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Retention of Golf Ball Performance Following Up to One-Year Submergence in Ponds

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Golfing is a popular but expensive sport, in part due to the cost of replacing balls lost to water hazards. Many golfers choose to purchase cheaper used balls recovered by golf ball diving companies. A prior study found reduced ball performance following extended pond submersion, but their findings may be outdated due to changes in ball technology including widespread adoption of environmentally resistant urethane-elastomer covers. We conducted a replicated experiment measuring performance of the Titleist Pro V1 golf ball following one-year submergence in permanent golf ponds, in comparison to unsubmerged control balls. We found no significant evidence of changes in either the total travel distance or carry dispersion of pond-submerged versus control balls, despite consistent changes in surface coloration following one year of pond exposure. Given the results, golfers can probably expect used golf balls to perform similarly to new balls, especially when balls have no visible discoloration.

Introduction

Golf is a popular sport in the U.S., with over 450 million rounds played per year (Golf Industry Report, 2018). One of the major costs of golfing arises from the need to replace lost golf balls. U.S.A. golfers are estimated to go through 300 million golf balls a year, greatly increasing the cost of this game (Hansson & Persson, 2012). For this reason, many golfers choose to purchase used golf balls recovered by golf ball divers and resold at lower prices than new balls (Vilorio, 2014). For golfers purchasing used golf balls, an important question is whether and to what extent golf balls lose performance following submersion in water hazards. A prior article in a popular golf magazine reported evidence of performance losses (i.e., shorter travel distances) for both two- and three-piece golf balls following up to 6 months of submersion in water hazard ponds (Farricker, 1996). Following a six-month submersion period, Farricker's (1996) experiment reported average losses of 8.2 and 15.4 m carry distances for 2-piece and 3-piece and balls, respectively. However, golf ball technology has changed significantly since this article was published (Sullivan et al., 1998; Two Guys with Balls, 2020), and to our knowledge there has been no peer-reviewed scientific assessment of golf ball performance losses following water submersion. The primary purpose of this study was to assess whether and to what extent water submersion reduces the performance of a widely used brand of modern golf ball.

There have been several changes to golf ball technology in the last several decades that might influence ball resistance to environmental degradation (Hogge et al., 2004, 2006, 2007, 2011; Ishii et al., 2015; Kim & Hwang, 1993; Sullivan et al., 1998). Perhaps the most relevant changes have been to the composition of ball covers and vapor barriers, which are thin layers designed to

protect the interior of the ball and prevent moisture from entering (Hogge et al., 2006; Ishii et al., 2015). A "two-piece" ball has a single layer surrounding the core that acts as both cover and vapor barrier, and a "three-piece" ball has two outer layers including at least one extra vapor barrier between the core and the cover (Hogge et al., 2006; Ishii et al., 2015). Farricker's (1996) paper did not specify the brands of golf ball used, but it did mention that the two-piece balls had a lithium-Surlyn cover and the three-piece balls had a Balata style cover. Balata is an older style of cover comprised of a natural latex-based compound (Rajagopalan et al., 2012; Sullivan et al., 1998); in contrast, lithium-Surlyn is a type of ionomeric resin that might be expected to be somewhat more resistant to environmental degradation (Hogge et al., 2006). Consistent with this idea, the lithium-Surlyn covered balls had less performance loss following submersion than the Balata covered balls (Farricker, 1996). Another popular vapor barrier system used in the 1990's was comprised of polyvinylidene chloride (PVDC). PVDC balls were designed to have greater resistance to water entry but were nevertheless thought to be sensitive to environmental degradation, particularly at high humidities or temperatures outside its optimal range of 25-77°C (Hogge et al., 2011).

In contrast, more recently manufactured golf balls like the popular Titleist Pro V1 have replaced older vapor barrier systems with a hard ionomer casing and a urethane elastomer cover (Rajagopalan et al., 2012). This elastomer-based cover might allow newer golf balls to resist degradation from golf games and water hazards better than the earlier generations of golf ball tested by Farricker (1996). Therefore, we hypothesized that modern golf balls should have less performance loss than reported for older ball models, because the elastomeric covers of modern golf balls should be more resistant to water penetration and environmental degradation. We tested this hypothesis by submerging Pro V1 golf balls for up to one year in water hazard ponds on the Oakland University golf course and comparing their performance characteristics to unsubmerged control balls.

