Additive Manufacturing for the Design of an Adjustable Putter

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Abstract

In golf, there is use for a putter which can be customized to fit a golfer's need on a given day. By adjusting the openness of the club, known as toe-hang, the angle of the face, known as loft, and the surface material of the face of the putter which impacts the ball, a golfer's putting game can be significantly improved. By using direct metal laser sintering, a method of additive manufacturing, an adjustable putter was successfully manufactured in stainless steel. The successful print proves the feasibility of printing such a complexly designed putter head on a highly sophisticated machine, paving the way for more high stakes parts to be successfully printed. This putter is useful to golfers, performing better in percentage of shots made, skid distance, and average speed allowing for the null hypothesis that the prototype performs worse than a commercially available putter to be rejected with a 95% confidence level.

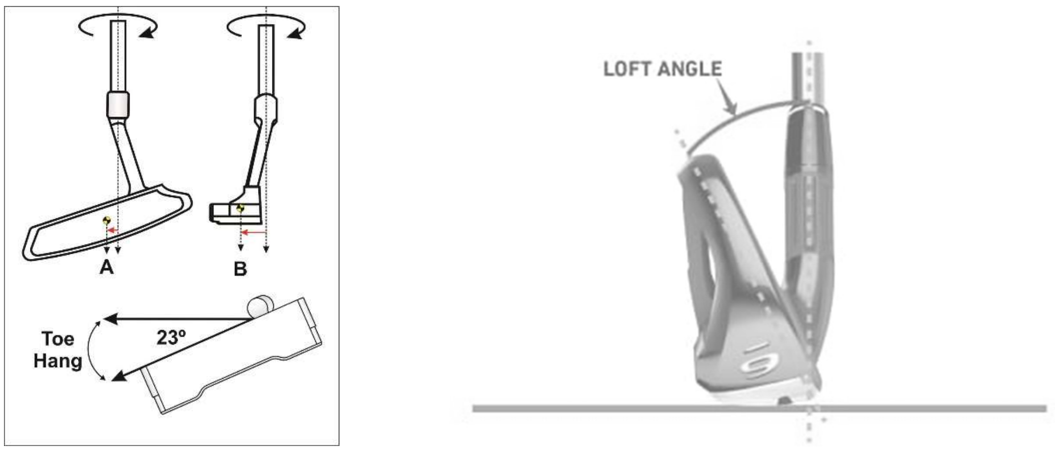
Introduction

An average golfer uses their putter for just over 40% of strokes in a round of golf [1]. During a round, golfers are allowed 14 clubs and often have a variety of drivers and irons in their bag,but tend to have just one putter. With this in mind, having a putter that is well suited to each player's game and the day's course conditions is paramount to success during the game. When a club-fitting professional fits a golfer, three common factors are addressed: toe-hang, loft, and face material.

Toe-hang addresses the degree of openness of the putter face in relation to the plane in which the golf ball lies (Fig.1). The amount of toe-hang which works best for a player is largely dependent on the arc of their swing, which can change throughout a golfer's career as they modify their putting technique [2]. A putter with 0 degrees of toe-hang is referred to as face balanced and anything greater than that is referred to as a putter with toe-hang.

When choosing a face material, there are many options ranging from metals to polymers, and most golfers choose what works for them based on "feel." Feel is largely based on the golfer's preference for the sound, feeling, and tactile experience that comes with hitting the ball and is unique to each golfer.

Lastly, loft is a somewhat standardized measure that refers to the angle of the putter face (Fig.2). Most putters are tilted upwards to provide some lift and spin to the ball [3]. The degree of loft that is best for a game typically depends on the course conditions with considerations made to the season, the type of grass being played on, the dampness of the course, and the length of the grass on the green.



