ukupna razina buke prelazi 69 dB(A), razumijevanje govora je narušeno (Studebaker, Sherbecoe, McDaniel, i Gwaltney, 1999), što znači da u takvim uvjetima učenici nisu u stanju pratiti upute nastavnika. Djeca imaju više poteškoća s razumijevanjem govora u bučnim uvjetima od odraslih (Papso i Blood, 1989; Valente, Plevinsky, Franco, Heinrichs-Graham, i Lewis, 2012). Što su djeca mlađa, to manje učinkovito čuju u bučnim uvjetima (Astolfi, Bottalico, i Barbato, 2012; Elliott, 1979; Jamieson, Kranjc, Yu, i Hodgetts, 2004) i slabije razumiju govor koji odjekuje (Bradley i Sato, 2008; Johnson, 2000). S povećanjem udaljenosti od izvora zvuka slušatelji ga sve teže razumiju (Leavitt i Flexer, 1991). Preintenzivna i prečesta izloženost zvuku može izazvati trajne probleme sa sluhom (Holmes i sur., 2004;

Niskar i sur., 2001). Potrebno je osigurati posebne uvjete u okolini u kojoj se uči kako bi se postigla kvalitetna komunikacija s učenicima koji imaju probleme s pažnjom, poteškoće pri učenju, jezične probleme (Cunningham, Nicol, Zecker, Bradlow, i Kraus, 2001), probleme sa sluhom (Bess, Dodd-Murphy, i Parker, 1998; Holmes i sur., 2004; Niskar i sur., 2001) i s djecom koja prate nastavu na jeziku koji nije njihov materinski jezik (Picard i Bradley, 2001).

Slaba akustika u zadanom prostoru predstavlja problem i po zdravlje nastavnika. Dok učenici, uslijed buke, slabo čuju nastavnike pa stoga obraćaju manju pozornost u većem prostoru, nastavnici teško uspijevaju biti dovoljno glasni kako bi nadvladali okolinsku buku i prenijeli željenu poruku. Stoga se problemi s glasom (Kovač, Leskošek, Hadžić, i Jurak, 2013; Simberg, Sala, Vehmas, i Laine, 2005; Smith, Kirchner, Taylor, Hoffman, i Lemke, 1998; Smith, Lemke, Taylor, Kirchner, i Hoffman, 1998) i sluhom (Kovač i sur., 2013; Lemoyne i sur., 2007) nalaze među najčešćim profesionalnim zdravstvenim problemima s kojima se susreću nastavnici tjelesnoga odgoja. Zbog prethodno opisanih radnih uvjeta nastavnici tjelesnog odgoja imaju problema s glasom češće nego što je to slučaj s ostalim nastavnicima (Jonsdottir, Boyle, Martin, i Sigurdardottir, 2002; Preciado, Perez, Calzada, i Preciado, 2005; Smith, Kirchner i sur., 1998). Česta izloženost buci ima i dugoročne posljedice poput umora tijekom dana, povećane psihološke i emocionalne napetosti, osjećaja nervoze i iritacije, problema s koncentracijom, hrapavosti glasa i kašljanja (Augustynska i sur., 2010). Osim toga, problemi s glasom također utječu na radnu sposobnost i kvalitetu života (Ma i Yiu, 2001; Smith i sur., 1996; Yiu, 2002) te iziskuju znatne zdravstvene troškove (Smith, Lemke i sur., 1998; Verdolini i Ramig, 2001). Imajući u vidu sve navedeno, Smith i sur. (1998) izvještavaju o tome da otprilike 20% nastavnika izostaje s posla zbog problema s glasom, a u ostalim zanimanjima samo 4% zaposlenika izostaje s posla zbog navedenoga razloga.

Stoga je svrha ovoga rada bila istražiti posebne akustičke uvjete u sportskim dvoranama u kojima rade nastavnici tjelesnoga odgoja u Sloveniji.

Metode

Odabir dvorana

Za potrebe ovoga istraživanja tim stručnjaka odabrao je 35 školskih sportskih dvorana koje pripadaju četirima različitim tipovima kategorija školskih sportskih dvorana koje nalazimo u Sloveniji (Jurak i sur., 2012; vidi Tablicu 1).

Tablica 1.