A secondary goal of this project was to assess color changes to the ball surface as a possible indicator of ball submergence time and potential performance. Farricker (1996) noted visible color changes in ball surfaces following six months of pond submersion, suggesting that visual signs might be useful in estimating submergence times and potential performance characteristics of used golf balls. Furthermore, technology exists to incorporate color-changing indicators in modern golf balls, which would further enhance golfers' ability to assess how long a ball was submerged (Winskowicz, 1998). We therefore assessed changes in ball coloration throughout the experiment and tested for possible relationships between ball coloration and performance.

Methods

We selected three water hazard ponds on the Oakland University campus (Oakland County, MI), located near holes 14 & 15 of the Katke-Cousins Golf Course (Fig. 1). All three were typical of permanent man-made wetlands, each surrounded by lawn and woody vegetation and containing patches of woody

Figure 1. Map of three experimental water hazard ponds, located near holes 14 & 15 of the Katke-Cousins Golf Course at Oakland University (Rochester, MI).

Balls were deployed at the locations indicated by white X's.

debris and submergent vegetation. All three have soil profiles of silt loam or silty clay loam at shallow depths (< 30 cm) and a thick (>10 cm) layer of fine-grained organic rich sediment at 1 m depth (USDA Soil Survey, 1982). To secure the golf balls, we placed them in cages comprised of standard rubberized minnow traps, whose openings were covered with wire mesh to prevent entry by aquatic animals. To ensure ball contact with natural sediment including the possibility of microbial degradation, we sunk cages to the bottom of each pond and secured them to the bank with rope. Two cages were placed at each location indicated in Fig. 1, one in shallow water (60 cm) and one in deeper water (100 cm). The clips used to hold cages closed were later supplemented with zip ties after one cage fell open, resulting in some balls being lost (see Results). We attached HOBO Pendant® data loggers to the cages to track changes in temperature in each pond at 2-hour intervals throughout the submergence period.

Both the control balls and the pond golf balls used throughout this experiment were Titleist Pro V1 2016 golf balls. On June 30, 2017, we placed eight balls in each of twelve cages and deployed them to predetermined locations and depths in each of the three ponds (total of 4 cages per pond). During the course of the experiment, a set of control balls was stored in a dry, 21-degree Celsius room in their original packaging. Two balls were retrieved from each cage following one, three, five, and twelve months of pond submersion.

To reproduce the cleaning process a lost golf ball would undergo following retrieval by a typical golf ball diving company (A. Resnik, Golf Ball Divers LCA, personal communication), we subjected each pond-soaked ball to a standardized washing procedure. Each ball was briefly rinsed with cold tap water, soaked for 6 hours in a soapy water bath (100 mL Dawn dishwashing detergent per 4 L water), and wiped with a microfiber cloth. After the washing step, we labeled both pond-soaked and control golf balls with randomized identification numbers to create a double-blind test. We recorded the color category of each golf ball, based on an index of ball condition used by a local golf ball reclamation company (Mint, Near Mint, or Fair; described below). At the 12-month time point, we also obtained a mass measurement for each pond-soaked and control ball for comparison. We then shipped the balls to Golf Labs Incorporated (San Diego, CA) for standardized performance testing using a robot (described below). With every batch of 24 pond golf balls, we included twelve control balls to be tested along with the pond balls. At each time point, half of the control golf balls were subjected to the same washing process as the pond-soaked balls, to assess any possible effects of the washing procedure on ball performance. Control balls were labeled with their own unique random code numbers and mixed in with the pond balls prior to shipping, to ensure an unbiased test.

Ball color index

Following the washing step, we classified each pond-soaked ball according to an index of ball coloration used by a local golf ball retrieval company (A. Resnik, personal communication). Balls were photographed and classified as "Mint" (no signs of discoloration), "Near Mint" (translucent yellow color over <10% of ball surface), or "Fair" (translucent to opaque yellow color over >10% of ball surface).

