



**Real ear acoustical characteristics of impulse sound generated by golf drivers and the risk to hearing**

Journal:	<i>BMJ Open</i>
Manuscript ID:	bmjopen-2013-003517
Article Type:	Research
Date Submitted by the Author:	01-Jul-2013
Complete List of Authors:	Bardsley, Barry; Swansea University, College of Human & Health Science Zhao, Fei; University of Bristol, Centre for Hearing and Balance Studies
<b>Primary Subject Heading</b>:	Ear, nose and throat/otolaryngology
Secondary Subject Heading:	Communication
Keywords:	Audiology < OTOLARYNGOLOGY, Adult otolaryngology < OTOLARYNGOLOGY, PREVENTIVE MEDICINE

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4 **Real ear acoustical characteristics of impulse sound generated by**  
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7 **golf drivers and the risk to hearing**  
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47 **Keywords: Golf, Sports Injuries, Noise, Hearing**  
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49 **Word count: 2993**  
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51 **References: 12**  
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## ARTICLE SUMMARY

### Article focus

1. Is there a risk to hearing for amateur golfers when using the driver golf club?
2. If so, is this risk more prominent in one ear or equal across ears?
3. Does the speed of the swing influence the sound generated?

### Key Messages

1. The results indicate varying levels of noise produced by clubs but negligible risk to hearing of amateur golfers, with a daily noise exposure of 2.5% when averaging the results of the loudest club.
2. No difference was found between ears.
3. Swing speed does not have a significant correlation to the sound generated.

### Strengths

1. An innovative approach taken by using in-the-ear recordings that provide sound pressure levels at the tympanic membrane. This provides a more accurate estimation because it takes ear canal resonance properties into consideration, whereas the alternative of using a sound level meter equidistant does not provide this detail.
2. Using the recordings in-the-ear canal provides ear independent recordings.

### Limitations

1. Three standard clubs as well as the participants own club meant that a small sample of golf clubs was used in the study.

## ABSTRACT

### Background/Aims

This study investigated the intensity and frequency responses generated from golf club drivers at impact with a golf ball. In situ recordings were made from the ear canals in order that ear specific information was obtained. The risk of hearing loss from these results was then calculated.

### Methods

19 adult male participants struck 6 golf balls with each of the 4 golf drivers clubs. GN Otometric Freefit wireless Real Ear Measurement System (REM) was used to record the acoustical responses of the impulses sounds generated. A Swing Speed Radar® system was used to investigate the relationship between noise level and swing speed.

### Results

One club generated significantly higher intensity levels of impulse noise than the others with a mean dBA recordings of 100.0 and 98.2 for the far and near ear respectively. There was no significant difference between the ears and a small positive correlation was found between noise intensity and swing speed.

### Conclusions

If a basket of 40 balls are consistently hit at 116 dBA mean intensity, there is significant risk to hearing. When using the maximum recorded levels from the study with club 1 which was 123dBA, this only required 8 strikes before posing a significant risk to hearing.

## INTRODUCTION

The popularity of Golf has seen significant increases in the past 25 years, particularly in Europe and the United States. In the U.K. alone figures from 2011 showed 1.3 million golf players and close to 3000 golf courses [1]. Golf requires the player to swing various types of clubs to hit balls into a relatively wide open space with the ultimate aim of sending the ball into a hole with the least amount of shots.

Golf is perceived as a low-risk sport compared with other sports such as rugby, football, basketball or skiing that have higher injury rates, however several studies have provided insight into injuries related to golf. These range from the common spine and upper or lower limb injuries [2] to the less frequent injuries related to golf ball trauma [3].

Golf has not been attributed to leisure noise exposure and noise induced hearing loss (NIHL) until recently [4]. Noise can be described as sound at an intensity that can interfere with verbal communication and may cause discomfort of the ears or reduction of hearing sensitivity, defined as hearing damage [5]. Any exposure to noise of significant intensity and duration increases the risk of ear damage and causes permanent hearing damage, known as noise induced hearing loss (NIHL). Both industrial noise exposure and noise in leisure are the major causes of avoidable permanent hearing loss throughout the world. Within the categories of leisure noise, noise exposure from sporting activities is a major recreational noise sources relevant to various social activities, such as, motor sport [6], shooting [7], and spectators at a football match [8].

A study that investigated the potential hazard of modern Driver golf clubs in damaging users hearing from excessive exposure to loud sounds has highlighted this link [4]. They reported

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3 on a case of a 55 year old man who had appeared to developed unilateral noise induced  
4 hearing loss due to the exposure of loud noises generated from his driver golf club. When  
5 using a professional golfer, they found that many of the clubs generated sounds in excess of  
6 120dBA, particularly the thin faced titanium drivers. Therefore, the authors recommended  
7 caution should be exercised by any golfers using the thin faced titanium drivers to avoid  
8 damage to their hearing.  
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11 This raises a number of interesting questions. The use of a sound level meter (SLM)  
12 equidistant from the golfer provided information in the free field. However, in using a SLM it  
13 is unclear what acoustical effects the ear canal resonance would have on the noise generated.  
14 Further, the methods used previously did not provide ear specific information and whether  
15 the head shadow effect was implicated. In having one professional take part in the study it  
16 was unclear if this could be applied to amateur golfers, and whether the sound generated  
17 correlated with swing speed. So, there is uncertainty of the immediate and long-term dangers  
18 of such issues in Golf, and a significant knowledge gap remains regarding effective guidance  
19 on hearing health awareness and prevention of this sport leisure noise damage to hearing.  
20 Therefore, the aim of this study was to further investigate the acoustical characteristics in situ  
21 using real ear measurement using various driver clubs. The relationship between swing speed  
22 and the noise levels generated was also investigated.  
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## **MATERIAL AND METHOD**

### **Participants**

19 male participants volunteered to take part in the study, with an age range of 19-54 years (mean 38 years). Of the 19 participants, 2 were left handed and 17 right handed. Each participant had at least 2 years of golfing experience, with no history of industrial noise exposure or recent ear infection.

### **Audiological investigation**

All participants completed a brief questionnaire, otoscopic examination, and pure tone audiometry measurement. Pure tone hearing thresholds were measured for both ears at the frequencies 250, 500, 1,000, 2,000, 3,000 4,000, 6,000 and 8,000 Hz, using a calibrated Essilor Audioscan audiometer with DT 48 headphones. The procedure followed was that recommended by the British Society of Audiology [9]. The background ambient noise level was approximately 35-40 dBA.

### **Measurement of peak sound pressure levels in situ**

Three different branded clubs (coded as Club1, Club 2 and Club3) were used in the study along with the participants own club (Club 0). The three clubs chosen were reflective of modern technology and incorporating some of the clubs used in a previous study [4]. Following a warm-up period, the participants were asked to choose the clubs in a random order and hit 6 two-piece range golf balls with each club.

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3 The frequency responses and peak sound pressure levels in situ of the transient sound  
4 generated from the club at impact were recorded bilaterally using the GN Otometric Freefit  
5 wireless Real Ear Measurement System (REM). Probe placement was 25mm along the  
6 external auditory canal [10]. Room and probe tube calibration were carried out before each  
7 participant. All recordings were completed at a golf driving range in South Wales, UK.  
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14 For the purpose of measuring the real ear acoustic characteristics in situ when the golfer was  
15 striking the ball and to allow comparisons based on dexterity, a label of far and near ear was  
16 used. This was implemented because it was unclear if there were differences between the  
17 right and left ears due to their distances from the ball, which would be determined by the  
18 position of each ear exposed to the ball depending on the golfer's dexterity. In essence the  
19 ball is positioned opposite the leading foot when using a driver club to promote an upward  
20 impact and trajectory. Therefore, right-handed golfers had their left ear defined as the near  
21 ear, while the right ear was defined as the far ear and vice versa for the left handed golfers  
22 (Figure 1).  
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36 **[Insert Figure 1]**  
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### 38 **Swing speed measurement**

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41 The participant swing speed was recorded using the Swing Speed Radar® system. The unit  
42 houses a small microwave Doppler radar velocity sensor that provides an accurate  
43 measurement of club head speed at impact. The unit was position within 6 inches of the ball  
44 and in line with the swing plane.  
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### 50 **Ethics**

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55 The study gained ethical approval from the Graduate School of Education (GSoE), University  
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3 of Bristol. All participants were informed about the purpose, potential risks of the study,  
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5 their roles and rights as participants, the nature of the study; and issues of confidentiality and  
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7 anonymity of the data. Participation was on a voluntary basis and information was provided  
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9 regarding withdrawal from the study at any time. With the possibility of detecting hearing  
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11 loss through the audiological evaluation, participants were provided with a copy of the  
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13 hearing test and informed if they needed to consult with their General Practitioner for further  
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15 investigation.  
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### 20 21 **Statistical design and analyses**

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23 Collected data was stored in an Excel database and all relevant analyses were carried out on  
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25 Statistical Package for Social Science (SPSS) version 19.0 for Windows software.  
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## RESULTS

### 1. General information and hearing thresholds

Of the 19 amateur golfers who participated in the study, 10 had less than 10 years experience (53%), 6 participants had golfing experience between 10 and 20 years (31%), three participants had more than twenty years experience (16%). Table 1 provides the mean hearing levels over the frequency range from 0.25 to 8 kHz. A paired t-test results showed that the mean pure tone thresholds did not differ significantly.

Subject	Age	Height	Dexterity	Time playing	Driver	Near ear average threshold	Far ear average threshold
1	43	5.10"	Right	2-5 years	Taylormade 2.0	9	8
2	30	6.0"	Left	5-10 years	Taylormade R9	8	6
3	29	6.3"	Right	5-10 years	Misushiba V-Max	3	2
4	33	5.9"	Right	>20 years	Taylormade R5	8	19
5	41	6.0"	Right	10-20 years	Nike Sashquash	10	10
6	32	5.10"	Right	5-10 years	Mizuno MP001	6	4
7	42	5.10"	Left	5-10 years	Titleist 909 D	4	11
8	50	5.11"	Right	10-20 years	King Cobra L4V	8	8
9	54	5.11"	Right	>20 years	Ping G2	8	9
10	34	6.0"	Right	10-20 years	Titleist 910 D3	2	4
11	29	6.0"	Right	10-20 years	Titleist 907 D1	6	6
12	36	6.2"	Right	5-10 years	Taylormade 2.0	4	4
13	28	6.1"	Right	10-20 years	Ping G5	2	1
14	33	6.0"	Right	5-10 years	Titleist D1	14	6
15	47	6.0"	Right	2-5 years	Titleist 983	12	21
16	48	5.7"	Right	10-20 years	Mizuno MX560	11	4
17	35	5.10"	Right	5-10 years	Taylormade R11	6	5
18	50	5.7"	Right	>20 years	Ping G5	13	14
19	19	5.9"	Right	5-10 years	Titleist 910 D2	3	4

Table 1: General information for participants.

### 2. Real ear acoustical characteristics of sound impulses generated by golf drivers

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3 Three popular golf drivers together with the participant's individual driver were used for the  
4 experiment. Figure 2 shows the averaged sound pressure level (SPLs) in the far and near ears  
5 generated by the golf drivers.  
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10 **[Insert Figure 2]**

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13 The averaged SPLs were 85-88 dBA while using club 2, 3 and the varied drivers that belong  
14 to the participants. However, the averaged SPL for club 1 was approximately 100 dBA. A  
15 one-way repeated measure ANOVA was conducted to compare the sound levels generated  
16 from the different golf clubs and to investigate the dB recorded in each ear. There was a  
17 significant effect for club, Wilks' Lambda = .06,  $F(3, 16) = 85.01$ ,  $p < .0005$ . Post-hoc  
18 comparisons using the Tukey HSD test for mean score of club 1 ( $M = 99.114$ ,  $SE 1.189$ ) was  
19 significantly different from every other club at the .0005 significance level. None of the other  
20 clubs were significantly different from each other. The main effect for ear, Wilks' Lambda=  
21 .89,  $F(1, 18) = 3.318$ ,  $p = .085$ ] did not reach statistical significance.  
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Furthermore, frequency analysis showed that the different golf drivers had different  
frequency characteristics, as shown in figure 3.

41 **[Insert Figure 3]**

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44 In the present study, club 2 and 3 had similar peak frequency characteristics when striking the  
45 balls that were around 3.5 kHz, while the average peak frequency characteristics of club 1  
46 was 2.5 kHz. . A one-way repeated measure ANOVA was conducted to compare the peak  
47 frequency generated from the different golf clubs and to investigate the peak frequency  
48 recorded in each ear. There was a significant effect for club, Wilks' Lambda = .33,  $F(3,$   
49  $111) = 74.22$ ,  $p < 0.0005$ . Post-hoc comparisons using the Tukey HSD test for mean score  
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3 demonstrated club 1 (M = 2511.136, SE 28.02) was significantly different from every other  
4 club at the .0005 significance level. Club 4 was also statistically different from every club  
5 (M= 2982.557, SE 93.767) at the 0.0005 significance level. The main effect for ear, Wilks'  
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7 Lambda= 0.89, F (3, 111) =74.22,  $p < 0.0005$  was also statistical significant.  
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### 14 15 **3. Correlation between the sound intensity and swing speed**

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18 Figure 4 shows the averaged swing speed when using different golf drivers. Similar swing  
19 speeds were found across with an average of 167.9 kph.  
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23 **[Insert Figure 4]**  
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28 The relationship between sound intensity (dB level) and swing speed (kph) was investigated  
29 using Pearson product-moment correlation coefficient. There was a small, positive correlation  
30 between the two variables, but no statistical significance was found ( $r = 0.29$ ,  $p = 0.228$ ).  
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### 38 **4. Hearing risk estimation by calculating the percentage of daily noise exposure for** 39 **hitting a basket of golf balls**

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42 Hearing risk was estimated by calculating the percentage of daily noise exposure for hitting a  
43 basket of golf balls using the drivers described above. The sound duration of striking a golf  
44 ball was recorded at 0.5 seconds. If hitting a basket of golf balls, which are typically 40 in  
45 number, the total sound exposure duration was 20 seconds (i.e., 0.00556 hours). Thus, the  
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52 formula used in the present study was  
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$$55 \quad \% = T_1/T$$

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3           **Where  $T=8/2^{((SPL-85)/3)}$**   
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6       On the basis of the SPLs measured in the present study, the percentage of daily noise  
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8       exposure for hitting a basket of golf balls using the drivers described above were less than  
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10       2.5% (Figure 5). For instance, 1800 balls would generate noise damage if they all gave  
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12       100dBA output to the ear canal. Interestingly, an impact noise of 116dBA average over a  
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14       basket of balls (40) provided the 100% exposure limit. Of the 228 recorded dB responses for  
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16       the near and far ear for club 1, 4 in the far ear and 3 in the near ear were in excess of  
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18       116dBA. Participant 7 had the maximum dB level recorded at 123dBA, and all 3 near ear  
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20       recordings above 116dBA were attributed to him (122, 123, 123dBA). When using club 1  
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22       and a level of 123dBA, the risk to hearing is significant once only 8 balls have been struck.  
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27                           **[Insert Figures 5 & 6]**  
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## DISCUSSION

Although a small sample of clubs was used in the present study, and therefore the findings cannot be attributed to all driver clubs on the market, it does demonstrate that there is significant variance in the output generated from thin faced titanium drivers, with the output from club 1 significantly higher than the others. The findings in this study can be contrasted with an earlier report using a professional golfer to hit three balls with six thin faced titanium drivers [4]. Their results showed that all three strikes of each of the six clubs were in the region of 120-130 dB. We know from the calculation used in our study that only a few balls hit at these intensities is needed to cause noise induced hearing loss. However, the results derived from this study with 19 amateur golfers will provide some reassurance that the noise levels generated on the whole are not a significant risk. In a typical round of golf, the driver would be used between 12-18 times. Of our 19 amateur participants, 79% report that they play golf 1-2 times per week on separate days. All but one participant use the driving range less than 3 times a week, with 67% hitting 10 or less balls with the driver. These findings would imply that the risks are, on the whole, negligible. However, the exposure analysis completed on the highest generator of noise, club 1, does provide important insight. At the maximum value of 123dBA, only 8 balls would be needed for hearing damage. Interestingly, subject 7 who recorded this value uses the range 3-4 times per week and would hit 11-20 balls with the driver. Of the six strikes with club 1, subject 7 had 3 recordings in excess of 120 dB in the near ear (122, 123 & 123). On the basis that half of the strikes would be close to 123dB, a typical visit to the range using club 1 would result in 5-10 strikes generating noise that would pose a significant risk of noise induced hearing loss in the near ear. This

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3 would fit with the case study of an amateur golfer presenting with unilateral hearing loss [4].  
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5 It is worth noting that subject 7's own club was not the same as club 1.  
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8 The results did not provide evidence of a head shadow effect in that there was not a  
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10 significant difference between the recordings from the near and far ear. This is surprising  
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12 considering that head diffraction increases with increasing frequency because of the  
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14 increasingly shorter wavelengths [12], with the average frequencies generates between 2.5  
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16 and 3.5 kHz in this study. There are number of possible explanations for this. The published  
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18 work on head diffraction [12] has used a stationary object to cast the acoustic shadow. The  
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20 speed at which the golf swing starts and finishes and the movement of the torso and the head  
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22 mean that the exposure to the impact noise generated is spread across the two ears. At impact  
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24 the torso is uncoiling and moments later the body and head move to a position where both  
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26 ears face the impact zone. It would appear from the group results of this study that the  
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28 movement is so quick that one ear is not overly exposed and therefore, we would not expect a  
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30 unilateral hearing loss to develop from using a golf driver. However, that expectation is based  
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32 on an assumption that all golfers have a similar result from their swing. It is possible that an  
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34 individual swings a driver and keeps the head completely stationary throughout impact and  
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36 the entirety of the swing. However, if this was the case, it would unlikely be an effective  
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38 swing that would restrict weight transfer and momentum and therefore unlikely generate high  
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40 levels of noise.  
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46 Swing speed was shown to have a small positive but non-significant correlation with noise  
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48 levels generated. A variable that was uncontrollable in this study was area of the club face the  
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50 ball made impact. The face of the driver club has a 'sweet spot' where the trampoline effect is  
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52 optimal. An investigation of strikes out of the heel, toe and sweet spot using an automated  
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54 and controlled swing motion with a robot [11] would add valuable insight into this enquiry,  
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3 particularly when comparisons are made from amateurs and professional golfers. It is  
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5 expected that swing speed and frequency of impact on the sweet spot would be significantly  
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7 higher in professional golfers compared to amateurs.  
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## 10 11 12 13 14 15 16 17 **CONCLUSION**

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19 The immediate danger of noise induced hearing loss for amateur golfers is relatively small.  
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21 However, this is dependent on exposure time and the more balls that are struck the greater  
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23 chance of excessive exposure. It is unclear what the long-term risks are. A large scale  
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25 longitudinal study that recorded hearing thresholds would provide a valuable insight.  
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## 30 31 32 **ACKNOWLEDGMENTS, COMPETING INTERESTS, FUNDING & DATA SHARING**

33  
34 This study was supported by the Great Britain Sasakawa (application number B68) and GN  
35  
36 Otometrics. There are no competing interests addition data is available by emailing the  
37  
38 contact author.  
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## 42 43 **CONTRIBUTORSHIP**

44  
45 B Bardsley developed the idea, designed the study, collected the data, analysed the data and  
46  
47 wrote the article.

