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# Influence of Grip Mass on Driving Performance †

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**Abstract:** The purpose of the study was to determine the influence of grip mass on driver clubhead kinematics at impact as well as the resulting kinematics of the golf ball. Three club mass conditions (275, 325, and 375 g) were tested by 40 experienced golfers (handicap = 7.5 ± 5.3) representing a range of clubhead speeds (36 to 54 m/s). Each participant executed 12 drives per condition using matched grips and shafts and a single clubhead. Club mass was modified by inserting 50 g and 100 g into the grips of the two heavier conditions. The heaviest condition was associated with the slowest clubhead speed ($p$ = 0.018) and highest vertical launch ($p$ = 0.002), which resulted in no net influence on driving distance ($p$ = 0.91). Lateral dispersion was greatest with the 325 g condition ($p$ = 0.017), as was horizontal impact spot variability on the driver face ($p$ = 0.031). Findings at the individual golfer level were not reliable enough to suggest that grip mass could be effectively used in a fitting environment to either shift ball flight tendencies or improve consistency.

**Keywords:** golf; driving; grip mass; performance

## 1. Introduction

All else equal, more clubhead speed means increased driving distance, and the inertia of the striking implement has been shown to have a meaningful influence on the maximum speed that can be generated [1,2]. More recently, and specific to golf, [3] found that increasing clubhead mass by 26 g resulted in a significant and meaningful decrease in clubhead speed (~2.7 mph). However, adding mass to the clubhead will influence both the golfer's swing mechanics as well as clubhead–ball dynamics during impact. This was evident in the findings of [3], as the differences in clubhead speed were inconsequential to carry distance since the increased clubhead mass was also associated with a significantly higher smash factor (increased mechanical energy transfer to the ball). Adding mass to the grip (or upper portion of shaft) will influence swing mechanics and clubhead delivery, but not impact dynamics. Given the small duration of impact (~0.00045 s), only the mass of the clubhead and bottom portion of the shaft play a role during impact [4]. Twelve golfers were recruited to investigate the influence of adding 22 g of mass to the driver at a distance of 355 mm from the butt of the grip [5]. On average, they found no difference in clubhead speed. At the individual level, only a single participant generated a significantly slower clubhead speed with the heavier shaft. Interestingly, the only other significant difference was achieved by a participant that swung the heavier club faster. It is possible that the addition of only 22 g at that point on the club was not sufficient to exhibit a meaningful influence on a majority of the golfing population. This study focused solely on clubhead speed and did not report on other outcome variables, such as accuracy [5].

Club mass might also influence dispersion—the variance in the finish location of the golf ball. There is anecdotal commentary on the PGA Tour, which implies that heavier golf clubs can be swung more consistently [6], resulting in tighter dispersions. This notion is supported by research demonstrating that rods with higher moments of inertia were swung in a more consistent manner [7]. Furthermore, [3] showed a trend of decreasing lateral variability with increases in clubhead mass, as well as a tendency for faster swing speed players to drive more consistently with a heavier clubhead. There is no published research isolating the effect of grip mass on swing mechanics, clubhead delivery kinematics, and the resulting ball trajectory. Therefore, the purpose of this study was to investigate the influence of grip mass on swing kinematics and ball flight.

## 2. Methods

### 2.1. Participants and Procedures

Forty right-handed, low-handicap golfers (handicap: 7.5 ± 5.3; height: 1.78 ± 0.1 m; mass: 84.3 ± 11.9 kg) volunteered to participate. The study was approved by the University's Research Ethics Board, and testing procedures, risks, and the amount of time required were fully explained to each participant before they provided an informed consent. Participants performed a standardized golf warm-up consisting of dynamic stretches and swings of increasing intensity, which was followed by 6 practice drives. Three driver mass conditions were tested in a repeated measurements design. The tested driver masses were 275 g, 325 g, and 375 g (Table 1). The same Ping G 10.5 driver head (196.1 g) was used for all conditions, and all grips (26.9 ± 0.1 g) and shafts (52.0 ± 0.1 g, 258 ± 0.25 cpm) were matched as closely as possible. A mass of 50 g was placed inside the grip of the 325 g club, while 100 g was placed inside the 375 g club. Both masses were centered 10 cm down from the butt of the club and the assembled driver lengths were all 1.15 m. Each participant executed 12 drives with each grip mass condition. Shafts were changed every 6 shots and the order of conditions was blinded and balanced across participants to minimize any ordering effect. Ball flight simulation software (FlightScope Software V10.1, FlightScope Ltd., Orlando, FL, USA) was used to display a target, and resulting shot trajectory, onto a projection screen. Participants were informed that the clubs were different, but were given no indication as to what parameter(s) were dissimilar. In order to get a sense of player–condition matching over time, 15 participants completed a second session with a modified order of conditions relative to their first session.