Golf ball robotic testing

Balls were shipped to Golf Laboratories Incorporated (GLI: 2514 San Marcos Ave., San Diego, CA, 92104) for testing using their automated ball testing system. This company uses a proprietary computer-controlled golf ball hitting robot with a servo motor to duplicate the acceleration forces of a human golfer's swing (Parente & Dynes, 1998). They use a digital data-collection system to obtain precise measurements of golf ball performance on a grass field that simulates fairway conditions. Data is collected using internal sensors, radar-based monitors, and camera-based monitors to confirm swing characteristics, club head delivery, launch characteristics, and flight data. More details about the system are provided on the company website (https://www.golflabs.com/). For our project, the company used a Taylor Made club with a 10.5° head and Xcons-6 R Flex shaft. Before conducting any tests, they set standardized launch conditions including the club head speed, face impact position, and open or closed angle for optimum launch conditions. Once these conditions were met, robot settings were held constant until each set of measurements was concluded. Robot settings as reported by

the company were: maximum power of machine ("Amps"): 27 A; initial power as a percent of maximum amps ("initial percent"): 60%; maximum position of the club on the backswing ("release point"): 160°; club position relative to the release point where maximum power is applied ("ramp distance"): 22°; and the tilt of the machine's swing plane relative to the ground ("lie angle"): 54°. Club positions are defined in angle degrees relative to the club's starting point near the ball ("zero position"). Before testing any of the experimental golf balls, GLI staff use ten random golf balls from their own selection to evaluate whether launch conditions were consistent. GLI staff noted the identification number of each experimental ball and included this in their data spreadsheets, which also included measurements of carry distance (horizontal distance traveled through the air from the starting point to the initial landing spot), roll distance (distance traveled from the initial landing spot to the stopping point), total distance (combination of carry distance and roll distance), and carry dispersion (lateral deviation from center of the initial landing spot). To control for differences in measurement conditions between sessions, we asked the testing company to retest all Control and Pond balls from each time point within a single set of measurements, in a randomized order determined by the balls' identification numbers. GLI also retested the 1-month Control balls for comparison with Control and Pond balls from a later time point, to confirm that among-session differences in mean performance were caused by variation in test conditions, rather than actual differences in Control ball performance from one time point to the next.

Results

We obtained data from a total of 143 golf balls across four time points, including control balls present (36 golf balls per time point including controls; two balls were lost due to cages coming open between collections). Pond water temperatures varied seasonally between 0.2 and 28.0°C, with the coldest temperatures occurring in Jan–Feb and the warmest in Jun–Jul. We found no significant main effect of pond submersion on total distance traveled of experimental balls (Table 1, Fig. 2), though there was a nearly significant overall trend toward lower total distance traveled for submerged balls after accounting for differences among measurement sessions (Table 1, Fig. 2). Even if this non-significant trend represents a real pattern, pond submersion would have reduced ball performance only about 1 yard on average, or approximately 0.5% of the total distance traveled (Fig. 2). The greatest (though still non-significant) observed difference between Pond and Control balls was at the 1-month time point ($F_{1,34} = 3.9$, $P = 0.057$), with less evidence of a difference at later time points (all $P > 0.3$), suggesting that the apparent overall trend was driven by random variation in the first measurement session. There was no significant interactive effect of pond submersion and time point ("Session") on total distance traveled in the overall linear model (Table 1), indicating a lack of evidence that Pond submersion had different effects following different time periods. There were also no significant main or interactive effects of either pond submersion or time point on the carry dispersion of experimental balls,

Table 1. Linear regression results testing for main and interactive effects of pond submergence and time point ("Session") on the two primary response variables (Total distance and Carry dispersion). Each of the four test sessions represented a different period of pond submergence as shown in Fig. 2. The numerator and denominator degrees of freedom ("d.f.") are presented for each F statistic.

Response	Predictor	F	d.f.	P
Total distance	Pond submergence	2.9	1,133	0.092
	Session	113.1	3,133	< 0.001
	Pond submergence × Session	1.3	3,133	0.287
Carry dispersion	Pond submergence	0.1	1,133	0.755
	Session	0.7	3,133	0.549
	Pond submergence × Session	0.9	3,133	0.425

here defined as the absolute value of lateral deviation from the average landing point for balls within a given measurement session (Table 1, Fig. 3). Ball masses were not significantly different from control balls following 12 months submersion, based on a two-sample t-test assuming equal variances ($t_{34} = 0.78$, $P = 0.442$).

Total distance traveled varied significantly from one time point (i.e., measurement session) to the next (Fig. 2), but the average distance traveled for submerged balls was always similar to that for control balls, suggesting that these differences were caused by among-session changes in the robotic test apparatus instead of true changes in ball performance. In support of this interpretation, control balls from the 1-month time point had statistically indistinguishable performance from the 3-month set of control balls when they were re-tested in the second measurement session ($F_{1,22} = 0.8$, $P = 0.369$), despite a large change in the mean distance traveled for these balls from one session to the next (Fig. 2).