Figures 1 and 2: Left, Toe-hang addresses the angle that the face rotates about the shaft of the club, while loft, depicted on the right, is the rotation of the club face relative to the vertical plane. [4, 5]

During a club fitting, one would typically need to try multiple clubs until the perfect combination of all three factors is found. However, with new advances in additive manufacturing, a putter could be designed and feasibly manufactured in a way that allows for a golfer to adjust each factor all in one club, in order to optimize the club for the day's game without having to purchase a new golf club each time one desires to try something new. This project proposes a design that utilizes direct metal laser sintering (DMLS) to create a putter which can be easily adjusted to the preferences of the golfer. DMLS is a 3D printing process which allows for lattice structures and metallic gradients to come together in one, continuous piece by using a laser to solidify metallic powder(s) into solid bodies. Using DMLS would allow a designer to create a customizable club with very specific placement of the center of mass within the club, thus allowing for the moment of inertia to be optimized to create a club which is both customizable and forgiving.

By endeavoring to use DMLS to create an adjustable putter, we are not just making golf a more enjoyable sport, but also opening the door to increased innovation in the realm of sports equipment manufacturing. With the initial design completed and the first prototype successfully printed, future semesters still hold design challenges. The printer currently used allows for bi-metallic printing, which would allow for one continuous body composed of two metals, such as aluminum and tungsten or osmium and titanium. By using two metals with drastically different densities, we increase the methods at our disposal to control the placement of the center of mass (COM) and thus manipulate the moment of inertia (MOI). However, certain metal powders can be explosive and pose other safety concerns, so they are not yet an option that can be feasibly used at Georgia Tech.

By using new manufacturing methods to better engineer a fairly well understood system, we can gain a better understanding of the limitations and advantages of these methods and apply this new information less understood systems. As we study the effect and benefits of using DMLS on putting, we can better understand the impacts of lattice structures and metallic gradients on vibration properties and other mechanical properties. This knowledge can then be expanded to the understanding of how physical parts used in other industries, such as the aerospace industry, can be expected to perform and the qualities that we expect to find in such things as rocket and airplane components. To accomplish this, future acoustics modeling is expected to be done in collaboration with the Mechanical Engineering department at Georgia Tech.

Literature Review

Each golfer, whether professional or casual, should have a putter that is suited to both the player and the course that they are playing on. With the advent of additive manufacturing, this is becoming increasingly feasible. By studying the performance of golfers using a variety of clubs, it has been found that fitting a player with an individualized club to optimize their swing is paramount to a player's putting performance [6]. By using additive manufacturing (AM) technologies such as DMLS which use a laser to solidify metal powder into 3D printed parts, our project aims to create a putter that can be customized for the user's loft, toe-hang, and face surface preferences and is accessible to both casual and professional golfers.

When a product is designed, the end-user should always be at the forefront of the process. As such, our decision to adjust each of these three variables comes from consultation with members of the Professional Golfer's Association (PGA) who specialize in fitting individuals with golf clubs in addition to PGA members who are actively involved in tournament play [2]. All of the factors that they suggested, such as the impact of toe-hang, face surface, and loft, arise repeatedly in literature, showcasing the importance of these measures in increasing the forgivability (ability of the golf club to compensate for a bad swing), and thus the usability, of a putter [3, 7, 8].

Each golfer has their own unique way of swinging a putter, with differing amounts of arc. These differences are usually accounted for by using a club with toe-hang. In the literature investigating the relationship between golfer applied kinetics and the impact of toe-hang the assertion is made that a face-balanced putter is best for making impact with the ball towards the toe, while a putter with a degree of toe-hang is best for making impact with the ball closer to the heel of the club [8]. From this, one can determine that as a golfer's swing changes, so does the degree of toe-hang which best supports the desired impact of the clubhead on the ball. Thus arises our work to create a singular golf club which can be tuned to the specific needs of a player at any given time without permanent structural alteration.

