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Effects of Bone-Conducted Music on Swimming performance

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Abstract

Music has been shown to be a useful adjunct for many forms of exercise, and has been observed to improve athletic performance in some settings. Nonetheless, because of the limited availability of practical applications of sound conduction in water, there are few studies of the effects of music on swimming athletes. The SwiMP3™ is a novel device that utilizes bone-conduction as a method to circumvent the obstacles to transmitting high fidelity sound in an aquatic environment. Thus, we studied the influence of music on swimming performance and enjoyment using the SwiMP3™. Twenty-four competitive swimmers participated in a randomized crossover design study in which they completed timed swimming trials with and without use of music delivered via bone-conduction with the SwiMP3™. Each participant swam four 50 meter trials and one 800 meter trial, then completed a physical enjoyment survey. Statistically significant improvements in swimming performance times were found in both the 50 meter (0.32 seconds, p=0.013) and 800 meter (6.5 seconds, p=0.031) trials with music using the SwiMP3™. There was no significant improvement in physical enjoyment with the device as measured by a validated assessment tool. Bone-conducted music appears to have a salutary influence on swimming performance in a practice environment among competitive adult swimmers.

Keywords

Exercise; swimming; music; performance; sports

Introduction

Music is a well known motivational tool that is used in recreational sports and athletic training. Improved enjoyment, particularly in repetitive endurance sports, has been reported (10), and satisfaction with music is a major enhancing influence in many participatory sports (22). Some researchers have found that music reduces the psychological stress and boredom

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of exercise routines, and improved performance times have been found in both elite and non-elite athletes (20).

There are multiple mechanisms that have been proposed to explain the beneficial effects of music on athletic performance (10). For instance, music may have dissociative properties during exercise and may offer a diversion from the muscle discomfort, generalized fatigue and shortness of breath that can accompany maximal exercise efforts. Some researchers have distinguished between an “internal focus”, where attention is directed towards the performance of complex athletic movements, and “external focus”, when attention is directed away from the effects of physical exertion (1). Research findings on the effects of attentional focus on athletic performance are mixed. Some researchers have reported benefits of an internal focus with better athletic performance (12). Still others have found that an external focus improves performance (14) and may even affect physiological performance measures, such as oxygen consumption (19).

While music has been utilized as an adjunct to many sports and exercise routines, it has had limited applications to swimming. With its low impact on weight-bearing joints and its valuable role in achieving cardiovascular fitness, swimming can be an ideal lifetime exercise. In fact, there are approximately 50 million recreational swimmers in the United States, making swimming second only to exercise walking as the nation's largest participatory recreational sport (16). Thus, the potential for music to influence performance and enjoyment for an exercise like swimming is highly desirable. And yet, because of the dearth of effective devices to transmit high fidelity sound in an aquatic environment, the effects of music on participant enjoyment and on swimming performance are unknown.

Transcutaneous bone conduction is a novel method for conducting sound in aquatic environments. The main route for the transfer of sound is through the transmission of vibratory energy on the skull to the inner ear or through cochlear excitation via skull cavity contents (7). Bone conductors can be placed at various points along the skull to transmit the vibrations, including the mastoid, temporal and frontal (forehead) bones (8).

The SwiMP3™ device (US Patent 7,310,427; Australian Patent 60/399,699; Finis, Inc., Livermore, California.) utilizes bone conduction to transmit sound (i.e., music) via ceramic plates and is suitable for use in shallow water while swimming (see Figure 1).

Because the fidelity of bone-conducted sound in an aquatic environment can approach the quality of air-conducted music, the influence of music on swimming performance could be similar to that observed in other participatory sports.

Methods

Experimental Approach to the Problem

The purpose of this study was to evaluate the effects of music conducted via the SwiMP3™ device on swimming performance and exercise enjoyment by adult competitive swimmers. The study hypotheses were that bone-conducted music would improve swimming performance times and reported exercise enjoyment in a cohort of competitive swimmers.

