Mechanical Properties of Weightlifting Bars

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Abstract

Chiu, LZF. Mechanical properties of weightlifting bars. *J Strength Cond Res* 24(9): 2390–2399, 2010—Weightlifting training and competition involves lifting a revolving shaft bar loaded with weights. The design of a bar and the location of the weights result in bar deformation during lifting tasks. Because there are many manufacturers of weightlifting bars, the actual deformation of a bar may vary, depending on the steel alloys used. A modified 4-point static bending test was used to assess deformation of 8 weightlifting bars and 1 general purpose weight training bar. The apparent stiffness of the bars was determined by plotting bending moment vs. bar deformation (the vertical height difference between the center vs. ends of the bar). All bars tested had an absence of hysteresis during cyclic loading and unloading in 50-kg increments (up to 220-kg total barbell weight), demonstrating pure elastic properties. At maximum loading, bar deformation was 4–5 cm. A large range existed for apparent stiffness. Based on apparent stiffness calculations, recommendations are made for which bars are suitable for weightlifting training and competition. The deformable nature of weightlifting and weight training bars should be considered before their use in exercise, sport, or research.

Key Words resistance exercise, motion analysis, barbell, equipment testing

Introduction

The weightlifting bar is one of the most important implements used in resistance exercise. The weightlifting bar allows heavy free weight exercises, such as squats, cleans, and snatches to be performed. These exercises, and their variations, are commonly used in athletic performance training programs and in general health and wellness programs (2). The modern weightlifting bar consists of a cylindrical metal shaft, with revolving metal sleeves fitted on the ends of the shaft. The revolving sleeve weightlifting bar allows the shaft to rotate independently of the weights placed on the sleeve, which is essential for performance of the snatch, and clean and jerk exercises. The dimensions of the weightlifting bar are specified by the International Weightlifting Federation (IWF [9]).

The use of revolving sleeve bars in weightlifting competition at the Olympic Games is likely the reason why such bars are referred to as "Olympic bars." However, only bars meeting the criteria specified and formally approved by the IWF can be considered for use in the Olympic Games (9). Many commercially available bars are available, which are commonly found in sporting goods stores, fitness facilities, and athletic performance training centers. However, it is likely that not all of these bars meet IWF specifications. Additionally, revolving sleeve bars may be designed for other uses and have other specifications, for example, for powerlifting training and competition. Thus, not all revolving sleeve bars can be designated as a weightlifting bar, nor are all revolving sleeve bars suitable for use when performing weightlifting exercises.

Weightlifting exercises are characterized by high power outputs, imparting large forces at high velocities to the barbell (3,7,13). The application of these high forces near the center of the bar, contrasted with the weights placed near the ends of the bar, generates large bending moments deforming the bar (3). Anecdotally, proper execution of weightlifting exercises involves taking advantage of bar deformation to enhance the ability to raise the bar to sufficient height for a successful lift. Chiu et al. (3) characterized the deformation of a weightlifting bar during performance of the clean pull exercise, reporting differences between the kinematics of the center of the bar vs. the ends of the bar from lift-off until completion of the second pull. Zernicke et al. (13) also described deformation of the bar during a jerk performed in competition.

Because the mechanical properties of a weightlifting bar influence the bar's deformation, it is important to investigate these properties and compare them between different manufacturers. Although some manufacturers report "quality standards tests" (3,11), there are no standardized methods for evaluating bars, nor do standard mechanical properties tests replicate the use of a bar in training and competition. Additionally, it is important to consider how all bars, weightlifting or otherwise, used in strength and conditioning

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Table 1. Manufacturers and models of bars tested.

Bar manufacturer	Bar model	Advertised use
Eleiko (Halmstad, Sweden)	Unavailable	Weightlifting training
Iron Grip (Santa Ana, CA, USA)	Olympic competition bar	Weightlifting training
Iron Grip (Santa Ana, CA, USA)	Power Bar	General weight training
Ivanko (San Pedro, CA, USA)	OB-20 kg	Weightlifting training
Mavrik (North Hills, CA, USA)	Men's SS training bar	Weightlifting training
Uddeholm (Sweden)	Unavailable	Weightlifting training
Uesaka (Tokyo, Japan)	WG-158TW	Weightlifting training
York (York, PA, USA)	#211015	Weightlifting training and general weight training

may behave under loading because this may have implications for appropriate use and minimizing injury risk. For example, it is now common for linear position, velocity, or acceleration transducers to be attached to the end of the bar to estimate the biomechanical characteristics of various exercises. Because the ends of the bar behave differently than the center, bar deformation may influence the accuracy of these characteristics. The purpose of this investigation was to assess the mechanical properties of several weightlifting bars from a number of manufacturers.