The second factor of interest is the surface properties of the clubface when it makes impact with the ball. While material choice for the putter face is important, most research is centered around the texture of the face. Brouillette, having controlled for the mass of the club and altering only the texture of the face, concluded that while grooves and patterns on the face reduce skidding (thus increasing ball control), they also have an impact on putt length. However, when distance is normalized, the grooves have no discernable impact on skid length [7]. While this research is interesting, putts during a round will naturally all be of varying lengths. Because of this, it is still unknown if it is better for a golfer to have a shorter putt with the ball spending less time skidding resulting from the addition of grooves to a face, or if it is better to have a longer putt with higher rotational speed and a longer time spent with the ball skidding resulting from a smooth face.

In more recent research, the question of optimal ball rotation and motion is indirectly investigated by examining the effects of a varied groove pattern on forgiveness of the putter. A forgivable putter is a highly desirable trait, as every shot is not always hit in the sweet spot of the club. After looking at the effects of variable milling (varied grooves cut into the face), it was determined that a milling pattern customized to the mass distribution properties of the club head itself make a club more forgiving, as it slows down the ball when coming off of a mishit, minimizing the effects of the hit on the overall putting game [9]. While this agrees with prior assertions that milling and other face patterns decrease the speed of the ball off the club, it goes beyond previous work by deeming milling to be a favorable feature, as most golfers can benefit from a forgiving face.

With this knowledge, it is clear that determining a texture for the face of the putter being developed will make it more appealing to players regardless of their skill. Working from the literature, there is a solid baseline of the process for determining what this varied milling should look like depending on other mass properties of the club, but the specific pattern is dependent on the club. Because of this, it is yet to be determined what this pattern looks like for a club with a variety of features which can be adjusted to the user's preferences. As our research progresses, this is one of the many questions we will need to investigate in order to develop a top-of-the-line putter.

Of the factors being considered, loft is the most likely to change often because of its dependance on course conditions on a given day. Because of this, a golfer should be able to adjust the loft of a club without having to be fitted for an entirely new putter [2]. The effect of loft is generally quantified by roll ratio in the same way that the effect of putter face surfaces is quantified. The roll ratio describes the ratio of vertical spin induced peripheral speed of the ball to the translational speed of the ball. For most putters this is a negative number which is indicative of backspin. Backspin results in skidding which is a less controlled motion as discussed previously [7]. However, by combining vertical gear effect (Fig.4) and oblique impact (Fig.5), topspin can be produced which is favorable to putt control.

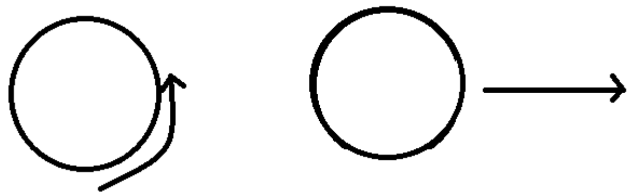


Figure 3: Roll ratio describes the ratio of peripheral speed caused by vertical spin to translational speed of the ball.

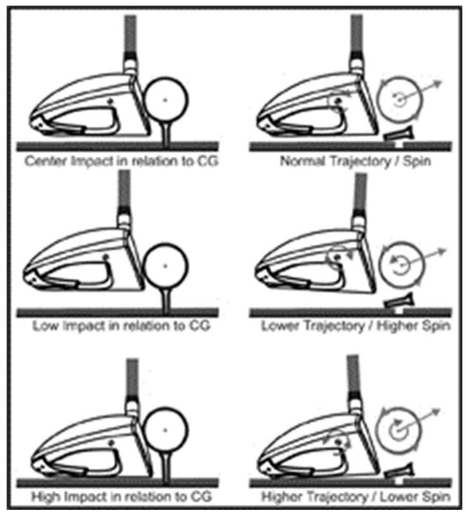


Figure 4: An explanation of the impact of vertical gear effect shows that it is impacted by the relative position of the COM of the club to the COM of the ball [10]