48 F Zhao wrote the grant application, designed the study, collected the data, revised the article.

49 F Zhao is the guarantor.  
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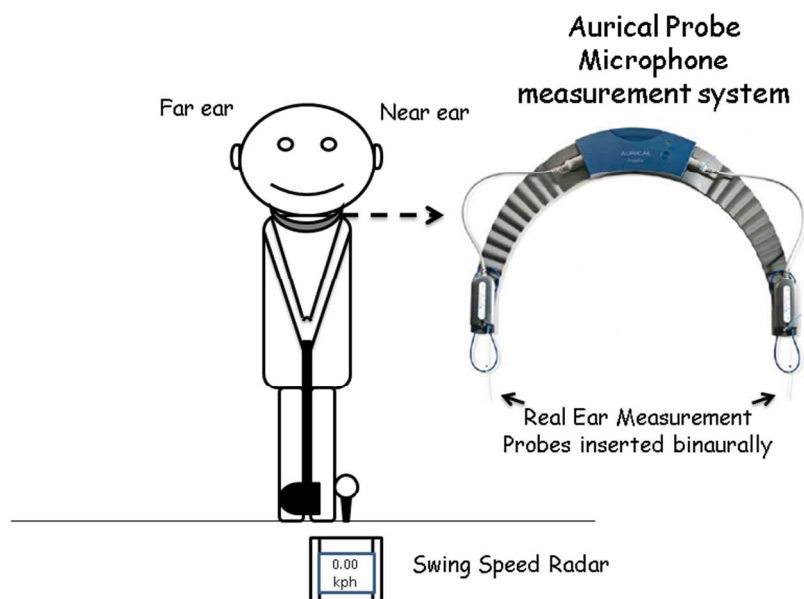


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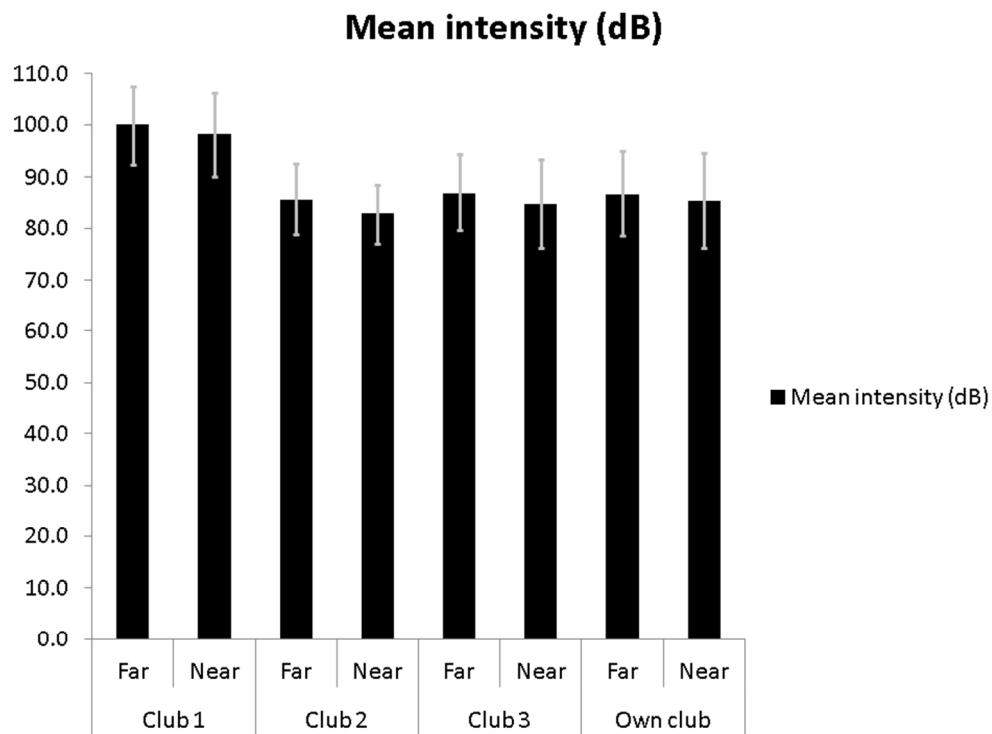
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Experimental set-up  
254x190mm (96 x 96 DPI)

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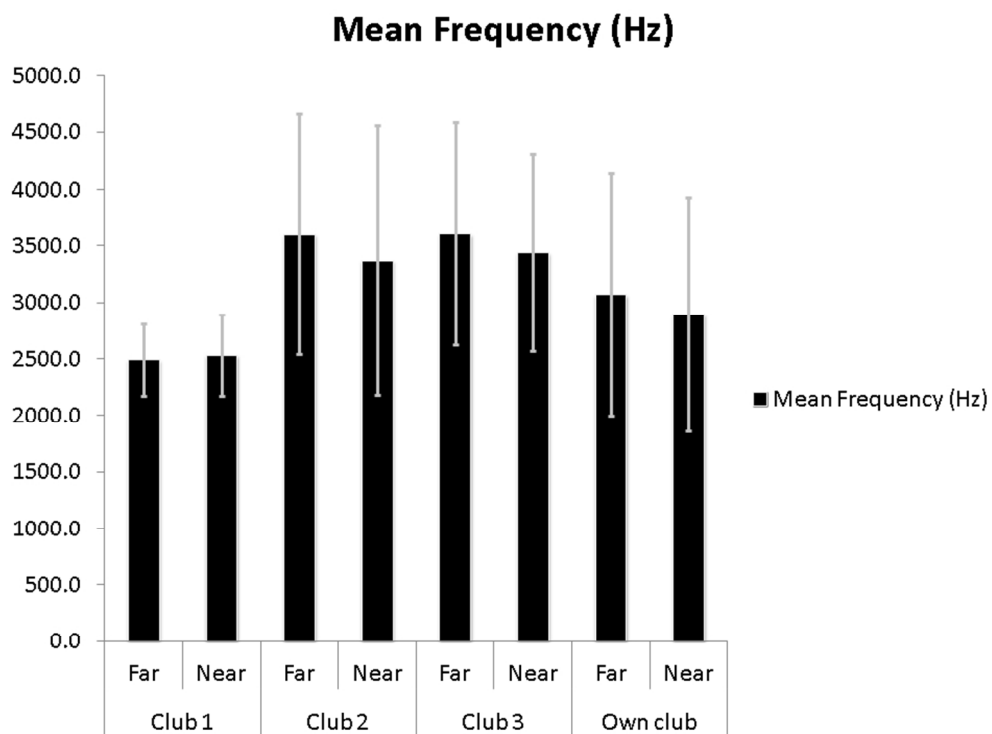
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Mean intensity with standard deviation for each ear of each of the clubs  
254x190mm (96 x 96 DPI)

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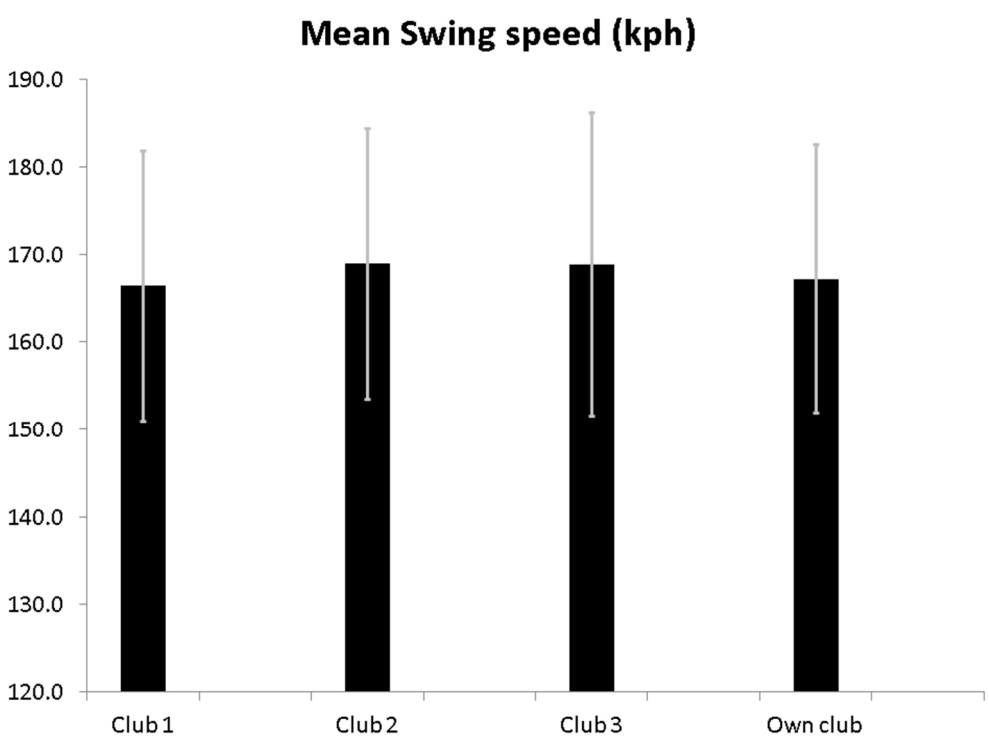
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Peak frequency with standard deviation for each ear of each of the clubs  
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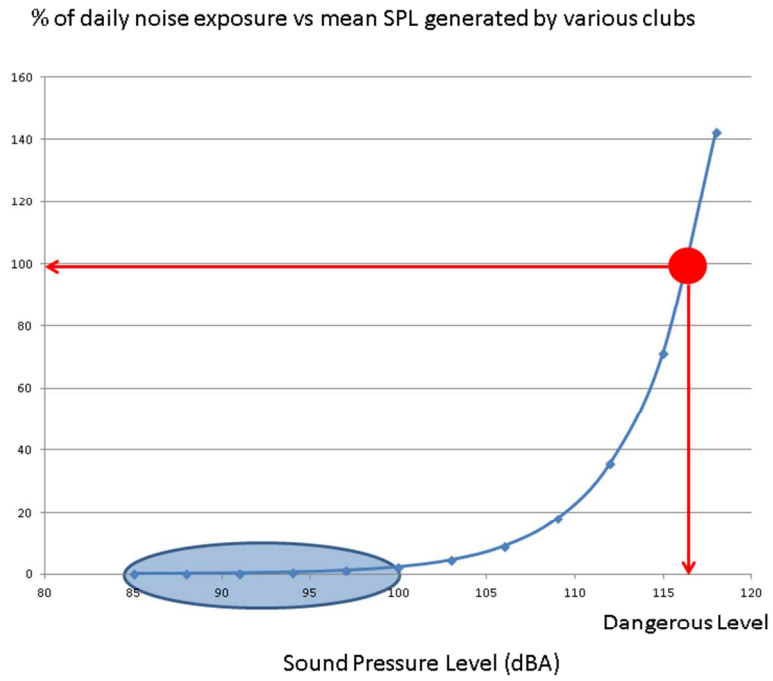


Swing speed mean with standard deviation for each club  
254x190mm (96 x 96 DPI)

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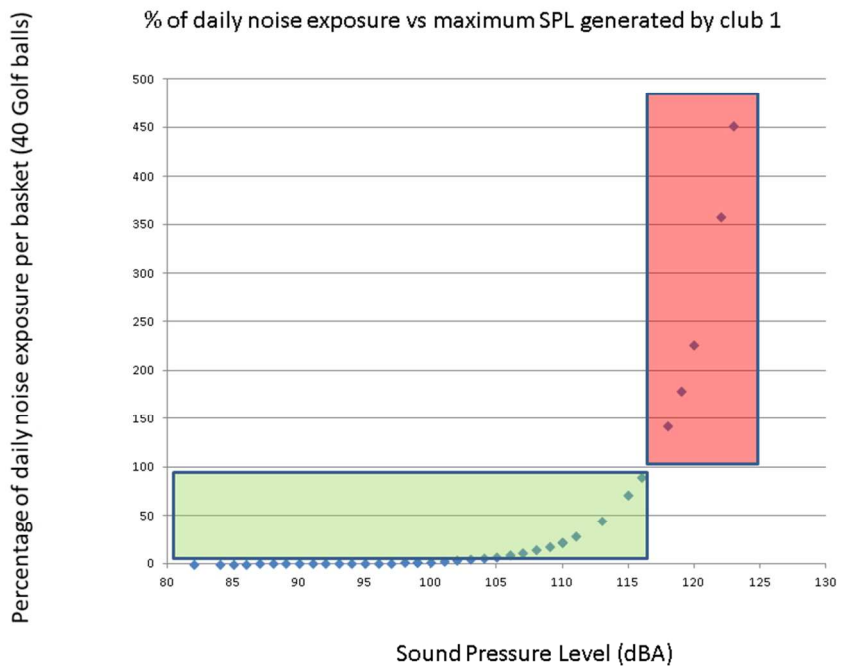
Percentage of daily noise exposure per basket (40 Golf balls)



Daily noise exposure calculated from a basket of 40 golf balls  
254x190mm (96 x 96 DPI)

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Daily noise exposure plotted against the maximum sound pressure level from club 1 using 40 balls  
254x190mm (96 x 96 DPI)

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**Real ear acoustical characteristics of impulse sound generated by golf drivers and the estimated risk to hearing**

Journal:	<i>BMJ Open</i>
Manuscript ID:	bmjopen-2013-003517.R1
Article Type:	Research
Date Submitted by the Author:	24-Oct-2013
Complete List of Authors:	Zhao, Fei; University of Bristol, Centre for Hearing and Balance Studies Bardsley, Barry; Swansea University, College of Human & Health Science
<b>Primary Subject Heading</b>:	Ear, nose and throat/otolaryngology
Secondary Subject Heading:	Sports and exercise medicine, Occupational and environmental medicine
Keywords:	Audiology < OTOLARYNGOLOGY, Adult otolaryngology < OTOLARYNGOLOGY, SPORTS MEDICINE

SCHOLARONE™  
Manuscripts

Peer Review Only

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4 **Real ear acoustical characteristics of impulse sound generated by**  
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7 **golf drivers and the estimated risk to hearing**  
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17 **2: College of Human and Health Science, University of Wales, Swansea, Swansea, UK**

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44 **Keywords: Golf, Sports Injuries, Noise, Hearing**  
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## ABSTRACT

### Objectives

This study investigated real ear acoustical characteristics in terms of the sound pressure levels (SPLs) and frequency responses in situ generated from golf club drivers at impact with a golf ball. The risk of hearing loss caused by hitting a basket of golf balls using various drivers was then estimated.

### Design:

Cross-sectional study.

### Setting:

The three driver clubs were chosen on the basis of reflection of the commonality and modern technology of the clubs. The participants were asked to choose the clubs in a random order and hit 6 two-piece range golf balls with each club. The experiment was carried out at a golf driving range in South Wales, UK.

### Participants:

Nineteen male amateur golfers volunteered to take part in the study, with an age range of 19-54 years.

### Outcome measures:

The frequency responses and peak sound pressure levels in situ of the transient sound generated from the club at impact were recorded bilaterally and simultaneously using the GN Otometric Freefit wireless Real Ear Measurement System (REM). A Swing Speed Radar system was also used to investigate the relationship between noise level and swing speed.

### Results:

Different clubs generated significantly different real ear acoustical characteristics in terms of sound pressure levels and frequency responses. However, they did not differ significantly between the ears. No significant correlation was found between the swing speed and noise

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3 intensity. On the basis of the SPLs measured in the present study, the percentage of daily  
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5 noise exposure for hitting a basket of golf balls using the drivers described above were less  
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7 than 2.0%.  
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### 9 10 **Conclusions**

11 The immediate danger of noise induced hearing loss for amateur golfers is quite unlikely.  
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13 However, it may be dangerous to hearing if the noise level generated by the golf clubs  
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15 exceeded 116 dBA.  
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## ARTICLE SUMMARY

### Article focus

1. Is there a risk to hearing for amateur golfers when using the driver golf club?
2. If so, is this risk more prominent in one ear or equal across ears?
3. Does the speed of the swing influence the sound generated?

### Key Messages

1. The results indicate varying levels of noise produced by clubs but negligible risk to hearing of amateur golfers, with a daily noise exposure less than 2.0% when averaging the results of the loudest club.
2. No difference was found between ears.
3. Swing speed does not have a significant correlation to the sound generated.

### Strengths

An innovative approach taken by using in-the-ear recordings that provide sound pressure levels at the tympanic membrane. This provides a more accurate estimation because it takes ear canal resonance properties into consideration, whereas the alternative of using a sound level meter equidistant does not provide this detail.

### Limitations

Limited clubs as well as a small sample size the participants own club meant of golf clubs was used in the study.

## INTRODUCTION

The popularity of Golf has seen significant increases in the past 25 years, particularly in Europe and the United States. In the U.K. alone figures from 2011 showed 1.3 million golf players and close to 3000 golf courses.[1] By the nature of the game, Golf requires the player to swing various types of clubs to hit balls into a relatively wide open space with the ultimate aim of sending the ball into a hole with the fewest number of shots. Therefore, Golf is perceived as a low-risk sport compared with other highly competitive sports such as rugby, football, basketball or skiing that have higher injury rates.

However, several studies have shown insight into injuries related to golf. These range from common spine and upper or lower limb injuries to the less frequent injuries related to golf ball trauma.[2,3] In addition, Golf has not been attributed to leisure noise exposure and noise induced hearing loss (NIHL) until recently.[4] Noise can be described as sound at an intensity that can interfere with verbal communication and may cause discomfort of the ears or reduction of hearing sensitivity, defined as hearing damage.[5,6] Any exposure to noise of significant intensity and duration increases the risk of ear damage and causes permanent hearing damage, known as noise induced hearing loss (NIHL). Both industrial noise exposure and noise in leisure are the major causes of avoidable permanent hearing loss throughout the world. Within the categories of leisure noise, noise exposure from sporting activities is a major recreational noise sources relevant to various social activities, such as, motor sport, shooting, and spectators at a football match.[7-9]

A study that investigated the potential hazards of modern driver golf clubs in damaging users' hearing from excessive exposure to loud sounds has highlighted this link.[4] The authors reported on a case of a 55 year old man who had appeared to developed unilateral noise induced hearing loss due to the exposure of loud noises generated from his driver golf club.