Navedene kategorije (tipovi) sportskih dvorana oblikovane su s obzirom na vrijeme izgradnje. Prva školska sportska dvorana u Sloveniji izgrađena je 1874. godine, a neke njoj slične sportske dvorane izgrađene su prije početka Drugoga svjetskog rata. S obzirom na to da su takve dvorane rijetke te da su neke oštećene tijekom rata, nastava tjelesnoga odgoja se u zimskim uvjetima uglavnom održavala u preuređenim učionicama. Takozvani nametnuti doprinos koji se provodio šezdesetih i sedamdesetih godina prošloga stoljeća osigurao je inženjerski napredak u izgradnji školskih sportskih dvorana. Od toga vremena pa sve do danas pri izgradnji škola predviđa se i izgradnja sportskih dvorana, a s vremenom su narasli standardi veličine i opremljenosti prostora za vježbu (Jurak i sur., 2012).

Tip *1-C stara* predstavlja tip starih školskih sportskih dvorana (prosjek starosti: 51 godina). Prosječna površina tih sportskih dvorana je 343 m^2, a prosječan volumen im je 2.527 m^3. Starije su dvorane iz te skupine renovirane, ali su ti zahvati napravljeni prije 20 ili više godina. Sve su te dvorane pravokutnoga oblika s izuzetkom njihova stropa. Opremljene su poliuretanskom sportskom podlogom, švedske ljestve postavljene su na jednom od dva duga zida prostorije, a košarkaški su obruči postavljeni na dva kraća zida dvorane. Zidovi tih dvorana nisu posebno tretirani niti zaštićeni. Zid pod zabatom prostorije ima pad od 22°, a strop nije posebno tretiran.

Tip *2-C* obuhvaća novije i veće školske sportske dvorane u kojima dva razreda mogu istodobno vježbati. Prosječna površina takvih dvorana je 671 m^2, a volumen im je 4.772 m^3. Prosječna starost tih dvorana je 18 godina i one nikad nisu renovirane. Te su dvorane pravokutnoga oblika, a opremljene su drvenim sportskim podlogama. Spušteni strop postavljen je paralelno s podom, a načinjen je od heraklith ploča od drvene vune. Švedske su ljestve postavljene na jednom od dva duga zida prostorije, a preostali su zidovi opremljeni košarkaškim obručima i drugom fiksnom ili sklopivom sportskom opremom (golovima, hvatištima za penjanje, užadi, motkama ili ljestvama). Te su sportske dvorane također opremljene košarkaškim koševima postavljenima na nosačima pričvršćenima za strop dvorane.

Tipu *3-C* pripadaju najveće sportske dvorane u Sloveniji. Te dvorane daju optimalan omjer uloženoga troška izgradnje i mogućnosti uporaba. U tim dvoranama istodobno mogu raditi tri skupine učenika. Njihova prosječna površina je 1.272 m^2, a volumen im je 13.857 m^3. S izuzetkom dvije dvorane, sve dvorane koje pripadaju toj kategoriji izgrađene su u posljednjih dvadeset godina (prosjek starosti tih dvorana je 16 godina). Pravokutne su, s izuzetkom gornje površine (zid pod zabatom ima pad od 18° i vidljivu strukturu krova ili ravan krov s vidljivim gredama koji u kombinaciji s ostalim instalacijama oblikuje blago neravan strop) te su opremljene drvenom sportskom podnom podlogom. Švedske su ljestve postavljene na jednom od dva duga zida prostorije, a na drugoj su strani postavljene manje tribine (starije dvorane imaju fiksne, a u novijima su opremljene teleskopskim tribinama). Ostali zidovi i strop opremljeni su fiksnom ili sklopivom sportskom opremom (golovima, obručima, hvatištima za penjanje, užadi, motkama ili ljestvama). S izuzetkom dvije najstarije dvorane, zidovi svih dvorana opisanoga tipa izolirani su drvenim oblogama, koje su podstavljene heraklith pločama od drvene vune na stropovima i uz stropove. Nijedna od tih dvorana nije renovirana. U novijim dvoranama toga tipa na švedske su ljestve postavljene podloge za vježbanje, a na čeone zidove postavljena je zaštitna podloga.