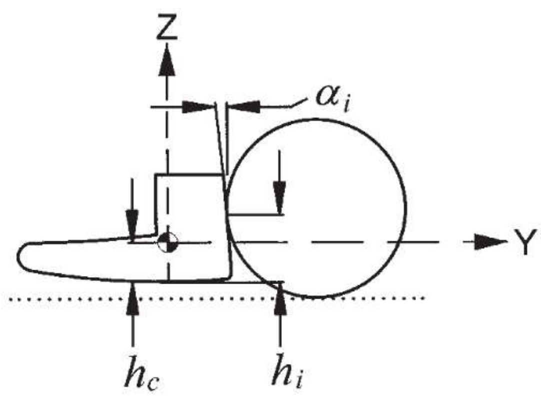


Figure 5: Oblique impact is a function of the angle between the club face and the ball, known as the obliqueness angle [3]

While vertical gear effect has a larger impact on roll ratio, oblique impact is determined by the loft of the putter. By lofting the clubface downwards instead of upwards, one imparts some topspin on the ball, but also drives it into the ground which can be combated by only contacting the ball when the putter is on the upswing, lifting the ball into the air [3]. In theory, this is a useful concept, but it can be difficult to have a golfer adjust their swing in order to contact the ball at the right moment. We aim to give the golfer the opportunity to adjust the loft by easily adding, removing, or flipping a faceplate, so they can experiment incrementally with the effects of both positive and negative loft, based not only on course conditions, but also on the kinetics of their swing.

To be successful in this design, it must have all of the features previously discussed with reasonable mass properties while still confirming to the USGA and R&A regulations for clubs [11]. For this project, we propose that the clubhead is manufactured using a 3D printer which creates metallic parts using DMLS. One of the advantages of this is the ability to create a semi-porous clubhead by creating lattice structures in the main body. By controlling the porosity of the lattice, we can target a specific mass, control the placement of the COM, and impact the moment of inertia (MOI).

In multiple proposed methods for mathematically modeling roll ratio and ball kinetics, the mass properties of the putters play a significant role. Lindsay proposes three design criteria for maximizing vertical gear effect and topspin in putters, centered around low placement of MOI, low COM, and a COM far back from the face of the putter [3]. One strategy for controlling these properties is to leverage functionally graded porosity (FGP) which can be used as a way to vary the density of material throughout a solid body.

This principle of using FGP to control mass properties is approximately 10 years old, but not studied in-depth for putters [12]. Current work focuses largely on a related AM technique, electron beam melting, for use in irons and drivers, with an emphasis on modeling coefficient of restitution (COR) which is one of the key governing metrics of the game [12]. This is useful because it provides a method to model interactions before manufacturing a prototype, as most metallic AM methods are generally expensive and time-consuming. From these, we can calculate and adjust the mass of the clubhead and calculate the effects of different FGPs on proposed designs. In order to do this, the given models would need to be altered. They currently do not account for the proposed material being stainless steel, nor are they specific to the kinematics of putters. On the other hand, it does provide solid footing for further research on the crossroads of golf and AM, with models which can be adapted to model the properties of our novel club design.

When most golfers are asked what they look for in a club, they tend to respond with a vague answer about how it simply “feels right” [2]. This proves to be an issue in golf club design, as it is difficult to quantify a feeling or set clear design goals for an abstract feeling. When previous work has been done to quantify the relationship between perceived feel and sound, the conclusions drawn were largely in relation to ball qualities and even then, the researchers admitted that the relationships are “complex and need further investigation” [13]. From this, we can determine that attempting to qualify the validity of a new putter design based on feel would not be a valid approach.

Ideally, a novel design that incorporates multiple degrees of customization would result in just as much, if not better, ball control and just as many, successful putts as one would expect from a putter that is currently on the market. In order to compare the results of using a novel putter to the results with a commercially available putter, one could adopt a strategy of testing using metrics obtained with SAM PuttLab [14]. This technology is available at most fitting centers and golf academies and for the purpose of this project, is readily available at Bobby Jones Golf Course.

