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Effects of an Aqua-Titanium Necklace on Running Speed when Examined at the Individual and Group Levels

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Abstract

Results from previous evaluations of athletic wearables infused with Aqua Titanium have been mixed with respect to ergogenic effectiveness. This might be due to exclusive reliance on group designs in previous studies. The purpose of our study was to evaluate and compare the individual and group differences in responsiveness to an Aqua-Titanium necklace. Using a single-subject (reversal) design, we measured the running speed of 10 healthy adults across baseline (no necklace), test (Aqua-Titanium necklace) and placebo conditions using a 61-m indoor track. The entire sample was then considered for group analyses. Results showed that our single-subject and group analyses produced similar outcomes, and that these outcomes provided little evidence to support the ergogenic effectiveness of the Aqua-Titanium necklace.

Keywords: Aqua Titanium; single-subject design; group designs; athletic wearables; ergogenic aids

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The U.S. Department of Health and Human Services (2019) provides many recommendations to produce improvements in physical performance, fitness, and health. The recommendations range from simple, lifestyle changes (e.g., sitting less throughout the day and taking the stairs instead of the elevator), to specific guidelines regarding type and volume of exercise (e.g., achieving at least 150 min of moderate-to-vigorous activity weekly and alternating aerobic and strength training activities). Each of these recommendations has been shown empirically to improve physical health in adults, which provides support for their promotion and adoption (see Center for Disease Control and Prevention, 2018). However, each of these recommendations also requires a certain level of commitment, which some individuals find unfavorable (Richard, 2016). For example, Humpel, Owen, and Leslie (2002) and Seefeldt, Malina, and Clark (2002) noted that the absence of immediate improvements, lack of resources and time, competing responsibilities, and other environmental and personal factors can make adherence to established recommendations difficult to achieve and maintain. Under these conditions, some individuals endorse alternative strategies that claim to produce faster and more effective results, although these alternative strategies lack empirical support. A recent example is the use of ergogenic aids, which can include any technique or substance reported to give an individual a mental or physical edge while engaging in or preparing for physical activity (Fraczek, Warzecha, Tyrala, & Pieta, 2016).

A popular category of ergogenic aids is athletic wearables, which can include sports apparel (e.g., water-wicking cloth, stretch fabrics, and hydrophobic swimsuits), as well as high-tech accessories (e.g., smart watches, scales, and monitors) and low-tech accessories (e.g., tapes, bands, and necklaces). Sylvia, Bernstein, Hubbard, Keating, and Anderson (2014) hypothesized athletic wearables can provide many benefits as an ergogenic aid, such as making it easier for an individual to monitor heart rate and oxygen levels, calculate calories burned and distance traveled, and reduce body temperature and feelings of stress. Some empirical data support these assertions. For example, Sousa et al. (2014) compared cotton and water-wicking synthetic polyester shirts and found the latter kept athletes significantly cooler during physical activity, which may have allowed users to exercise for longer periods without fatigue. As another example, Støve, Haucke, Nymann, Sigudsson, and Larsen (2018) found that a wearable heart rate monitor (i.e., Garmin Forerunner 235) produced outcome measures that were accurate and reliable when compared to photoplethysmography, suggesting that the wearable could produce similar ergogenic benefits to more advanced technology, but at a lower cost to the user. Together, these data suggest that some sports apparel and high-tech accessories can potentially serve as ergogenic aids. However, research on the ergogenic effectiveness of low-tech accessories has been limited in comparison to research on sports apparel and high-tech accessories, and it is unclear whether positive results would generalize.

One producer of low-tech accessories is Phiten, which manufactures and distributes athletic wearables, such as necklaces, tapes, and other relaxation and stress-management related products. Users of Phiten’s products report marked improvements in athletic performance and recovery, pain, and general well-being, and these effects are ascribed to the Aqua Metals infused into each product (Phiten USA, 2018). Although the evidence for these effects is largely anecdotal (Foster, McLernon, & Reich 2016; Riper, 2013) and Phiten has been sued previously for making claims that their products are ergogenic aids (see Gritzner, 2011), public support for Phiten has continued to grow, and many athletes and individuals continue to use Phiten’s products as if they were ergogenic aids (Foster et al., 2016; Riper, 2013). In response, researchers across domains have become increasingly interested in the ergogenic effects of Phiten's products, specifically their low-tech accessories infused with Aqua Titanium.

Research on low-tech accessories infused with Aqua Titanium has produced mixed findings regarding ergogenic effects in three areas. With respect to physical performance and recovery, Hughes, Fink, Graham, and Rowlands (2013) reported Aqua-Titanium tape resulted in reduced stiffness in the Achilles tendon, which may improve running economy following endurance exercises. Using similar procedures, Black et al. (2018) reported some improvement in joint range-of-motion but found little evidence for an effect on physical performance. With respect to pain reduction, Nishiyama, Kino, Tsukagoshi, Tobe, and Otomo (2014) found that patches infused with Aqua Titanium reduced pain when applied daily, but Matsumoto et al. (2015) failed to replicate these results using the same Aqua-Titanium patches in a follow-up study. With respect to general well-being, Aoi et al. (2012) found that sleeping in a room containing Aqua Titanium produced lower physiological and psychological stress, but Foster et al. (2016) found that wearing necklaces infused with Aqua Titanium had no marked effect on participants' self-reported stress levels. Together, these data show some previous evaluations of Aqua-Titanium products have produced evidence of ergogenic effects, but the strength and consistency of these effects has varied considerably within and across studies.