Dvorane tipa *1-C spc* ubrajaju se u najmanje sportske dvorane. U tim dvoranama istodobno može raditi samo jedan razred, a izgrađene su s namjenom treniranja određenih sportova (npr. fitnes, gimnastika, ples). Njihova je prosječna površina 180 m^2, a volumen im je 932 m^2. Mnoge od njih originalno su izgrađene kao glavne školske dvorane, ali su s vremenom postale pomoćni prostori za vježbu. To su stare dvorane (prosječna im je starost 42 godine). Starije među njima su renovirane, ali te su preinake bile prije 15 ili više godina. Sve su te dvorane pravokutnoga oblika, ali se odnosi duljina zidova (s iznimkom visine stropa) od dvorane do dvorane vrlo razlikuju. Pod je prekriven poliuretanskom ili drvenom sportskom podlogom, a u gimnastičkim su dvoranama na navedenu podlogu položene strunjače ili podne obloge za gimnastički parter. Švedske su ljestve većinom postavljene na jednom od dva duga zida prostorije. Zidovi prostorija nisu podstavljeni, a najistaknutija mjesta opremljena su sigurnosnom podlogom. Takve dvorane imaju obične stropove koji nisu ničim podstavljeni.

Mjerne karakteristike

Sve odabrane škole pristale su na mjerenje akustike u svojim sportskim dvoranama te su ustupile dokumentaciju o starosti dvorana. Za izračunavanje volumena svake sportske dvorane upotrijebljen je laserski uređaj. Akustička su mjerenja provedena u praznim sportskim dvoranama. U skladu s ENISO 3382-2:2008 protokolom (2008) na nekoliko je mjesta u svakoj sportskoj dvorani primijenjena metoda vanjskoga impulsa (na tri točke mjerenja u svim dvoranama i na dvije dodatne točke mjerenja u dvoranama tipa *3-C*). Prva točka mjerenja nalazila se na sredini dvorane, druga tik izvan prostora slobodnog bacanja ispred koša, a treća u jednom od uglova dvorane smještenih nasuprot druge točke mjerenja. Dodatne dvije točke mjerenja definirane za potrebe mjerenja u dvoranama tipa 3-C smještene su tik izvan prostora slobodnog bacanja ispred koša nasuprot drugoj točki mjerenja i na tribinama.

Startni pištolj upotrijebljen je za proizvodnju zvuka te je mjereno vrijeme odjeka zvuka. Dobiveni akustički podatci za svaku sportsku dvoranu registrirani su s pomoću Nor140 opreme za analizu zvuka (Norsonic, Norway). Zvučni zapis prenesen je na računalo na kojemu je procesiran s pomoću DIRAC Room Acoustic softvera (Bruel i Kjaer). Vrijeme odjeka izmjereno na pojedinačnim točkama mjerenja izračunato je za cijeli spektar frekvencija čujnih ljudskome uhu. Mjerenja su uzeta jednom na svakoj točki mjerenja. Mjerenje je ponovljeno u slučaju kad je tehničar sumnjao u kvalitetu provedenog mjerenja ili ako je nešto omelo mjerenje. U takvim se slučajevima u analizi koristilo ponovljeno mjerenje.

Mjerenje vremena odjeka u pojedinačnim sportskim dvoranama dalo je podatke o vremenu zadržavanja zvuka u prostoru nakon što je aktivnost proizvodnje zvuka završila (npr. koliko je dugo zvuk odjekivao prije nego što je u potpunosti nestao). Taj je rezultat uspoređen s optimalnim vremenom odjeka, vodeći računa o karakteristikama svake sportske dvorane. Referentne vrijednosti optimalnog vremena odjeka izračunate su s obzirom na DIN 18041 (2004). Elementi korišteni u izračunu i određivanju optimalnog vremena odjeka bili su volumen dvorane (u m^3) i broj razreda koji istodobno rade u dvorani. Tu su informaciju osigurali nastavnici koji održavaju nastavu u tim dvoranama. Sljedeća je formula korištena za izračun optimalnog vremena odjeka za dvorane u kojima u jednom vremenu može raditi samo jedan razred (Sport-1): optimalno vrijeme odjeka za Sport-1 = 1,27 × logV – 2,49 (sekundi), a sljedeća je formula korištena za izračun optimalnog vremena odjeka za dvorane u kojima istodobno može raditi više razreda (Sport-2): optimalno vrijeme odjeka zaSport-2 = 0,95 × logV – 1,74 (sekundi).