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3 When using a professional golfer, they found that many of the clubs generated sounds in  
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5 excess of 120dBA, particularly the thin faced titanium drivers. Therefore, the authors  
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7 recommended caution should be exercised by any golfers using the thin faced titanium  
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9 drivers to avoid damage to their hearing.  
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11  
12 This raises a number of interesting questions. The use of a sound level meter (SLM)  
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14 equidistant from the golfer provided information in the free field. However, in using a SLM it  
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16 is unclear what acoustical effects the ear canal resonance would have on the noise generated.  
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18 Further, the methods used previously did not provide ear specific information and whether  
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20 the head shadow effect was implicated. In having one professional take part in the study it  
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22 was unclear if this could be applied to amateur golfers, and whether the sound generated  
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24 correlated with swing speed. So, there is uncertainty of the immediate and long-term dangers  
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26 of such issues in Golf, and a significant knowledge gap remains regarding effective guidance  
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28 on hearing health awareness and prevention of this sport leisure noise damage to hearing.  
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30 Therefore, the aim of this study was to further investigate the acoustical characteristics in situ  
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32 using real ear measurement using various driver clubs. The relationship between swing speed  
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34 and the noise levels generated was also investigated.  
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## 42 MATERIAL AND METHOD

### 43 Participants

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45 19 male amateur golfers volunteered to take part in the study, with an age range of 19-54  
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47 years (mean 38 years). Of them, 2 were left handed and 17 right handed. Ten had less than 10  
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49 years experience (53%), six participants had golfing experience between 10 and 20 years  
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51 (31%), three participants had more than twenty years experience (16%). Approximately 80%  
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53 of participants reported that they play golf 1-2 times per week on separate days, and all but  
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3 one participant used the driving range less than 3 times a week.  
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### 5 **Golf driver clubs**

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8 The three driver clubs were chosen on the basis of reflection of the commonality and modern  
9 technology of the clubs together with consideration of their potentially high loudness levels  
10 as listed in the study by Buchannan *et al.*[4] Due to the potential commercial dispute and  
11 conflicts of interest, the names of the manufacturers of the clubs were not disclosed, and  
12 consequently these differently branded clubs were coded as Club 1, Club 2 and Club 3 in the  
13 present study. However, this information can be discussed by contacting the authors if there  
14 is any concern about the potential hazard of hearing damage to the golf players. In addition,  
15 in accordance with experimental protocol, each participant was invited to bring their own  
16 driver and use it along with three other driver clubs.  
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### 29 **Measurement of real ear responses**

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31 Because of natural amplification of the external ear canal, for the purpose of this study, the  
32 real ear acoustical characteristics in terms of sound frequency spectrum (i.e. frequency  
33 response) and sound pressure level were investigated using a probe microphone at the  
34 position near the eardrum. Following a warm-up period, the participants were asked to  
35 choose the clubs in a random order and hit 6 two-piece range golf balls with each club. The  
36 frequency responses and peak sound pressure levels in situ of the transient sound generated  
37 from the club at impact were recorded bilaterally and simultaneously using the GN Otometric  
38 Freefit wireless Real Ear Measurement System (REM). Probe placement was 25mm along  
39 the external auditory canal.[10] Room and probe tube calibration were carried out before each  
40 participant.  
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3 All recordings were completed at a golf driving range in South Wales, UK.  
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6 For the purpose of measuring the real ear acoustic characteristics in situ when the golfer was  
7  
8 striking the ball, and to allow comparisons based on dexterity, a label of far and near ear was  
9  
10 used. This was implemented because it was unclear if there were differences between the  
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12 right and left ears due to their distances from the ball, which would be determined by the  
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14 position of each ear exposed to the ball depending on the golfer's dexterity. In essence the  
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16 ball was positioned opposite the leading foot when using a driver club to promote an upward  
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18 impact and trajectory. Therefore, right-handed golfers had their left ear defined as the near  
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20 ear, while the right ear was defined as the far ear and vice versa for the left handed golfers  
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22 (Figure 1).  
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27 **[Insert Figure 1]**  
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30 All recorded real ear responses were reviewed and analysed. In the present study, the peak  
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32 SPL was determined as the highest point of the curve, whereas the frequency response was  
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34 referred to as the point corresponding to the measured peak SPL. Both peak SPL and  
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36 frequency response were chosen from visual inspection by the authors, and then measured  
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38 directly in the real ear response curves.  
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#### 41 **Swing speed measurement**

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43 The participant swing speed was recorded using the Swing Speed Radar® system. The unit  
44  
45 houses a small microwave Doppler radar velocity sensor that provides an accurate  
46  
47 measurement of club head speed at impact. The unit was position within 6 inches of the ball  
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49 and in line with the swing plane.  
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#### 51 **Ethics**

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53 The study gained ethical approval from the Graduate School of Education (GSoE), University  
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3 of Bristol. All participants were informed about the purpose, potential risks of the study,  
4 their roles and rights as participants, the nature of the study; and issues of confidentiality and  
5 anonymity of the data. Participation was on a voluntary basis and information was provided  
6 regarding withdrawal from the study at any time. With the possibility of detecting hearing  
7 loss through the audiological evaluation, participants were provided with a copy of the  
8 hearing test and informed if they needed to consult with their General Practitioner for further  
9 investigation.  
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### 18 **Statistical design and analyses**

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20 Collected data was stored in an Excel database and all relevant analyses were carried out on  
21 Statistical Package for Social Science (SPSS) version 19.0 for Windows software. A one-way  
22 repeated measure ANOVA was performed to examine the effects of golf club (i.e., Clubs 1,  
23 2, 3) and ear side (Far ear, Near ear) on the real ear acoustical characteristics. The mean value  
24 and standard deviation of the frequency responses and peak sound pressure levels were  
25 calculated and compared using a post-hoc test (i.e., Tukey HSD). A Pearson correlation  
26 analysis between swing speed and the real ear acoustical characteristics was also performed.  
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A  $p < 0.05$  was considered to be statistically significant.

## 41 **RESULTS**

### 42 **I. Real ear acoustical characteristics of sound impulses generated by golf drivers**

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Figure 2 shows a scatter plot of the averaged sound pressure level (SPLs) obtained in individuals in the far and near ears generated by three golf drivers, which were used for the experiment. The averaged SPLs were approximately 82-88 dBA while using Clubs 2 and 3 (Club 2 far ear and near ear: 85.7 and 82.8 dBA; Club 3 far ear and near ear: 87.0 and 84.8 dBA), whereas the averaged SPLs for Club 1 were 100.0 and 98.2 dBA on far ears and near

ears, respectively (Table 1). The repeated measures ANOVA was conducted to compare the sound levels generated from the different golf clubs and to investigate the dB recorded in each ear. The repeated measures ANOVA results showed that there were significant differences in the SPLs obtained from Clubs 1, 2 and 3 (Wilks' Lambda=0.06,  $F(2, 17)=134.33, p<0.0005$ ). However, no significant differences were found in the SPLs between the far ears and the near ears ( $F[1, 18]=3.48, p=0.08$ ). Further analysis showed that the SPLs generated by Club 1 was significantly greater than those found in Clubs 2 and 3 ( $p<0.0005$ ). In contrast, there was no significant difference in the SPLs between Club 2 and Club 3.

[Insert Figure 2]

[Insert Table 1]

Furthermore, frequency response analysis showed that the different golf drivers had different frequency characteristics. As shown in Figure 3, Clubs 2 and 3 had similar peak frequency characteristics around 3.5 kHz when striking the balls, while the average frequency response characteristic of Club 1 was 2.5 kHz on either the far ear or the near ear. Although no significant differences were found in frequency responses between the far ears and the near ears ( $F[1, 18]=2.18, p=0.16$ ), the repeated measures ANOVA results showed that the peak frequencies differed significantly among the three clubs ( $F[2, 17]=38.72, p<0.0005$ ). Further analysis showed that the frequency responses found in the Club 1 were significantly lower than those in Clubs 2 and 3 ( $p<0.0005$ ). In contrast, there was no significant difference in the frequency responses between Club 2 and Club 3.

[Insert Figure 3]

## II. Correlation between sound intensity and swing speed

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3 Table 1 shows the averaged swing speed when using different golf drivers. A one way  
4 ANOVA test showed that there were no significant differences in swing speeds between  
5 Clubs 1, 2 and 3 (Club 1 vs. Club 2 vs. Club 3: 166.5 vs. 169.0 vs. 168.9,  $F=0.18$ ,  $p=0.84$ ).  
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7 The relationship between sound intensity (dB level) and swing speed (kph) was investigated  
8 using the Pearson product-moment correlation coefficient. There was a small, positive  
9 correlation between the two variables, but no statistical significance was found ( $r_{\text{far-ear}}=0.13$ ,  
10  $p=0.32$ ;  $r_{\text{near-ear}}=0.05$ ,  $p=0.72$ ).  
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### 19 **III. Hearing risk estimation by calculating the percentage of daily noise exposure for** 20 **hitting a basket of golf balls** 21 22

23  
24 Hearing risk was estimated by calculating the percentage of daily noise exposure for hitting a  
25 basket of golf balls using those drivers described above. The sound duration of striking a golf  
26 ball was measured by recording the sound waveforms from the beginning of the impulse  
27 sound until it fell away when crossing the baseline. On average, the sound duration of  
28 striking a golf ball was recorded as approximately 0.5 seconds. If hitting a basket of golf  
29 balls, which are typically 40 in number, the total sound exposure duration was 20 seconds  
30 (i.e., 0.00556 hours).  
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40 In the present study, in order to estimate hearing risk, the damage criteria of 85 dBA for a  
41 maximum 8 hour period advocated by the National Institute for Occupational Safety and  
42 Health (NIOSH) [11] was adapted with an exchange rate of 3 dB and using the A-weighting  
43 scale. Thus, the following formula was used:  
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$$50 \text{ *Daily Noise Dose* \% = } T_1 \text{ (total exposure duration) / } T \text{ (reference duration) * 100}$$

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52  
53 *Where*  $T=8/2^{((SPL-85)/3)}$ , and  $T_1=0.00556$ .  
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3 Because the sound intensities generated by the golf clubs were recorded and measured in the  
4 ear canal, in order to compare them with the NIOSH standard, the transformation from real  
5 ear sound pressure levels to free-field equivalent values was performed according to ISO  
6 11904-1[12] (i.e., inversion of the average field-to-eardrum transfer function).  
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12 On the basis of the SPLs measured in the present study, the percentage of daily noise  
13 exposure for hitting a basket of golf balls using the drivers described above were minimal  
14 (0.05- 1.8%) (Figure 4). For instance, when using Club 1, the noise of hitting approximately  
15 2200 balls with SPLs around 99 dBA would reach 100% of the daily noise exposure dose. In  
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[Insert Figure 4]

## DISCUSSION

Although a small sample of clubs was used in the present study, and therefore the findings cannot be attributed to all driver clubs on the market, it does demonstrate that there is significant variance in the output generated from thin faced titanium drivers used in the present study, showing significant differences in the intensity and frequency characteristics obtained from this Club compared with the others. It implies that golf driver clubs differ in terms of a potential risk to hearing damage. On the basis of the results derived from the present study with 19 amateur golfers, the noise levels generated on the whole (approximately 90.0 on average) do not indicate immediate risk. This is consistent with one previous studies,[13,14] which shows 80-94 dB when measuring accurate hitting sounds using the ArtemiS system, which includes a binaural headset in connection with integrated microphones near the opening of the ear canal. However, the current result is contrasted with

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3 an earlier report using a professional golfer to hit three balls with six thin faced titanium  
4 drivers,[4] which demonstrated a significantly high noise level in the region of 120-130 dBA,  
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6 although only a few balls were hit at these intensities in the present study.  
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9  
10 Such a discrepancy is mainly due to different measurement methods employed between the  
11 study carried out by Buchanan and the present study. Real ear measurement (REM) used in  
12 the present study is a common method for measuring SPL near the tympanic membrane.[15]  
13  
14 It offers an accurate and objective approach including the individual's real ear acoustic  
15 characteristics. By contrast, in the study by Buchanan et al.,[4] the SPL was measured using a  
16 sound level meter (SLM) in the free field equidistant from the golfer. The limitation of this  
17 measurement is not accurate because the acoustical effects of the ear canal resonance are not  
18 taken into account. Moreover, the other key issue is that the SPLs measured in the free field  
19 are not the actual SPLs in the ear canal because the baffle effect of head and torso is also  
20 important for measuring sound transfer from the free field to the ear. In addition, the skills  
21 and power possessed by professional golfers may play a role in generating louder SPLs than  
22 is the case for amateur golfers.  
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38 Although various studies have suggested that exposure to stimuli exceeding the 100% daily  
39 noise dose would cause hearing damage, including a hearing sensitivity reduction, tinnitus,  
40 hyperacusis and distortion,[5,6,16] recent research argued the appropriateness of applying  
41 industrial risk criteria with recreational noise exposure, because these standards were  
42 developed specifically for spectrally dense industrial noise with limited dynamic range as an  
43 exposure dose for an 8 hour workday. Therefore, comparisons with industrial standards have  
44 to be made with caution. Nevertheless, according to the intensity and noise exposure dose  
45 calculation found in the present study, the risks are, on the whole, negligible, i.e., the golf  
46 players, particularly amateur players are most unlikely to have hearing damage. However, it  
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3 is noteworthy that some golf clubs can generate extremely high levels of noise, such as at the  
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5 maximum value of 123dBA recorded from Club 1 used in the study. With such high noise  
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7 intensity exposure, it is most likely to pose a significant risk of noise induced hearing loss if  
8  
9 the driver is used frequently. This would fit with the case study of an amateur golfer  
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11 presenting with significant hearing loss.[4]  
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15 Furthermore, the sound of a golf club hitting a golf ball is one of the influencing factors at a  
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17 subconscious level on a golfer's perception of quality and his/her choice of equipment,  
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19 because it provides information on whether the ball was hit correctly. Therefore, golf club  
20  
21 manufactures tend to make new models of golf driver clubs using various materials (such as  
22  
23 titanium) not only to achieve longer distances, but also to create unique sound characteristics  
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25 to attract attention. The study by Roberts et al.[17] investigated the relationship between the  
26  
27 impact sound and elite golfers' subjective perceptions of a shot. They found a strong relationship  
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29 between the characteristics of sharpness and loudness of sound, and pleasantness and liveliness of  
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31 perception. Significantly positive correlations were also obtained between the subjective ratings and  
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33 parameters of the impact sound such as sound pressure level, loudness level and sharpness. This  
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35 suggests that the golfers' perceptions are influenced by frequency components, loudness and duration.  
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39 In addition, the FFT analysis in the previous study [13] showed different sounds in terms of  
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41 frequency characteristics and reverberation of the tonal components generated by different  
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43 clubs when they hit the balls. This is in keeping with the findings of the present study,  
44  
45 demonstrating that the peak frequency characteristics recorded from golf driver clubs varied  
46  
47 significantly between 2.5 and 3.5 kHz. This is associated with the design (e.g., the structure  
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49 of the club head) and materials used to make these modern clubs, which have been created by  
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51 the manufactures in order to achieve a more balanced frequency distribution and thus a better  
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3 sound quality. However, with such clubs, they are likely to create louder hitting sounds than  
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5 conventional golf clubs, which potentially causes damage to golfers' hearing.  
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9 In the present study, the results did not show evidence of a head shadow effect in that there  
10  
11 was not a significant difference between the recordings from the near and far ear. This is  
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13 consistent with some previous studies on hearing performance between ears in participants in  
14  
15 the army having no asymmetrical shooting posture.[18] Although several early studies found  
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17 that the ear opposite to the dominant hand sustained a more pronounced hearing loss, a recent  
18  
19 research study did not reveal a significant preference between ears, irrespective of the  
20  
21 dominant hand after recreational firearm use.[8] In addition, no head diffraction effect found  
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23 in this study can be explained as rapid movement of the torso and the head when swinging  
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25 the golf club, which means that exposure to the impact noise generated is spread across the  
26  
27 two ears. When the torso is uncoiling, the body and head move to a position where both ears  
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29 face directly into the impact sound sources. Therefore, one side of the ear is overly exposed,  
30  
31 and as a consequence, a unilateral hearing loss is unlikely to be developed from playing golf.  
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36 Swing speed did not show any significant correlations with either acoustical characteristics  
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38 measured in the golf driver clubs (i.e., intensity levels and peak frequencies), or golfers'  
39  
40 heights. Golfers' skill and power (particularly among professional golfers) may be one of the  
41  
42 important influencing factors on swing speed. In addition, it is noteworthy that another  
43  
44 important factor is the area of the club face hitting the ball to make an impact because the  
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46 face of the driver club has a 'sweet spot' where the trampoline effect is optimal. An  
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48 investigation of strikes out of the heel, toe and sweet spot using an automated and controlled  
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50 swing motion with a robot [19] would add valuable insight into this enquiry, particularly  
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52 when comparisons are made between amateur and professional golfers.  
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## 56 **CONCLUSION**



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3 Different clubs generated significantly different real ear acoustical characteristics in terms of  
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5 sound pressure levels and frequency responses. On the basis of the SPLs measured in the  
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7 present study, the immediate danger of noise induced hearing loss for amateur golfers is quite  
8  
9 unlikely. However, it is most likely to pose a significant risk of noise induced hearing loss if  
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11 the driver generates high noise intensity greater than 116 dBA. Provision of detailed  
12  
13 information on a club's acoustical characteristics may help consumers choose the appropriate  
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15 device for their needs, particularly for people who are prone to hearing damage. A  
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17 longitudinal study monitoring hearing thresholds would provide a valuable insight in terms of  
18  
19 the long-term risks to hearing.  
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#### 24 25 **ACKNOWLEDGMENTS**

26  
27 We would like to thank two reviewers and for their helpful suggestions. We would also like  
28  
29 to acknowledge GN Otometrics UK for providing the Freefit wireless Real Ear Measurement  
30  
31 System and technical support during the study. Mrs Norma Meechem kindly provided kind  
32  
33 help with proof reading.  
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#### 40 41 **COMPETING INTERESTS**

42  
43 There are no competing interests.  
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45

#### 46 47 **FUNDING**

48  
49 This study was supported by the Great Britain Sasakawa Foundation (B68).  
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51

#### 52 53 **DATA SHARING**

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55 Additional data is available by contacting authors.  
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3 **CAPTIONS OF FIGURES**  
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5 **Figure 1 Diagram of experimental settings and equipment used**  
6

7 **Figure 2 Scatter plot of averaged sound pressure levels (SPLs) obtained in individuals in**  
8 **the far and near ears generated by three golf drivers.**  
9

10 **Figure 3 Scatter plot of averaged frequency responses obtained in individuals in the far**  
11 **and near ears generated by three golf drivers.**  
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13 **Figure 4 Percentage of daily noise exposure when hitting golf balls using the drivers**  
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4 **Real ear acoustical characteristics of impulse sound generated by**  
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7 **golf drivers and the estimated risk to hearing**  
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44 **Keywords: Golf, Sports Injuries, Noise, Hearing**  
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## ABSTRACT

### Objectives

This study investigated real ear acoustical characteristics in terms of the sound pressure levels (SPLs) and frequency responses in situ generated from golf club drivers at impact with a golf ball. The risk of hearing loss caused by hitting a basket of golf balls using various drivers was then estimated.

### Design:

Cross-sectional study.

### Setting:

The three driver clubs were chosen on the basis of reflection of the commonality and modern technology of the clubs. The participants were asked to choose the clubs in a random order and hit 6 two-piece range golf balls with each club. The experiment was carried out at a golf driving range in South Wales, UK.

### Participants:

Nineteen male amateur golfers volunteered to take part in the study, with an age range of 19-54 years.

### Outcome measures:

The frequency responses and peak sound pressure levels in situ of the transient sound generated from the club at impact were recorded bilaterally and simultaneously using the GN Otometric Freefit wireless Real Ear Measurement System (REM). A Swing Speed Radar system was also used to investigate the relationship between noise level and swing speed.

### Results:

Different clubs generated significantly different real ear acoustical characteristics in terms of sound pressure levels and frequency responses. However, they did not differ significantly between the ears. No significant correlation was found between the swing speed and noise

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3 intensity. On the basis of the SPLs measured in the present study, the percentage of daily  
4 noise exposure for hitting a basket of golf balls using the drivers described above were less  
5 than 2.0%.  
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10 **Conclusions**

11 The immediate danger of noise induced hearing loss for amateur golfers is quite unlikely.

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13 However, it may be dangerous to hearing if the noise level generated by the golf clubs  
14 exceeded 116 dBA.  
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## ARTICLE SUMMARY

### Article focus

1. Is there a risk to hearing for amateur golfers when using the driver golf club?
2. If so, is this risk more prominent in one ear or equal across ears?
3. Does the speed of the swing influence the sound generated?