The outer layer of many balls took on a yellowish coloration following extended pond submersion, with increasing numbers of balls falling into the "Near Mint" and "Fair" color categories at later time points (Fig. 3). All Control balls remained in "Mint" condition throughout the study. All submerged balls remained in "Mint" condition through the first month, and all balls remained in the "Mint" or "Near mint" categories through the first 5 months (Fig. 3). We only observed balls in the "Fair" color category at the 12-month time point (Fig. 3). We found no relationship between the color condition of a ball and either total distance or carry dispersion, after accounting for among-session variation (Total distance: $F_{1,136} = 0.15$, $P = 0.701$; Carry dispersion: $F_{1,136} = 0.48$, $P = 0.480$). There was also no significant difference in mass between pond-soaked and control balls at the 12-month time point.

Discussion

We found no evidence of degraded golf ball performance following up to 12 months submergence in a golf pond, with no significant differences between pond and control balls in either distance traveled or carry dispersion (i.e., deviation from a straight path). As predicted, pond submerged balls did experience color changes following extended submersion in golf ponds,

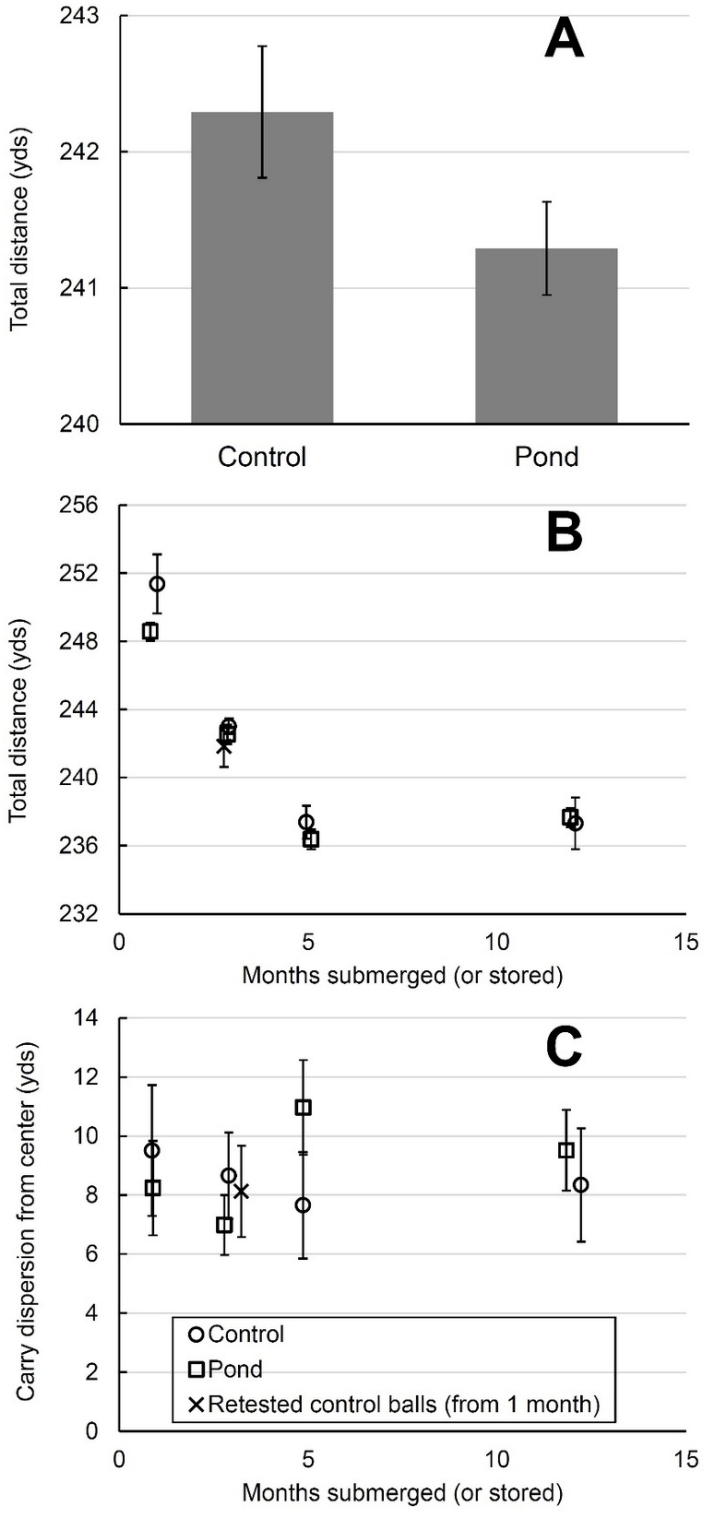

Figure 2. Overall effect of pond submergence on the total distance traveled of golf balls.