Prema DIN 18041 standardu prihvatljiv odmak od optimalnog vremena odjeka jest ±20%. Standard za prostore volumena većeg od 8.500 m^3 i manjeg od 2.000 m^3 ne određuje kriterij optimalnog vremena odjeka, niti daje formulu potrebnu za njegov izračun. Optimalno vrijeme odjeka za dvorane volumena većeg od 8,500 m^3 određeno je kao maksimalna vrijednost za Sport-1 (2,5 sekundi) i za Sport-2 (2,0 sekundi) uz dodatni kriterij broja razreda koji istodobno vježbaju u dvorani. Prosječna vrijednost između Sport-1 i Sport-2 varijabli uzeta je kao optimalno vrijeme odjeka, ne uzimajući u obzir broj razreda koji u dvorani istodobno vježbaju.

Akustički uvjeti za održavanje nastave u pojedinačnim sportskim dvoranama procijenjeni su s obzirom na dva kriterija.

– Mjereno je vrijeme odjeka (u 1/100 sekundi) na 500Hz i 2000Hz jer prostor između te dvije frekvencije predstavlja područje ljudskome uhu najbolje čujnih frekvencija („IEC 61672-3, Electroacoustics – Soundlevelmeters“, 2003). Izmjereno vrijeme odjeka uspoređeno je s optimalnim vremenom odjeka svakog pojedinačnog prostora kako bi se odredila kvaliteta akustike svake dvorane.
– *Indeks prijenosa govora (IPG)* izračunat je na temelju izmjerenog vremena odjeka u svakom pojedinačnom prostoru i svakoj pojedinačnoj točki mjerenja u prostoru. IPG se koristi za predviđanje vjerojatnosti razumijevanja slogova, riječi i rečenica. Vrijednosti IPG-a kreću se između 0 i 1. Što je viši IPG, to je bolja razumljivost govora u danom prostoru (v. Tablicu 2).

IPG je zbroj indikatora modulacije prijenosa (IMP), jednoga za svaki frekvencijski pojas od 125 Hz do 8 kHz (gdje se svaka IMP vrijednost izvodi iz vrijednosti indeksa modulacijskoga prijenosa od više od 14 različitih modulacijskih frekvencija), a uzimajući u obzir zvučne efekte u skladu s EN 60268-16 (2003).

Analiza

Podatci su analizirani s pomoću SPSS 18.0 statističkoga softvera. S pomoću jednostavne deskriptivne statistike izračunata je distribucija rezultata. S pomoću χ^2 testa i Cramerova V koeficijenta testirane su razlike između akustičkih varijabli s obzirom na tip sportske dvorane. Korelacija između pojedinačnih akustičkih varijabli i starosti sportskih dvorana izračunata je s pomoću Spearmanova koeficijenta korelacije ranga ρ_s.

Rezultati

Optimalna vremena odjeka u odnosu na volumene dvorana kretala su se između 1,7 i 2,2 sekunde (v. Sliku 3), a neka su trajala i do 7 sekundi (v. Sliku 1). Čini se da je stvarno vrijeme odjeka ponekad bilo vrlo kratko u manjim sportskim dvoranama (tipovi *1-C stara* i *1-C spc*). Pronađena je visoka korelacija (ro = 0,73) između izmjerenog vremena odjeka na 500 Hz i 2000 Hz, no u većini dvorana vrijeme odjeka na 500 Hz bilo je nešto dulje nego na 2000 Hz (v. Sliku 1).

Slika 1. i 2.

IPG vrijednosti kretale su se između 0,30 i 0,66 (v. Sliku 2). S obzirom na prethodno uočeno dugo vrijeme odjeka, očekivalo se da će manje sportske dvorane (tipovi *1-C stara* i *1-C spc*), koje su uglavnom starije dvorane (v. Sliku 3), postići niže vrijednosti indeksa.

Tablica 2.

Usporedbom procjene razumljivosti govora u različitim skupinama sportskih dvorana s obzirom na vrijednosti IPG-a (v. Tablicu 2) uočeno je da nijedna dvorana nije ocijenjena „odličnom“ ocjenom jer je najviši IPG bio 0,66. Većina sportskih dvorana (preko 80%) smještena je u skupine „prolazno“ ili „loše“ (srednja vrijednost=0,49±0,10).