In order to develop a methodology for collecting the data and analyzing it, the work of Sherwin et. al proposes a detailed methodology for comparing the performance of two putters and analyzing the resulting data. In this experiment, course conditions are accounted for and the experiment is adjusted for as many human factors as possible [14]. By designing an experiment which both uses humans and accounts for human error, this is far more comparable to typical game conditions than many of the current proposed equations and models, which fail to account for factors such as friction on the green and an assumed skill level of the player [7].

With all of this in mind, it is clear that there is a great deal to be gained by our proposed work on the design and manufacture of a singular putter that can adapt to the needs of the player and the conditions of the course. By combining a large body of scientific knowledge with the practical experience of PGA professionals, concepts which address toe-hang, topspin, face surface texture, and ideal mass properties, we expect to design a singular putter which maximizes each design input to create a putter that elevates the putting game of golfers regardless of skill. All this is possible with the rise of new additive manufacturing technology, which we plan to use to prototype and produce this design. By using DMLS, which allows for FGP through the introduction of lattice structures to the putter head, we expect to bring quantitative improvement, results, and value to both recreational and professional golfers.

Materials and Methods

Our goal was to successfully create a first prototype in metal using DMLS. To accomplish this, we have four major tasks: ensure the manufacturability of the design, verify the functionality of the design, manufacture the clubhead and associated components, and evaluate the performance of the club.

The design for the club was initially created in Solidworks. Here, we were able to specify the material and model mass properties, and make a few structural changes to minimize the amount of supports which the clubhead required for printing. Materialise Magics was used to modify the original Solidworks design, creating a honeycomb structure which reduces the mass of the clubhead and thus the amount of material needed (Fig.6).

Figure 6: On the left is the printed prototype with the honeycomb pattern, as compared to a solid body prototype seen on the right.

The most complicated and crucial element of the design is a rectangular channel in the top of the club which is where the shaft connects to the clubhead, which allows for the adjustment of toe-hang (Fig.7). After redesigning the shape to be optimized for 3D printing (Fig.8), the size had to be adjusted to ensure that the nut would slide easily into the channel to be attached to the shaft. In order to verify the channel was the right size before printing the entire clubhead, the channel itself was 3D printed in a few iterations before being finalized in the overall design (Fig.9).