Subjects

There were 24 adult swimmers from two sources who participated in the study: collegiate swimmers from a Division III university team and members or swimmers practicing with a United States Masters Swim (USMS) team. Eligible participants were required to attend two consecutive swim practices at the time of the study and complete the workout designed by the USMS coach. Swimmers needed to be literate in English. Descriptive information of the participants can be found in Table 1. The average age of the 24 participating swimmers was approximately 25 years old, with a range of 18 to 48. More than 60 percent of the swimmers were female.

Although we did not assess the fitness of the subjects, most of the participants were either collegiate swimmers, or had previously been competitive swimmers in college (54%). Some were members of a USMS team (21%). Only one-fifth of the swimmers surveyed said they “swim alone” for “general fitness”. Most of the participants characterized themselves as “distance swimmers” and spent an average of approximately 8 hours a week in swimming workouts. The average number of years swimming was 11 years, but there was a wide range. The participants reported listening to music an average of 2.3 hours per day, comparable to patterns observed elsewhere in similar cohorts (21). Prior to testing, all participants signed a consent form approved by Arcadia University Institutional Review Board. The study was also approved by a Virginia Commonwealth University Institutional Review Board for the Protection of Human Subjects. Participating swimmers were introduced to the SwiMP3™ during a normal swimming workout and were permitted to swim with it in order to obtain optimal device placement. For instance, some swimmers preferred to have the device in front of the ear while others preferred behind the ear. Swimmers were given verbal instructions by the primary author of this study to load self selected music onto the device prior to the testing session. Written instructions were also available on the Finis, Inc., website (6). All swimmers downloaded their own music and no attempt was made to solicit information or explicitly determine participant preferences. Prior research has demonstrated that music chosen by the participant (i.e., “preferred music”) may have a more favorable influence on the dissociative effects during exercise than non-preferred, or randomly assigned, music choices (5,15).

Procedures

This study used a randomized, crossover design in which each swimmer was timed without the SwiMP3™ and with SwiMP3™ on consecutive workouts. Participants self-selected practice lanes, or were placed in lanes with swimmers of similar speed by their coach. For the first testing session, swimmers were randomized to swim with the SwiMP3™ device, or without it, based on random allocation to odd or even numbered swim lanes. Thus, trial sequence (i.e., whether the swimmer began with the device, or without device) was random and was tested for effects on the results through a mixed-effects model (see below). For the second session, the device assignment was reversed. Swimmers were timed by trained graduate students using an Accusplit Pro Survivor stopwatch (Livermore, CA) for 4 freestyle trials of 50 meters each. Because the swim trials were conducted in the context of usual practice routines for the participants, no attempt was made to control the circumstances of the environment or time of day. However, virtually all of the trials were conducted in the late afternoons. There was no effort to control for participant conditions (e.g., level of hydration). Moreover, since the replicated trials were conducted in random sequence, participating swimmers had similar conditioning for during swim trials with, and without, the device. Swimmers completed a warm up prior to testing for 4 freestyle trials of 50 meters each. They were given a 3-minute rest period in between trials, to allow adequate rest between sets. Times were manually recorded to one hundredth of a second on a data collection sheet and the data were later transferred to a spreadsheet. Each swimmer was given a 5:00 minute rest period before starting the single distance event, an 800 meter freestyle swim. Prior to data collection, reliability among 3 timers was tested and the intra-class correlation coefficient was .99.

Swimmers also completed the Physical Activity Enjoyment Scale (PACES) instrument after swimming with and without the SwiMP3™. The PACES is a 16-item survey that assesses enjoyment of physical exercise or leisure activity (4). The PACES includes items that are ‘positively worded’ (n=9) and those that are ‘negatively worded’ (n=7). An example for the ‘positively worded’, with reference to swimming, is: “I enjoy it”. An example for the ‘negatively worded’ is: “It frustrates me.” Each item response represented a 5 point Likert scale, from ‘Strongly Disagree’ to ‘Strongly Agree’.