### Key Messages

1. The results indicate varying levels of noise produced by clubs but negligible risk to hearing of amateur golfers, with a daily noise exposure less than 2.0% when averaging the results of the loudest club.
2. No difference was found between ears.
3. Swing speed does not have a significant correlation to the sound generated.

### Strengths

An innovative approach taken by using in-the-ear recordings that provide sound pressure levels at the tympanic membrane. This provides a more accurate estimation because it takes ear canal resonance properties into consideration, whereas the alternative of using a sound level meter equidistant does not provide this detail.

### Limitations

Limited clubs as well as a small sample size the participants own club meant of golf clubs was used in the study.

## INTRODUCTION

The popularity of Golf has seen significant increases in the past 25 years, particularly in Europe and the United States. In the U.K. alone figures from 2011 showed 1.3 million golf players and close to 3000 golf courses.[1] By the nature of the game, Golf requires the player to swing various types of clubs to hit balls into a relatively wide open space with the ultimate aim of sending the ball into a hole with the fewest number of shots. Therefore, Golf is perceived as a low-risk sport compared with other highly competitive sports such as rugby, football, basketball or skiing that have higher injury rates.

However, several studies have shown insight into injuries related to golf. These range from common spine and upper or lower limb injuries to the less frequent injuries related to golf ball trauma.[2,3] In addition, Golf has not been attributed to leisure noise exposure and noise induced hearing loss (NIHL) until recently.[4] Noise can be described as sound at an intensity that can interfere with verbal communication and may cause discomfort of the ears or reduction of hearing sensitivity, defined as hearing damage.[5,6] Any exposure to noise of significant intensity and duration increases the risk of ear damage and causes permanent hearing damage, known as noise induced hearing loss (NIHL). Both industrial noise exposure and noise in leisure are the major causes of avoidable permanent hearing loss throughout the world. Within the categories of leisure noise, noise exposure from sporting activities is a major recreational noise sources relevant to various social activities, such as, motor sport, shooting, and spectators at a football match.[7-9]

A study that investigated the potential hazards of modern driver golf clubs in damaging users' hearing from excessive exposure to loud sounds has highlighted this link.[4] The authors reported on a case of a 55 year old man who had appeared to developed unilateral noise induced hearing loss due to the exposure of loud noises generated from his driver golf club.

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3 When using a professional golfer, they found that many of the clubs generated sounds in  
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5 excess of 120dBA, particularly the thin faced titanium drivers. Therefore, the authors  
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7 recommended caution should be exercised by any golfers using the thin faced titanium  
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9 drivers to avoid damage to their hearing.  
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12 This raises a number of interesting questions. The use of a sound level meter (SLM)  
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14 equidistant from the golfer provided information in the free field. However, in using a SLM it  
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16 is unclear what acoustical effects the ear canal resonance would have on the noise generated.  
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18 Further, the methods used previously did not provide ear specific information and whether  
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20 the head shadow effect was implicated. In having one professional take part in the study it  
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22 was unclear if this could be applied to amateur golfers, and whether the sound generated  
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24 correlated with swing speed. So, there is uncertainty of the immediate and long-term dangers  
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26 of such issues in Golf, and a significant knowledge gap remains regarding effective guidance  
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28 on hearing health awareness and prevention of this sport leisure noise damage to hearing.  
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30 Therefore, the aim of this study was to further investigate the acoustical characteristics in situ  
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32 using real ear measurement using various driver clubs. The relationship between swing speed  
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34 and the noise levels generated was also investigated.  
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## 42 MATERIAL AND METHOD

### 43 Participants

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45 19 male amateur golfers volunteered to take part in the study, with an age range of 19-54  
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47 years (mean 38 years). Of them, 2 were left handed and 17 right handed. Ten had less than 10  
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49 years experience (53%), six participants had golfing experience between 10 and 20 years  
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51 (31%), three participants had more than twenty years experience (16%). Approximately 80%  
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53 of participants reported that they play golf 1-2 times per week on separate days, and all but  
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3 one participant used the driving range less than 3 times a week.  
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### 5 **Golf driver clubs**

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8 The three driver clubs were chosen on the basis of reflection of the commonality and modern  
9 technology of the clubs together with consideration of their potentially high loudness levels  
10 as listed in the study by Buchanan *et al.*[4] Due to the potential commercial dispute and  
11 conflicts of interest, the names of the manufacturers of the clubs were not disclosed, and  
12 consequently these differently branded clubs were coded as Club 1, Club 2 and Club 3 in the  
13 present study. However, this information can be discussed by contacting the authors if there  
14 is any concern about the potential hazard of hearing damage to the golf players. In addition,  
15 in accordance with experimental protocol, each participant was invited to bring their own  
16 driver and use it along with three other driver clubs.  
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### 29 **Measurement of real ear responses**

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31 Because of natural amplification of the external ear canal, for the purpose of this study, the  
32 real ear acoustical characteristics in terms of sound frequency spectrum (i.e. frequency  
33 response) and sound pressure level were investigated using a probe microphone at the  
34 position near the eardrum. Following a warm-up period, the participants were asked to  
35 choose the clubs in a random order and hit 6 two-piece range golf balls with each club. The  
36 frequency responses and peak sound pressure levels in situ of the transient sound generated  
37 from the club at impact were recorded bilaterally and simultaneously using the GN Otometric  
38 Freefit wireless Real Ear Measurement System (REM). Probe placement was 25mm along  
39 the external auditory canal.[10] Room and probe tube calibration were carried out before each  
40 participant.  
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3 All recordings were completed at a golf driving range in South Wales, UK.  
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6 For the purpose of measuring the real ear acoustic characteristics in situ when the golfer was  
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8 striking the ball, and to allow comparisons based on dexterity, a label of far and near ear was  
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10 used. This was implemented because it was unclear if there were differences between the  
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12 right and left ears due to their distances from the ball, which would be determined by the  
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14 position of each ear exposed to the ball depending on the golfer's dexterity. In essence the  
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16 ball was positioned opposite the leading foot when using a driver club to promote an upward  
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18 impact and trajectory. Therefore, right-handed golfers had their left ear defined as the near  
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20 ear, while the right ear was defined as the far ear and vice versa for the left handed golfers  
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22 (Figure 1).  
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27 **[Insert Figure 1]**  
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30 All recorded real ear responses were reviewed and analysed. In the present study, the peak  
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32 SPL was determined as the highest point of the curve, whereas the frequency response was  
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34 referred to as the point corresponding to the measured peak SPL. Both peak SPL and  
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36 frequency response were chosen from visual inspection by the authors, and then measured  
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38 directly in the real ear response curves.  
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#### 41 **Swing speed measurement**

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43 The participant swing speed was recorded using the Swing Speed Radar® system. The unit  
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45 houses a small microwave Doppler radar velocity sensor that provides an accurate  
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47 measurement of club head speed at impact. The unit was position within 6 inches of the ball  
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49 and in line with the swing plane.  
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#### 51 **Ethics**

52  
53 The study gained ethical approval from the Graduate School of Education (GSoE), University  
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of Bristol. All participants were informed about the purpose, potential risks of the study, their roles and rights as participants, the nature of the study; and issues of confidentiality and anonymity of the data. Participation was on a voluntary basis and information was provided regarding withdrawal from the study at any time. With the possibility of detecting hearing loss through the audiological evaluation, participants were provided with a copy of the hearing test and informed if they needed to consult with their General Practitioner for further investigation.

### Statistical design and analyses

Collected data was stored in an Excel database and all relevant analyses were carried out on Statistical Package for Social Science (SPSS) version 19.0 for Windows software. A one-way repeated measure ANOVA was performed to examine the effects of golf club (i.e., Clubs 1, 2, 3) and ear side (Far ear, Near ear) on the real ear acoustical characteristics. The mean value and standard deviation of the frequency responses and peak sound pressure levels were calculated and compared using a post-hoc test (i.e., Tukey HSD). A Pearson correlation analysis between swing speed and the real ear acoustical characteristics was also performed. A  $p < 0.05$  was considered to be statistically significant.

## RESULTS

### I. Real ear acoustical characteristics of sound impulses generated by golf drivers

Figure 2 shows a scatter plot of the averaged sound pressure level (SPLs) obtained in individuals in the far and near ears generated by three golf drivers, which were used for the experiment. The averaged SPLs were approximately 82-88 dBA while using Clubs 2 and 3 (Club 2 far ear and near ear: 85.7 and 82.8 dBA; Club 3 far ear and near ear: 87.0 and 84.8 dBA), whereas the averaged SPLs for Club 1 were 100.0 and 98.2 dBA on far ears and near

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3 ears, respectively (Table 1). The repeated measures ANOVA was conducted to compare the  
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5 sound levels generated from the different golf clubs and to investigate the dB recorded in  
6  
7 each ear. The repeated measures ANOVA results showed that there were significant  
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9 differences in the SPLs obtained from Clubs 1, 2 and 3 (Wilks' Lambda=0.06, F (2,  
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11 17)=134.33,  $p<0.0005$ ). However, no significant differences were found in the SPLs between  
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13 the far ears and the near ears (F [1, 18] =3.48,  $p=0.08$ ). Further analysis showed that the SPLs  
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15 generated by Club 1 was significantly greater than those found in Clubs 2 and 3 ( $p<0.0005$ ).  
16  
17 In contrast, there was no significant difference in the SPLs between Club 2 and Club 3.  
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21 [Insert Figure 2]

22 [Insert Table 1]

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25 Furthermore, frequency response analysis showed that the different golf drivers had different  
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27 frequency characteristics. As shown in Figure 3, Clubs 2 and 3 had similar peak frequency  
28  
29 characteristics around 3.5 kHz when striking the balls, while the average frequency response  
30  
31 characteristic of Club 1 was 2.5 kHz on either the far ear or the near ear. Although no  
32  
33 significant differences were found in frequency responses between the far ears and the near  
34  
35 ears (F [1, 18] =2.18,  $p=0.16$ ), the repeated measures ANOVA results showed that the peak  
36  
37 frequencies differed significantly among the three clubs (F [2, 17] =38.72,  $p<0.0005$ ). Further  
38  
39 analysis showed that the frequency responses found in the Club 1 were significantly lower  
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41 than those in Clubs 2 and 3 ( $p<0.0005$ ). In contrast, there was no significant difference in the  
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43 frequency responses between Club 2 and Club 3.  
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50 [Insert Figure 3]

## 51 52 53 54 II. Correlation between sound intensity and swing speed

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3 Table 1 shows the averaged swing speed when using different golf drivers. A one way  
4 ANOVA test showed that there were no significant differences in swing speeds between  
5 Clubs 1, 2 and 3 (Club 1 vs. Club 2 vs. Club 3: 166.5 vs. 169.0 vs. 168.9, F=0.18, p=0.84).  
6  
7 The relationship between sound intensity (dB level) and swing speed (kph) was investigated  
8 using the Pearson product-moment correlation coefficient. There was a small, positive  
9 correlation between the two variables, but no statistical significance was found ( $r_{\text{far-ear}}=0.13,$   
10  $p=0.32; r_{\text{near-ear}}=0.05, p=0.72$ ).  
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### 20 **III. Hearing risk estimation by calculating the percentage of daily noise exposure for** 21 **hitting a basket of golf balls**

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24 Hearing risk was estimated by calculating the percentage of daily noise exposure for hitting a  
25 basket of golf balls using those drivers described above. The sound duration of striking a golf  
26 ball was measured by recording the sound waveforms from the beginning of the impulse  
27 sound until it fell away when crossing the baseline. On average, the sound duration of  
28 striking a golf ball was recorded as approximately 0.5 seconds. If hitting a basket of golf  
29 balls, which are typically 40 in number, the total sound exposure duration was 20 seconds  
30 (i.e., 0.00556 hours).  
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41 In the present study, in order to estimate hearing risk, the damage criteria of 85 dBA for a  
42 maximum 8 hour period advocated by the National Institute for Occupational Safety and  
43 Health (NIOSH) [11] was adapted with an exchange rate of 3 dB and using the A-weighting  
44 scale. Thus, the following formula was used:  
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$$50 \quad \text{Daily Noise Dose \%} = T_1 (\text{total exposure duration}) / T (\text{reference duration}) * 100$$

51  
52  
53 Where  $T=8/2^{((SPL-85)/3)}$ , and  $T_1=0.00556$ .  
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3 Because the sound intensities generated by the golf clubs were recorded and measured in the  
4 ear canal, in order to compare them with the NIOSH standard, the transformation from real  
5 ear sound pressure levels to free-field equivalent values was performed according to ISO  
6 11904-1[12] (i.e., inversion of the average field-to-eardrum transfer function).

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12 On the basis of the SPLs measured in the present study, the percentage of daily noise  
13 exposure for hitting a basket of golf balls using the drivers described above were minimal  
14 (0.05- 1.8%) (Figure 4). For instance, when using Club 1, the noise of hitting approximately  
15 2200 balls with SPLs around 99 dBA would reach 100% of the daily noise exposure dose. In  
16 addition, by theoretical calculation, the noise level of hitting a basket of balls (40) at 116 dBA  
17 appeared to reach the 100% exposure limit.

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27 **[Insert Figure 4]**

## 28 29 30 31 32 **DISCUSSION**

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34 Although a small sample of clubs was used in the present study, and therefore the findings  
35 cannot be attributed to all driver clubs on the market, it does demonstrate that there is  
36 significant variance in the output generated from thin faced titanium drivers used in the  
37 present study, showing significant differences in the intensity and frequency characteristics  
38 obtained from this Club compared with the others. It implies that golf driver clubs differ in  
39 terms of a potential risk to hearing damage. On the basis of the results derived from the  
40 present study with 19 amateur golfers, the noise levels generated on the whole  
41 (approximately 90.0 on average) do not indicate immediate risk. This is consistent with one  
42 previous studies,[13,14] which shows 80-94 dB when measuring accurate hitting sounds  
43 using the ArtemiS system, which includes a binaural headset in connection with integrated  
44 microphones near the opening of the ear canal. However, the current result is contrasted with

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3 an earlier report using a professional golfer to hit three balls with six thin faced titanium  
4 drivers,[4] which demonstrated a significantly high noise level in the region of 120-130 dBA,  
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6 although only a few balls were hit at these intensities in the present study.  
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10 Such a discrepancy is mainly due to different measurement methods employed between the  
11 study carried out by Buchanan and the present study. Real ear measurement (REM) used in  
12 the present study is a common method for measuring SPL near the tympanic membrane.[15]  
13  
14 It offers an accurate and objective approach including the individual's real ear acoustic  
15 characteristics. By contrast, in the study by Buchanan et al.,[4] the SPL was measured using a  
16 sound level meter (SLM) in the free field equidistant from the golfer. The limitation of this  
17 measurement is not accurate because the acoustical effects of the ear canal resonance are not  
18 taken into account. Moreover, the other key issue is that the SPLs measured in the free field  
19 are not the actual SPLs in the ear canal because the baffle effect of head and torso is also  
20 important for measuring sound transfer from the free field to the ear. In addition, the skills  
21 and power possessed by professional golfers may play a role in generating louder SPLs than  
22 is the case for amateur golfers.  
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38 Although various studies have suggested that exposure to stimuli exceeding the 100% daily  
39 noise dose would cause hearing damage, including a hearing sensitivity reduction, tinnitus,  
40 hyperacusis and distortion,[5,6,16] recent research argued the appropriateness of applying  
41 industrial risk criteria with recreational noise exposure, because these standards were  
42 developed specifically for spectrally dense industrial noise with limited dynamic range as an  
43 exposure dose for an 8 hour workday. Therefore, comparisons with industrial standards have  
44 to be made with caution. Nevertheless, according to the intensity and noise exposure dose  
45 calculation found in the present study, the risks are, on the whole, negligible, i.e., the golf  
46 players, particularly amateur players are most unlikely to have hearing damage. However, it  
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3 is noteworthy that some golf clubs can generate extremely high levels of noise, such as at the  
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5 maximum value of 123dBA recorded from Club 1 used in the study. With such high noise  
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7 intensity exposure, it is most likely to pose a significant risk of noise induced hearing loss if  
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9 the driver is used frequently. This would fit with the case study of an amateur golfer  
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11 presenting with significant hearing loss.[4]

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15 Furthermore, the sound of a golf club hitting a golf ball is one of the influencing factors at a  
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17 subconscious level on a golfer's perception of quality and his/her choice of equipment,  
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19 because it provides information on whether the ball was hit correctly. Therefore, golf club  
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21 manufactures tend to make new models of golf driver clubs using various materials (such as  
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23 titanium) not only to achieve longer distances, but also to create unique sound characteristics  
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25 to attract attention. The study by Roberts et al.[17] investigated the relationship between the  
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27 impact sound and elite golfers' subjective perceptions of a shot. They found a strong relationship  
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29 between the characteristics of sharpness and loudness of sound, and pleasantness and liveliness of  
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31 perception. Significantly positive correlations were also obtained between the subjective ratings and  
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33 parameters of the impact sound such as sound pressure level, loudness level and sharpness. This  
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35 suggests that the golfers' perceptions are influenced by frequency components, loudness and duration.

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39 In addition, the FFT analysis in the previous study [13] showed different sounds in terms of  
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41 frequency characteristics and reverberation of the tonal components generated by different  
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43 clubs when they hit the balls. This is in keeping with the findings of the present study,  
44  
45 demonstrating that the peak frequency characteristics recorded from golf driver clubs varied  
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47 significantly between 2.5 and 3.5 kHz. This is associated with the design (e.g., the structure  
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49 of the club head) and materials used to make these modern clubs, which have been created by  
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51 the manufactures in order to achieve a more balanced frequency distribution and thus a better  
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sound quality. However, with such clubs, they are likely to create louder hitting sounds than conventional golf clubs, which potentially causes damage to golfers' hearing.

In the present study, the results did not show evidence of a head shadow effect in that there was not a significant difference between the recordings from the near and far ear. This is consistent with some previous studies on hearing performance between ears in participants in the army having no asymmetrical shooting posture.[18] Although several early studies found that the ear opposite to the dominant hand sustained a more pronounced hearing loss, a recent research study did not reveal a significant preference between ears, irrespective of the dominant hand after recreational firearm use.[8] In addition, no head diffraction effect found in this study can be explained as rapid movement of the torso and the head when swinging the golf club, which means that exposure to the impact noise generated is spread across the two ears. When the torso is uncoiling, the body and head move to a position where both ears face directly into the impact sound sources. Therefore, one side of the ear is overly exposed, and as a consequence, a unilateral hearing loss is unlikely to be developed from playing golf.

Swing speed did not show any significant correlations with either acoustical characteristics measured in the golf driver clubs (i.e., intensity levels and peak frequencies), or golfers' heights. Golfers' skill and power (particularly among professional golfers) may be one of the important influencing factors on swing speed. In addition, it is noteworthy that another important factor is the area of the club face hitting the ball to make an impact because the face of the driver club has a 'sweet spot' where the trampoline effect is optimal. An investigation of strikes out of the heel, toe and sweet spot using an automated and controlled swing motion with a robot [19] would add valuable insight into this enquiry, particularly when comparisons are made between amateur and professional golfers.