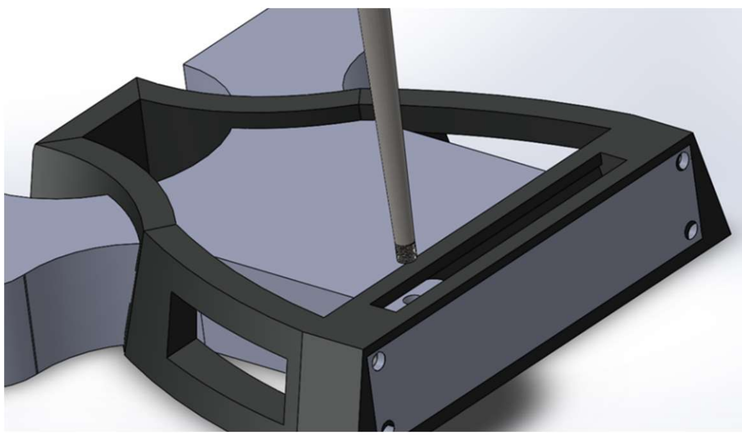


Figure 7: The design for the shaft attachment channel

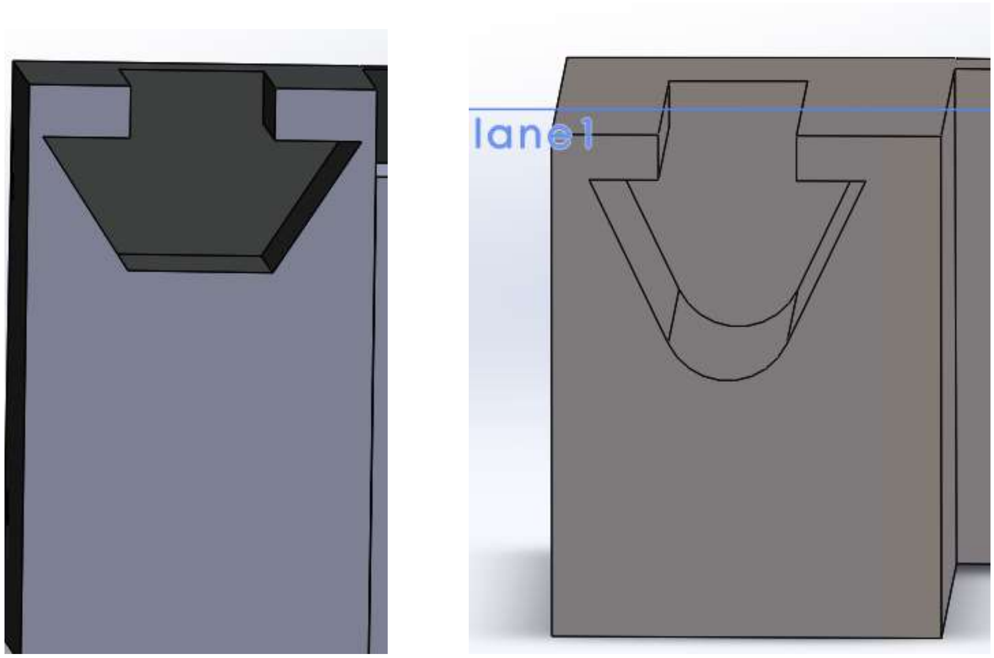


Figure 8: The original design (left) as compared to the update design, optimized for 3D printing

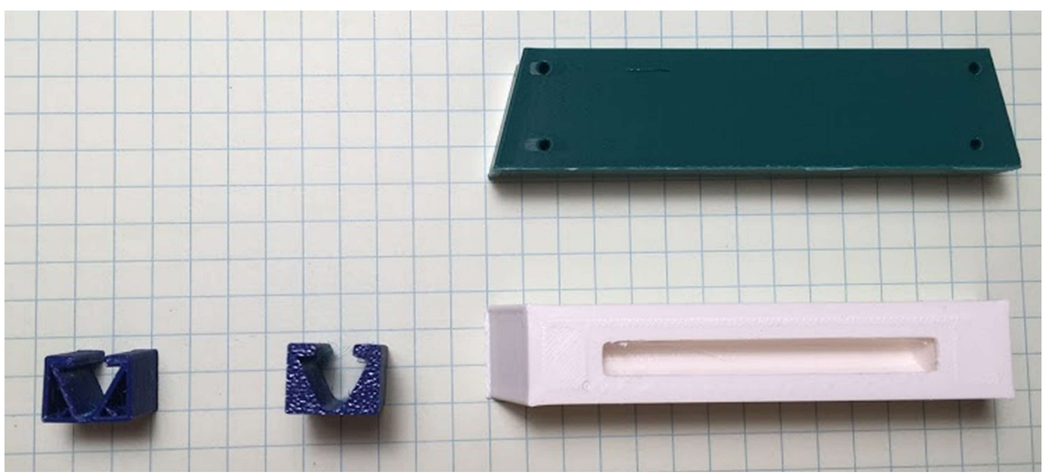


Figure 9: The progression of 3D prints made to test the size of the attachment channel.

With the design finalized, it was successfully printed in 316L stainless steel on an EOS M 280 printer in the Advanced Manufacturing Pilot Facility (Fig.10). Following printing, the clubhead was removed from the printing plate using a bandsaw and the supports were removed using a Dremel. Polymer face plates which allow for the golfer to select the desired degree of loft were designed in Solidworks and manufactured by Carbon3D in RPU130 (Fig.11). A custom shaft to attach to the club was created by epoxying a screw onto the point of a club shaft (Fig.12).