Statistical analyses

For comparison of timed swimming performances with and without the SwiMP3™ device, model parameters were estimated with restricted maximum likelihood models using PROC MIXED in SAS (version 9.2). The mixed-effects model permits both fixed and random effects and allows for intra-subject correlated observations. The mixed-effects model also adjusts the test statistics for each variable according to this correlation structure. Variables can be either qualitative or quantitative. The former would be similar to an analysis of variance while the latter would be like a standard linear regression. However, the covariance parameters are what distinguishes the mixed linear model from the standard linear model. Intra-subject observations were assumed to be correlated following a compound symmetric structure – i.e., an exchangeable structure assuming the bivariate correlation is constant within a subject's measurements.

The mixed-effects model for the 50 meter sprint trials included the following variables: whether or not the SwiMP3™ device was used; the swim session (or period) observed; the trial number; the trial sequence (i.e., with, and then without; or without and then with the device); age; gender; and, whether the swimmer was on a team, or swam alone. The model for the 800 meter trials included similar variables except without the trial number, since there were only 2 trials for the 800 meter swim, with and without the SwiMP3™ device. Alpha was set at .05 with a 95% confidence interval. The PACES data were analyzed by comparing the means for the positively worded, and negatively worded, items, respectively, using the Wilcoxon Matched-Pairs Signed-Rank Test. This non-parametric test was used because the meaningfulness of the scale differences were unknown. Thus, the analysis attempted to detect trends in enjoyment differences through the signed-ranks test. The sample size was sufficient to detect a moderately large effect size (i.e., Cohen d) of approximately .75 in average PACE scores with a one-tail test of significance at the .05 level with a power of 80 percent (3).

Results

The results of the mixed-effects model testing with resulting parameter estimates and their standard errors for the 50 meter swim trials are shown in Table 2.

The intra-subject correlation was estimated to be 0.97 ($p<0.001$) which indicates the times are highly correlated across the four trials for each swimmer – i.e., those swimmers who were fastest in trial 1 tended to be the fastest in subsequent trials, and similarly for slower swimmers. A reference cell parameterization was used for the categorical variables; thus, the parameter estimates may be interpreted as increases (indicated by a positive value) or decreases (indicated by a negative value) from the ‘reference group’. The reference group was defined as the time for a 50 meter sprint with the device, 4th trial, the second sequence, male gender, and those who swam on a team. The average sprint time for the reference group as predicted at the average age (25.3 yrs) was 34.6 seconds. The swim performance times increased 0.32 seconds, on average, for the 50 meter sprints when the swimmer swam without the SwiMP3™ device, compared with the times with the device ($p=0.013$). There was not a significant period effect or sequence effect ($p=0.543$ and $p=0.494$, respectively); thus, there was no training effect from repeated testing and swimming with the SwiMP3™ device for the testing sessions. However the swimmers swam faster, on average, in trial 1 by about 0.6 seconds compared to trial 4 ($p<0.001$); and by about 0.32 seconds in trial 2 compared to trial 4 (p=0.055). Older swimmers were somewhat slower, with an increase in time of about 0.37 seconds per decade (p=0.016). Sprint times did not change significantly between swimmers on a team compared with those who swam alone. Females swam an average of 3.6 seconds lower than their male counterparts (p=0.091).

Twenty-one swimmers participated in both 800 meter trials, with and without the SwiMP3™ device. Three swimmers did not complete the 800 meter trials due to a cramp or other physical ailment. The results of the mixed-effects model testing of the SwiMP3™ device and covariates are shown in Table 3.

The intra-subject correlation was estimated to be 0.99 ($p<0.001$) indicating relatively little difference in the times within participants. A reference cell parameterization was used for the categorical variables as previously described. The reference group was defined as the 800 meter trial time with the SwiMP3™ device, the second period, second sequence, male gender, and swam on a team. As shown in the Table, the average 800 meter time without the SwiMP3™ device increased 6.5 seconds compared with swim performance with the SwiMP3™ device (p=0.031). There was not a significant period effect or sequence effect (p=0.725 and p=0.628, respectively). Performance did not change significantly between swimmers who practiced on a team were compared with those who swam alone, age of swimmer, or by gender.

The results of the participant responses on the PACE instrument are shown in Table 4. While there were modest trends for some improvement in enjoyment by swimmers with the SwiMP3™ device, none of the differences were significant.