(A) Effect of pond submergence on total distance traveled by golf balls, after controlling for among-session differences (marginal least-squares means ± SE). There was a non-significant trend toward pond-submerged balls traveling a shorter distance than control balls ($P = 0.093$). (B) Total distance traveled of submerged ("Pond") versus Control balls following different periods of pond submergence (or storage of control balls), measured in yards. We observed among-session variation in the mean distance traveled, likely due to changes in equipment settings or weather from time point to time point rather than actual changes in ball performance. (C) Carry dispersion of submerged versus control balls following different periods of pond submergence (or storage of control balls). Here, "carry dispersion" refers to the absolute value of lateral deviation from the average landing point for balls from a particular measurement session. The control balls from the first test session (labeled with an "x") were re-tested in the second test session along with the 3-month Pond and Control balls. Error bars = SE.

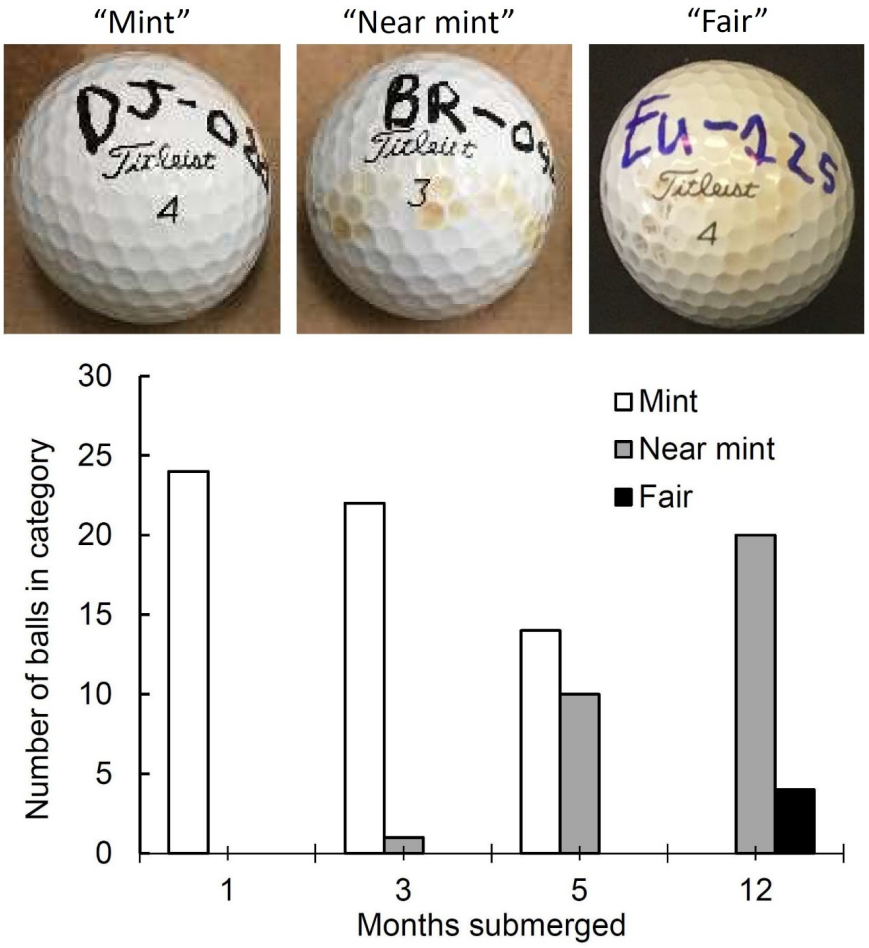

Figure 3. Changes in golf ball coloration following different periods of pond submersion, categorized as "Mint" (no signs of discoloration), "Near Mint" (translucent yellow color over <10% of ball surface), or "Fair" (translucent to opaque yellow color over >10% of ball surface).