Methods

Experimental Approach to the Problem

The mechanical properties of weightlifting bars were studied using a modified 4-point bending test, designed to simulate the pulling phase of the clean exercise. Several weightlifting bars from a number of manufacturers were tested, and 1 bar not designed for weightlifting training or competition. The deformation of the bars was photographed during cyclic loading and unloading of weights. The bending moment applied to the bar was estimated using static calculations, and the apparent stiffness was determined by plotting bending moment vs. deformation. Apparent stiffness was operationally defined as the slope of bending moment vs. deformation and did not account for the diameter of the bars (i.e., calculation of the metal's stiffness).

Bars

Nine bars were selected for testing. The 9 bars were available to the investigator, thus representing a sample of convenience. Details of the bars, their manufacturers, and advertised use were gathered from print and Internet promotional materials and are listed in Table 1. Eight of the bars were advertised by their manufacturers to be used for weightlifting training. One bar was advertised for general weight room use. Two bars were identical model bars from the same manufacturer. Under the assumption that these 2 bars should have identical mechanical properties, the concurrent validity of the testing procedures could be assessed. The dimensions of the unloaded bar were determined using a steel measuring tape and a pair of digital calipers. Each of these tools allowed measurements to be determined to within 0.05 cm. The length of the bar, each sleeve, and the sleeve minus the inside collar was measured. The mass of each bar was determined using a beam-type medical scale. The scale allowed measurements to be determined to within 0.05 kg. These instruments were not calibrated to a reference scale; however, because all bars were measured with the same equipment, errors in the instruments would introduce bias but not random error.

Procedures

A modified 4-point bending test was used to assess bar deformation (Figure 1). The unloaded bar was placed on a set of squat stands. The distance between the outside edge of each upright support was 66.2 cm. The position of the

Figure 1. Experimental setup for modified 4-point bending test.

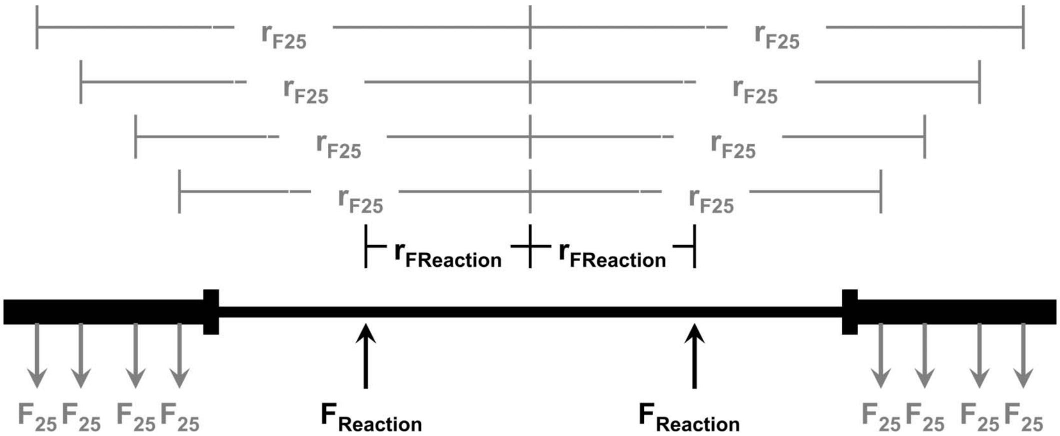

Figure 2. Free-body diagram to determine bending moments acting on the center of a bar. *F* = force; *r* = moment arm for force.

Table 2. Measured physical dimensions for bars.