Discussion

While music has been shown to have beneficial effects on athletic preparation and performance, previous studies of music and exercise were limited to non-aquatic environments. Using a novel swimming device, the SwiMP3™, that transmits sound via bone-conduction, this study evaluated the effects of music on swimming performance and enjoyment in highly motivated swimmers using a crossover designed randomized trial. The results indicated improved performance in both sprints and long distance swimming with bone-conducted music, similar to results in non-aquatic sports with music as an adjunct. The magnitude of improvement observed in this study of dedicated swimmers using bone-conducted music during both sprints and longer distances was comparable to other training adjuncts used to improve swim performance. For example, sodium bicarbonate, ingested by swimmers to reduce the lactate load from anaerobic glycolysis, has been shown to improve performance by similar magnitudes as the SwiMP3™ (24).

Despite the theoretical mechanics of music and its positive effect on athletic performance, application for competitive swimmers has had limited study previously. Nonetheless, music has been shown to reduce the prevalence of “non-productive” behaviors and improve the effectiveness of warm-up periods prior to swimming (9). Further, some swim coaches have used tempo ‘click’ devices to enhance the rhythm of repetitive stroke techniques. With non-aquatic sports, comparisons between simple ‘click’ rhythms and music have generated a clear preference for music as a method for creating an appropriate tempo, for instance with cycling techniques (13).

In this study, athletes were instructed how to download their own music for the sessions. Thus, swimmers were not prescribed specific types of music and no guidelines were given regarding music tempos. However, while ‘preferred music’ appears to be a better adjunct for athletic performance, the type and tempo of music used during exercise may also be influential. For example, some have suggested that music should match the type of athletic sport (e.g., repetitive movements) and intensity. Further, for aerobic exercise, some researchers have found that a gradual increase in tempo to the targeted heart rate is the ideal approach; a target of 70 percent of maximal heart rate has been suggested as the most effective motivational tempo (11). Conversely, for interval or circuit training that involve exercise performance bursts, experts have used music rhythms that alternate between faster and slower tempos, to allow for sprints followed by recovery times. Thus, the best approach for athletic preparation and training may be to allow athletes to select preferred music choices from a menu tailored toward specific practice goals.

The SwiMP3™ device did not have an effect on swimming enjoyment as measured by the PACES instrument. And yet, the application of music for exercise enjoyment and motivation is not a trivial concern. Despite the well documented beneficial effects of physical exercise and fitness on health, compliance with training programs is often poor. For instance, even though the benefits of regular exercise for individuals with coronary artery disease are well known, less than half of those with the condition are active enough to derive significant health benefits (18), and 25% to 50% of those who initiate cardiac rehabilitation programs discontinue the regimen within the first six months (2). Nonetheless, the positive influence of music on performance may have made it less likely to also observe beneficial effects on enjoyment. Novice or less dedicated athletes may be more susceptible to the motivating influence of music, but less sensitive to the dissociative, or external focus, effects. Other factors could have also influenced the observed improvements in performance. For instance, studies have demonstrated that differing expertise levels of athletes can influence exercise performance (23). Since the participants in this study were highly dedicated athletes, with an average of 11 years of swimming experience, it is unclear whether differing levels of expertise might interact with attentional focus and moderate the influence of music on performance.

There are several limitations to this study. First, we did not attempt to standardize specific tempos or types of music. It could be that swimmers, or their coaches, could coordinate the beat of the music to the desired cadence of specific swim strokes for optimal results. For a rhythmic exercise like swimming, a synchronized tempo could be a critical adjunct toward optimal performance. Second, the number of swimmers who participated in this study was small and mostly limited to competitive swimmers at the college or Masters level. Thus, the negative findings regarding enjoyment may have been a result of a Type II error since statistical power was relatively low. Third, the observed effects of music on performance in this study were conducted in practice routines. It is unclear if the improved swimming performance can be sustained if the device is used routinely. Further, while the SwiMP3™ device was carefully randomized with a crossover design, obviously the swimmers could not be blinded to the intervention. A 'Hawthorne' effect, the bias that occurs when the consequences of participant performance affect the performance itself, could explain the results (17). While a Hawthorne bias would be nearly impossible to eliminate with music as an adjunct to exercise, sustainability of the effect on performance with future studies would mitigate its relevance. Lastly, as noted, most of the participants in this study were highly fit athletes; more than half were either currently, or previously, competitive athletes. With a crossover design, each swimmer served as their own control and, therefore, levels of fitness should not have influenced the results. Nonetheless, this does limit the applicability of the results to other groups of swimmers who are more, or less, fit.