Slika 3.

Statistički značajne razlike u vrijednostima IPG-a (χ^2=9,924; p=0,019) pronađene su između različitih tipova sportskih dvorana. Srednje vrijednosti akustičkih uvjeta prema tipu sportske dvorane prikazane su na Slici 3. Vidljivo je da je volumen sportskih dvorana u kojima u isto vrijeme mogu raditi tri razreda (*3-C*) puno veći u usporedbi s ostalim dvoranama. Stoga je vrijeme odjeka u tim dvoranama dulje. No, izmjereno vrijeme odjeka na 500 Hz i 2000 Hz u takvim dvoranama u prosjeku nije bilo dulje od vremena odjeka u ostalim skupinama sportskih dvorana, što upućuje na bolju razumljivost govora u tim prostorima. Vidljivo je da se vrijednosti IPG-a smanjuju s obzirom na pojedinačne tipove sportskih dvoranama, tako da su one najviše u sportskim dvoranama tipa *3-C*, a najniže u dvoranama tipa *1-C stara*. Taj trend prati prosječnu starost pojedinačnih tipova sportskih dvorana. Daljnjom su analizom utvrđene statistički značajne korelacije između starosti dvorana i IPG-a (Spearman ρ_s=0,49, p=0,003; v. Sliku 2), gdje je izmjereno vrijeme odjeka bilo na 500 Hz (ρ_s =-0,42, p=0,013), a izmjereno je vrijeme odjeka na 2000 Hz bilo na granici statističke značajnosti (ρ_s =-0,32, p=0,057).

Rasprava

Ovo istraživanje predstavlja doprinos znanju o akustičkim uvjetima učenja i poučavanja u sportskim dvoranama. Pokazalo se da su akustički uvjeti u sportskim dvoranama u Sloveniji loši, što otežava provođenje pedagoških procesa i nastavnicima tjelesnoga odgoja uzrokuje probleme s glasom zbog čega oni smatraju da je to drugi najteži zdravstveni problem vezan uz njihovo zanimanje (Kovač i sur., 2013). Nailazimo na razlike u akustici između pojedinačnih skupina sportskih dvorana.

Najbolji akustički uvjeti izmjereni su u velikim višenamjenskim sportskim dvoranama koje u isto vrijeme mogu koristiti tri razreda, a najlošiji su uvjeti zatečeni u starim sportskim dvoranama u kojima u istom vremenu može vježbati samo jedan razred. Pokazalo se da je akustika sportske dvorane povezana s njezinom starošću.

Pri evaluaciji akustike kao važnoga čimbenika koji karakterizira okolinu u kojoj se odvija nastava iz predmeta tjelesni odgoj ili bilo koja druga sportska aktivnost treba definirati sljedeće čimbenike na koje nailazimo u takvoj okolini: govornik (nastavnik, trener, učenik), pozadinska buka (vikanje, driblanje lopti, zvukovi koraka, zviždanje, glazba, ventilacija), akustički uvjeti prostora (obloge na zidovima, podu i stropu, geometrijske karakteristike dvorane, oblik stropa itd.) i slušači (učenici). Svi ti čimbenici utječu na učinkovitost i uspješnost poučavanja. Istraživanja su pokazala da se napredak u tjelesnom odgoju može postići s pomoću takve vježbe u kojoj nastavnik učenicima pruža individualnu povratnu informaciju (Silverman, Tyson, i Krampitz, 1992) pa time povećava vrijeme utrošeno na vježbu jer se manje vremena troši na organizaciju sata (Evertson i Harris, 1992; Siedentop, 2002). Nastavnici mogu utjecati na pozadinsku buku primjenom primjerenih tehnika organizacije i čujnosti upotrebom nastavne opreme. Međutim, oni ne mogu utjecati na akustičke uvjete koji utječu na sposobnosti učenja učenika i sposobnosti poučavanja nastavnika. Ti uvjeti ovise o konstrukcijskim karakteristikama sportske dvorane. Dakle, nastavnici mogu samo neizravno utjecati na te uvjete tako što će nastojati postići primjerene akustičke karakteristike dvorane u trenutku njezine izgradnje ili tako što će ih poboljšati u trenutku renoviranja tog prostora.