Bar	Mass (kg)	Length (cm)	Sleeve length (cm)	Collar length (cm)	Length – inside sleeves (cm)	Bar diameter (cm)
Eleiko	20.0	220.20	44.40	2.80	131.40	2.80
Iron Grip (Olympic competition)	20.0	220.00	44.50	3.00	131.00	2.80
Iron Grip (Power)	20.5	221.50	43.75	3.80	134.00	3.00
Ivanko	20.0	219.40	42.10	4.10	135.20	2.80
Mavrik	20.0	220.00	44.50	3.05	131.00	2.90
Uddeholm	20.0	220.00	44.50	2.80	131.00	2.80
Uesaka (1)	20.0	220.00	44.50	3.05	131.00	2.80
Uesaka (2)	20.0	220.00	44.50	3.05	131.00	2.80
York	20.0	220.00	43.30	3.60	133.40	2.80

Table 3. Regression coefficients (R^2) for bar hysteresis analyses.*

	Cycle			
Bar	Loading 1	Unloading 1	Loading 2	Unloading 2
Eleiko	0.977	0.978	0.977	0.977
Iron Grip (Olympic competition)	0.994	0.967	0.985	0.996
Iron Grip (Power)	0.975	0.975	0.980	0.983
Ivanko	0.986	0.986	0.995	0.986
Mavrik	0.999	0.999	0.997	0.995
Uddeholm	0.996	0.995	0.996	0.992
Uesaka (1)	0.989	0.974	0.989	0.993
Uesaka (2)	0.999	0.982	0.966	0.934
York	0.966	0.966	0.988	0.988

*Each loading cycle involved loading the bar in 50-kg increments to 220 kg (unloading cycles were performed in reverse).

Table 4. Deformation of bars (mean ± *SD*), averaged across loading-unloading cycles.*

Bar	Load							
	70 kg	CV	120 kg	CV	170 kg	CV	220 kg	CV
Iron Grip (Olympic competition)	1.1 ± 0.0	0.0	2.1 ± 0.1	6.1	2.8 ± 0.1	2.9	3.9 ± 0.0	0.0
Iron Grip (Power)	1.5 ± 0.0	0.0	2.5 ± 0.0	0.0	3.1 ± 0.2	4.9	3.9 ± 0.0	0.0
Eleiko	1.5 ± 0.0	0.0	2.5 ± 0.0	0.2	3.7 ± 0.0	0.0	4.4 ± 0.0	0.0
Uddeholm	1.6 ± 0.1	5.5	2.2 ± 0.0	0.0	3.3 ± 0.1	2.3	4.2 ± 0.1	1.9
Uesaka (1)	1.3 ± 0.0	0.0	2.3 ± 0.1	3.6	3.1 ± 0.2	5.0	3.9 ± 0.0	0.0
Uesaka (1)	1.4 ± 0.1	6.6	2.2 ± 0.1	3.7	3.2 ± 0.2	6.3	3.8 ± 0.1	2.4
Mavrik	1.3 ± 0.1	6.2	2.0 ± 0.1	6.6	2.9 ± 0.1	2.8	3.9 ± 0.0	0.0
York	1.2 ± 0.0'	0.0	2.0 ± 0.0	0.0	3.3 ± 0.1	2.2	4.0 ± 0.0	0.0
Ivanko	1.5 ± 0.0	0.0	2.4 ± 0.1	4.3	3.3 ± 0.1	2.6	4.1 ± 0.1	2.0

*CV = coefficient of variation (%).

upright supports was determined based on the grip width of the investigator (a former national caliber weightlifter) performing cleans. A steel measuring tape was placed on one upright support for later use as a reference measure. Thus, the modified 4-point bending setup attempted to mimic the pulling phase for the clean. However, it should be noted that the dynamic nature of the pulling phase of the clean may alter the distribution of forces along the length of the barbell. A digital camera (Powershot S5 IS; Canon USA; Lake Success, NY, USA) was placed 10 m in front of the bar. The height of the camera's optical axis was 1.25 m, equal to the height of the unloaded bar. The bar setup was illuminated using a 50-W halogen floor lamp placed 4 m in front of the bar.