## CONCLUSION

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3 Different clubs generated significantly different real ear acoustical characteristics in terms of  
4 sound pressure levels and frequency responses. On the basis of the SPLs measured in the  
5 present study, the immediate danger of noise induced hearing loss for amateur golfers is quite  
6 unlikely. However, it is most likely to pose a significant risk of noise induced hearing loss if  
7 the driver generates high noise intensity greater than 116 dBA. Provision of detailed  
8 information on a club's acoustical characteristics may help consumers choose the appropriate  
9 device for their needs, particularly for people who are prone to hearing damage. A  
10 longitudinal study monitoring hearing thresholds would provide a valuable insight in terms of  
11 the long-term risks to hearing.  
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## 25 **ACKNOWLEDGMENTS**

26  
27 We would like to thank two reviewers and for their helpful suggestions. We would also like  
28 to acknowledge GN Otometrics UK for providing the Freefit wireless Real Ear Measurement  
29 System and technical support during the study. Mrs Norma Meechem kindly provided kind  
30 help with proof reading.  
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## 40 **COMPETING INTERESTS**

41  
42 There are no competing interests.  
43  
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## 46 **FUNDING**

47  
48 This study was supported by the Great Britain Sasakawa Foundation (B68).  
49  
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## 52 **DATA SHARING**

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54 Additional data is available by contacting authors.  
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## CAPTIONS OF FIGURES

**Figure 1 Diagram of experimental settings and equipment used**

**Figure 2 Scatter plot of averaged sound pressure levels (SPLs) obtained in individuals in the far and near ears generated by three golf drivers.**

**Figure 3 Scatter plot of averaged frequency responses obtained in individuals in the far and near ears generated by three golf drivers.**

**Figure 4 Percentage of daily noise exposure when hitting golf balls using the drivers**

Table 1

	Club 1	Club 2	Club 3
<b>Sound Pressure Level in the ear canal (dBA)</b>			
<i>Far Ear</i>	100.3±1.3	85.7±1.2	87.0±1.3
<i>Near Ear</i>	98.2±1.4	82.8±1.0	84.8±1.6
<b>Frequency Response in the ear canal (kHz)</b>			
<i>Far Ear</i>	2.49±0.03	3.60±0.01	3.60±0.09
<i>Near Ear</i>	2.53±0.03	3.37±0.11	3.44±0.08
<b>Swing Speed (kph)</b>			

Figure 1

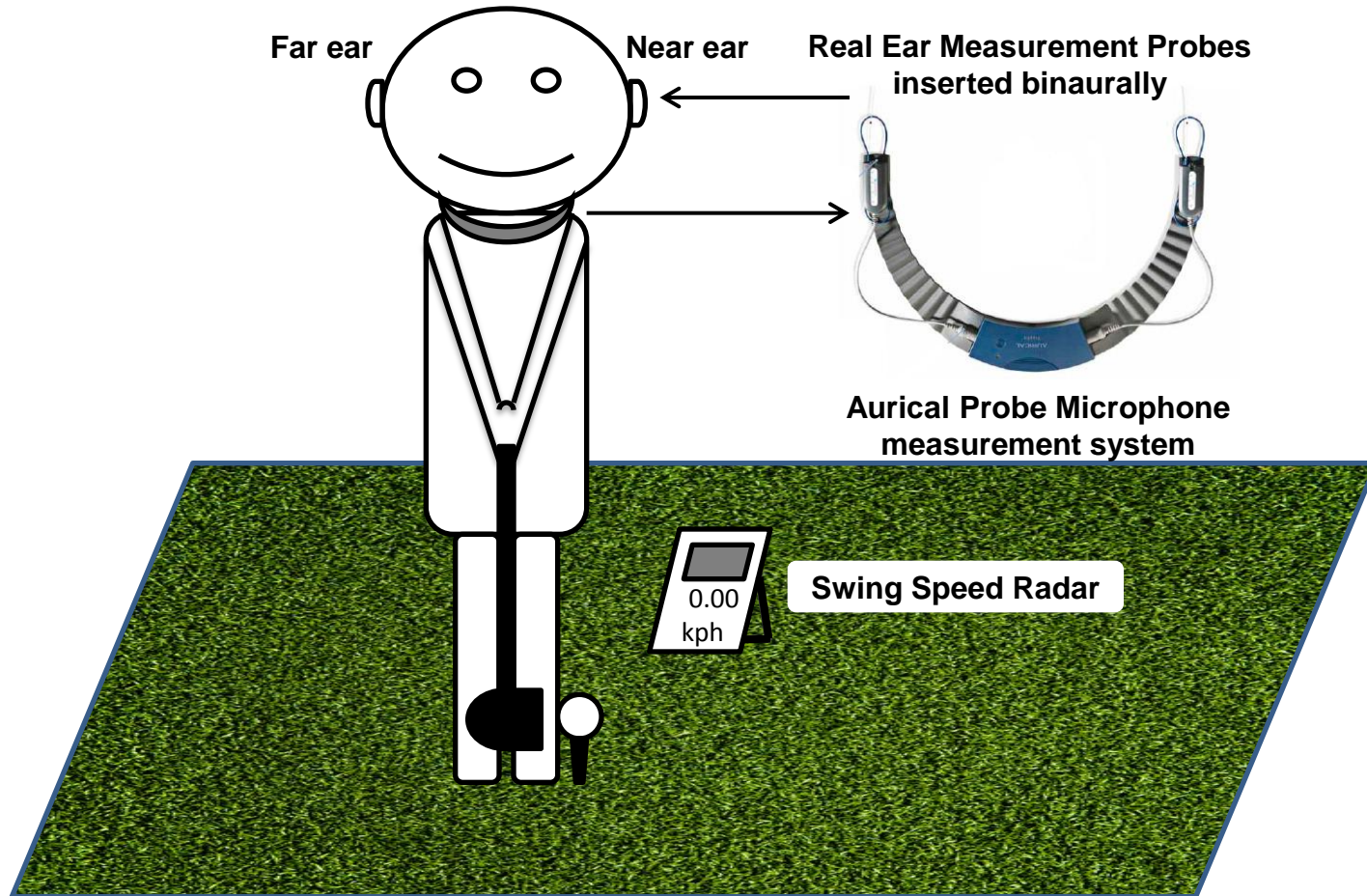


Figure 2

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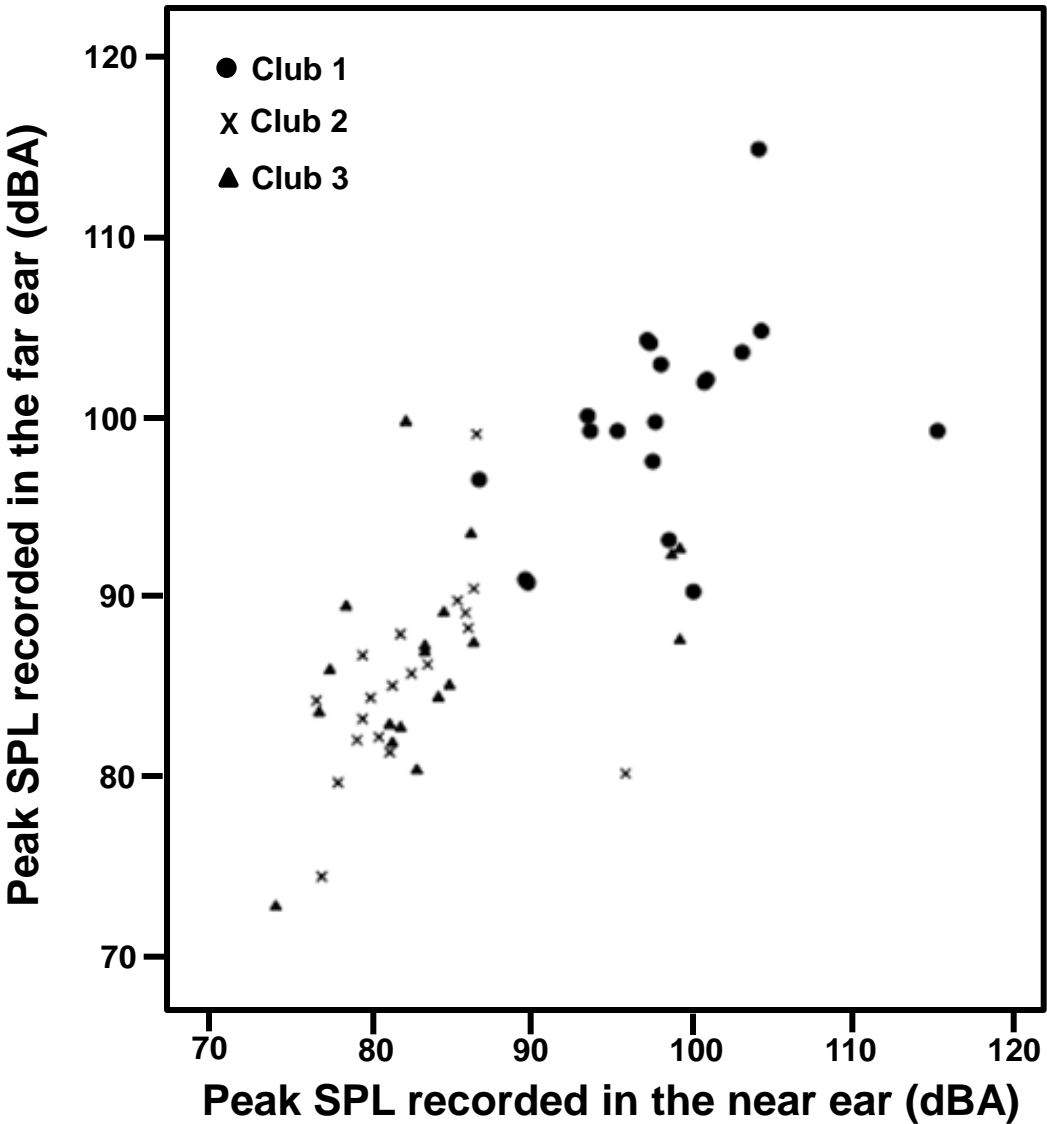
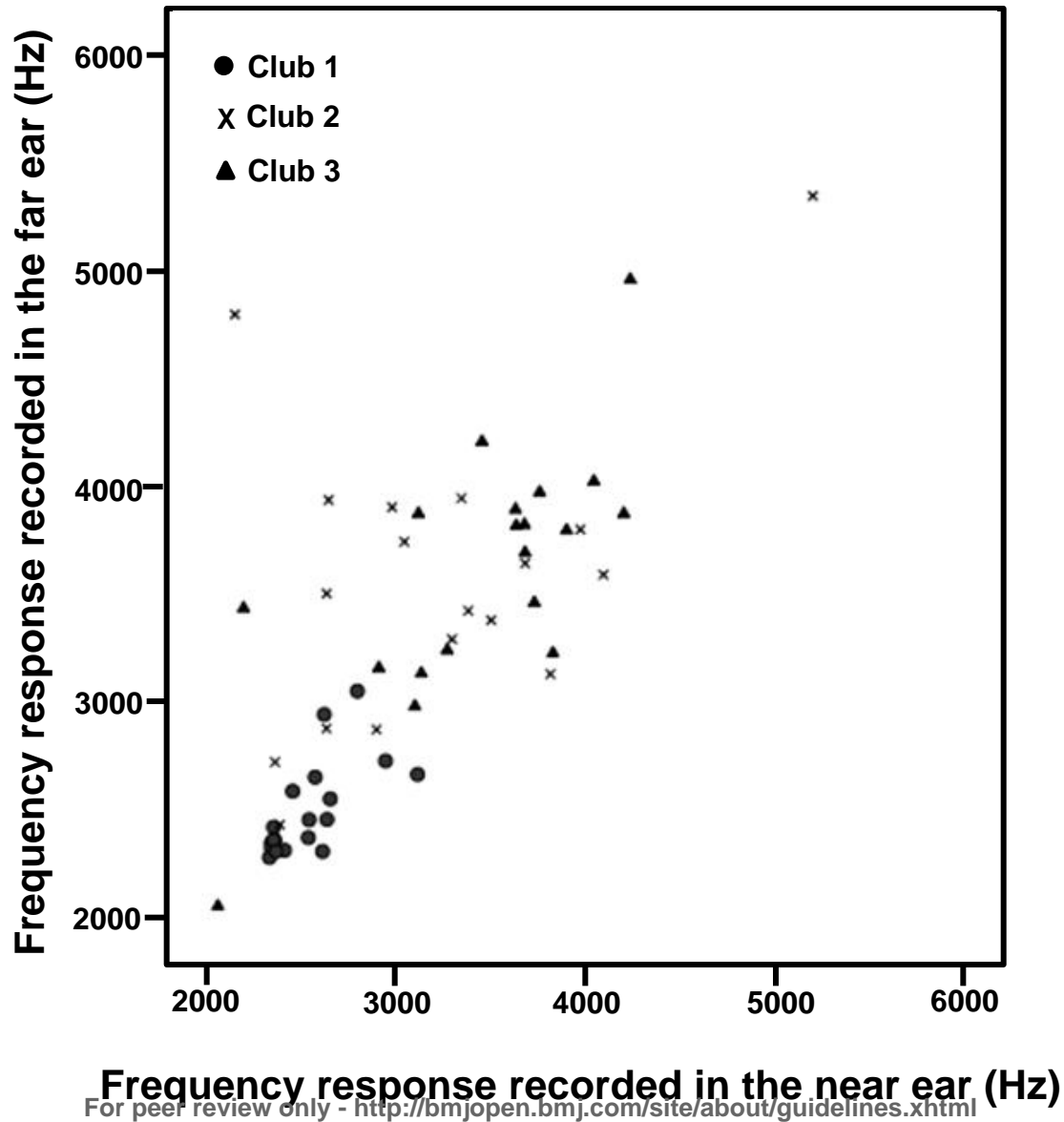


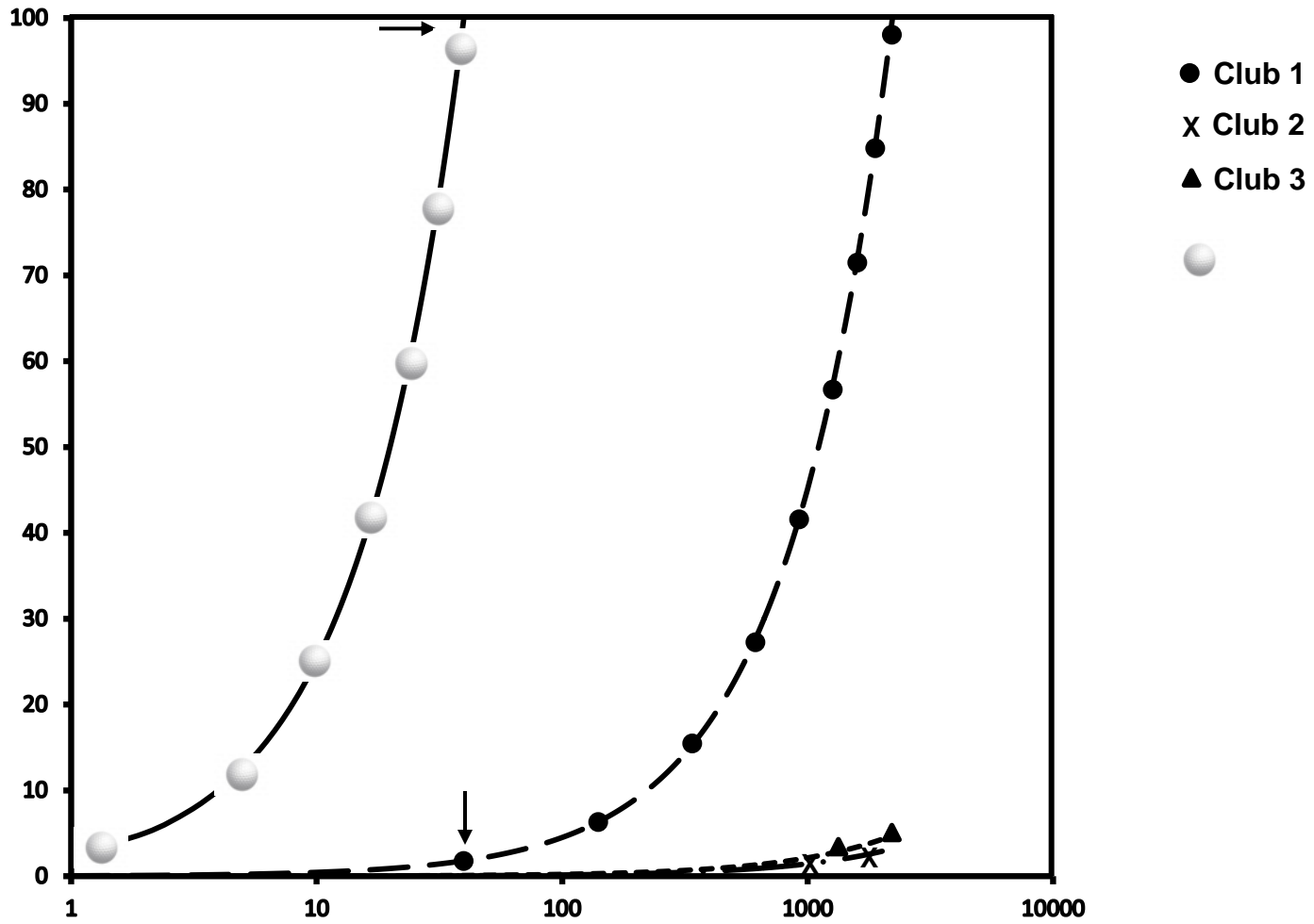
Figure 3



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Figure 4

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**Real ear acoustical characteristics of impulse sound generated by golf drivers and the estimated risk to hearing**

Journal:	<i>BMJ Open</i>
Manuscript ID:	bmjopen-2013-003517.R2
Article Type:	Research
Date Submitted by the Author:	12-Nov-2013
Complete List of Authors:	Zhao, Fei; University of Bristol, Centre for Hearing and Balance Studies Bardsley, Barry; Swansea University, College of Human & Health Science
<b>Primary Subject Heading</b>:	Ear, nose and throat/otolaryngology
Secondary Subject Heading:	Sports and exercise medicine, Occupational and environmental medicine
Keywords:	Audiology < OTOLARYNGOLOGY, Adult otolaryngology < OTOLARYNGOLOGY, SPORTS MEDICINE

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4 **Real ear acoustical characteristics of impulse sound generated by**  
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7 **golf drivers and the estimated risk to hearing**  
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44 **Keywords: Golf, Sports Injuries, Noise, Hearing**  
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## ABSTRACT

### Objectives

This study investigated real ear acoustical characteristics in terms of the sound pressure levels (SPLs) and frequency responses in situ generated from golf club drivers at impact with a golf ball. The risk of hearing loss caused by hitting a basket of golf balls using various drivers was then estimated.

### Design:

Cross-sectional study.

### Setting:

The three driver clubs were chosen on the basis of reflection of the commonality and modern technology of the clubs. The participants were asked to choose the clubs in a random order and hit 6 two-piece range golf balls with each club. The experiment was carried out at a golf driving range in South Wales, UK.

