Muscular Power, Neuromuscular Activation, and Performance in Shot Put Athletes At Preseason and at Competition Period

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Abstract

Kyriazis, TA, Terzis, G, Boudolos, K, and Georgiadis, G. Muscular power, neuromuscular activation, and performance in shot put athletes at preseason and at competition period. *J Strength Cond Res* 23(6): 1773–1779, 2009—The aim of this study was to investigate changes in shot put performance, muscular power, and neuromuscular activation of the lower extremities, between the preseason and the competition period, in skilled shot put athletes using the rotational technique. Shot put performance was assessed at the start of the pre-season period as well as after 12 weeks, at the competition period, in nine shot putters. Electromyographic (EMG) activity of the right vastus lateralis muscle was recorded during all shot put trials. Maximum squat strength (1RM) and mechanical parameters during the countermovement jump (CMJ) on a force platform were also determined at pre-season and at competition period. Shot put performance increased 4.7% ($p < 0.05$), while 1RM squat increased 6.5% ($p < 0.025$). EMG activity during the delivery phase was increased significantly ($p < 0.025$) after the training period. Shot put performance was significantly related with muscular power and takeoff velocity during the CMJ, at competition period ($r = 0.66$, $p < 0.05$ and 0.70, $p < 0.05$), but not with maximum vertical force. One RM squat was not related significantly with shot put performance. These results suggest that muscular power of the lower extremities is a better predictor of rotational shot put performance than absolute muscular strength in skilled athletes, at least during the competition period.

Key Words rotational shot put, electromyographic activity, countermovement jump

Introduction

Shot put is a track and field event requiring high power production (11,14). Muscular power is mainly determined by muscular strength, maximum movement velocity, and neuromuscular activation (7). However, scientific data regarding the muscular power of shot put athletes and the association of this parameter with performance are rare (8,10). Furthermore, these data refer exclusively to the linear shot put style. In the recent years, the rotational shot put style has been particularly popular among shot put athletes (9). There are certain important kinesiological differences between the linear and rotational shot put styles. For example, during the delivery phase of the rotational style, the acceleration of the implement must be performed in a shorter time frame than during the linear style (1,5). This implies that muscular power is equally or even more important for rotational shot put performance. However, no data exist as to the muscular strength and power output in skilled shot put athletes using the rotational style.

Shot put athletes follow a structured training program for a number of weeks/months in order to get prepared for a specific important contest. This year-round preparation usually results in an increase in performance (3). A recent study (10) showed that moderately trained shot putters can increase their performance by 5.5% after 8 weeks of training towards content. However, there are no studies regarding the change in performance from the preseason to the competition period in skilled shot putters using the rotational technique. Moreover, to our knowledge, no scientific data exist regarding the alteration in muscular strength and power after a structured training program in skilled shot putters using the rotational style.

A recent study revealed a close relationship between the electromyographic activity of vastus lateralis and pectoralis muscles during the delivery phase of the lineal shot put style with shot put performance, in skilled shot putters (12). However, as mentioned above, there are a lot of kinesiological differences between the two shot put styles. For example, the duration of the support on the right leg during the power position is much longer for the rotational style compared to the linear style (9). Furthermore, during the

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Table 1. General characteristics of the training program followed by nine skilled shot putters using the rotation style, aiming at the national indoors event.