Each bar was loaded and unloaded in 2 cycles. For each cycle, loading (and unloading) occurred incrementally. For each increment, a 25-kg rubber bumper plate (RB Rubber; McMinnville, OR, USA) was placed on each side of the bar. After the plates were loaded, the bar was allowed to settle for one minute to standardize the magnitude of creep, at which point, a digital photograph was taken. A second 25-kg rubber bumper plate was then added, allowed to settle, and the digital photograph was taken. This was repeated until 4 plates were loaded on each side, at which point, the unloading cycle was conducted in reverse order. Before use, each bumper plate was weighed on a medical scale, each having a mass of 25 kg.

The digital photographs were analyzed for the amount of bar deformation. Photographs were imported into Microsoft Powerpoint 2003 software (Redmond, WA, USA). Photographs were enlarged to the largest size that allowed the entire length of the bar to be visible on a 19-in. liquid crystal display (LCD) monitor (Dell #1908FPb; Round Rock, TX, USA) displaying at 1,280 × 1,024 pixels. This setup allowed a resolution of 2 mm per pixel. Two horizontal lines were drawn: (a) along the length of the bar through the vertical center of the middle of the bar and (b) intersecting the vertical centers of the left and right ends of the bar (Figure 1). Bar deformation was operationally defined as the perpendicular distance between the lines, which was determined from the steel reference measuring tape.

The bending moment for each loading scenario for each bar was determined based on the bar dimensions and the dimensions of the rubber bumper plates. A free-body diagram was drawn (Figure 2) for the bar. The forces acting on the bar were the vertical reaction forces from the squat stands and the weight of the rubber bumper plates. Because the vertical reaction forces were not known, they could be solved using the equivalence of force equation, assuming that the system was symmetrical about the horizontal center of the bar, and therefore, reaction forces were equal at each point of application. The bending moment was calculated about the center of the bar from the known and estimated forces, and their respective moment arms.

Statistical Analyses

For each bar, bar deformation for each loading and unloading cycle was plotted relative to the bending moment to assess hysteresis. Simple linear regression was used to assess the linearity of each loading or unloading cycle. To assess the apparent stiffness of each bar, bending moment was plotted vs. bar deformation for each data point (i.e., all loading and unloading cycles combined). The slope of the plots was used as an indicator of apparent stiffness. Regression analyses were performed in Microsoft Excel 2003 software.

Results

The physical dimensions for each bar are presented in Table 2. All of the bars designed for use in weightlifting training or competition were reasonably similar to IWF specifications, except for the York and Ivanko bars. Hysteresis plots indicated that bending of each bar was uniform and linear