Rezultati toga istraživanja pokazali su da se tjelovježba često odvija u lošim akustičkim uvjetima. Većini sportskih dvorana iz uzorka ovoga istraživanja dodijeljena je loša ili tek prolazna ocjenu prema IPG kriterijima. Stvarno izmjereno vrijeme odjeka u dvoranama iz uzorka bilo je dulje od optimalnoga (v. Slike 1 i 3). Stoga je razumljivost govora u tim sportskim dvoranama uglavnom nezadovoljavajuća (v. Tablicu 2). S obzirom na IPG vrijednosti to znači da učenici u proučavanim dvoranama razumiju samo polovinu slogova, manje od četvrtine riječi i manje od jedne desetine rečenica. Izmjerene akustičke karakteristike razlikuju se s obzirom na tipove sportskih dvorana (v. Sliku 3) i njihovu starost (v. Sliku 2). Najbolji akustički uvjeti utvrđeni su u višenamjenskim, većinom novijim, sportskim dvoranama u kojima tri razreda mogu vježbati u isto vrijeme. Najlošiji su uvjeti utvrđeni u starim višenamjenskim sportskim dvoranama, kojima se u istom vremenu može koristiti samo jedan razred. No, najveći raspon izmjerenih vrijednosti uočen je u velikim višenamjenskim sportskim dvoranama jer su se u toj skupini građevina našle dvorane s najboljim i najlošijim akustičkim uvjetima (vrijeme odjeka od 7 sekundi). To pokazuje da se manje pažnje posvetilo primjerenoj akustičkoj prilagodbi prostora u najstarijim sportskim dvoranama tipa *3-C*.

Valja spomenuti iznimno lošu akustiku malih sportskih dvorana. Primarna namjena tih dvorana bila je izvođenje nastave tjelesnoga odgoja u prve tri godine, zatim djelomično u druge tri godine osnovnoškolskoga razdoblja u Sloveniji. U tim sportskim dvoranama nastavu tjelesnoga odgoja održavaju učitelji primarnoga obrazovanja koji posjeduju slabije znanje o organizaciji takve nastave (Kovač, Strel, i Jurak, 2008), a broj učenika u skupini može doseći 28, što je u skladu s Propisom o standardima izvođenja nastave u osnovnoj školi (Regulation on teaching standards in primary school, 2010). Održavanje discipline još je problematičnije s mlađim učenicima s kojima se nastava izvodi u velikim skupinama i u ograničenom prostoru (Lemoyne i sur., 2007). Stoga nije neuobičajeno da razina motornih vještina učenika prvoga trogodišnjega razdoblja uvelike ovisi o kvaliteti materijalnih uvjeta u kojima se u pojedinoj školi odvija nastava tjelesnoga odgoja (Štemberger, 2003).

Osim o volumenu prostorije vrijeme odjeka također ovisi o građevinskim rješenjima i materijalima korištenima u izradi dvorane. Ti su čimbenici povezani s vremenom izgradnje sportske dvorane pa se s tim u skladu očekuju razlike između tipova sportskih dvorana. Iz opisa pojedinačnih tipova sportskih dvorana zaključujemo da najstarije dvorane imaju najtvrđe paralelne površine (prazni zidovi, poliuretanski pod i tvrdi strop). Nešto novije male dvorane izgrađene su na istim principima. U skladu s njihovom specifičnom uporabom one su većinom opremljene dodatnom opremom (sigurnosna zaštita zidova, gimnastičke podloge na podu), čime se unaprjeđuju njihovi akustički uvjeti. Zajedničke karakteristike sportskih dvorana koje pripadaju posljednjim dvjema generacijama (tipovi *3-C* i *2-C*), a koje utječu na akustičke uvjete, predstavljaju drvene sportske podloge i zidne obloge (zidne obloge u slučaju dvorana tipa *2-C* i većinom zidne obloge u slučaju dvorana tipa *3-C*). Volumen prostorije predstavlja ključnu razliku između tih dvaju tipova sportskih dvorana jer su školske sportske dvorane najnovije generacije (*3-C*) gotovo tri puta veće, čime se povećava optimalno vrijeme odjeka. Osim toga, u najnovijoj generaciji nalazimo veće površine koje su pokrivene nekom vrstom materijala koji predstavlja zvučnu izolaciju (ponekad su to drvene obloge na svim zidovima i gimnastičke podloge na švedskim ljestvama). Na akustičke uvjete u tim sportskim dvoranama također utječu nešto različitiji prostorni oblici (vidljivi elementi strukture krova i stropa koji nisu paralelni s površinom poda, prostor u kojemu se nalaze tribine).