### Participants:

Nineteen male amateur golfers volunteered to take part in the study, with an age range of 19-54 years.

### Outcome measures:

The frequency responses and peak sound pressure levels in situ of the transient sound generated from the club at impact were recorded bilaterally and simultaneously using the GN Otometric Freefit wireless Real Ear Measurement System (REM). A Swing Speed Radar system was also used to investigate the relationship between noise level and swing speed.

### Results:

Different clubs generated significantly different real ear acoustical characteristics in terms of sound pressure levels and frequency responses. However, they did not differ significantly between the ears. No significant correlation was found between the swing speed and noise

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3 intensity. On the basis of the SPLs measured in the present study, the percentage of daily  
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5 noise exposure for hitting a basket of golf balls using the drivers described above was less  
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7 than 2.0%.  
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### 9 10 **Conclusions**

11 The immediate danger of noise induced hearing loss for amateur golfers is quite unlikely.  
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13 However, it may be dangerous to hearing if the noise level generated by the golf clubs  
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15 exceeded 116 dBA.  
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## ARTICLE SUMMARY

### Article focus

1. Is there a risk to hearing for amateur golfers when using the driver golf club?
2. If so, is this risk more prominent in one ear or equal across both ears?
3. Does the speed of the swing influence the sound generated?

### Key Messages

1. The results indicate varying levels of noise produced by clubs but negligible risk to hearing of amateur golfers, with a daily noise exposure of less than 2.0% when averaging the results of the loudest club.
2. No difference was found between ears within the same golfer.
3. Swing speed does not have a significant correlation to the sound generated.

### Strengths

An innovative approach taken by using in-the-ear recordings that provide sound pressure levels at the tympanic membrane. This provides a more accurate estimation because it takes ear canal resonance properties into consideration, whereas the alternative of using a sound level meter equidistant from the ball does not provide this detail.

### Limitations

Only three golf clubs were examined, and a relatively small sample of participants was recruited in the study.

## INTRODUCTION

The popularity of Golf has seen significant increases in the past 25 years, particularly in Europe and the United States. In the U.K. alone figures from 2011 showed 1.3 million golf players and close to 3000 golf courses.[1] By the nature of the game, golf requires the player to swing various types of clubs to hit balls into a relatively wide open space with the ultimate aim of sending the ball into a hole with the fewest number of shots. Therefore, golf is perceived as a low-risk sport compared with other highly competitive sports such as rugby, football, basketball or skiing that have higher injury rates.

However, several studies have shown insight into injuries related to golf. These range from common spine and upper or lower limb injuries to the less frequent injuries related to golf ball trauma.[2,3] In addition, golf has not been attributed to leisure noise exposure and noise induced hearing loss (NIHL) until recently.[4] Noise can be described as sound at an intensity that can interfere with verbal communication and may cause discomfort of the ears or reduction of hearing sensitivity, defined as hearing damage.[5,6] Any exposure to noise of significant intensity and duration increases the risk of ear damage and causes permanent hearing damage, known as noise induced hearing loss (NIHL). Both industrial noise exposure and noise in leisure are the major causes of avoidable permanent hearing loss throughout the world. Within the categories of leisure noise, noise exposure from sporting activities is a major recreational noise sources relevant to various social activities, such as, motor sport, shooting, and spectators at a football match.[7-9]

A study that investigated the potential hazards of modern driver golf clubs in damaging users' hearing from excessive exposure to loud sounds has highlighted this link.[4] The authors

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2  
3 reported on a case of a 55 year old man who had appeared to have developed unilateral noise  
4 induced hearing loss due to the exposure of loud noises generated from his driver golf club.  
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7 When using a professional golfer, they found that many of the clubs generated sounds in  
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10 excess of 120dBA, particularly the thin faced titanium drivers. Therefore, the authors  
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12 recommended caution should be exercised by any golfers using the thin faced titanium  
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14 drivers to avoid damage to their hearing.  
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17 This raises a number of interesting questions. The use of a sound level meter (SLM)  
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19 equidistant from the golfer provided information in the free field. However, in using a SLM it  
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21 is unclear what acoustical effects the ear canal resonance would have on the noise generated.  
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24 Further, the methods used previously did not provide ear specific information and whether  
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26 the head shadow effect was implicated. In having one professional take part in the study it  
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28 was unclear if this could be applied to amateur golfers, and whether the sound generated  
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30 correlated with swing speed. So, there is uncertainty of the immediate and long-term dangers  
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32 of such issues in golf, and a significant knowledge gap remains regarding effective guidance  
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34 on hearing health awareness and prevention of this sport leisure noise damage to hearing.  
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37 Therefore, the aim of this study was to further investigate the acoustical characteristics in situ  
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39 using real ear measurement using various driver clubs. The relationship between swing speed  
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41 and the noise levels generated was also investigated.  
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## 46 47 **MATERIAL AND METHOD**

### 48 49 **Participants**

50  
51 19 male amateur golfers volunteered to take part in the study, with an age range of 19-54  
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53 years (mean 38 years). Of them, 2 were left handed and 17 right handed. Ten had less than 10  
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55 years experience (53%), six participants had golfing experience between 10 and 20 years  
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3 (31%), three participants had more than twenty years experience (16%). Approximately 80%  
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5 of participants reported that they play golf 1-2 times per week on separate days, and all but  
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7 one participant used the driving range less than 3 times a week.  
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### 9 10 **Golf driver clubs**

11  
12 The three driver clubs were chosen on the basis of reflection of the commonality and modern  
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14 technology of the clubs together with consideration of their potentially high loudness levels  
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16 as listed in the study by Buchanan *et al.*[4] Due to the potential commercial dispute and  
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18 conflicts of interest, the names of the manufacturers of the clubs were not disclosed, and  
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20 consequently these differently branded clubs were coded as Club 1, Club 2 and Club 3 in the  
21  
22 present study. However, this information can be discussed by contacting the authors if there  
23  
24 is any concern about the potential hazard of hearing damage to the golf players. In addition,  
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26 in accordance with experimental protocol, each participant was invited to bring their own  
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28 driver and use it along with three other driver clubs.  
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### 33 **Measurement of real ear responses**

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35 Because of natural amplification of the external ear canal, for the purpose of this study, the  
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37 real ear acoustical characteristics in terms of sound frequency spectrum (i.e. frequency  
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39 response) and sound pressure level were investigated using a probe microphone at the  
40  
41 position near the eardrum. Following a warm-up period, the participants were asked to  
42  
43 choose the clubs in a random order and hit 6 two-piece range golf balls with each club. The  
44  
45 frequency responses and peak sound pressure levels in situ of the transient sound generated  
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47 from the club at impact were recorded bilaterally and simultaneously using the GN Otometric  
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49 Freefit wireless Real Ear Measurement System (REM). Probe placement was 25mm along  
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51 the external auditory canal.[10] Room and probe tube calibration were carried out before  
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53 performing the experiment for each participant.  
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6 All recordings were completed at a golf driving range in South Wales, UK.  
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9 For the purpose of measuring the real ear acoustic characteristics in situ when the golfer was  
10 striking the ball, and to allow comparisons based on dexterity, a label of far and near ear was  
11 used. This was implemented because it was unclear if there were differences between the  
12 right and left ears due to their distances from the ball, which would be determined by the  
13 position of each ear exposed to the ball depending on the golfer's dexterity. In essence the  
14 ball was positioned opposite the leading foot when using a driver club to promote an upward  
15 impact and trajectory. Therefore, right-handed golfers had their left ear defined as the near  
16 ear, while the right ear was defined as the far ear and vice versa for the left handed golfers  
17 (Figure 1).  
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30 **[Insert Figure 1]**  
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32 All recorded real ear responses were reviewed and analysed. In the present study, the peak  
33 SPL was determined as the highest point of the curve, whereas the frequency response was  
34 referred to as the point corresponding to the measured peak SPL. Both peak SPL and  
35 frequency response were chosen from visual inspection by the authors, and then measured  
36 directly in the real ear response curves.  
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#### 45 **Swing speed measurement**

46 The participant swing speed was recorded using the Swing Speed Radar® system. The unit  
47 houses a small microwave Doppler radar velocity sensor that provides an accurate  
48 measurement of club head speed at impact. The unit was positioned within 6 inches of the  
49 ball and in line with the swing plane.  
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#### 55 **Ethics**

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3 The study gained ethical approval from the Graduate School of Education (GSoE), University  
4 of Bristol. All participants were informed about the purpose, potential risks of the study,  
5 their roles and rights as participants, the nature of the study; and issues of confidentiality and  
6 anonymity of the data. Participation was on a voluntary basis and information was provided  
7 regarding withdrawal from the study at any time. With the possibility of detecting hearing  
8 loss through the audiological evaluation, participants were provided with a copy of the  
9 hearing test and informed if they needed to consult with their General Practitioner for further  
10 investigation.  
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### 20 21 **Statistical design and analyses**

22 Collected data was stored in an Excel database and all relevant analyses were carried out on  
23 Statistical Package for Social Science (SPSS) version 19.0 for Windows software. A one-way  
24 repeated measure ANOVA was performed to examine the effects of golf club (i.e., Clubs 1,  
25 2, 3) and ear side (Far ear, Near ear) on the real ear acoustical characteristics. The mean value  
26 and standard deviation of the frequency responses and peak sound pressure levels were  
27 calculated and compared using a post-hoc test (i.e., Tukey HSD). A Pearson correlation  
28 analysis between swing speed and the real ear acoustical characteristics was also performed.  
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A  $p < 0.05$  was considered to be statistically significant.

## 43 **RESULTS**

### 45 **I. Real ear acoustical characteristics of sound impulses generated by golf drivers**

48 Figure 2 shows a scatter plot of the averaged sound pressure level (SPLs) obtained in  
49 individuals in the far and near ears generated by three golf drivers, which were used for the  
50 experiment. There was a significant correlation in the SPLs recorded between the far and near  
51 ears ( $r=0.77$ ,  $p < 0.0005$ ). The averaged SPLs were approximately 82-88 dBA while using  
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3 Clubs 2 and 3 (Club 2 far ear and near ear: 85.7 and 82.8 dBA; Club 3 far ear and near ear:  
4 87.0 and 84.8 dBA), whereas the averaged SPLs for Club 1 were 100.0 and 98.2 dBA on far  
5 ears and near ears, respectively (Table 1). The repeated measures ANOVA was conducted to  
6 compare the sound levels generated from the different golf clubs and to investigate the dB  
7 recorded in each ear. The repeated measures ANOVA results showed that there were  
8 significant differences in the SPLs obtained from Clubs 1, 2 and 3 (Wilks' Lambda=0.06, F  
9 (2, 17)=134.33,  $p<0.0005$ ). However, no significant differences were found in the SPLs  
10 between the far ears and the near ears (F [1, 18] =3.48,  $p=0.08$ ). Further analysis showed that  
11 the SPLs generated by Club 1 were significantly greater than those found in Clubs 2 and 3  
12 ( $p<0.0005$ ). In contrast, there was no significant difference in the SPLs between Club 2 and  
13 Club 3.

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28 **[Insert Figure 2]**

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34 Furthermore, frequency response analysis showed that the different golf drivers had different  
35 frequency characteristics. As shown in Figure 3, there was a significant correlation in the  
36 peak frequencies recorded between the far and near ears ( $r=0.73$ ,  $p<0.0005$ ). Clubs 2 and 3  
37 had similar peak frequency characteristics around 3.5 kHz when striking the balls, while the  
38 average frequency response characteristic of Club 1 was 2.5 kHz on either the far ear or the  
39 near ear. Although no significant differences were found in frequency responses between the  
40 far ears and the near ears (F [1, 18] =2.18,  $p=0.16$ ), the repeated measures ANOVA results  
41 showed that the peak frequencies differed significantly among the three clubs (F [2, 17]  
42 =38.72,  $p<0.0005$ ). Further analysis showed that the frequency responses found in the Club 1  
43 were significantly lower than those in Clubs 2 and 3 ( $p<0.0005$ ). In contrast, there was no  
44 significant difference in the frequency responses between Club 2 and Club 3.

[Insert Figure 3]

## II. Correlation between sound intensity and swing speed

Table 1 shows the averaged swing speed when using different golf drivers. A one way ANOVA test showed that there were no significant differences in swing speeds between Clubs 1, 2 and 3 (Club 1 vs. Club 2 vs. Club 3: 166.5 vs. 169.0 vs. 168.9,  $F=0.18$ ,  $p=0.84$ ). The relationship between sound intensity (dB level) and swing speed (kph) was investigated using the Pearson product-moment correlation coefficient. There was a small, positive correlation between the two variables, but no statistical significance was found ( $r_{\text{far-ear}}=0.13$ ,  $p=0.32$ ;  $r_{\text{near-ear}}=0.05$ ,  $p=0.72$ ).

## III. Hearing risk estimation by calculating the percentage of daily noise exposure for hitting a basket of golf balls

Hearing risk was estimated by calculating the percentage of daily noise exposure for hitting a basket of golf balls using those drivers described above. The sound duration of striking a golf ball was measured by recording the sound waveforms from the beginning of the impulse sound until it fell away when crossing the baseline. On average, the sound duration of striking a golf ball was recorded as approximately 0.5 seconds. If hitting a basket of golf balls, which are typically 40 in number, the total sound exposure duration was 20 seconds (i.e., 0.00556 hours).

In the present study, in order to estimate hearing risk, the damage criteria of 85 dBA for a maximum 8 hour period advocated by the National Institute for Occupational Safety and Health (NIOSH) [11] was adapted with an exchange rate of 3 dB and using the A-weighting scale. Thus, the following formula was used:

$$\text{Daily Noise Dose \%} = T_1 (\text{total exposure duration}) / T (\text{reference duration}) * 100$$

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3 *Where  $T=8/2^{((SPL-85)/3)}$ , and  $T_f=0.00556$ .*  
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6 Because the sound intensities generated by the golf clubs were recorded and measured in the  
7 ear canal, in order to compare them with the NIOSH standard, the transformation from real  
8 ear sound pressure levels to free-field equivalent values was performed according to ISO  
9 11904-1[12] (i.e., inversion of the average field-to-eardrum transfer function).  
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16 On the basis of the SPLs measured in the present study, the percentage of daily noise  
17 exposure for hitting a basket of golf balls using the drivers described above were minimal  
18 (0.05- 1.8%) (Figure 4). For instance, when using Club 1, the noise of hitting approximately  
19 2200 balls with SPLs around 99 dBA would reach 100% of the daily noise exposure dose. In  
20 addition, by theoretical calculation, the noise level of hitting a basket of balls (40) at 116 dBA  
21 appeared to reach the 100% exposure limit.  
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30 **[Insert Figure 4]**  
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## 35 **DISCUSSION**

36 Although a small sample of clubs was used in the present study, and therefore the findings  
37 cannot be attributed to all driver clubs on the market, it does demonstrate that there is  
38 significant variance in the output generated from thin faced titanium drivers used in the  
39 present study, showing significant differences in the intensity and frequency characteristics  
40 obtained from this type of club compared with the others. It implies that golf driver clubs  
41 differ in terms of a potential risk to hearing damage. On the basis of the results derived from  
42 the present study with 19 amateur golfers, the noise levels generated on the whole  
43 (approximately 90.0 dB on average) do not indicate immediate risk. This is consistent with  
44 previous studies,[13,14] which show 80-94 dB when measuring accurate hitting sounds using  
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3 the ArtemiS system, which includes a binaural headset in connection with integrated  
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5 microphones near the opening of the ear canal. However, the current result is contrasted with  
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7 an earlier report using a professional golfer to hit three balls with six thin faced titanium  
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9 drivers,[4] which demonstrated a significantly high noise level in the region of 120-130 dBA,  
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11 although only a few balls were hit at these intensities in the present study.  
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15 Such a discrepancy is mainly due to different measurement methods employed between the  
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17 study carried out by Buchanan et al. and the present study. Real ear measurement (REM)  
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19 used in the present study is a common method for measuring SPL near the tympanic  
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21 membrane.[15] It offers an accurate and objective approach including the individual's real  
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23 ear acoustic characteristics. By contrast, in the study by Buchanan et al.,[4] the SPL was  
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25 measured using a sound level meter (SLM) in the free field equidistant from the golfer. The  
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27 limitation of this measurement is not accurate because the acoustical effects of the ear canal  
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29 resonance are not taken into account. Moreover, the other key issue is that the SPLs measured  
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31 in the free field are not the actual SPLs in the ear canal because the baffle effect of head and  
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33 torso is also important for measuring sound transfer from the free field to the ear. In addition,  
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35 the skills and power possessed by professional golfers may play a role in generating louder  
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37 SPLs than is the case for amateur golfers.  
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43 Although various studies have suggested that exposure to stimuli exceeding the 100% daily  
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45 noise dose would cause hearing damage, including a hearing sensitivity reduction, tinnitus,  
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47 hyperacusis and distortion,[5,6,16] recent research argued the appropriateness of applying  
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49 industrial risk criteria with recreational noise exposure, because these standards were  
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51 developed specifically for spectrally dense industrial noise with limited dynamic range as an  
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53 exposure dose for an 8 hour workday. Therefore, comparisons with industrial standards have  
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55 to be made with caution. Nevertheless, according to the intensity and noise exposure dose  
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3 calculation found in the present study, the risks are, on the whole, negligible, i.e., the golf  
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5 players, particularly amateur players are most unlikely to have hearing damage. However, it  
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7 is noteworthy that some golf clubs can generate extremely high levels of noise, such as at the  
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9 maximum value of 123dBA recorded from Club 1 used in the study. With such high noise  
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11 intensity exposure, it is most likely to pose a significant risk of noise induced hearing loss if  
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13 the driver is used frequently. This would fit with the case study of an amateur golfer  
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15 presenting with significant hearing loss.[4]  
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19 Furthermore, the sound of a golf club hitting a golf ball is one of the influencing factors at a  
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21 subconscious level on a golfer's perception of quality and his/her choice of equipment,  
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23 because it provides information on whether the ball was hit correctly. Therefore, golf club  
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25 manufactures tend to make new models of golf driver clubs using various materials (such as  
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27 titanium) not only to achieve longer distances, but also to create unique sound characteristics  
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29 to attract attention. The study by Roberts et al.[17] investigated the relationship between the  
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31 impact sound and elite golfers' subjective perceptions of a shot. They found a strong relationship  
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33 between the characteristics of sharpness and loudness of sound, and pleasantness and liveliness of  
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35 perception. Significantly positive correlations were also obtained between the subjective ratings and  
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37 parameters of the impact sound such as sound pressure level, loudness level and sharpness. This  
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39 suggests that the golfers' perceptions are influenced by frequency components, loudness and duration.  
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44 In addition, the FFT analysis in the previous study [13] showed different sounds in terms of  
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46 frequency characteristics and reverberation of the tonal components generated by different  
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48 clubs when they hit the balls. This is in keeping with the findings of the present study,  
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50 demonstrating that the peak frequency characteristics recorded from golf driver clubs varied  
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52 significantly between 2.5 and 3.5 kHz. This is associated with the design (e.g., the structure  
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54 of the club head) and materials used to make these modern clubs, which have been created by  
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3 the manufactures in order to achieve a more balanced frequency distribution and thus a better  
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5 sound quality. However, with such clubs, they are likely to create louder hitting sounds than  
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7 conventional golf clubs, which potentially causes damage to golfers' hearing.  
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11 In the present study, the results did not show evidence of a head shadow effect insofar as  
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13 there was no significant difference in sound intensity between the recordings from the near  
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15 and far ears. There is some controversy about asymmetrical noise exposure even though both  
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17 ears are exposed directly to impact sound sources. (8,18,19,20) Some previous studies argued  
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19 that left ear noise-induced hearing losses are predominantly common in the army, because the  
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21 ear opposite to the dominant hand sustains over exposure mainly due to the shooting posture.  
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23 [18,19] However, a recent study on hearing performance after recreational firearm use did not  
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25 reveal a significant preference in terms of temporary threshold shift between ears,  
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27 irrespective of the dominant hand.[8] The other study by Job et al. [20] showed that the  
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29 asymmetry of hearing thresholds between the left ear and right ear was not associated with  
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31 the subject's shooting posture. They suggested that it is most likely due to different intrinsic  
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33 characteristics in each side of the ears. In addition, no head diffraction effect found in this  
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35 study can be explained as rapid movement of the torso and the head when swinging the golf  
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37 club, which means that exposure to the impact noise generated is spread across the two ears.  
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39 When the torso is uncoiling, the body and head move to a position where both ears face  
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41 directly into the impact sound sources. Therefore, one side of the ear is overly exposed, and  
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43 as a consequence, a unilateral hearing loss is unlikely to be developed from playing golf.  
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50 Swing speed did not show any significant correlations with either acoustical characteristics  
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52 measured in the golf driver clubs (i.e., intensity levels and peak frequencies). Golfers' skill  
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54 and power (particularly among professional golfers) may be one of the important influencing  
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56 factors on swing speed. It is noteworthy that another important factor is the area of the club  
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3 face hitting the ball to create an impact because the face of the driver club has a 'sweet spot'  
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5 where the trampoline effect is optimal. The trampoline effect refers to a pronounced  
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7 deformation of the club face upon impact followed by a quick restoration to its original  
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9 dimensions, acting like a slingshot. When the club face hits the ball right on the sweet spot, it  
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11 results in very high ball speeds. In the present study, it is impossible for the participants to  
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13 control this factor in order to deliver the same performance with each strike. An investigation  
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15 of strikes out of the heel, toe and sweet spot using an automated and controlled swing motion  
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17 with a robot [21] would add valuable insight into this enquiry, particularly when comparisons  
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19 are made between amateur and professional golfers.  
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## 22 23 24 **CONCLUSION**