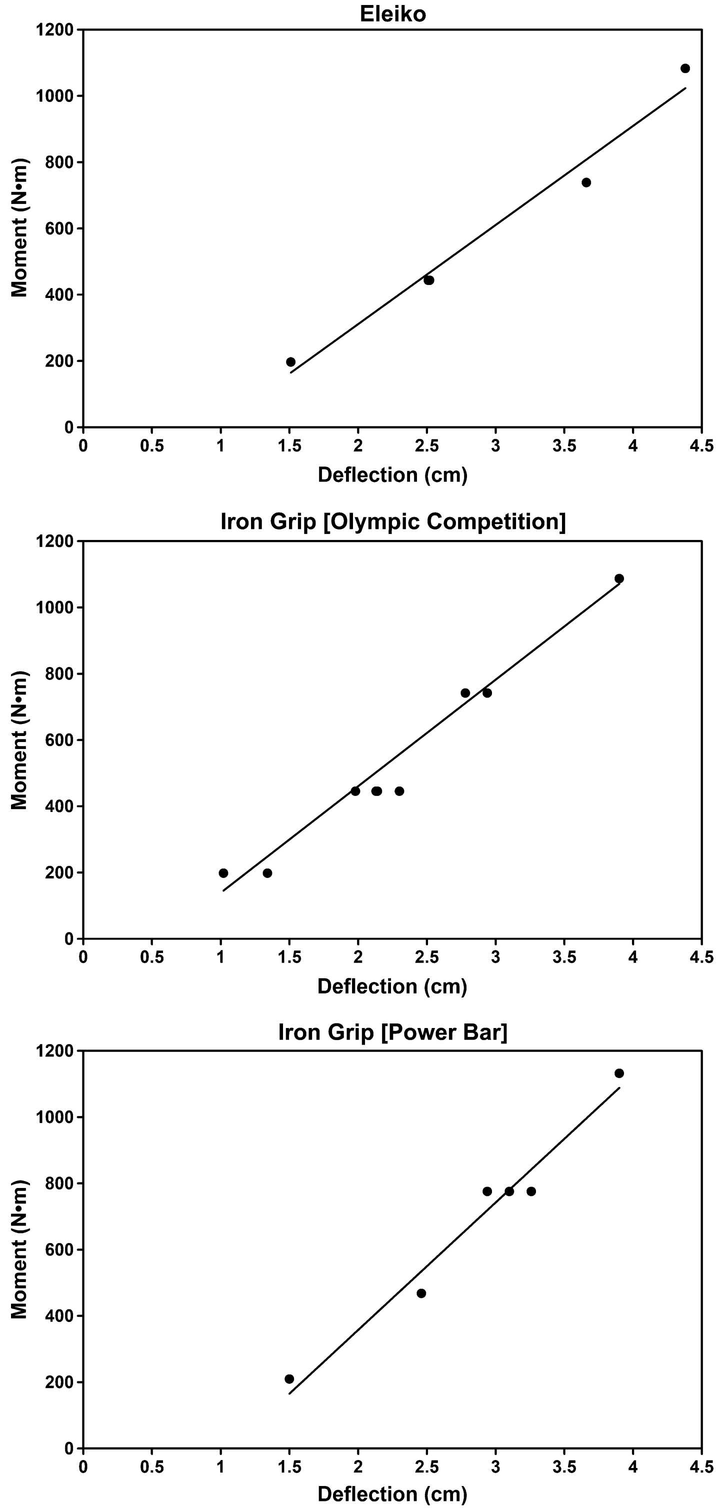

Figure 3. Plots to determine apparent stiffness for Eleiko, Iron Grip [Olympic Competition] and Iron Grip [Power] bars. Data are combined from the loading-unloading cycles. Because of the uniformity of data, some points may overlap.