U više od polovine svih sportskih dvorana (57%) izmjereno vrijeme odjeka na 500 Hz niže je nego na 2000 Hz. U prostorima bez akustičkoga tretmana taj je trend obično obratan jer se, zahvaljujući karakteristikama apsorpcijskih materijala, s povećanjem frekvencije vrijeme odjeka smanjuje. Taj efekt ne ovisi o tipu sportske dvorane (u kojima nalazimo različite akustičke uvjete) pa se nameće pitanje njegova uzroka. Detaljnija je analiza pokazala da je samo u nekolicini sportskih dvorana proveden akustički tretman (npr. heraklith ploče od drvene vune). U mnogim sportskim dvoranama u kojima je vrijeme odjeka na 500 Hz bilo niže nego na 2000 Hz izmjerena su neujednačena vremena odjeka između 100 Hz i 4000 Hz (npr. vrijeme odjeka od 2,3 sekunde na 100 Hz, 1,7 sekundi na 500 Hz, 2,5 sekundi na 1600 Hz i 1,9 sekundi na 4000 Hz) (Jurak i sur., 2012). Potrebna je temeljitija analiza da bi se taj problem istražio.

Kako bi se unaprijedile akustičke karakteristike slovenskih sportskih dvorana, potrebno je najprije znati da su problemi s akustikom puno manji u novoizgrađenim dvoranama, a veći u starijima. U prošlosti je izgrađena primjerena mreža školskih sportskih dvorana, a njihova prosječna starost je 32 godine (Jurak i sur., 2012). Najveća skupina dvorana obuhvaća male građevine prosječne starosti od 34 godine. Rezultati ovoga istraživanja o akustičnoj primjerenosti individualnih tipova sportskih dvorana stoga otkrivaju potrebu za akustičkom modernizacijom sportskih dvorana u Sloveniji. Studije slučaja mogućih postupaka modernizacije (Jurak i sur., 2012) pokazuju da bi se uvođenjem raznih akustičkih panela i materijala koji apsorbiraju zvuk mogli osigurati primjereni akustički uvjeti. Takvi dodatci dvoranama trebaju biti otporni i postavljeni na primjereno mjesto (tako da se izbjegnu udarci učenika, udaranje loptom i ostalom opremom) te na oku ugodan način kako bi se omogućila njihova primjerena upotreba u dvorani.

Druga mogućnost za poboljšanje akustičkih uvjeta u sportskim dvoranama leži u primjerenijoj organizaciji nastavnih sati i upotrebi informacijsko-komunikacijskih tehnologija (IKT) u nastavi. Neki autori preferiraju tehničku pomoćnu opremu, kao što su pojačivači glasa za nastavnike i slušalice za učenike (Ryan, 2009) kako bi se unaprijedila čujnost. Autori ovoga rada smatraju da bi upotreba pojačivača glasa ili zvučnika samo uzrokovala dodatne probleme jer bi se povećala razina buke. Slušalice za učenike nisu primjerene tipovima kretnji predviđenih kurikulom tjelesnog i zdravstvenog odgoja, a u nekim slučajevima mogu biti i opasne (npr. udarac loptom u glavu). Autori smatraju da je rješenje problema u organizaciji rada, odnosno temeljitom planiranju nastave. Pritom treba uzeti u obzir broj i individualne karakteristike učenika, zatim opremu koja bi se koristila, površinu na kojoj bi se radilo, kao i aktivnosti koje bi u isto vrijeme u dvorani provodili drugi razredi.

S time u skladu nastavnici trebaju učenicima pružiti većinu objašnjenja na početku sata, dok je razina buke u sportskoj dvorani najniža. Učenici trebaju sjediti u polukrugu tako da svaki od njih bude jednako udaljen od nastavnika te da se glas prenosi odozgo prema dolje.