One explanation for variability in previous findings related to Aqua Titanium could be the use of group research designs to the exclusion of other research designs. Group research designs have many benefits, such as including approaches that allow researchers to sample a large number of individuals quickly and efficiently (Price, Jhangiani, & Chiang, 2015). However, group designs also rely on mean (average) values, which can be strongly influenced by the distribution of individual scores (Aron, Coups, & Aron, 2013). For example, Wadsworth, Walmsley, and Rowlands (2010) and Rowlands, Graham, Fink, Wadsworth, and Hughes (2014) used identical methods to compare the ergogenic effects of a low-tech accessory infused with Aqua Titanium to a placebo. Wadsworth et al. found minimal evidence to support the ergogenic effects of Aqua Titanium, but noted that extremely low variability in individual scores across conditions might have potentially masked an ergogenic effect at the group level, causing a false negative result. In contrast, Rowlands et al. found substantial evidence to support the ergogenic effects of Aqua Titanium, but noted high variability in individual scores across conditions might have potentially amplified evidence of an ergogenic effect, causing a false positive result. If these authors are correct in their interpretations, then the mixture of positive and negative support for the ergogenic effects of Aqua Titanium could be explained by the breadth of individual scores across evaluations, which suggests that alternatives to group designs might be needed for further clarity.

Single-subject designs are a viable alternative to group designs for determining the effectiveness of an ergogenic aid. Single-subject designs are similar to group designs insofar as they are both quantitative approaches that attempt to establish causal relationships by manipulating an independent variable (e.g., the presence and absence of Aqua Titanium) while measuring changes in a dependent variable (e.g., running speed). In contrast to group designs, single-subject designs involve researchers repeatedly measuring a dependent variable under distinct conditions over time with each participant (Krasny-Pacini & Evans, 2018; Sidman, 1988). That is, each participant serves as his or her own control and treatment group, which allows the outcomes from each condition to be directly compared for each participant. The individual results can then be compared across participants to determine different levels of a given effect if observed, and statistical analysis can be applied to the sample as a whole, which allows for a direct comparison of individual and group scores within the same analysis (DeHart & Kaplan, 2019). In this way, single-subject designs can clarify how the effects of Aqua Titanium differ across individuals and how these differences impact group outcomes. However, no published evaluations of Aqua Titanium using single-subject designs are available for review, and so whether these designs can add to our understanding of the ergogenic effects produced by Aqua Titanium remains an empirical question.

The purpose of the current study was to extend previous evaluations of Aqua Titanium by incorporating a more fine-grained analysis of individual outcomes and subsequently comparing those individual outcomes to those obtained at the group level. Specifically, we used a single-subject (reversal) design to determine whether a low-tech accessory infused with Aqua Titanium would improve running speed compared to a placebo and in the absence of an athletic wearable. Overall outcomes were then evaluated to determine differences in running speed at the individual and group levels.

Method

Participants and Setting

Undergraduate students from a public university in Alaska were invited to participate in this study via class announcements. In contrast to group designs that focus on the generality of results to a population and therefore require larger sample sizes (i.e., 10 or more participants per group; Price et al., 2015), single-subject designs require much smaller sample sizes because these designs involve each individual serving as their own control comparison; between 1 and 10 total participants is common in single-subject research (Krasny-Pacini & Evans, 2018). Therefore, we enrolled the first 10 participants (eight females, two males) who volunteered and did not report any conditions that could limit athletic performance. Participants ranged in age from 18 to 22 years (*M* = 19.4 years), and the majority were Caucasian or White (80%), followed by Hispanic or Latinx (10%), and Asian or Pacific Islander (10%). Four participants also reported knowing about Aqua-Titanium products and having heard of their ergogenic effects prior to their participation; no participant reported believing these claims.

Sessions took place at an indoor gymnasium (30.5 m x 24.4 m) and were conducted between 10:00 am and 5:00 pm daily, with the specific time and date of each session mutually agreed upon by the research team and the participant. Each session took approximately 7 min to complete, and multiple sessions conducted in a single day were allowed provided the participant returned to their target heart rate zone between each session (see below).

Observational Materials

Running tracks. We created two running tracks by separating the gym into two 30.5 m by 12.2 m spaces using a floor-to-ceiling privacy screen that ran along the width of the gym floor. Separating the larger gym into two smaller spaces allowed us to conduct sessions with two participants simultaneously while ensuring that neither participant could see the other. On each side of the privacy screen, two orange traffic cones were placed at each end of the space to mark the track. During sessions, participants were asked to run from one traffic cone to the other and return, for a total running distance of 61 m. In this way, our track simulated the Loughborough Intermittent Shuttle Test, which has been used in previous evaluations of Aqua-Titanium products (e.g., Rowlands et al., 2014; Wadsworth et al., 2010).

Electronic timer. A smartphone or digital kitchen timer was used to collect data on running speed. All timers displayed minutes (min) and seconds (s).

Wearable heart rate monitor. A wearable Sport BP Heart Rate Monitor (Shenzhen Wo-Smart Technologies Co., LTD) was used to obtain heart rate measurements before each session. The purpose of obtaining heart rate measures was to ensure that participants returned to a target heart rate zone prior to beginning each run. The device used a Nordic nRF5182 CPU and KXT J2-1009 (PD70-01C-TR7) sensor attached to a wristband that measured the participant's pulse. Heart rate data were transmitted synchronously to a Bluetooth-enabled smartphone controlled and monitored by a member of the research team.