Figure 10: Top, side, and bottom views of the clubhead

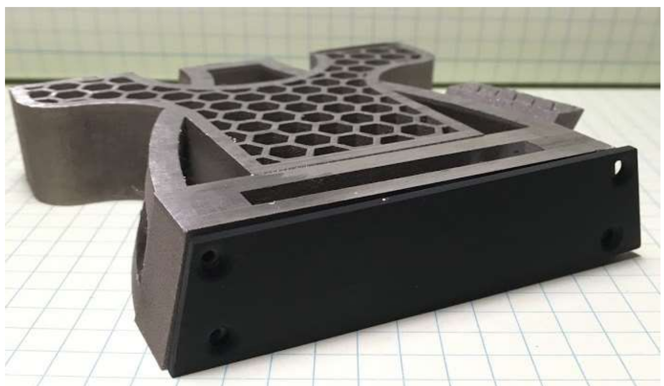


Figure 11: The clubhead with a Carbon3D Faceplate

Figure 12: The shaft, unattached (left) and attached to the club head (right)

With the design completed and the initial prototype fully manufactured, the validity of the design must be tested. We expected to verify there is no negative, significant performance of the novel club design when compared to commercially available putters.

For this non-blinded, non-randomized proposed study, data will primarily be collected at Bobby Jones Golf Course in Atlanta, GA. A sample of 14 regular golfers with handicaps between

-25 and 5 completed a series of 15 putts with a commercially available putter and the novel putter from 8 feet. For the trials with the novel putter, loft was set to 3 degrees with a polymeric face. Subjects were asked to putt 5 times with the putter set to a face balanced setting, 5 times with a toe-hang of 20 degrees, and 5 times with a toe-hang of 40 degrees. Data was collected and reported by the SAM PuttLab. The player's handicap, total face rotation, face rotation inside 10cm, and path arc was recorded for both the player's personal, commercial putter as well as for all three settings of the novel putter.

Participants were recruited via word of mouth. Participants must be at least 18 years of age. Three skill level groups will be tested: GHIN handicaps less than 0, between 0 and 10, and between 10 and 20, and above 20. If a participant has experienced injury in the last month, they will be excluded from the study, as to prevent further injury. Clearance from the Georgia Tech IRB was granted before the start of the study, and participants were informed of the risks, and signed waivers acknowledging the terms of the study.

To control environmental conditions, the testing was carried out inside the Grand Slam Academy at the Bobby Jones Golf Course on flat, artificial turf. Distance from the hole was indicated by marking the green to ensure a consistent starting point for each putt. Additionally, the SAM PuttLab base unit was positioned 0.5m perpendicular to the starting tee and the triplet unit was attached to the putter to transmit data. Putts were lined up with the hole to control for any variance due to aim. Participants were encouraged to bring their own putter for the baseline data, but one was on hand for anyone who is unable to bring their own. For data collection, Titleist practice balls will be used and data will be captured by a SAM PuttLab unit. Data was relayed to a laptop computer connected to the unit.

Participants were allowed an unlimited number of putts to warm up. The triplet transmitting device used for the PuttLab was attached to the club before it is given to the participant. The participant was then be asked to attempt to putt the ball into the hole from the set distance 15 times using their personal, commercial putter, then given the other club, and asked to complete 5 putts with each of the toe-hang settings. Data was analyzed using a paired T-test with a 95% confidence level.

Results

Data for total face rotation (degrees), face rotation withing 10cm of impacting the ball (degrees), and path arc (degrees/m) was recorded and averaged for the 15 commercial putts and each of the three toe-hang settings. The data for each subject's personal putter was compared to the novel putter with a toe-hang setting as close to the personal putter as possible (Fig. 13). For example, a subject with a putter with 8 degrees of toe-hang has personal putter data compared to the face balanced novel putter.