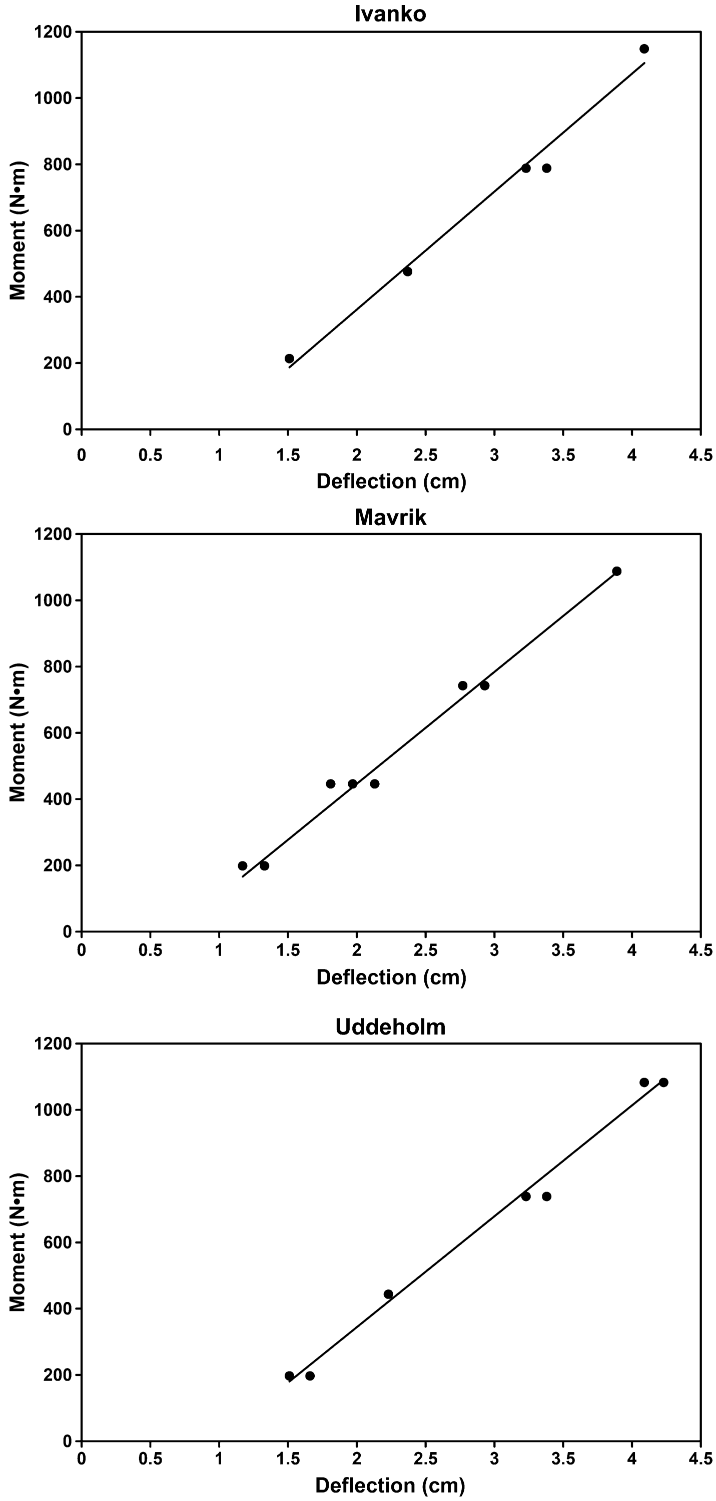

Figure 4. Plots to determine apparent stiffness for Ivanko, Mavrik and Uddeholm bars. Data are combined from the loading–unloading cycles. Because of the uniformity of data, some points may overlap.