Aqua-Titanium necklace. We selected an Aqua-Titanium product for testing using two criteria. First, we identified the product category noted by Phiten to be the most popular on their homepage in Fall 2017. All product categories listed included low-tech accessories infused with Aqua Titanium (e.g., necklaces, tapes, headbands, bracelets, etc.). Second, we used the number of product reviews listed for each product in the category as a proxy for the number of units sold, and subsequently selected the product with the highest number of posted reviews. In this way, we selected the 45.7 cm, Navy/Dark Blue version of the Tornado Titanium Necklace (henceforth called Aqua-Titanium necklace), which consisted of two cloth necklaces infused with Aqua Titanium twisted together to form one necklace. We purchased two identical Aqua-Titanium necklaces to allow sessions with two participants to be conducted simultaneously. Aqua-Titanium necklaces were only worn during the test condition.

Placebo necklace. After our Aqua-Titanium necklace was selected, we selected a similar product to serve as a placebo during our evaluation using three criteria. First, we used the search string "fashion braided rope necklace" in Google to identify a retailer that offered braided-rope necklaces. Second, we selected the first retailer identified, which was MapOfBeauty.com. Finally, we searched through the available products listed until we found a necklace that was nearly identical to the Aqua-Titanium necklace but did not contain Aqua Titanium. In this way, we selected a 45.7 cm, Black/Azure Blue version of a Fashion Braided Rope Necklace (henceforth called Placebo necklace), which consisted of two cloth necklaces twisted together to form one necklace. We purchased two identical Placebo necklaces to allow sessions with two participants to be conducted simultaneously. Placebo necklaces were only worn during the placebo condition.

Dependent Measures and Interobserver Agreement

Running speed. Our primary dependent measure was running speed, which was defined as the number of seconds it took participants to run from one traffic cone to the other, and then return (a total of 61 m). Running speed was measured by starting and stopping a timer when the researcher said “Go” and the participant returned to the first traffic cone, respectively.

Heart rate. To ensure that each participant started each run in the same physiological state, we incorporated heart rate as a secondary measure. We recognized that heart rate as a recovery measure is limited in isolation, but when access to more advanced equipment is not available (e.g., isokinetic dynamometers and respiratory gas collection systems), heart rate has been considered an acceptable measure of recovery (Achten & Jenkendrup, 2003; Daanen, Lamberts, Kallen, Jin, & Meeteren, 2012). We also recognized that each participant’s resting heart rate would have been ideal for this purpose, but resting heart rate is best obtained immediately upon waking (MacGill, 2017). We did not have the ability to run sessions that early in the day, nor did we want to rely on participants’ self-reported resting heart rates. Thus, we determined a target heart rate zone (THZ) for each participant, and the THZ was used to increase the likelihood that participants began each session in approximately the same physiological state.

Each participant's THZ was determined in four steps. Prior to the first session, the participant was asked to sit quietly in a chair with the wearable heart rate monitor worn on the wrist of their non-dominant hand. Next, we checked the heart rate displayed every minute until stable, which we defined as two consecutive heart rate readings within 5 beats per minute (BPM) of each other. When stability was reached, we identified the target heart rate for that participant by using the higher of the last two heart rate readings. Finally, we determined the THZ for the participant by setting a range of 5 BPM around the target heart rate. For example, if a participant's initial heart rate readings were 66 and 61 BPM, we selected 66 BPM as that participant's target heart rate, and then set their THZ as 61 to 71 BPM; this participant's heart rate would need to be within this zone to begin the next session. In this way, we developed a method for approximating recovery between runs despite not having access to more advanced equipment.

Necklace identification. To determine whether participants could discriminate between the Aqua-Titanium and Placebo necklaces, we asked participants to verbally report which necklace they were wearing after each session in the test and placebo conditions. Researchers wrote down each participant's response but made no comments about the accuracy of their responses.

Interobserver agreement. We analyzed interobserver agreement (IOA) using a time-window analysis. A secondary researcher independently collected data on running speed for 20% of sessions during the baseline condition and 43% of sessions during the test and placebo conditions, which resulted in an average of 39% of sessions being evaluated for IOA with each participant (range, 33%-60% of sessions). An agreement between researchers was defined as the secondary researcher recording a running speed that was within 1 s of the running speed recorded by the primary researcher. IOA was calculated by dividing the number of agreements by the total number of agreements and disagreements, and then converting the quotient to a percentage. Agreement between researchers was 100% for the baseline and placebo conditions, and 96.2% (range, 83%-100%) for the test condition.

Procedure

Design. Ten participants independently ran 61 m during baseline, test, and placebo conditions in either an ABCBC or ACBCB reversal design (Baer, Wolf, & Risley, 1968), where A corresponds to the baseline condition (no necklace), B corresponds to the test condition (Aqua-Titanium necklace), and C corresponds to the placebo condition (Placebo necklace). Participants were assigned to the ABCBC and ACBCB reversal designs based on their participant identification number. Participants assigned an odd identification number (e.g., P1) were assigned to the ABCBC reversal design, and participants assigned an even identification number (e.g., P2) were assigned to the ACBCB reversal design. The only exceptions to this assignment process were P3 and P7 and P4 and P8 who were incorrectly assigned to the ACBCB and ABCBC reversal designs, respectively. However, each participant experienced all conditions and the lack of sequence effects observed in our results (see Results below) suggest that this error did not impact our individual or overall outcomes. Participants were unaware of which necklace contained Aqua Titanium until after the study was completed.