**Table 1.** Golf club inertial properties relative to a shaft-based reference frame. At impact, Z points down the shaft, X points down the target line, and Y is according to the right-hand rule.

| Driver Mass (g) | $CoM_Z$ From Butt (cm) | Swing Weight | $I_{YY}$ Butt ($kg \cdot cm^2$) | $I_{YY}$ CoM ($kg \cdot cm^2$) | $I_{XX}$ CoM ($kg \cdot cm^2$) | $I_{ZZ}$ CoM ($kg \cdot cm^2$) | Added Mass (g) |
|---|---|---|---|---|---|---|---|
| **275** | −88.4 | D0.4 | 2924 | 516 | 515 | 6.4 | 0 |
| **325** | −76.8 | C0.0 | 2942 | 818 | 818 | 6.8 | 50 |
| **375** | −70.6 | A9.6 | 3027 | 987 | 987 | 7.1 | 100 |

### 2.2. Data Collection and Processing

Golf club kinematics were collected using an 11-camera optical system (Raptor-E, Motion Analysis Corporation, Santa Rosa, CA, USA). Camera shutter speeds were set to 4000 Hz, and data were sampled at 500 Hz. The residuals reported by the system were < 1 mm and the accuracy (root mean square error when measuring a known distance) and precision (SD of the length of a rod) were approximately 0.3 mm. A bespoke software program was written in MatLab (version R2014a, MathWorks, Natick, MA, USA) to process the 3D coordinate data and generate dependent variables of interest.

### 2.3. Statistical Analysis

One-way repeated measures analyses of variance were conducted on each dependent variable of interest (e.g., clubhead speed). The within-participants independent variable (club mass) had three levels: 275, 325, and 375 g. If the assumption of sphericity was not met, then Greenhouse–Geisser corrections were applied. When significant values were determined ($p < 0.05$), Bonferroni post-hoc tests, with adjustments to the control for Type I error, were used to determine where significant differences existed between conditions. Effect sizes were estimated using partial eta squared ($\eta p^2$): 0.02~small, 0.13~medium, 0.26~large. Following the testing sessions, participants were asked questions about any perceived differences between the clubs in terms of feel, preference, and performance.

## 3. Results

There was a significant difference in strokes gained: off the tee (Appendix A) across conditions ($F(2, 78) = 3.96$, $p = 0.023$, $\eta p^2 = 0.09$), with the 325 g condition underperforming relative to the 275 g and significantly so relative to the 375 g (Figure 1a). On average, the absolute lateral error from the target line was significantly greater with the 325 g condition (25.3 yards) relative to the 375 g condition (22.0 yards) ($F(2, 78) = 4.3$, $p = 0.017$, $\eta p^2 = 0.10$) (Figure 1b). The absolute lateral error findings are in agreement with the optical system measurements in that there were differences in terms of the variability in horizontal impact location on the face. On average, participants showed the greatest standard deviation in horizontal impact location while using the 325 g condition (11.1 mm), which was significantly greater than the 275 g condition (9.6 mm), ($F(2, 78) = 3.5$, $p = 0.031$, $\eta p^2 = 0.09$) (not shown). There was no systematic influence on driving distance with all conditions associated with average total distances of approximately 277 yards ($F(2, 78) = 0.1$, $p = 0.883$, $\eta p^2 = 0.002$) (Figure 1c). On average, the 275 g condition was associated with a marginally higher clubhead speed (44.6 m/s) than the 325 g (44.5 m/s), which was slightly higher than the 375 g (44.4 m/s), ($F(2, 78) = 4.24$, $p = 0.018$, $\eta p^2 = 0.1$) (Figure 1d).