Photographed balls are representative of each category.

suggesting that surface color is a good indicator of how long a ball has been present in a pond. However, we found no evidence of any relationship between ball discoloration and performance. Based on our results, golfers buying used ProV1 balls (and likely any ball model with a urethane elastomer cover) can be confident that used balls in the "Mint" color category have been submerged for less than one year, and that even balls in the "Fair" color category will likely have similar performance characteristics to new balls.

Our results differed substantially from those of Farricker (1996), who found significant performance losses following pond submergence despite having a shorter maximum submergence period than our study (6 mo vs. 12 mo). Farricker also did not provided variance estimates for their treatment comparisons, making it difficult to judge the strength of their conclusions. However, their mean differences were greater than observed in this study. Also, none of our golf balls came close to the level of color changes reported by Farricker for their 6-month time point, despite submerging balls for a longer period in our study. Farricker included a three-piece ball in their experiment, but these balls came from an earlier generation of golf ball, prior to the widespread adoption of elastomeric covers. These earlier balls used natural

latex or ionomeric resins in their covers, which are thought to be less resistant to environmental degradation (Hogge et al., 2006; Rajagopalan et al., 2012; Sullivan et al., 1998). This is the most likely explanation for the difference in our results, though the apparent lack of a cleaning procedure in Farricker's study, with potential effects on ball surface textures or mass, might also account for differences (Farricker, 1996).

A recent study by Weber et al. (2019) discovered substantial golf ball degradation following extended submersion in marine environments. They introduced an index of golf ball degradation ranging from "Pristine to Good" (Stage 1) to balls lacking surface dimples (Stage 4) or with exposed cores (Stage 5). None of the balls in our study would have been classified outside of their "Stage 1" index of ball condition (intact coating & lettering and no more than minor scuff marks; Weber et al., 2019). This suggests that the balls observed by Weber et al. (2019) were either exposed to environmental conditions longer than 1 year, or that the marine and riverine conditions experienced by their golf balls are substantially more destructive than the conditions experienced by balls in our study. Importantly, the pond conditions experienced by balls in our study are more representative of the typical environments from which ball retrieval companies obtain their balls than those observed by Weber et al. (2019).

The primary limitation of the current study was that we only tested a single brand of golf ball, limiting our ability to draw general conclusions. However, the Titleist Pro V1 ball (along with the recently updated version Pro V1X) is by far the most common golf ball model, commanding 28.5% of market share in 2015 (Sauerhaft, 2015). Furthermore, other models with urethane elastomer covers likely have similar levels of resistance to environmental degradation. We also observed changes in average distance traveled by golf balls in different measurement sessions, likely due to changes in environmental conditions. For example, the first test session was the only date when Golf Labs Inc. reported tailwinds during tests, and this might help account for greater mean distances for the one-month time point (Fig. 2B). We also learned that Golf Labs Inc. changed the location of their testing site between the first and second time points, possibly contributing to among-session variation. However, we were able to account for these changes statistically by including control balls in each test session and incorporating a random effect of session in our primary statistical models. Importantly, we ensured interspersion of control and pond balls within each session by mixing control and pond balls together with randomly assigned labels prior to shipment, such that the technicians at Golf Labs Inc. were unable to tell which balls came from which treatment. This allowed us to ensure that any treatment effects we might have observed were caused by the pond treatment itself, rather than random effects due to among-session variation. Another caveat is that the balls we submerged were fresh out of the box, in contrast to used balls whose covers might in principle have received damage from use. We think this would have been unlikely to change

our results unless ball covers became cracked or perforated from use; nevertheless, future studies should consider the possibility that ball use prior to submergence might result in more evidence of water damage.

In summary, our study found no evidence of degradation of Titleist Pro V1 golf ball performance following up to one-year submergence in a typical golf pond, despite consistent changes in ball coloration during this time frame. These results suggest that golfers who want to save money by purchasing reused pond balls can do so without worrying about losses in golf ball performance, especially if they purchase balls with elastomeric covers and low amounts of yellow coloration (i.e., "Mint" condition). This should be welcome news to the tens of millions of golfers with tight budgets, who may be able to afford spending more time enjoying this popular sport by playing with used golf balls.

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