Baseline condition. The purpose of our baseline condition was to determine the running speed for each participant with no athletic wearable. As participants arrived for their first scheduled baseline session, they were asked to complete the informed consent form and an entrance survey designed to screen for common health-related conditions that could impact safety while running (e.g., cardiovascular disease, respiratory distress, pregnancy, or recent surgery); no such conditions were identified for any of our participants. Participants were then asked to sit in a chair, and a researcher obtained the target heart rate that would be used to identify the participant's THZ. Next, the researcher led the participant through a brief (< 2 min) series of warm-up exercises (see Figure 1) before escorting the participant to the first traffic cone. Each participant was then instructed to run from the first traffic cone to the other and return as quickly as he or she could after the researcher said "Go!". When the participant and the researcher were ready, the researcher said "Go!", started the electronic timer, and the participant ran the entire track. When the participant returned to the first traffic cone, the electronic timer was stopped, and the session was ended.

Procedures during subsequent baseline sessions were identical to those described above with two exceptions. First, the informed consent form and entrance survey were not present. Second, prior to running but before warm-up, a researcher obtained a heart rate measure to ensure the participant was within their THZ. Baseline sessions continued until running speed was stable, which we defined across all conditions as a less than or equal to 2-s difference in obtained running speed across three consecutive sessions.

Test condition. The purpose of the test condition was to determine the running speed for each participant when wearing a low-tech accessory infused with Aqua Titanium (i.e., the Aqua-Titanium necklace). Procedures during the test condition were identical to baseline procedures except participants wore the Aqua-Titanium necklace when running, and, at the end of each session, participants were asked to identify which necklace they were wearing.

Placebo condition. The purpose of the placebo condition was to determine the running speed for each participant when wearing a regular braided-rope necklace. Procedures were identical to baseline procedures except participants wore the Placebo necklace when running, and, at the end of each session, participants were asked to identify which necklace they were wearing.

Results

Figure 2 displays the running speed (in seconds) for our participants across sessions during the baseline, test, and placebo conditions. In the interpretation of single-subject designs, it is common to examine experimental effects using graphically depicted results and three considerations with respect to the obtained data: variability, level, and trend. Variability is the difference or dissimilarity of data points in a given experimental condition. Level is the relative pattern of data points across conditions, and trend is the direction of that pattern (see Sidman, 1988 for a seminal discussion of visual interpretation). For P1, P2, P5, and P9, little variation in running speed was observed across sessions, and little difference in level was observed across conditions; no trends were observed for these participants. For P6 and P8, minimal variability and trend in running speed was observed across sessions, but slight level shifts were evident during the first introduction of the placebo condition; these level shifts did not maintain across subsequent reversals. Similar shifts in running speed were observed for P3 during reversal to the test condition, and for P7 during the first introduction of the test condition, but these level shifts maintained for P3 only. For P4 and P10, moderate variability in running speed was observed across sessions and conditions, but slight level shifts were evident during the first introduction of the test (P4) and placebo (P10) conditions. These level shifts did not maintain for P10 and increased consistently in a counter-therapeutic direction across sessions and conditions for P4. In summary, the majority of our participants (P1, P2, P3, P5, P7, and P9) showed no difference in running speed across any of our conditions, and when evidence of an effect (P6, P8, and P10) was observed at the individual level, it was observed during the placebo condition and did not maintain across repeated observations.

Evaluating the ergogenic effects of Aqua Titanium has previously involved the comparison of group means across experimental and control conditions. Table 1 displays each participant's mean running speed and corresponding standard deviation (rows 1 - 10), as well as the group mean and standard deviation for each condition (bottom row). With respect to individual differences in overall effect, we observed three general patterns of responding using condition means. First, half of our participants (P1, P2, P3, P4, and P7) had the lowest average running speed during the baseline condition. Second, four of our participants (P5, P6, P8, and P10) had the lowest average running speed during sessions in which a necklace was worn, regardless of whether that necklace did (not) contain Aqua Titanium. Finally, one participant (P9) ran at a consistent speed across all sessions and conditions. Figure 3 provides a visual summary of these outcome patterns as they relate to each participant. With respect to group outcomes, similar mean running speeds were observed during baseline (M = 14.1 s; range, 11.7 s to 18.3), test (M = 14.4 s; range, 12.5 s to 18.8 s) and placebo (M = 14.3 s; range, 12.2 to 19.5 s) conditions, regardless of which condition was conducted immediately following baseline, and differences between conditions at the group level were not statistically significant (F [2, 29] = .05, p = .95). Together, these data show some variability across participants with respect to overall outcome, but mean differences in running speed across conditions were not statistically significant at the individual or group levels.

With respect to internal validity, we asked participants to verbally report to the researcher which necklace they thought they were wearing following each session in the test and placebo conditions. We found that necklace identification accuracy was at or below chance levels for all participants except P4, who correctly identified each of the necklaces (data available from the last author). We also assessed whether prior knowledge of Phiten's low-tech accessories impacted participant's running speeds during test and placebo conditions. Of the four participants who originally reported having heard of Phiten's athletic wearables (P5, P6, P8, and P10), the lowest average running speeds were observed during the test condition (P5), placebo condition (P6 and P8), or both the test and placebo conditions (P10). However, running speed across conditions was not substantially differentiated and the relationship between prior knowledge of Phiten's Aqua-Titanium products and running speed was not statistically significant (t [18] = 0.44, p = 0.33). Together, these data suggest that most of our participants could not correctly identify the Aqua-Titanium and Placebo necklaces, and that prior knowledge of similar products did not appear related to running speed.