Kad nastavnik tijekom sata treba pružiti dodatna pojašnjenja, potrebno je upotrijebiti prethodno dogovoren signal (pljeskanje, zviždaljka, riječ) da bi se zaustavile učeničke aktivnosti. Potom se učenici trebaju okupiti oko nastavnika kako bi primili kratke i jasne dodatne informacije ili pojašnjenja nastavnoga gradiva. Tehnika govorenja kojom se nastavnik koristi također je ključna: riječi trebaju biti izgovorene jasno i primjerenim tempom. Pažnju učenika treba zadobiti neverbalnom komunikacijom. Pri pružanju primjera mogu se koristiti grafički prikazi (sadržaja ili organizacije vježbi), gradivo se može predstaviti prikazom pokreta ili davanjem dodatnih informacija. Tako će se skratiti vrijeme koje se koristi za prenošenje informacija, a nastavnici će izbjeći pretjeranu upotrebu govora.

Naprezanje glasa nastavnici također mogu reducirati primjerenom upotrebom informacijsko-komunikacijskih tehnologija. Moderna, potpuno opremljena sportska dvorana omogućit će nastavniku jednostavnu organizaciju vizualne informacije (Jurak i Kovač, 2011). Aktivno planiranje omogućuje instalaciju LCD ekrana na zidove sportskih dvorana. Ti se ekrani mogu povezati s računalom, internetom i rotirajućom kamerom koja se aktivira na pokret, a koju je moguće pričvrstiti na strop dvorane. S pomoću tog prilično jednostavnog rješenja nastavnici mogu pripremiti sustav za prikazivanje sadržaja i povratnih informacija učenicima, a moguće su i mnoge druge upotrebe takve opreme (npr. demonstracija pravilnog zagrijavanja učenicima u popodnevnoj smjeni, demonstracija pravilnog postavljanja i spremanja opreme u sportskoj dvorani). Neki se sadržaji mogu prikazati u obliku e-materijala u računalnoj učionici.

Glas nastavnika izvor je zvuka te je, kao takav, ključan element postizanja čujnosti pa nastavnici trebaju vježbati i čuvati svoj glas (Bruck Marçal i Peres, 2011; Simberg i sur., 2005; Yiu, 2002). Osim toga, obrazovne institucije trebale bi studentima (tj. budućim nastavnicima) pružiti relevantna znanja o profesionalnoj upotrebi glasa.

Ovo istraživanje ima svoja ograničenja. Potreban je oprez pri pokušaju generalizacije rezultata na različite zemlje jer se tipovi školskih sportskih dvorana i akustički tretman tih prostorija mogu razlikovati od zemlje do zemlje. Još jedan ograničavajući čimbenik ovoga istraživanja jest to što sportske dvorane iz uzorka nisu nasumično izabrane, već su u ovo istraživanje uključene na temelju procjene stručnjaka o tome da predstavljaju određene tipove sportskih dvorana.

Zaključak

Da bi se unaprijedili akustički uvjeti u sportskim dvoranama, potrebni su zahvati u prostoru dvorana kojima se omogućuju njihove promjene u akustičkim karakteristikama. Bolje akustičke uvjete u sportskim dvoranama moguće je postići prihvaćanjem standarda akustičkih uvjeta u sportskim dvoranama i modernizacijom i izgradnjom novih sportskih dvorana u skladu sa spomenutim standardom. Na temelju rezultata ovoga istraživanja i usporedbe s nekim međunarodnim standardima autori predlažu uvođenje IPG standarda višeg od 0,6 u slovenske sportske dvorane. Taj bi standard trebalo definirati na temelju optimalnog vremena odjeka u odnosu na volumen sportske dvorane. Međutim, IPG obuhvaća i neke druge akustičke kriterije i omogućuje bolji opis akustičkih uvjeta u sportskim dvoranama. Unapređivanjem nastavnih vještina nastavnika (tijekom njihova obrazovanja i prakse) i instalacijom primjerene ITK opreme u sportske dvorane moguće je osigurati upotrebu primjerenih nastavnih metoda. ITK oprema omogućuje jednostavniju pripremu i prezentaciju informacija. U skladu s navedenim intenzivno se potiče provođenje daljnjih istraživanja o učinkovitosti utjecaja različitih načina organizacije sati tjelesnoga odgoja na učeničko razumijevanje gradiva koje se poučava u sportskim dvoranama različitih akustičkih uvjeta.