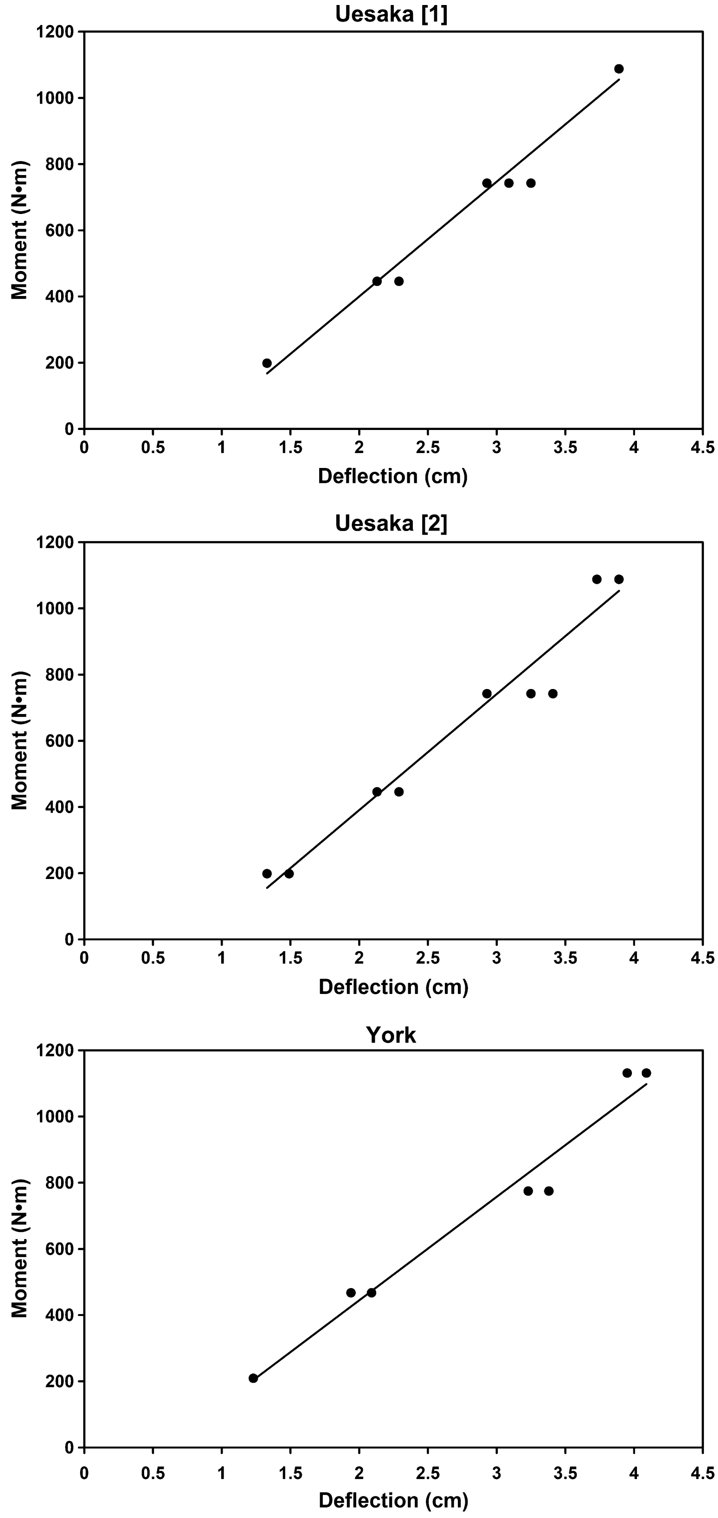

Figure 5. Plots to determine apparent stiffness for Uesaka and York bars. Data are combined from the loading–unloading cycles. Because of the uniformity of data, some points may overlap.

Table 5. Apparent stiffness coefficients for tested bars.

Bar	Stiffness ($N \cdot m \cdot cm^{-1}$)	R^2
Eleiko	299	0.977
York	313	0.977
Iron Grip (Olympic competition)	321	0.981
Uddeholm	335	0.992
Mavrik	338	0.994
Uesaka (1)	347	0.985
Uesaka (2)	350	0.965
Ivanko	356	0.988
Iron Grip (Power)	384	0.976

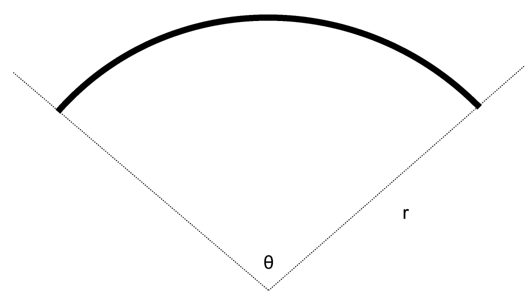

Figure 6. Alternative method to determine beam deformation. r = radius of arc formed by beam; θ = angle formed by the 2 radii perpendicular to the ends of the beam.

across each loading-unloading cycle. Regression coefficients for each bar are presented in Table 3.

Bar deformation, averaged across the loading–unloading cycles is presented in Table 4. Plots of apparent stiffness are presented in Figures 3– 5. Apparent stiffness coefficients are presented in Table 5, listed in increasing order of stiffness. The least stiff bar was the Eleiko, followed by the York, Iron Grip [Olympic Competition], Uddeholm and Mavrik. The apparent stiffness of the 2 Uesaka bars was similar (346.6 vs. 350.3 $N \cdot m \cdot cm^{-1}$). The stiffest bars were the Ivanko and Iron Grip [Power].

Discussion

The mechanical characteristics of 8 weightlifting bars and 1 general purpose weight training bar were assessed. Most of the bars had dimensions appropriate for use in weightlifting training and competition based on IWF specifications. The Iron Grip (Power) bar was slightly longer than recommended by IWF specifications, whereas the Ivanko was slightly shorter. The former is advertised as a general purpose weight training bar, whereas the latter has been advertised for use as a weightlifting bar. The length of the sleeves for the York and Ivanko bars was shorter than recommended by IWF specifications. The York bar was the oldest of all bars tested, manufactured more than 25 years before the time of testing. It is possible that specifications at the time were different than current specifications. It is not known why the Ivanko bar deviated so much from IWF specifications, while still being advertised as suitable for training and competition. All of the bars had a shaft diameter of 28 mm (as per IWF specifications) except for the Iron Grip (Power) (30 mm) and Mavrik (29 mm).

A modified 4-point bending test was used to assess deformation of bars when loaded with weights. A standard 4-point bending test involves supporting the ends of a beam and applying forces 2 points equidistant from the center of the beam. To increase external validity, the test was modified such that the points near the center of the bar were supported and forces were applied (via weights) *near* the end of the bar. Standard 4-point bending tests are also typically taken until material failure; however, the point of material failure was not of interest, nor was this logistically possible. First, the available rubber weight plates were 10 cm wide; therefore, the maximum number of plates that could be loaded was 4 per end. Secondly, it was not desirable to damage the bars because of their cost (typically US$400–600 or greater).