	Strength training* (3–5 sessions/week)			Shot throws (3 sessions/week)			Sprints, jumps, agility (2 session/week)
Training week	Structural exercises	Snatch, clean	Assistance exercises	8 kg	7.26 kg	6.25 kg	
Week 1	6 × 6	2–3 × 5–6 70–75% 1RM	2–3 × 12RM	4–8	10–15	–	(e.g. stair climbing, resisted sprints, agility sprints)
Week 2	5 × 6 RM	3–5 × 3–5 70–75% 1RM	2–3 × 12RM	4–8	10–15	–	
Week 3	5 × 5 RM	2–3 × 3–5 75–80% 1RM	2–3 × 10RM	8–12	12–18	–	
Week 4	4 × 5 RM	4–5 × 3–5 80–85% 1RM	2–3 × 10RM	8–12	12–18	–	
Week 5 Rest							
Week 6	3–5 × 3–5 RM	1–3 × 3–5 80-90% 1RM	2–3 × 6–8 RM	15–25	8–12	–	(e.g. 20–40 m sprints, 3–4 jumps for time, 5–6 jumps with hurdles)
Week 7	2–3 × 2–4 RM	2–3 × 2–3 85–90% 1RM	2–3 × 6–8 RM	15–25	8–12	4–8	
Week 8	2–3 × 1–3 RM	1–2 × 2–3 90–95% 1RM	1–2 × 4–6RM	20–30	4–8	4–8	
Week 9	1–2 × 2–3 RM	1–2 × 2–3 90–95% 1RM	1–2 × 4–6RM	15–25	8–12	4–8	
Week 10 Rest							
Week 11	Snatch, clean, structural exercises 4–6 × 6–8, 30–40% 1RM		–	4–8	12–18	8–12	(e.g. 20- to 30-m sprints, 3–4 jumps for time, 4–6 jumps with hurdles)
Week 12 (competition)	Snatch, clean, structural exercises 4–6 × 6–8, 30–40% 1RM		–	–	8–12	8–12	

*Strength training = sets × repetitions.

delivery phase of the linear shot put, the acceleration of the implement starts almost immediately after the placement of the right leg on the ground. In contrast, during the delivery phase of the rotational style, the acceleration of the implement follows much later after the placement of the right leg on the ground (5). Thus, it remains unknown whether the activation of the thigh muscles is related with rotational shot put performance and whether this activation is altered between preseason and competition.

Aim of the present study was to investigate a) possible changes in shot put performance, muscular strength and power, as well as neuromuscular activation, between preseason and competition period, in skilled athletes using the rotational style; and b) the association between muscular strength, power, and vastus lateralis electromyography (EMG), with the rotational shot put performance, in the same group of subjects at preseason and at competition period. We hypothesized that performance and muscular strength and power would increase in response to training and that absolute strength and power would be closely related with rotational shot put performance.

Methods

Experimental Approach to the Problem

Nine shot put athletes using the rotational style followed 12 weeks of individualized structured training, aiming to peak their performance for the indoors national championship (February). Measurements of shot put performance, muscular strength, and power, as well as electromyography activation of vastus lateralis muscle during the shot put performance, were performed before (November) and after (February) the training period (e.g., the preseason and the competition period). The athletes were trained under the supervision of their coaches and each training program was designed to maximize rotational shot put performance at the winter (indoors) national championship. The measurements corresponding to the competition period were performed during the week after the winter (indoors) national championship (February). The general characteristics of the training program, which was followed by the athletes, are presented in a subsequent paragraph. Performance parameters before and after the training period were statistically compared. Furthermore, a correlation analysis was performed between the rotational shot put performance, muscular strength, muscular power, and EMG from vastus lateralis muscle.

Subjects

Nine male shot put athletes (age: 26 ± 4 years; body height: 188.4 ± 6 cm, body mass at preseason 114.4 ± 10 kg, body mass at competition: 112.2 ± 8 kg) gave their written consent to participate in the study, after being thoroughly informed about the experimental procedures. They were the best shot putters at the national level, according to the previous year's official results. Individual best performance with the rotational style ranged between 19.98 to 14.19 m. This corresponds to 86.4% and 61.3% of the world shot put record. All of the subjects performed with the rotational style, at least during the previous 2 years, and they had right-hand dominance. All athletes had more than 6 years of structured shot put training. Furthermore, they were in good health and were receiving no medication. The study was approved by the local ethics committee.

Training

During the 12-week preparation period, each athlete followed an individualized training program designed by the respective coach in order to meet each individual needs. All training programs followed the principles of periodization (3). The details of each training

Table 2. Shot put performance, mechanical parameters during the countermovement vertical jump, and EMG activity of vastus lateralis, at preseason and at competition, in nine skilled shot putters competing with the rotational style.*