25  
26 Different clubs generated significantly different real ear acoustical characteristics in terms of  
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28 sound pressure levels and frequency responses. On the basis of the SPLs measured in the  
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30 present study, the immediate danger of noise induced hearing loss for amateur golfers is quite  
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32 unlikely. However, it is most likely to pose a significant risk of noise induced hearing loss if  
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34 the driver generates high noise intensity greater than 116 dBA. Provision of detailed  
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36 information on a club's acoustical characteristics may help consumers choose the appropriate  
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38 device for their needs, particularly for people who are prone to hearing damage. A  
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40 longitudinal study monitoring hearing thresholds would provide a valuable insight in terms of  
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42 the long-term risks to hearing.  
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## 49 50 **ACKNOWLEDGMENTS**

51  
52 We would like to thank two reviewers and managing editor for their helpful suggestions. We  
53  
54 would also like to acknowledge GN Otometrics UK for providing the Freefit wireless Real Ear  
55  
56 Measurement System and technical support during the study. This work was funded by the  
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3 Great Britain Sasakawa Foundation (Award number: B68). Mrs Norma Meechem kindly provided  
4  
5 help with proof reading.  
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### 10 11 **COMPETING INTERESTS**

12  
13 There are no competing interests.  
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### 16 17 **FUNDING**

18  
19 This study was supported by the Great Britain Sasakawa Foundation (B68).  
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21

### 22 23 **DATA SHARING**

24  
25 Additional data is available by emailing Fei.Zhao@bristol.ac.uk. This data is additional information  
26  
27 from a questionnaire regarding golf.  
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### 30 31 **CONTRIBUTORSHIP**

32  
33 B Bardsley developed the idea, designed the study, collected the data, analysed the data and wrote  
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35 the article.  
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37 F Zhao wrote the grant application, designed the study, collected the data, revised the article. F Zhao  
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39 is the guarantor.  
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3 CAPTIONS OF FIGURES  
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5 **Figure 1** Diagram of experimental settings and equipment used  
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7 **Figure 2** Scatter plot of averaged sound pressure levels (SPLs) obtained in individuals in  
8 the far and near ears generated by three golf drivers.  
9

10 **Figure 3** Scatter plot of averaged frequency responses obtained in individuals in the far  
11 and near ears generated by three golf drivers.  
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13 **Figure 4** Percentage of daily noise exposure when hitting golf balls using the drivers  
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15 *Figure legend:*  
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17 *Arrow label (→): The percentage of daily noise exposure per basket (40 golf balls)*  
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25 **Table 1**  
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	Club 1	Club 2	Club 3
<b>Sound Pressure Level in the ear canal (dBA)</b>			
<i>Far Ear</i>	100.3±1.3	85.7±1.2	87.0±1.3
<i>Near Ear</i>	98.2±1.4	82.8±1.0	84.8±1.6
<b>Frequency Response in the ear canal (kHz)</b>			
<i>Far Ear</i>	2.49±0.03	3.60±0.01	3.60±0.09
<i>Near Ear</i>	2.53±0.03	3.37±0.11	3.44±0.08
<b>Swing Speed (kph)</b>	166.5±15.4	169.0±15.4	168.9±17.3

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4 **Real ear acoustical characteristics of impulse sound generated by**  
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7 **golf drivers and the estimated risk to hearing**  
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44 **Keywords: Golf, Sports Injuries, Noise, Hearing**  
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**ABSTRACT****Objectives**

This study investigated real ear acoustical characteristics in terms of the sound pressure levels (SPLs) and frequency responses in situ generated from golf club drivers at impact with a golf ball. The risk of hearing loss caused by hitting a basket of golf balls using various drivers was then estimated.

**Design:**

Cross-sectional study.

**Setting:**

The three driver clubs were chosen on the basis of reflection of the commonality and modern technology of the clubs. The participants were asked to choose the clubs in a random order and hit 6 two-piece range golf balls with each club. The experiment was carried out at a golf driving range in South Wales, UK.

**Participants:**

Nineteen male amateur golfers volunteered to take part in the study, with an age range of 19-54 years.

**Outcome measures:**

The frequency responses and peak sound pressure levels in situ of the transient sound generated from the club at impact were recorded bilaterally and simultaneously using the GN Otometric Freefit wireless Real Ear Measurement System (REM). A Swing Speed Radar system was also used to investigate the relationship between noise level and swing speed.

**Results:**

Different clubs generated significantly different real ear acoustical characteristics in terms of sound pressure levels and frequency responses. However, they did not differ significantly between the ears. No significant correlation was found between the swing speed and noise

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3 intensity. On the basis of the SPLs measured in the present study, the percentage of daily  
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5 noise exposure for hitting a basket of golf balls using the drivers described above ~~were~~-was  
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7 less than 2.0%.  
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### 9 10 **Conclusions**

11 The immediate danger of noise induced hearing loss for amateur golfers is quite unlikely.  
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13 However, it may be dangerous to hearing if the noise level generated by the golf clubs  
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15 exceeded 116 dBA.  
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## ARTICLE SUMMARY

### Article focus

1. Is there a risk to hearing for amateur golfers when using the driver golf club?
2. If so, is this risk more prominent in one ear or equal across both ears?
3. Does the speed of the swing influence the sound generated?

### Key Messages

1. The results indicate varying levels of noise produced by clubs but negligible risk to hearing of amateur golfers, with a daily noise exposure of less than 2.0% when averaging the results of the loudest club.
2. No difference was found between ears within the same golfer.
3. Swing speed does not have a significant correlation to the sound generated.

### Strengths

An innovative approach taken by using in-the-ear recordings that provide sound pressure levels at the tympanic membrane. This provides a more accurate estimation because it takes ear canal resonance properties into consideration, whereas the alternative of using a sound level meter equidistant from the ball does not provide this detail.

### Limitations

Limited-Only three golf clubs were examined, and a relatively a small sample size of the participants was recruited in the study  
as well as a small sample size—the participants own club meant of golf clubs was used in the study-



## INTRODUCTION

The popularity of Golf has seen significant increases in the past 25 years, particularly in Europe and the United States. In the U.K. alone figures from 2011 showed 1.3 million golf players and close to 3000 golf courses.[1] By the nature of the game, Golf-golf requires the player to swing various types of clubs to hit balls into a relatively wide open space with the ultimate aim of sending the ball into a hole with the fewest number of shots. Therefore, Golf-golf is perceived as a low-risk sport compared with other highly competitive sports such as rugby, football, basketball or skiing that have higher injury rates.

However, several studies have shown insight into injuries related to golf. These range from common spine and upper or lower limb injuries to the less frequent injuries related to golf ball trauma.[2,3] In addition, Golf-golf has not been attributed to leisure noise exposure and noise induced hearing loss (NIHL) until recently.[4] Noise can be described as sound at an intensity that can interfere with verbal communication and may cause discomfort of the ears or reduction of hearing sensitivity, defined as hearing damage.[5,6] Any exposure to noise of significant intensity and duration increases the risk of ear damage and causes permanent hearing damage, known as noise induced hearing loss (NIHL). Both industrial noise exposure and noise in leisure are the major causes of avoidable permanent hearing loss throughout the world. Within the categories of leisure noise, noise exposure from sporting activities is a major recreational noise sources relevant to various social activities, such as, motor sport, shooting, and spectators at a football match.[7-9]

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3 A study that investigated the potential hazards of modern driver golf clubs in damaging users'  
4 hearing from excessive exposure to loud sounds has highlighted this link.[4] The authors  
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6 reported on a case of a 55 year old man who had appeared to have developed unilateral noise  
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8 induced hearing loss due to the exposure of loud noises generated from his driver golf club.  
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11 When using a professional golfer, they found that many of the clubs generated sounds in  
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13 excess of 120dBA, particularly the thin faced titanium drivers. Therefore, the authors  
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15 recommended caution should be exercised by any golfers using the thin faced titanium  
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17 drivers to avoid damage to their hearing.  
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21 This raises a number of interesting questions. The use of a sound level meter (SLM)  
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23 equidistant from the golfer provided information in the free field. However, in using a SLM it  
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25 is unclear what acoustical effects the ear canal resonance would have on the noise generated.  
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27 Further, the methods used previously did not provide ear specific information and whether  
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29 the head shadow effect was implicated. In having one professional take part in the study it  
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31 was unclear if this could be applied to amateur golfers, and whether the sound generated  
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33 correlated with swing speed. So, there is uncertainty of the immediate and long-term dangers  
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35 of such issues in Golfgolf, and a significant knowledge gap remains regarding effective  
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37 guidance on hearing health awareness and prevention of this sport leisure noise damage to  
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39 hearing. Therefore, the aim of this study was to further investigate the acoustical  
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41 characteristics in situ using real ear measurement using various driver clubs. The relationship  
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43 between swing speed and the noise levels generated was also investigated.  
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## 51 MATERIAL AND METHOD

### 52 Participants

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55 19 male amateur golfers volunteered to take part in the study, with an age range of 19-54  
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3 years (mean 38 years). Of them, 2 were left handed and 17 right handed. Ten had less than 10  
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5 years experience (53%), six participants had golfing experience between 10 and 20 years  
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7 (31%), three participants had more than twenty years experience (16%). Approximately 80%  
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9 of participants reported that they play golf 1-2 times per week on separate days, and all but  
10  
11 one participant used the driving range less than 3 times a week.

### 14 **Golf driver clubs**

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17 The three driver clubs were chosen on the basis of reflection of the commonality and modern  
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19 technology of the clubs together with consideration of their potentially high loudness levels  
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21 as listed in the study by Buchanan *et al.*[4] Due to the potential commercial dispute and  
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23 conflicts of interest, the names of the manufacturers of the clubs were not disclosed, and  
24  
25 consequently these differently branded clubs were coded as Club 1, Club 2 and Club 3 in the  
26  
27 present study. However, this information can be discussed by contacting the authors if there  
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29 is any concern about the potential hazard of hearing damage to the golf players. In addition,  
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31 in accordance with experimental protocol, each participant was invited to bring their own  
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33 driver and use it along with three other driver clubs.  
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### 38 **Measurement of real ear responses**

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40 Because of natural amplification of the external ear canal, for the purpose of this study, the  
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42 real ear acoustical characteristics in terms of sound frequency spectrum (i.e. frequency  
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44 response) and sound pressure level were investigated using a probe microphone at the  
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46 position near the eardrum. Following a warm-up period, the participants were asked to  
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48 choose the clubs in a random order and hit 6 two-piece range golf balls with each club. The  
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50 frequency responses and peak sound pressure levels in situ of the transient sound generated  
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52 from the club at impact were recorded bilaterally and simultaneously using the GN Otometric  
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54 Freefit wireless Real Ear Measurement System (REM). Probe placement was 25mm along  
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3 the external auditory canal.[10] Room and probe tube calibration were carried out before  
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5 performing the experiment for each participant.  
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11 All recordings were completed at a golf driving range in South Wales, UK.  
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14 For the purpose of measuring the real ear acoustic characteristics in situ when the golfer was  
15 striking the ball, and to allow comparisons based on dexterity, a label of far and near ear was  
16 used. This was implemented because it was unclear if there were differences between the  
17 right and left ears due to their distances from the ball, which would be determined by the  
18 position of each ear exposed to the ball depending on the golfer's dexterity. In essence the  
19 ball was positioned opposite the leading foot when using a driver club to promote an upward  
20 impact and trajectory. Therefore, right-handed golfers had their left ear defined as the near  
21 ear, while the right ear was defined as the far ear and vice versa for the left handed golfers  
22 (Figure 1).  
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38 All recorded real ear responses were reviewed and analysed. In the present study, the peak  
39 SPL was determined as the highest point of the curve, whereas the frequency response was  
40 referred to as the point corresponding to the measured peak SPL. Both peak SPL and  
41 frequency response were chosen from visual inspection by the authors, and then measured  
42 directly in the real ear response curves.  
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### 49 **Swing speed measurement**

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51 The participant swing speed was recorded using the Swing Speed Radar® system. The unit  
52 houses a small microwave Doppler radar velocity sensor that provides an accurate  
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3 measurement of club head speed at impact. The unit was position<sup>ed</sup> within 6 inches of the  
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5 ball and in line with the swing plane.  
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### 7 8 **Ethics**

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10 The study gained ethical approval from the Graduate School of Education (GSoE), University  
11 of Bristol. All participants were informed about the purpose, potential risks of the study,  
12 their roles and rights as participants, the nature of the study; and issues of confidentiality and  
13 anonymity of the data. Participation was on a voluntary basis and information was provided  
14 regarding withdrawal from the study at any time. With the possibility of detecting hearing  
15 loss through the audiological evaluation, participants were provided with a copy of the  
16 hearing test and informed if they needed to consult with their General Practitioner for further  
17 investigation.  
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### 27 28 **Statistical design and analyses**

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30 Collected data was stored in an Excel database and all relevant analyses were carried out on  
31 Statistical Package for Social Science (SPSS) version 19.0 for Windows software. A one-way  
32 repeated measure ANOVA was performed to examine the effects of golf club (i.e., Clubs 1,  
33 2, 3) and ear side (Far ear, Near ear) on the real ear acoustical characteristics. The mean value  
34 and standard deviation of the frequency responses and peak sound pressure levels were  
35 calculated and compared using a post-hoc test (i.e., Tukey HSD). A Pearson correlation  
36 analysis between swing speed and the real ear acoustical characteristics was also performed.  
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A  $p < 0.05$  was considered to be statistically significant.

## 50 51 **RESULTS**

### 52 53 **I. Real ear acoustical characteristics of sound impulses generated by golf drivers**

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3 Figure 2 shows a scatter plot of the averaged sound pressure level (SPLs) obtained in  
4 individuals in the far and near ears generated by three golf drivers, which were used for the  
5 experiment. There was a significant correlation in the SPLs recorded between the far and near  
6 ears ( $r=0.77$ ,  $p<0.0005$ ). The averaged SPLs were approximately 82-88 dBA while using  
7 Clubs 2 and 3 (Club 2 far ear and near ear: 85.7 and 82.8 dBA; Club 3 far ear and near ear:  
8 87.0 ~~abd-and~~ 84.8 dBA), whereas the averaged SPLs for Club 1 were 100.0 and 98.2 dBA on  
9 far ears and near ears, respectively (Table 1). The repeated measures ANOVA was conducted  
10 to compare the sound levels generated from the different golf clubs and to investigate the dB  
11 recorded in each ear. The repeated measures ANOVA results showed that there were  
12 significant differences in the SPLs obtained from Clubs 1, 2 and 3 (Wilks' Lambda=0.06, F  
13 (2, 17)=134.33,  $p<0.0005$ ). However, no significant differences were found in the SPLs  
14 between the far ears and the near ears (F [1, 18] =3.48,  $p=0.08$ ). Further analysis showed that  
15 the SPLs generated by Club 1 ~~was-were~~ significantly greater than those found in Clubs 2 and  
16 3 ( $p<0.0005$ ). In contrast, there was no significant difference in the SPLs between Club 2 and  
17 Club 3.