Discussion

Low-tech accessories infused with Aqua Titanium have become increasingly popular over the past decade, but popularity has outpaced empirical study of the ergogenic effects claimed to be produced by these athletic wearables. Moreover, the limited research conducted to date has produced a mixture of positive and negative outcomes. In our evaluation, we found no substantial effect of an Aqua-Titanium necklace on running speed when compared to a placebo and baseline condition using a single-subject design. We observed some variability in mean running speeds across conditions, but these differences were not statistically significant for any individual participant, nor were these differences significant when the entire sample was considered. Overall, our outcomes showed that our single-subject and group analyses produced similar outcomes, and that these outcomes provided little evidence to support claims regarding the ergogenic effects of a low-tech accessory infused with Aqua Titanium.

To our knowledge, only four other attempts to evaluate changes in physical performance following exposure to athletic wearables infused with Aqua Titanium have been reported. Hughes et al. (2013) and Rowlands et al. (2014) reported that exposure to Aqua-Titanium treated tapes and garments improved the recovery speed and running economy of healthy adults. Wadsworth et al. (2010) and Black et al. (2018) used a similar method to examine improvements in recovery and performance with healthy adults and older adults (> 60 years) respectively, but their results suggested improvements in recovery only. We extended the results of these evaluations in several ways. First, we conducted our evaluation using a single-subject design rather than a group design, which provided a detailed account of variation in individual performance. Second, we obtained direct measures of physical performance, which have only been included in two other evaluations (Black et al., 2018; Wadsworth et al., 2010). Third, we obtained independent, repeated measurements of running speed across 15 sessions for each participant, which almost triples the number of repeated measurements per participant reported previously (i.e., 4 to 5 measurements per participant). Fourth, we obtained reliability measures to assess interobserver agreement between independent researchers recording running speed. Finally, we included group comparisons as a secondary analysis to confirm the results we obtained at the individual level, allowing for a direct evaluation of the correspondence between these two levels of analysis. By contrast, Hughes et al., Rowlands et al., Wadsworth et al., and Black et al. included group level comparisons and analyses only.

Black et al. (2018) noted that quantitative and qualitative information about improvements in physical performance and recovery are needed to further our understanding of the ergogenic effects claimed to be afforded by Aqua Titanium. Such information could be used to refine empirical inquiries in this area or help determine the general relationship between recovery and performance. We included direct measures of physical performance (running speed), but we did not include an analysis of physical recovery for two reasons. First, the important question that only a few researchers have attempted to answer (Black et al., 2018; Wadsworth et al., 2010) is whether the claimed ergogenic effects of Aqua Titanium extend to physical performance when measured directly. By contrast, several researchers (Black et al., 2018; Hughes et al., 2013; Rowlands et al., 2014; Wadsworth et al., 2010) have directly measured physical recovery. Second, we did not have access to the advanced equipment necessary to obtain valid measures of physical recovery, such as calibrated treadmills, breath-by-breath gas collection systems, and goniometers. Notably, we did use a wearable heart rate monitor to observe pulse readings prior to each session, but we used these observations solely for the purpose of determining when to begin each session, and, for this reason, we did not record heart rate data for later analysis. Nonetheless, the inclusion of physical recovery measures in addition to performance measures might be important, because it is possible that these measures might be differentially affected by athletic wearables infused with Aqua Titanium. Future researchers might consider evaluating the correspondence between physical performance and recovery, and they might do so by combining more advanced assessments of recovery with the direct measures of physical performance we modeled.

We established a standardized stability criterion for determining when to end each of the phases in our single-subject design, which is a common approach taken in single-subject research (Krasny-Pacini & Evans, 2018). We considered running speed to be stable and warrant a phase change for a given participant when a less than or equal to 2-s difference in obtained running speed was observed across three consecutive sessions. This criterion resulted in relatively short phase lengths with each of our participants, and it is possible that increasing our phase lengths could have produced different outcomes. However, a majority (90%) of our participants met our established criterion within the first three sessions of each phase with no evidence of trending, which suggests that running speed was stable in each condition. Additionally, the total number of observations we included in our evaluation ultimately matched the total number of observations included in previous group designs (e.g., Hughes et al., 2013; Wadsworth et al., 2010). Thus, the consistency of our outcomes and our ability to replicate previous findings from studies directly evaluating physical performance (i.e., Black et al., 2018; Wadsworth et al., 2010) should give confidence to future researchers who use single-subject designs with similar stability criteria to evaluate the ergogenic effects of athletic wearables.

We evaluated the effects of an Aqua-Titanium necklace in comparison to a Placebo necklace, but we did not mask or cover either necklace and researchers were not blind to the identity of each necklace. In this way, our evaluation included only a quasi-single-blind preparation, which is a limitation in comparison to previous evaluations. However, we found that only one of our participants (P4) was able to correctly identify each necklace, and that there was not a significant relationship between necklace identification and running speed at the individual or group levels. Moreover, a secondary researcher who was blind to our necklaces collected reliability data for a significant proportion of sessions, and these data were closely aligned to the running speeds obtained by the primary researchers. Together, these data suggest it is unlikely the unmasked necklaces influenced participant responding or data collection, but future researchers should consider replicating and extending our methods using a double-blind procedure with integrity measures.