Variable	Preseason	Competition
Shot put performance (m)	15.26 ± 1.67	15.98 ± 2.11†
1RM Squat (kg)	216 ± 19	230 ± 17‡
Vastus lateralis EMG (mV)	0.66 ± 0.23	0.96 ± 0.44‡
Body mass (kg)	114.4 ± 10	112.2 ± 8
CMJ jumping height (m)		
Unloaded	0.370 ± 0.04	0.386 ± 0.06†
+20 kg	0.319 ± 0.04	0.330 ± 0.03
+30% 1RM	0.223 ± 0.05	0.226 ± 0.02
CMJ power (W)		
Unloaded	3042 ± 700	3315 ± 550†
+20 kg	2758 ± 601	2971 ± 533
+30% 1RM	2295 ± 566	2360 ± 377
CMJ vertical velocity ($m\cdot s^{-1}$)		
Unloaded	2.73 ± 0.1	2.92 ± 0.3†
+20 kg	2.51 ± 0.2	2.62 ± 0.3
+30% 1RM	2.08 ± 0.2	2.12 ± 0.1
CMJ vertical force (N)		
Unloaded	1538 ± 230	1465 ± 197
+20 kg	1484 ± 232	1449 ± 156
+30% 1RM	1329 ± 255	1291 ± 156

*CMJ = countermovement jump; 1RM = one repetition maximum; $n = 7$ for EMG.
†$p < 0.05$.
‡$p < 0.01$.

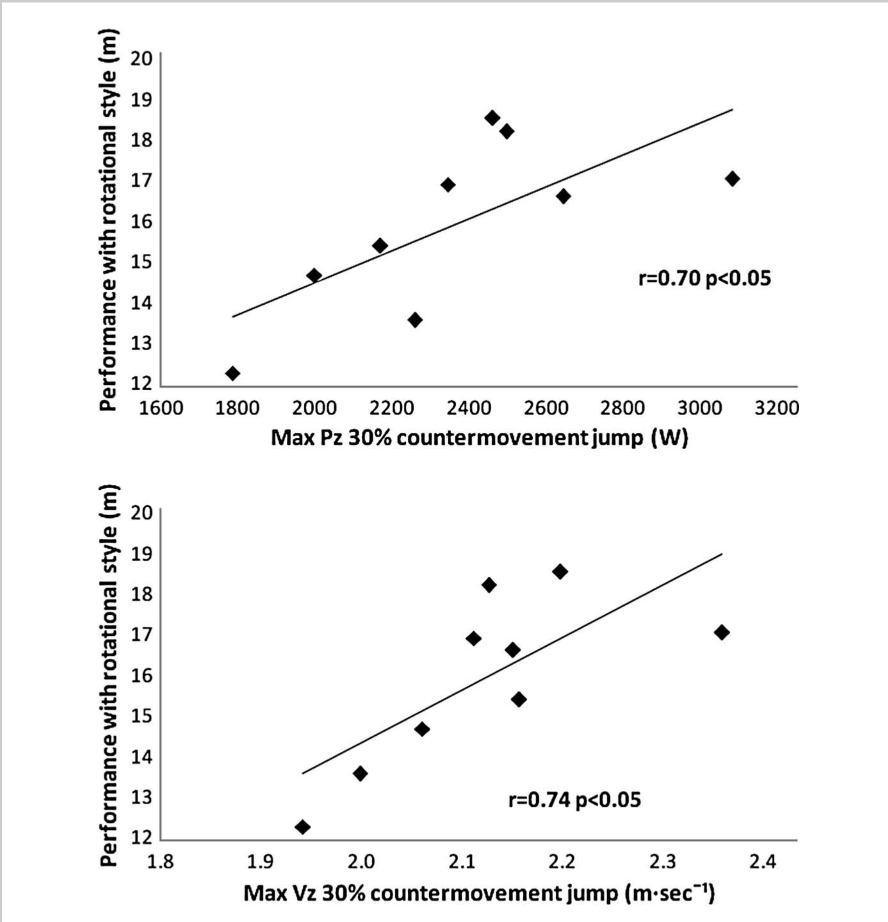

Figure 1. Correlation between rotational shot put performance and maximum power and take off velocity during the CMJ in skilled shot putters, at the competition period ($n = 9$).

session were recorded by the respective coach in the end of each training day. Four percent of all the training sessions scheduled were not completed due to small injury problems. The general characteristics of the training programs followed by the athletes are presented in Table 1.