Practical Applications

This study compared swim trial times of swimmers with and without music using a novel device that delivers high fidelity, bone-conducted sound in an aquatic environment. Significant improvements in athletic performance in adult swimmers with the use of music were observed for both sprints and endurance trials. Thus, the application of bone-conducted sound could be a unique supplement to swimming exercise. Swimmers may enjoy improved performance by using music for their practice routines, and their coaches should consider using music as an adjunct to swim training regimens.

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Figure 1. The SwiMP3™ device

Table 1
Demographics of participants (n=24) in SwiMP3™ Study

Characteristic	Mean (Std. Dev)	Range
Age (years)	25.3 (9.2)	18, 48
Number Female (%)	15 (63)	
Height		
Females	164.9 cm (6.1)	
Males	179.3 cm (5.6)	
Weight		
Females	62.6 kg (8.7)	
Males	77.7 kg (8.6)	
Number of distance swimmers (%)	15 (63)	N/A
Average number of hours swimming per week*	8.2 (4.0)	(3, 20)
Average number of months swimming per year	7.3 (3.0)	(4, 12)
Number of years swimming	11.1 (7.6)	(3, 30)
Number who swim as part of a group (%)	19 (80)	N/A
Members of U.S. Masters Swimming (%)	5 (21)	N/A
Number who currently swim competitively in college, or previously did (%)	13 (54)	N/A
Average number of hours per day listening to music†	2.3 (2.0)	(1, 8)

*One study subject who reported 88 hours per week of swimming was excluded from this calculation.

†Study subject who reported listening to music 20 hours per day was excluded from this calculation.

Table 2

Parameter estimates and standard errors from the mixed-effects model for the 50 m sprint trials to evaluate the SwiMP3™ device

Effect	Parameter	Standard Error	P value
Intercept	34.6	2.51	<0.001
Device: Reference=with SwiMP3™ device	0.320	0.118	0.013
Period: Reference=period 2	-0.073	0.118	0.543
Trial*: Reference= trial 4			
1	-0.57	0.162	<0.001
2	-0.32	0.162	0.055
3	-0.23	0.162	0.170
Trial Sequence: Reference = sequence 2	-1.58	2.26	0.494
Age (centered; in decades)	3.71	1.41	0.016
Alone or Team: Reference = Team†	0.36	3.20	0.911
Gender: Reference = Male	2.33	2.14	0.290

*Trial 4 was used for reference comparisons for each of the other 3 trials

†Swim teams were used as reference group

Table 3

Parameter estimates and standard errors from the mixed-effects model for the 800 m trials to evaluate the SwiMP3™ device

Effect	Parameter	Standard Error	P value
Intercept	770.6	68.7	<0.001
Device: Reference=‘PY’	6.5	2.80	0.031
Period: Reference=period 2	-1.0	2.80	0.725
Sequence: Reference = sequence 2	-31.9	64.5	0.628
Age (centered; in decades)	73.5	42.0	0.099
Alone or Team: Reference = Team	-1.12	89.0	0.990
Gender: Reference = Male	-10.5	64.0	0.872

Table 4

Participant Responses on Physical Activity Enjoyment Enjoyment Scale (PACE) with and without the SwiMP3™ device

	Average PACE scores without SwiMP3 device	Average PACE scores with SwiMP3 device	Number of swimmers with enhanced enjoyment with SwiMP3 (n=25)*
All Swimmers	3.79	3.90	16
Males (n=9)	3.46	3.83	6
Females (n=16)	3.99	3.91	10
Age > 22 (n=10)	4.11	4.15	5
Age < 23 (n=15)	3.55	3.68	11

*p > .1, according to Wilcoxon Matched-Pairs Signed-Ranks Test, for enhanced enjoyment scores with device