If Aqua-Titanium necklaces do afford individuals an ergogenic effect, it is possible that extraneous, uncontrolled situational factors such as differences in normal patterns of activity, additional responsibilities at the time of testing, and changes in sleep, could have masked those effects in our evaluation. To our knowledge, only one other evaluation of an Aqua-Titanium necklace has been reported for comparison. Foster et al. (2016) used a double-blind group design to compare differences in self-reported stress levels following exposure to Aqua-Titanium and Placebo necklaces. Like our outcomes for running speed, Foster et al. found no significant improvement in participants' stress levels following exposure to Aqua Titanium. Together, these data do not support claims that Aqua-Titanium necklaces produce ergogenic effects. However, it is possible that our participants, like Foster et al.'s participants, could have experienced situational factors that influenced their levels of physical performance and stress levels, respectively, during the course of evaluation. Future research on Aqua-Titanium necklaces and other athletic wearables should attempt to control as many situational factors as possible prior to evaluation, because this would potentially mitigate the likelihood of these variables influencing obtained outcomes.

Beyond measurement and design, further investigation into the role of practical effects in athletic wearable research might also be warranted. Practical effects of a treatment or intervention are those effects that do not cross the threshold of statistical significance but are like those effects that do (Sidman, 1988), and these effects might impact a participant's mindset insofar as they contribute to an individual's adoption and dissemination of fads and other pseudoscientific claims (Shermer, 2002). For example, if an individual experiences an improvement in physical performance following exposure to an athletic wearable, then that experience might serve as a mental advantage that reinforces continued adoption of the athletic wearable and motivates promotion of claims regarding ergogenic effectiveness, regardless of whether the effect generalizes to other individuals or is considered statistically significant (Black et al., 2018; Matsumoto et al., 2015; Wadsworth et al., 2010). We did not inquire about participants' experiences in the current study, and so whether practical effects impacted our participants' psychological experiences, performance, or both is unknown. Researchers might consider replications of our procedures with the addition of qualitative data focused on the psychological impact of practical effects, because these data might add to our understanding of the motivation underlying claims that athletic wearables produce ergogenic effects, especially when these claims have not been supported based on statistical significance.

Compared to research on athletic wearables and physical performance, there is a notable gap in the literature with respect to individual psychological responses to athletic wearables. Our results might illuminate some avenues for future research in this area. For example, placebo and nocebo effects are beneficial and detrimental effects, respectively, produced following exposure to an inert stimulus (i.e., a pill, medicine, or procedure) that is attributed to the individual's perception of that stimulus (Beedie & Foad, 2012; Rossettini et al., 2018). We found that participants who reported knowing about Phiten's products prior to the study ran fastest during the test condition (P5), placebo condition (P6 and P8), or both the test and placebo conditions (P10) compared to baseline. We also observed increasing running speeds across sessions and conditions with the only participant (P4) who correctly identified our necklaces. Together, these data might suggest the presence of placebo and nocebo effects. However, our evaluation involved a potentially active treatment component (i.e., an Aqua-Titanium necklace), which means our ability to isolate the perceived effects of Aqua Titanium is limited. Future attempts to isolate placebo and nocebo effects with athletic wearables might be accomplished through simple comparisons of control conditions (e.g., no necklace) and placebo conditions (e.g., placebo necklace), because this approach has been used successfully to isolate these effects in evaluations of nutritional supplements (e.g., Gutirrez-Sancho et al., 2006; Porcari, Otto, Felker, Mikat, & Foster, 2006; Shephard, 1983), high-tech accessories (Kerr, 1986), and pre-competition rituals (Beedie & Foad, 2012; Brolinson, 2003; Aragon-Vargas, 1993).

Isolating perceived effects might also prove useful for expanding our understanding of how shifts in attention and verbal instructions impact the effectiveness of an athletic wearable. Rossettini et al. (2018) demonstrated that instructions to shift focus from an internal stimulus (physical movement) to an external stimulus (an apparatus) differentially affected participant performance and subjective experiences during abduction exercises that required them to push an index finger against a piston. Specifically, when participants were instructed to focus on the movement of their finger an increase in physical force and reported positive experiences was observed. In our evaluation, we instructed participants to run as fast they could along our track, but during the test and placebo conditions we specifically noted the presence of the necklaces in our instructions. If the change in our instructions from baseline to the first treatment condition functioned similarly to the change in Rossettini et al.'s instructions, then we might have inadvertently caused a change in attention from an internal focus (running speed) to an external focus (athletic wearable) across conditions, which might explain why half of our participants performed best during baseline. Moreover, simply mentioning the necklaces in our instructions could have changed some participant's overall psychological experience, because previous research has suggested that athletic wearables tend to be related to reports of positive mental states (e.g., feeling motivated and capable; Ryan et al., 2019). We are unaware of any evaluations of athletic wearables that have addressed the role of attention and verbal instructions on the presence of ergogenic effects for comparison, but researchers might consider evaluating these variables in future replications and extensions of our procedures.

Researchers might also consider more generally evaluating how personal belief in effectiveness might impact the outcomes in future evaluations of athletic wearables. Prior belief and non-belief in an effect (positive or negative) has been shown to impact a variety of behaviors, including engagement in superstitious behavior (e.g., Wann & Hackathorn, 2019), belief in false claims (e.g., Gabbert & Machado, 2020), and changes in athletic performance (e.g., Porcari et al., 2006; Rossettini et al., 2018). Four of our participants reported a prior knowledge of Aqua-Titanium products, but none of these participants reported believing in claims that these products produce ergogenic effects. Nonetheless, we obtained this information through dichotomous (Yes/No) questioning, and so the relationship between prior knowledge, type of belief, and performance is unknown. Future researchers might therefore consider expanding our findings by including interval scales to measure an individual's level of belief prior to and following evaluations of athletic wearables, which could further illuminate how personal belief might improve or hinder physical performance and subjective experience.