Procedures

Shot Put Performance. Shot put was performed indoors, on a standard circle, during the morning hours. Ambient temperature was 20°C–23°C. The same circle was used at preseason and at the competition period. After a 30-minute warm-up (jogging, stretching, 4–6 submaximal puts), the EMG electrodes were placed (see below), and each subject performed six trials with the rotational style using a 7.260-kg implement. Three minutes of rest was allowed between the trials. The best shot put performance was used in further analysis. The fact that the best national shot putters participated in the study created a high competitive level between these athletes during the measurements. Furthermore, each trial of each subject was vocally encouraged by the researchers. Moreover, two of the subjects made a personal best record during these measurements.

1RM Squat Strength. Ten minutes after the shot put trials, the 1RM squat test with free weights followed. EMG electrodes were not removed in order to record the EMG activity from vastus lateralis during the 1RM squat. Before the initiation of the testing, each athlete performed an unloaded squat repetition, descending slowly, in order to determine the position of the 90° of the knees. A stool was placed under the hips at the right height in order to restrict the knee bending to no more than 90° (during the 1RM measurement, the subjects started the upward movement when their hips touched the stool). Subsequently, subjects performed incremental submaximal efforts, until they were unable to lift a heavier weight. Approximately 3 minutes of rest was allowed between the trials. In all cases, all of the authors were present and vocally encouraged each trial of each subject. It should be mentioned that the shot put performance preceded the measurement of 1RM squat in order to avoid fatigue from the squat exercise. Moreover, the EMG from vastus lateralis during shot put was normalized to the max EMG from vastus lateralis during the squat. Thus, shot put performance and 1RM squat were measured in the same day in order to have the same placement of the EMG electrodes on vastus lateralis.

Counter Movement Jumps. Two days after the shot put measurement, subjects visited the laboratory for the countermovement jump (CMJ) measurements. After 20 minutes of warm-up (cycling and stretching), they performed 9 CMJs on a force plate (Kistler 9281 B11 with external amplifier Kistler 9681 A, 60 × 40 cm, sampling frequency 750 Hz, sampling time 10 s) as follows: 3 CMJs holding a plastic bar of negligible weight, 3 CMJs with an olympic barbell (20 kg), and finally 3 CMJs with a load equal to 30% of 1RM squat (6). At all trials, the bar was placed behind the neck, supported be the athletes' hands. Three-minute interval was allowed between each trial. Data from the force platform were recorded and analyzed with the appropriate software (Bioware for Windows, Version 3.0, Kistler, Switzerland) in order to calculate the maximum vertical power, force and velocity during the contact phase. The best performance (jumping height) was calculated from the flight duration.

Electromyographic Recording and Analysis

EMG activity during the shot put trials and 1RM squat testing was recorded from vastus lateralis (VL) muscle of the right leg of only 7 of the subjects, due to technical difficulties. Bipolar surface electrodes (Ag/AgCl) were placed according to DeLuca (1997), with a bipolar distance of 20 mm. All wires were taped on the subjects' body in a way that they did not disturb the movement of the body parts. Electrode position was marked with a permanent marker. This was repeated every third day during the 12-week training period (4) in order to secure the same electrode positioning before and after the training period. The electrodes were connected with a preamplifier telemetric unit (TEL100D) and an analog to digital conversion unit MP100A (Biopac Systems, Inc. Santa Barbara, CA, USA). EMG signals were recorded (1 kHz) and analyzed as shown in a previous study (12). EMG signals were low cutoff filtered (10 Hz) and full wave rectified. The different phases of the technique could be easily identified by the EMG records (e.g., EMG silence during the take off of the right lower extremity before landing at the power position). Moreover, a video camera with recording frequency 25 frames/sec was used, in order to standardize the different phases of the technique.

The duration of the EMG activity of right VL after landing to the power position was approximately 400 ms. This activation corresponds to the single support on the right leg, turn on the right leg, power position, and final put. This period was divided in 100 ms intervals. Average EMG amplitude was calculated in mV between 100–200 msec and 300–400 msec (AcqKnowledge 3.5.2, BIOPAC Systems Inc., CA, USA). These time frames correspond, approximately, to the single support on the right leg (and deceleration of the implement) and the final put (acceleration of the implement, 5). The full wave rectified EMG signal during the 1RM squat measurement was also divided in 100ms intervals and the aEMG of these intervals was calculated. The highest of these aEMG values, corresponding to the second half of the activation period (concentric muscular contraction) was used to normalize the aEMG values during the shot put measurements (i.e., aEMG during shot put/aEMG during 1RM squat).