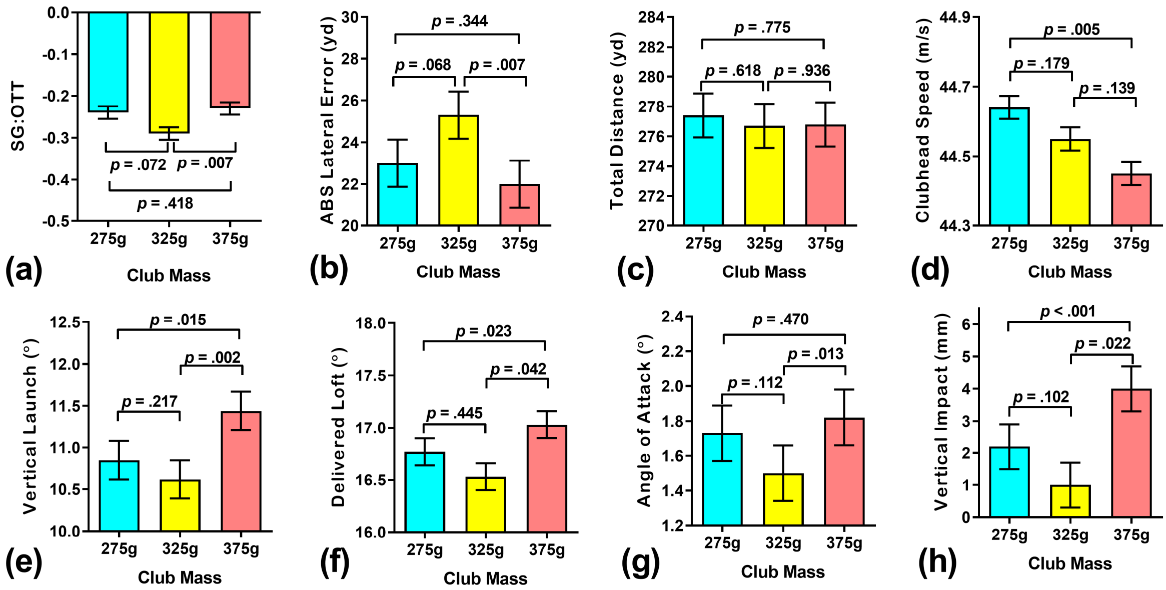


**Figure 1.** Influence of grip mass on various dependent variables (**a**) Strokes Gained: Off The Tee (**b**) Absolute lateral distance of the ball's finish position from the target line (**c**) Total distance of the drive (**d**) Clubhead speed at impact (**e**) Vertical launch angle of the ball (**f**) Loft of the clubhead at the predicted instant of ball contact (**g**) Angle of attack (**h**) Vertical location of where the ball contacted the clubface relative to the center of the face. These are average values across all participants. Error bars represent 95% within-subject confidence intervals. P-values for the Bonferonni tests are also shown.

On average, the 375 g condition was associated with a significantly higher vertical launch (11.4°) relative to both the 325 g (10.6°) and 275 g (10.8°) conditions, ($F(2, 78) = 7.16$, $p = 0.002$, $\eta p^2 = 0.16$) (Figure 1e). On average, the 375 g condition was associated with a significantly higher vertical impact location, relative to the center of the face (4 mm), in comparison to both the 275 g (2 mm) and 325 g

(1 mm), ($F(2, 78) = 8.81$, $p < 0.001$, $\eta p^2 = 0.18$) (Figure 1f). The same pattern was observed for both the angle of attack and delivered loft with the 375 g condition being higher than the lighter conditions (Figure 1g,h). An important contributor to the delivered loft outcome was the average location of the golfers' hands at impact. Specifically, the butt of the grip was significantly closer to the target (more shaft lean) with the 325 g condition (29 mm) relative to both the 275 g (24 mm) and 375 g (20 mm) conditions ($F(2, 78) = 15.5$, $p < 0.001$, $\eta p^2 = 0.29$) (not shown).