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37 **[Insert Figure 2]**

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42 **[Insert Table 1]**

43 Furthermore, frequency response analysis showed that the different golf drivers had different  
44 frequency characteristics. As shown in Figure 3, there was a significant correlation in the  
45 peak frequencies recorded between the far and near ears ( $r=0.73$ ,  $p<0.0005$ ). Clubs 2 and 3  
46 had similar peak frequency characteristics around 3.5 kHz when striking the balls, while the  
47 average frequency response characteristic of Club 1 was 2.5 kHz on either the far ear or the  
48 near ear. Although no significant differences were found in frequency responses between the  
49 far ears and the near ears (F [1, 18] =2.18,  $p=0.16$ ), the repeated measures ANOVA results

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3 showed that the peak frequencies differed significantly among the three clubs ( $F [2, 17]$   
4  $=38.72, p<0.0005$ ). Further analysis showed that the frequency responses found in the Club 1  
5 were significantly lower than those in Clubs 2 and 3 ( $p<0.0005$ ). In contrast, there was no  
6 significant difference in the frequency responses between Club 2 and Club 3.  
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12 **[Insert Figure 3]**  
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## 14 15 **II. Correlation between sound intensity and swing speed**

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17 Table 1 shows the averaged swing speed when using different golf drivers. A one way  
18 ANOVA test showed that there were no significant differences in swing speeds between  
19 Clubs 1, 2 and 3 (Club 1 vs. Club 2 vs. Club 3: 166.5 vs. 169.0 vs. 168.9,  $F=0.18, p=0.84$ ).  
20 The relationship between sound intensity (dB level) and swing speed (kph) was investigated  
21 using the Pearson product-moment correlation coefficient. There was a small, positive  
22 correlation between the two variables, but no statistical significance was found ( $r_{\text{far-ear}}=0.13,$   
23  $p=0.32; r_{\text{near-ear}}=0.05, p=0.72$ ).  
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## 35 **III. Hearing risk estimation by calculating the percentage of daily noise exposure for** 36 **hitting a basket of golf balls** 37

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39 Hearing risk was estimated by calculating the percentage of daily noise exposure for hitting a  
40 basket of golf balls using those drivers described above. The sound duration of striking a golf  
41 ball was measured by recording the sound waveforms from the beginning of the impulse  
42 sound until it fell away when crossing the baseline. On average, the sound duration of  
43 striking a golf ball was recorded as approximately 0.5 seconds. If hitting a basket of golf  
44 balls, which are typically 40 in number, the total sound exposure duration was 20 seconds  
45 (i.e., 0.00556 hours).  
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3 In the present study, in order to estimate hearing risk, the damage criteria of 85 dBA for a  
4 maximum 8 hour period advocated by the National Institute for Occupational Safety and  
5 Health (NIOSH) [11] was adapted with an exchange rate of 3 dB and using the A-weighting  
6 scale. Thus, the following formula was used:  
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$$11 \quad \text{Daily Noise Dose \%} = T_1 (\text{total exposure duration}) / T (\text{reference duration}) * 100$$

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16 *Where  $T = 8/2^{((SPL-85)/3)}$ , and  $T_1 = 0.00556$ .*  
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19 Because the sound intensities generated by the golf clubs were recorded and measured in the  
20 ear canal, in order to compare them with the NIOSH standard, the transformation from real  
21 ear sound pressure levels to free-field equivalent values was performed according to ISO  
22 11904-1[12] (i.e., inversion of the average field-to-eardrum transfer function).  
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29 On the basis of the SPLs measured in the present study, the percentage of daily noise  
30 exposure for hitting a basket of golf balls using the drivers described above were minimal  
31 (0.05- 1.8%) (Figure 4). For instance, when using Club 1, the noise of hitting approximately  
32 2200 balls with SPLs around 99 dBA would reach 100% of the daily noise exposure dose. In  
33 addition, by theoretical calculation, the noise level of hitting a basket of balls (40) at 116 dBA  
34 appeared to reach the 100% exposure limit.  
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43 [Insert Figure 4]  
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## 48 DISCUSSION

49 Although a small sample of clubs was used in the present study, and therefore the findings  
50 cannot be attributed to all driver clubs on the market, it does demonstrate that there is  
51 significant variance in the output generated from thin faced titanium drivers used in the  
52 present study, showing significant differences in the intensity and frequency characteristics  
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3 obtained from this ~~Club~~-type of club compared with the others. It implies that golf driver  
4 clubs differ in terms of a potential risk to hearing damage. On the basis of the results derived  
5 from the present study with 19 amateur golfers, the noise levels generated on the whole  
6 (approximately 90.0 dB on average) do not indicate immediate risk. This is consistent with  
7 ~~one~~ previous studies,[13,14] which shows 80-94 dB when measuring accurate hitting sounds  
8 using the ArtemiS system, which includes a binaural headset in connection with integrated  
9 microphones near the opening of the ear canal. However, the current result is contrasted with  
10 an earlier report using a professional golfer to hit three balls with six thin faced titanium  
11 drivers,[4] which demonstrated a significantly high noise level in the region of 120-130 dBA,  
12 although only a few balls were hit at these intensities in the present study.  
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26 Such a discrepancy is mainly due to different measurement methods employed between the  
27 study carried out by Buchanan *et al.* and the present study. Real ear measurement (REM)  
28 used in the present study is a common method for measuring SPL near the tympanic  
29 membrane.[15] It offers an accurate and objective approach including the individual's real  
30 ear acoustic characteristics. By contrast, in the study by Buchanan *et al.*,[4] the SPL was  
31 measured using a sound level meter (SLM) in the free field equidistant from the golfer. The  
32 limitation of this measurement is not accurate because the acoustical effects of the ear canal  
33 resonance are not taken into account. Moreover, the other key issue is that the SPLs measured  
34 in the free field are not the actual SPLs in the ear canal because the baffle effect of head and  
35 torso is also important for measuring sound transfer from the free field to the ear. In addition,  
36 the skills and power possessed by professional golfers may play a role in generating louder  
37 SPLs than is the case for amateur golfers.  
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53 Although various studies have suggested that exposure to stimuli exceeding the 100% daily  
54 noise dose would cause hearing damage, including a hearing sensitivity reduction, tinnitus,  
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3 hyperacusis and distortion,[5,6,16] recent research argued the appropriateness of applying  
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5 industrial risk criteria with recreational noise exposure, because these standards were  
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7 developed specifically for spectrally dense industrial noise with limited dynamic range as an  
8  
9 exposure dose for an 8 hour workday. Therefore, comparisons with industrial standards have  
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11 to be made with caution. Nevertheless, according to the intensity and noise exposure dose  
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13 calculation found in the present study, the risks are, on the whole, negligible, i.e., the golf  
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15 players, particularly amateur players are most unlikely to have hearing damage. However, it  
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17 is noteworthy that some golf clubs can generate extremely high levels of noise, such as at the  
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19 maximum value of 123dBA recorded from Club 1 used in the study. With such high noise  
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21 intensity exposure, it is most likely to pose a significant risk of noise induced hearing loss if  
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23 the driver is used frequently. This would fit with the case study of an amateur golfer  
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25 presenting with significant hearing loss.[4]  
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30 Furthermore, the sound of a golf club hitting a golf ball is one of the influencing factors at a  
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32 subconscious level on a golfer's perception of quality and his/her choice of equipment,  
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34 because it provides information on whether the ball was hit correctly. Therefore, golf club  
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36 manufactures tend to make new models of golf driver clubs using various materials (such as  
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38 titanium) not only to achieve longer distances, but also to create unique sound characteristics  
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40 to attract attention. The study by Roberts et al.[17] investigated the relationship between the  
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42 impact sound and elite golfers' subjective perceptions of a shot. They found a strong relationship  
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44 between the characteristics of sharpness and loudness of sound, and pleasantness and liveliness of  
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46 perception. Significantly positive correlations were also obtained between the subjective ratings and  
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48 parameters of the impact sound such as sound pressure level, loudness level and sharpness. This  
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50 suggests that the golfers' perceptions are influenced by frequency components, loudness and duration.  
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3 In addition, the FFT analysis in the previous study [13] showed different sounds in terms of  
4 frequency characteristics and reverberation of the tonal components generated by different  
5 clubs when they hit the balls. This is in keeping with the findings of the present study,  
6 demonstrating that the peak frequency characteristics recorded from golf driver clubs varied  
7 significantly between 2.5 and 3.5 kHz. This is associated with the design (e.g., the structure  
8 of the club head) and materials used to make these modern clubs, which have been created by  
9 the manufactures in order to achieve a more balanced frequency distribution and thus a better  
10 sound quality. However, with such clubs, they are likely to create louder hitting sounds than  
11 conventional golf clubs, which potentially causes damage to golfers' hearing.  
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23 In the present study, the results did not show evidence of a head shadow effect ~~in that insofar~~  
24 ~~as~~ there was not ~~a~~ significant difference ~~in sound intensities~~ intensity between the recordings  
25 from the near and far ears. ~~It has been~~ There is some controversy ~~on~~ about asymmetrical noise  
26 exposure even though both ears are exposed directly to impact sound sources. [8,18,19,20]  
27  
28 Some previous studies argued that left ear noise-induced hearing losses are ~~predominantly~~  
29 common in the army. ~~It is explained that,~~ because the ear opposite to the dominant hand  
30 sustains ~~overly exposed~~ exposure mainly due to the shooting posture. [18,19] However, a  
31 recent study ~~This is consistent with some previous studies~~ on hearing performance between  
32 ears ~~after recreational firearm use in participants in the army having no asymmetrical~~  
33 shooting posture [18]. Although several early studies found that the ear opposite to the  
34 dominant hand ~~sustained a more pronounced hearing loss,~~ a recent research study did not  
35 reveal a significant preference ~~in terms of temporary threshold shift~~ between ears,  
36 irrespective of the dominant hand ~~after recreational firearm use.~~ [8] The other study by Job et  
37 al. [20] showed that the asymmetry of hearing thresholds between the left ear and right ear  
38 was not associated with the subject's shooting posture. They suggested that it is ~~most likely~~  
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3 due to different intrinsic characteristics in each side of the ears. In addition, no head  
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5 diffraction effect found in this study can be explained as rapid movement of the torso and the  
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7 head when swinging the golf club, which means that exposure to the impact noise generated  
8  
9 is spread across the two ears. When the torso is uncoiling, the body and head move to a  
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11 position where both ears face directly into the impact sound sources. Therefore, one side of  
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13 the ear is overly exposed, and as a consequence, a unilateral hearing loss is unlikely to be  
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15 developed from playing golf.  
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19 Swing speed did not show any significant correlations with either acoustical characteristics  
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21 measured in the golf driver clubs (i.e., intensity levels and peak frequencies). Golfers' skill  
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23 and power (particularly among professional golfers) may be one of the important influencing  
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25 factors on swing speed. In addition, it is noteworthy that another important factor is the area  
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27 of the club face hitting the ball to ~~make~~ create an impact because the face of the driver club  
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29 has a 'sweet spot' where the trampoline effect is optimal. ~~The trampoline effect refers to a~~  
30  
31 pronounced deformation of the club face upon impact followed by a quick restoration to its  
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33 original dimensions, acting like a slingshot. When the club face hits the ball right on the  
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35 sweet spot, it results in very high ball speeds. In the present study, it is impossible for the  
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37 participants to control this factor ~~for delivering~~ in order to deliver the same performance  
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39 by with each strike. An investigation of strikes out of the heel, toe and sweet spot using an  
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41 automated and controlled swing motion with a robot [1921] would add valuable insight into  
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43 this enquiry, particularly when comparisons are made between amateur and professional  
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45 golfers.  
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## 50 51 CONCLUSION

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54 Different clubs generated significantly different real ear acoustical characteristics in terms of  
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56 sound pressure levels and frequency responses. On the basis of the SPLs measured in the  
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3 present study, the immediate danger of noise induced hearing loss for amateur golfers is quite  
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5 unlikely. However, it is most likely to pose a significant risk of noise induced hearing loss if  
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7 the driver generates high noise intensity greater than 116 dBA. Provision of detailed  
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9 information on a club's acoustical characteristics may help consumers choose the appropriate  
10  
11 device for their needs, particularly for people who are prone to hearing damage. A  
12  
13 longitudinal study monitoring hearing thresholds would provide a valuable insight in terms of  
14  
15 the long-term risks to hearing.  
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## 20 21 **ACKNOWLEDGMENTS**

22  
23 We would like to thank two reviewers and managing editor for their helpful suggestions. We  
24  
25 would also like to acknowledge GN Otometrics UK for providing the Freefit wireless Real Ear  
26  
27 Measurement System and technical support during the study. This work was funded by the  
28  
29 Great Britain Sasakawa Foundation (Award number: B68). Mrs Norma Meechem kindly provided  
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31 help with proof reading.  
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## 38 39 **COMPETING INTERESTS**

40  
41 There are no competing interests.  
42  
43

## 44 45 **FUNDING**

46  
47 This study was supported by the Great Britain Sasakawa Foundation (B68).  
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## 50 51 **DATA SHARING**

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53 Additional data is available by contacting authors.  
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3 CAPTIONS OF FIGURES  
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5 **Figure 1 Diagram of experimental settings and equipment used**  
6

7 **Figure 2 Scatter plot of averaged sound pressure levels (SPLs) obtained in individuals in**  
8 **the far and near ears generated by three golf drivers.**  
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10 **Figure 3 Scatter plot of averaged frequency responses obtained in individuals in the far**  
11 **and near ears generated by three golf drivers.**  
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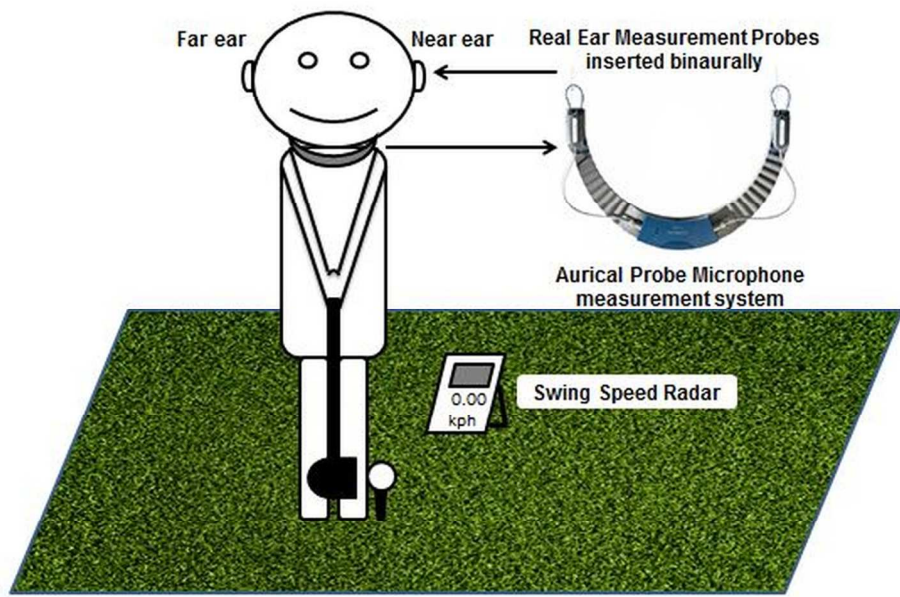
13 **Figure 4 Percentage of daily noise exposure when hitting golf balls using the drivers**  
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18 **Figure legend:**  
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21 **Arrow label (→): The percentage of daily noise exposure per basket (40 golf balls)**  
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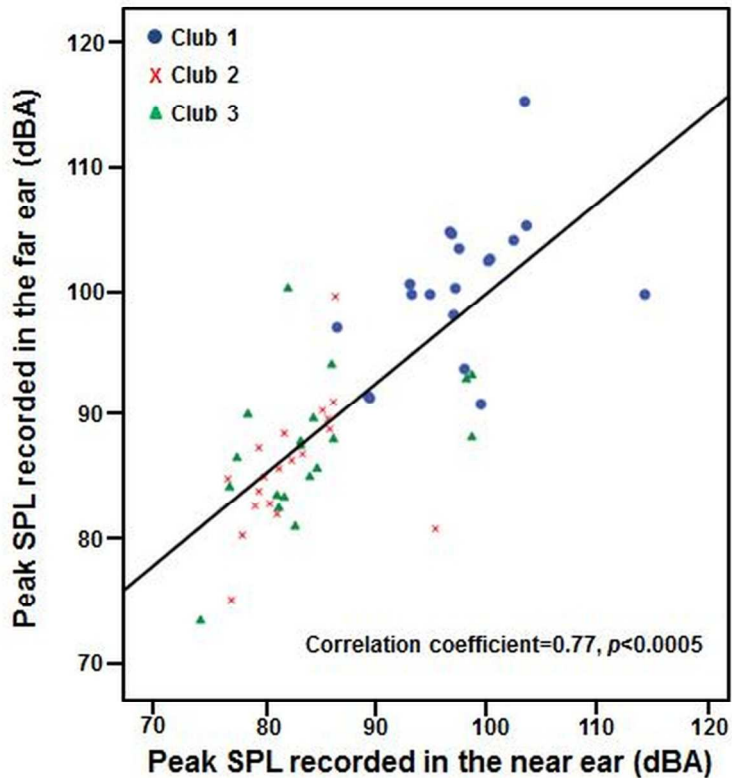
Figure 1



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Figure 2

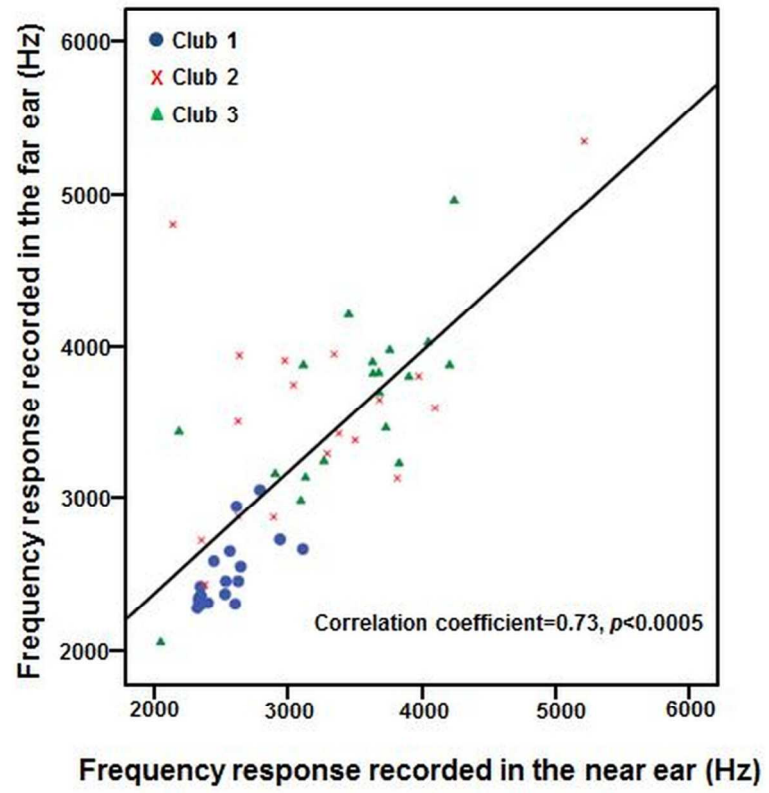


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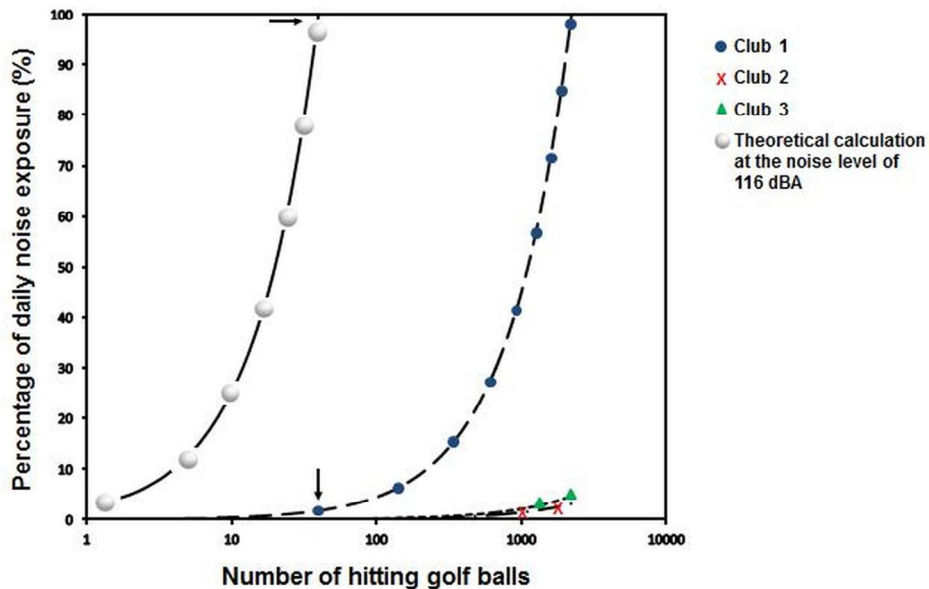
Figure 3



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Figure 4



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