Statistical Analyses

Each experimental variable was expressed as mean ± *SD*. Depended Student's *t*-tests were used to explore differences before and after the training period. Bonferroni correction was applied for multiple *t*-tests in groups of groups of tests: e.g., shot put performance, 1RM strength and EMG, CMJ jumping performance. Pearson's *r* product moment correlation coefficient was used to explore the linear relationships between different variables. In every analysis, $p \leq 0.05$ was used as a two-tail level of significance, except in *t*-tests where the Bonferroni correction was applied.

Results

Training Response

Shot put performance with the rotational technique was increased by 4.7 ± 2% ($p < 0.05$) after the training period (Table 2). Maximum squat strength was also increased by 6.5 ± 6% ($p < 0.025$, Table 2). Maximum vertical power and vertical velocity during the countermovement jump without

Table 3. Correlation coefficients between rotational shot put performance, mechanical parameters during the countermovement vertical jump, and EMG activity of vastus lateralis, at preseason and at competition, in skilled shot putters competing with the rotational style ($n = 9$).*

Variable	Preseason	Competition
1RM Squat (kg)	0.35	0.38
Vastus lateralis EMG (mV)	0.81†	0.80†
Body mass (kg)	0.65	0.58
CMJ jumping height (m)		
Unloaded	0.27	0.23
+20 kg	0.40	0.27
+30% 1RM	0.11	0.77†
CMJ power (W)		
Unloaded	0.60	0.66†
+20 kg	0.31	0.67†
+30% 1RM	0.24	0.70†
CMJ vertical velocity ($m \cdot s^{-1}$)		
Unloaded	0.44	0.70†
+20 kg	0.09	0.76†
+30% 1RM	0.14	0.74†
CMJ vertical force (N)		
Unloaded	0.10	0.04
+20 kg	0.13	0.20
+30% 1RM	0.24	0.12

*CMJ = countermovement jump; 1RM = one repetition maximum; $n = 7$ for EMG.
†$p < 0.05$.

external resistance tended to increase by 9.0 ± 9% and 7.0 ± 8%, respectively (NS). EMG from VL at the second half (300–400 ms) of the activation of the delivery phase was significantly increased ($p < 0.01$) from preseason to competition (Table 2).

Correlation between Shot Put, Jumping Performance, and EMG

Shot put performance at the competition period was significantly related with the maximum power produced during the unloaded CMJ ($r = 0.66, p < 0.05$), with 20-kg load ($r = 0.67, p < 0.05$) and 30% 1RM load ($r = 0.70, p < 0.05$, Figure 1, Table 3). Likewise, a close relationship was observed between the shot put performance and the maximum take off velocity during the unloaded CMJ ($r = 0.70$, $p < 0.05$), with 20-kg load ($r = 0.76, p < 0.05$) and 30% 1RM load ($r = 0.74, p < 0.05$, Figure 1, Table 3). In contrast, the correlation coefficients between the shot put performance and the mechanical parameters during the countermovement jumps at pre-season were moderate and nonsignificant. EMG from VL at the second half (300–400 ms) of the activation of the delivery phase was significantly related with shot put performance both at preseason and at competition ($r = 0.81$ and 0.80, respectively, $p < 0.05$, Table 3). Moreover, a close negative relationship was found between the EMG from VL during the initial 200 ms of muscle activation (touchdown of the right foot in order to turn and deliver the implement) and shot put performance at preseason and at competition ($r = -0.75$ at both time points, $p < 0.05$).

Discussion

The main result of the present study was that rotational shot put performance is better correlated with muscular power of the lower extremities than with absolute muscular strength at the competition period. Actually, the association between 1RM squat strength and shot put performance was low and nonsignificant at any time. Likewise, vertical force produced during the countermovement jump was not related with shot put performance at any time. In contrast, vertical power and vertical velocity during the countermovement jump were closely and significantly related with rotational shot put performance during the competition period. These results suggest that rotational shot put performance depends less on absolute muscular strength than linear shot put performance since previous sudies have shown that the latter is closely related with 1RM squat strength (8,12). However, the importance of muscular strength for the development of rotational shot put performance cannot be neglected. It may be that a certain (yet unknown) level of muscular strength is required as a base for the muscular power to be developed upon. Further increases in muscular strength might not be related with performance increaments, as shown in the present study.