On average, golfers achieved a significantly higher maximum hand speed with the 325 g condition (8.62 m/s) relative to both the 275 g (8.59 m/s) and 375 g (8.50 m/s) conditions ($F(2, 78) = 41.0$, $p < 0.001$, $\eta p^2 = 0.51$). Specifically, these values correspond to a point 10 cm down from the butt of the grip. On average, maximum hand speed occurred when the shaft was approximately 60° above the horizontal. This pattern among conditions occurred at impact as well ($F(2, 78) = 14.9$, $p < 0.001$, $\eta p^2 = .28$), with hand speed dropping by an average of approximately 2 m/s from the maximum. On average, the 275 g condition was associated with downswings that were marginally shorter in duration than both of the heavier conditions ($F(2, 78) = 2.5$, $p = 0.093$, $\eta p^2 = 0.06$)

At the individual level, 18 participants had the highest mean clubhead speed with the 275 g condition, 13 with the 325 g, and 9 with the 375 g. Of the 15 participants that completed a second session, only six showed the same result as the first session in terms of the club with which they attained the highest average clubhead speed. At the individual level, 16 participants had the lowest absolute lateral error relative to the target line with the 375 g condition, 10 with the 325 g, and 14 with the 375 g. Of the 15 participants that completed a second session, only four showed the same result as the first session in terms of the club with which they attained lowest average absolute lateral error.

Regarding the qualitative questions, 15 participants preferred the lightest club, 13 the heaviest, 6 the standard mass, and 6 had no preference. The 375 g club was correctly picked as being the heaviest by 27 participants, while 10 picked the 325 g, 2 picked the 275 g, and one participant stated that they did not know. All participants noted there were major differences in how the clubs 'felt'.

## 4. Discussion

The purpose of this study was to determine how grip mass influences both the kinematics of the club as well as the resulting kinematics of the ball. As expected, there was a statistically significant trend demonstrating that clubhead speed increases as grip mass decreases (Figure 1d). However, the magnitude of clubhead speed change was quite underwhelming considering the large manipulation to grip mass. A 275 g driver would be considered extremely light, while a 375 g driver would be considered extremely heavy; yet, there was less than a ½ mph difference in clubhead speed. In a study investigating shaft stiffness, [8] showed that individual players can react quite differently to a club's physical parameters and that important individual differences can be masked by group trend statistics. While 45% of the participants in this study had their highest average clubhead speed with the lightest condition, 65% broke from conventional theory and had a higher average with either the 325 g or 375 g condition. Although a few participants showed average differences over 2 mph, the vast majority of the differences would not be considered meaningful. This is especially true when you consider that only six of the 15 participants that repeated the testing on a separate day showed the same result as the first session in terms of the club with which they attained the highest average clubhead speed. Overall, the speed findings are in agreement with [5] in that changes were small and specific to the individual. The speed results also concur with [1] who found that softball bat swing speed varied predictably with bat moment of inertia (MOI) when mass was held constant, but showed no dependence on variations in mass when MOI was held constant. Another study [2] arrived at the same conclusion using a wider range of conditions (mass (0.208–0.562 kg) and MOI (103–1034 $kg \bullet cm^2$)) while examining an overhead single arm striking motion with a rod. In these two studies, MOI was measured about a point near the butt. The conditions in this study show that MOI, as measured about the butt, only varied by ~3%, while mass varied by ~30% (Table 1), which explains the subtle changes in clubhead speed.

The slight systematic trend of decreasing clubhead speed with increasing grip mass did not translate into the same pattern for driving distance. This was primarily due to the heaviest condition also being associated with the highest vertical ball launch, which offset the distance potential from the modest difference in clubhead speed. On average, participants were launching the ball at ~145 mph with ~2850 rpm of backspin. Given these parameters, an increase in average vertical launch angle from 10.6° to 11.4° (Figure 1e) would be expected to yield longer drives. The higher launch with the heaviest condition was the result of participants delivering the clubhead to the ball with more loft, a higher attack angle, and impacting the ball higher on the face. There was a 3 mm difference in the average vertical impact location between the 375 and 325 g conditions. This difference would be expected to further increase the 'dynamic' loft of the club during the impact interval. In fact, there was a statistically significant 1° difference in the dynamic loft reported by the launch monitor between the 325 (11.9°) and 375 g (12.9°) conditions (not covered in the Results). The difference in vertical impact location would also be expected to reduce the amount of backspin imparted to the ball due to vertical gear effect, which would offset the probable increase in backspin due to the higher delivered loft. It seems intuitive that the heaviest condition would result in the clubhead travelling closer to the ground through impact, yielding a higher impact location on the face. It also seems intuitive that the heaviest condition would be associated with the slowest hand speed during the last portion of the downswing. The slower hand speed would result in the hands being further behind the ball at impact, creating the impact geometry associated with the increase in delivered loft (Figure 1f).