It is unlikely that the popularity of athletic wearables and their use as ergogenic aids will fade in the near future (Fraczek et al., 2016), and further research will be needed to bolster our understanding of the boundary conditions under which these products are effective. We did not find that an Aqua-Titanium necklace produced improvements in running speed compared to a placebo and a baseline condition. Black et al. (2018) and Wadsworth et al. (2010), and Foster et al. (2016) found similar null results with respect to physical performance and stress levels, respectively. By contrast, other researchers have demonstrated a positive effect of Aqua-Titanium with respect to improving physical recovery (e.g., Hughes et al., 2013), pain (e.g., Nishiyama et al., 2014), and general well-being (e.g., Aoi et al., 2012), and, more broadly, some promising results connecting ergogenic effects to specific sports apparel (e.g., Sousa et al., 2014) and high-tech accessories (e.g., Støve et al., 2018) have been reported. Future evaluations will be necessary to clarify these mixed findings. Given single-subject designs would provide a more fine-grained analysis of individual outcomes that can subsequently be combined and interpreted at the group level (DeHart & Kaplan, 2019), researchers might rely more heavily on these designs in conjunction with group designs and qualitative measures to understand the broad and specific physical and psychological effects of different athletic wearables.

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Table 1

Mean Running Speed and Standard Deviations for Each Participant by Condition

	Baseline		Test		Placebo	
	M	SD	*M*	SD	*M*	SD
P 1	14.67	0.58	15.00	0.00	12.17	0.29
P 2	11.67	0.58	12.50	0.00	12.17	0.29
P 3	14.00	0.00	14.33	0.29	14.17	0.29
P 4	18.33	0.58	18.83	1.04	19.50	0.50
P 5	14.00	0.00	13.83	1.04	19.50	0.50
P 6	12.67	0.58	13.17	0.29	12.50	0.00
P 7	13.00	0.00	13.83	0.29	13.33	0.29
P 8	14.00	0.00	13.67	0.29	13.50	0.00
P 9	14.00	0.00	14.00	0.00	14.00	0.00
P 10	14.67	0.58	14.33	0.58	14.33	0.29
Group	**14.10**	**1.76**	**14.35**	**1.71**	**12.72**	**4.47**

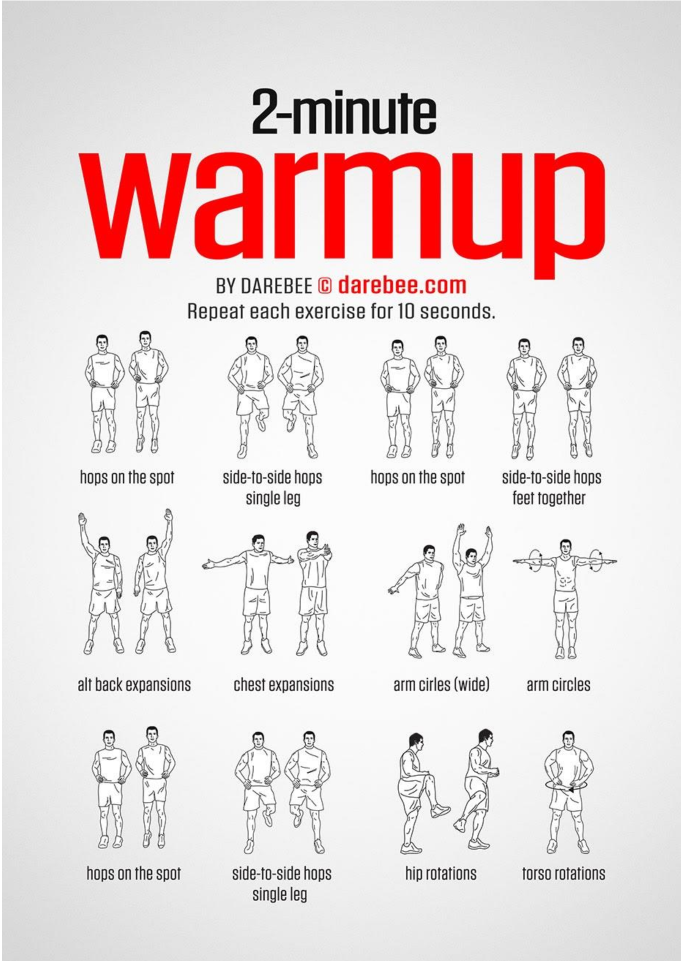

Figure 1. Before a participant could begin a trial, they would do warm-up exercises lead by the researcher. Each exercise was done for 10 seconds. Participants would start by hopping in place with both feet together, then they would hop from side-to-side, one foot at a time. Participants would then hop in place again with their feet together, then hop from side-to-side with their feet together. Participants would then alternate raising their arms over their head and then bring their arms in front of them and then apart. Participants would then rotate their arms in larger circles from their front to their back, and then smaller circles out their sides. Participants would then hop in place again with their feet together and then hop from side-to-side one foot at a time. Participants would then rotate their legs outward in a circle, then twist their body across their waist.