Face Rotation Inside 10cm		Total Face Rotation		Path Arc	
Personal	Closest to Personal	Personal	Closest to Personal	Personal	Closest to Personal
-4.6	-4.6	-8.7	-6.3	17.9	15
-1.4	-1.3	-2.2	-2.9	25.9	22.2
-1.7	-1.6	-8.4	-9.2	2.2	6.2
-2.4	-2.8	-4.7	-4.8	24.6	23.2
-0.8	-1.4	-3.7	-6	-0.1	-1.5
4.2	3.4	1	-1.4	-9.2	-6.5
-7	-6.3	-17.1	-6.3	11.1	15.1
-3.1	-1.9	-12.9	-7.9	12.3	13.9
-5.1	-4.7	-14.6	-17.6	-24	-13.6
-4.6	-4.9	-17.1	-15.5	13.7	18.1
-4.4	-4.6	-18.6	-16.6	-9	-3.3
-5.6	-5.1	-19.6	-21.2	10.4	6.8
-6.1	-7.3	-18	-23	10.8	9.6
-6.6	-5.2	-13.5	-6.3	8	10.9

Figure 13: Data tables for average face rotation within 10cm of impact (given in degrees), total face rotation (given in degrees), and path arc (given in degrees/m).

Paired two-tailed T-tests were done for each measure with no assumed variance and a confidence level of 95%. For each test, the null hypothesis is unable to be rejected. There is no significant difference between the rotation dynamics of the commerically available putter and the novel putter.

Discussion

The results of the first print indicate that the club printed successfully and according to design specifications, indicating that the printer can handle larger prints, as this was the largest print to date on this printer at the AMPF. There are some small gaps and protrusions present in the metal prototype which are not visible in the PLA prototype. From this, we can conclude they are the result of the metallic printing process or an issue in the design which caused gaps too small to be seen in the PLA. These deformities could be due to faults in the initial Solidworks design, as they occur in areas where two bodies were digitally joined. In order to address this, the Solidworks design will be re-analyzed for any faulty junctions which are not fully bonded. From initial observation, these deformities are not structurally significant and thus, the print can be deemed overall successful in producing a workable prototype with which design testing and analysis can be carried out.

The results from prototype performance testing indicate that there is no significant difference between the printed prototype and a commercially available putter, so we are able to unable to reject the null hypothesis with a 95% confidence level that the prototype performs with the same rotation dynamics as a commercially available putter. This indicates that the novel putter is comparable to a commercial putter and can be successfully adjusted to fit an individual golfer.

In considering the limitations of this study, the sample size is limited due to COVID-19, so future work includes further testing to increase the significance of the results. Additionally, the participants recruited have a large variety of skill levels. This can impact study results, as less experienced putters are more likely to have inconsistent, unrepeatable putts and by contrast professional golfers are more likely to have an extremely consistent putt, with both groups exhibiting these characteristics regardless of the putter configuration. This could be controlled for by larger samples within skill level blocks, allowing for the effect of experience to be more closely considered.

Conclusion

After designing and testing, it is clearly feasible to manufacture a putter which adjusts for loft, toe-hang, and face material by using DMLS. This putter is also usable on the course, with the null hypothesis that the prototype under performs when compared to a commercial putter unable to be rejected with a 95% confidence level. By printing the putter head, we successfully demonstrated that DMLS can be used at Georgia Tech to create stand-alone parts, expanding on the proven capabilities for the printer used. This lays the groundwork for future putter heads to be printed with a bimetallic gradient, which can then be used as a foundation for printing higher stakes parts, such as airplane components or satellite parts. On a smaller scale, this signifies the feasibility of introducing a high-tech, custom putter into the golf industry, which could improve the quality of game for golfers of all skill levels. While there is still much work to be done in understanding how smaller design details impact the performance of a club, this proof of concept is promising in demonstrating advancements both in the world of golf and in the world of additive manufacturing.

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