A second objective was to determine the influence of grip mass on performance consistency. Since each participant was clearly instructed to attempt to hit the same golf drive with a ball finish location on the target line for all trials, it was felt that the absolute error in lateral finish position of the ball was a good reflection of consistency. In driving, it is typically more important to have less lateral variability than it is to have less variability in distance. There was no clear pattern to suggest that adding mass to the grip reduced lateral dispersion from the target line. Interestingly, if the 275 g condition was considered the base-line, then 'back-weighting' a similar club with 50 g in grip tended to increase dispersion. To the contrary, if the 325 g condition was considered the baseline—which is a typical driver mass—then back-weighting a similar club with 50 g in grip tended to decrease dispersion (Figure 1b). The individual responses reported in the results suggests an even less clear relationship between grip mass and consistency.

Arguably, the most interesting outcome is the apparent non-linear relationships between grip mass and several important dependent measures. In terms of statistically significant findings at the group level, clubhead speed was the only dependent variable that followed an anticipated linear pattern. Even the linear speed of the grip, which—along with the angular velocity component—kinematically determines clubhead speed, did not follow a linear pattern. Specifically, why would the 325 g condition be associated with a higher linear hand speed than either the 275 g or the 375 g? The answer may lie in the complex interaction between the applied golfer forces at the grip and the three inertial components (mass, center of mass location, and MOI) with which they interact to change the motion of the club. The center of mass (CoM) location varied considerably between conditions. This CoM location relative to the forces applied to the grip by the golfer will have a meaningful impact on the torque the golfer applies to club. Future research is required to further investigate this line of reasoning.

It is possible that these non-linear findings could be explained by some limitations having an influence on the internal validity of the study. Although all parameters except grip mass were controlled as closely as possible (Table 1), three separate shafts were employed. Moreover, golfers did not use their own club. Switching to a new and unfamiliar club may have increased variability so much that underlying improvements in consistency were not noticeable. This may influence external validity as well. Future research could employ a repeated measures design with the participants' own drivers in which the mass would be temporarily added to their own grip. Moreover, from an external validity concern standpoint is the inertial properties of the 325 g 'typical mass' condition. While having a familiar mass, the center of mass is much closer to the hands than a typical Ping Driver (~10 cm closer) resulting in a very atypical, C0, swing weight. Starting each build with the lightest condition made it relatively easy to have symmetrical differences in overall mass due solely to changes in grip mass (i.e., one grip was 50 g lighter and the other 50 g heavier), while keeping the same clubhead and nominally identical shafts. Starting with a typical driver build would prohibit testing a lighter condition. Future research should investigate using a single build with the addition of 25 g and 50 g into the grip as separate conditions. As an aside, one can see the failure in the application of swing weight to understand how a club's inertial properties may influence swing dynamics. As grip mass increased, the moment of inertia of the club about the center of mass increased, and the moment of inertia about the butt remained relatively constant (3% change); however, the swing weight meaningfully decreased.

## 5. Conclusions

This study has provided novel insights into the understanding of how the grip mass of a driver influences driving performance. Based on these findings, relatively large changes in grip mass should not be expected to have meaningful or predictable changes to performance with the driver. While the results of this study do not provide strong evidence in favor of back-weighting, there is also no clear indication of a detrimental effect. In particular, players should not worry about a reduction in clubhead speed due to the increased mass.

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**Conflicts of Interest:** The authors declare no conflict of interest.

## Appendix A

The strokes gained statistic was developed by determining the average number of strokes it would take a PGA tour player to hole out from every distance and location (tee, fairway, rough, sand, recovery, and green) and comparing the result of a shot to this baseline [9]. This statistic has become widely used over some more traditional statistics, such as fairways hit and total putts to determine the performance of a single shot. The key to calculating strokes gained on a drive is to establish a tee location and offline penalty. For the purposes of this study, the tee distance was set to 425 yards, which reflects a long par 4 where most players would hit with a driver. In order to determine the condition (e.g., fairway, rough, etc.), a gradient of conditions was used. Every shot that is less than 10 yards offline is considered to hit the fairway, while shots outside this range were determined by a gradient average of the baselines for fairway, rough, and recovery, with shots more offline weighted more heavily toward the recovery baseline. The intention of the gradient is to reflect that a shot that is 50 yards offline is worse than a shot that is 30 yards offline because it will have a greater chance of going in the water, desert or a recovery position on the course.

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