Shot put performance with the linear style is thought to be a power-demanding event (11,14). Indeed, a previous study (13) revealed a significant relationship between linear shot put performance and standing broad jump ($r = 0.61, p < 0.05$). Futhermore, in an extensive correlational study, Morrow et al. (8) demonstrated that linear shot put performance is significantly associated with vertical jump performance ($r = 0.66, p < 0.05$), 20-yard sprint ($r = 0.64, p < 0.05$), and long jump performance ($r = 0.69, p < 0.05$), in shot putters of similar level as those which participated in the present study. More recently, Stone et al. (10) revealed that muscular power, measured at 30% or 60% of the maximum isometric force, was significantly related with shot put performance in moderately trained shot putters during the indoor competition period ($r = 0.80$ and 0.87, respectively, $p < 0.01$). However, the present study demonstrates, for the first time, that rotational shot put performance is closely related with muscular power of the lower extremities during the countermovement jump ($r = 0.70, p < 0.05$). Moreover, present data suggest that muscle power predicts better the rotational shot put performance than absolute muscular strength.

The disagreement regarding the importance of absolute muscular strength in linear or rotational shot put performance might be due to the significant kinesiological differences between these two shot put styles. One of the most striking differences between the two styles is that the acceleration of the implement during the delivery phase must be performed significantly faster during the rotational style than during the linear style (5). This implies that rotational shot put performance might be influenced more by muscular power than muscular strength, as the present data suggest. To reinforce this notion, the lean body mass of two of the athletes who participated in the present study (the two best performers), actually decreased by 3%, from the preseason to the competition period (measured with dual x-ray absorptiometry, data not shown) and their 1RM squat remained unchanged. At the same time, their shot put performance increased by 7%.

As expected, shot put performance increased significantly from the preseason to the competition period. However, this is the first study reporting absolute and percentage increases in performance from preseason to competition in skilled shot put athletes using the rotational style (i.e., 4.7%). A similar increase in performance (5.5%) was reported after 8 weeks of strength-power training in moderately trained shot putters (10).

The electromyographic activity of right vastus lateralis muscle was significantly related with shot put performance both at preseason and at competiton. This is in concert with the results of a study that revealed a close relationship between the EMG of vastus lateralis during the delivery phase and the linear shot put performance (12). Especially during the preseason, the activation of VL during the delivery phase was the only parameter significantly related with performance. This result suggests that the activation of VL is indicative of the power produced by the lower extremities during the delivery phase of the shot put, both with the linear and the rotational style. This has been linked to the concept of specific strength (i.e., the strength produced by a certain protagonist muscle group during the actual athletic movement) (12). The present results suggest that muscular effort during the actual event determines a large part of the performance outcome, and this is independent of the training status of the athletes (i.e., preseason versus competion period). Furthermore, EMG amplitude during the shot put was significantly increased after the training period. This suggests that significant neural adaptations occurred in response to the training stimulus and were manifested during the delivery phase of the rotational shot put (i.e., recruitment of higher threshold motor units, synchronization of the motor units, etc). However, this issue requires further investigation. Moreover, the EMG activity of vastus lateralis during the initial 200 ms of the delivery phase was negatively related with shot put performance. During this phase of the rotational style, the velocity of the implement is actually decreased because the athlete is rotating on the right toe (5). Thus, this inverse relationship suggest that a high vastus lateralis activation during this phase corresponds to a high braking force which probably leads to a lower implement velocity at the initiation of delivery phase, which might result in a lower final throwing velocity and performance.

In conclusion, the results of the present study reveal that shot put performance with the rotational style may improve significantly from the preseason to the competition period. Furthermore, present results suggest that muscular power of the lower extremities is a better predictor of rotational shot put performance than absolute muscular strength in skilled athletes, at least during the competition period.

Practical Applications

The present results suggest that shot put performance with the rotational style depends more on muscular power than absolute strength both at the preseason and especially during the competition period. Thus, training for shot put performance in athletes using the rotational style might focus more on developing muscular power and velocity of movement, and less on developing muscle mass and absolute muscular strength after a certain (yet unknown) level of strength has been developed. Alternatively, shot put athletes with a moderate capability of increasing muscle mass and absolute strength benefit more from the rotational style than the linear one.

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