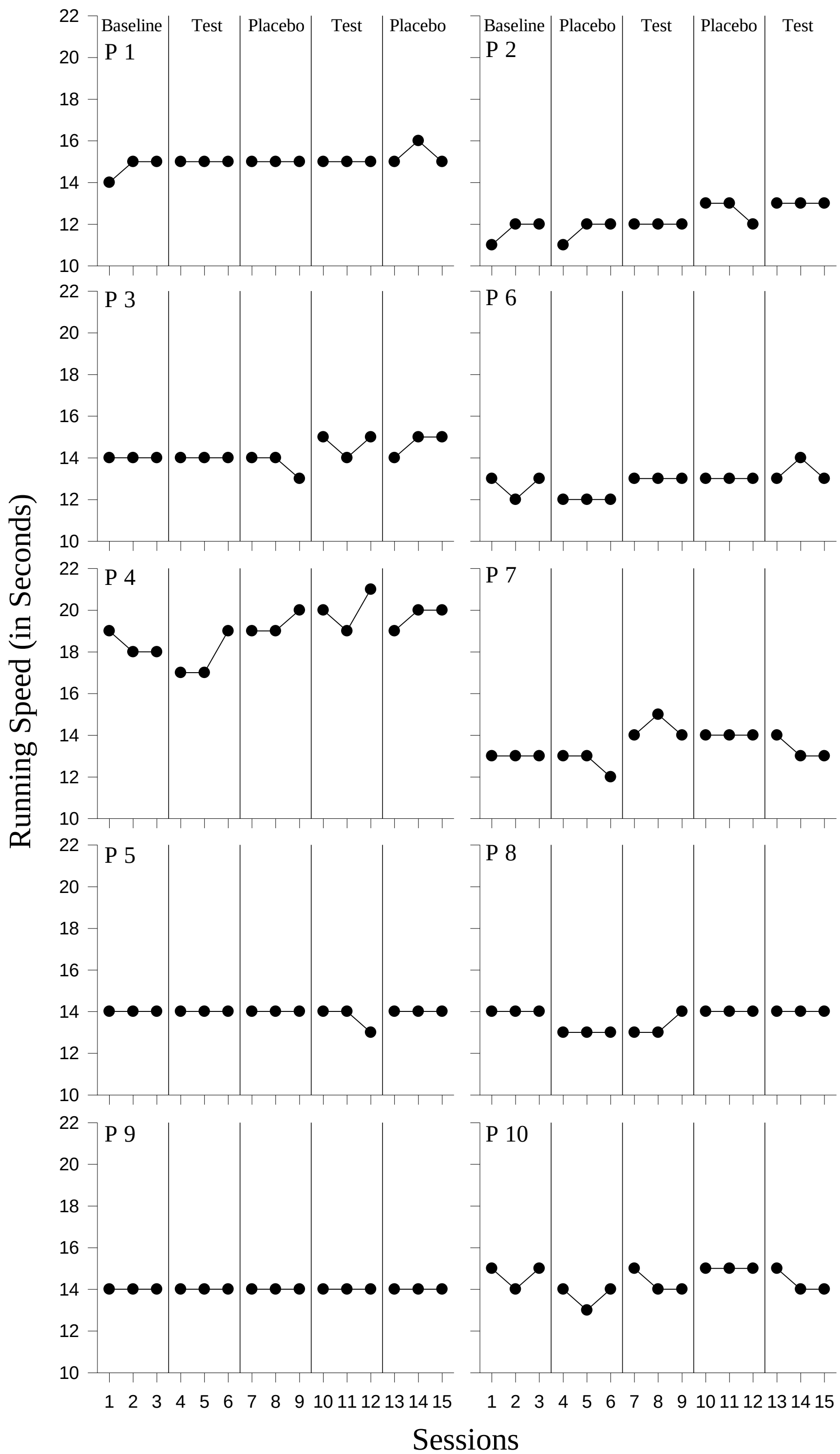

Figure 2. Running speed (in seconds) for each participant across baseline, test, and placebo conditions. Aqua-Titanium and Placebo necklaces were worn during test and placebo conditions, respectively. No necklace was present during baseline. Condition order was administered across participants in either an ABCBC (left column) or ACBCB (right column) reversal design.

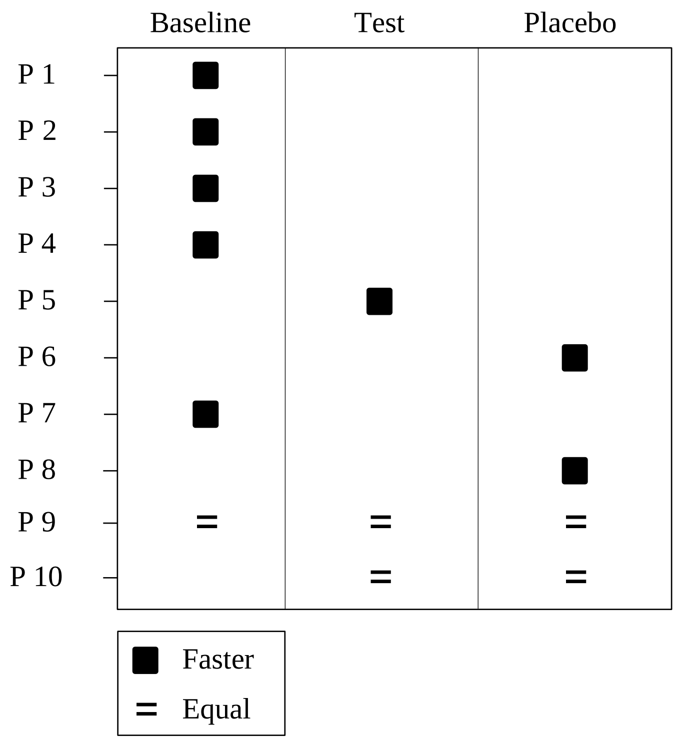

Figure 3. Participants are located on the y-axis, and the overall outcomes across baseline (column 1), test (column 2), and placebo (column 3) conditions are summarized. For each participant, a black box denotes “faster” and an equal sign denotes equal relative running speeds, respectively, across conditions.