In engineering, bending stiffness is the product of the object's area moment of inertia and elastic modulus (6). Bending stiffness is directly proportionate to the bending moment and inversely proportionate to deformation (6). An additional modification in this investigation was that apparent bar stiffness was calculated as the slope of the deformation (x-axis) vs. bending moment (y-axis) plot. Thus, the area moment of inertia was essentially ignored. Furthermore, bar deformation was operationally defined as the vertical distance between the center vs. the ends of the bar. Typically, in the bending of a beam, the horizontal distance is also considered; however, this distance could not be measured with precision. Alternatively, Bolton (1) defined beam deformation as the angle of the arc formed by the bent beam (Figure 6). Based on the experimental methodology used, initial attempts to calculate deformation as per Bolton (1) were not successful. The problem arose in accurately generating the intersecting lines required to determine this angle. However, because the angle is determined from the movement of the ends of the bar, it is likely that each method would yield comparable results.

The uniform and linear hysteresis plots for each bar indicated that each bar demonstrated pure elastic bending behavior, which is consistent with metal beams (6). The elastic behavior of the bars may be useful in considering how the bars may behave under dynamic conditions. The modified 4-point bending test examined bar deformation under static conditions; however, weightlifting bars are used under dynamic conditions, with high acceleration and velocity characteristics (3,7,13). In dynamic testing conditions, steel is observed to increase its yield and ultimate strength linearly with strain rate (10). Although the mechanical properties of steel are sensitive to strain rate, this linearity of change with increasing strain rate suggests that the ranking of apparent bar stiffness in the current investigation may also be observed under dynamic conditions. However, future research is required to corroborate such a hypothesis.

Bar deformation has been reported under dynamic conditions by Chiu et al. (3). Notwithstanding changes in material properties, bar deformation under dynamic conditions may be greater than static conditions, because the forces applied to the bar under dynamic conditions may be greater than used in the static test. This is dependent on the weight loaded on the bar. In Chiu et al. (3), the deformation of a bar (York) during the clean pull exercise ranged from 4 to 6 cm, with a maximum load of 155 kg. These deformation values are comparable to those observed in the current investigation, where a maximum load of 220 kg was used. However, it should be noted that peak forces applied to the bar during the clean range from 1.5 to 1.7 times the weight of the bar (6). This further underscores the importance of future research assessing bar mechanical properties under static and dynamic conditions to determine the influence of static and dynamic forces of varying magnitude and changes in mechanical properties with increasing strain rate.

Anecdotally, weightlifters often report that Eleiko bars have the greatest "spring," whereas Uesaka bars are reported to be stiffest. The current results are supportive of these anecdotal reports, as the apparent stiffness was greater for the Uesaka bars vs. the Eleiko bar. The majority of the remaining bars had an apparent stiffness greater than the Eleiko bar, but less than the Uesaka bars. Both the Eleiko and Uesaka bars have been used for international level competitions. For example, Uesaka bars were used in the Olympic Games from 1988 to 2004, and the Eleiko bar has been used at numerous World Weightlifting Championships, including 2001–2003 and 2005. Although no standards exist for bar stiffness in weightlifting, the current results can be used to make recommendations. A bar with an apparent stiffness between the Eleiko and Uesaka is likely to offer appropriate "spring" for use in weightlifting training and competition. From the bars tested, this includes the Iron Grip [Olympic Competition], Mavrik, Uddholm and York bars. Additionally, these bars would be appropriate for use in facilities where weightlifting exercise variations are used, such as athletic strength and conditioning programs.

The bars with the greatest apparent stiffness were the Iron Grip [Power] and the Ivanko. The greater apparent stiffness of the Iron Grip [Power] bar was expected due to the larger diameter of this bar. This bar is advertised as a general purpose weight training bar. The high apparent stiffness of this bar indicates that this bar may be appropriate where "spring" is not desired. For example, "spring" may be undesirable for squats with very high loads (i.e., in powerlifting training and competition). Although the Ivanko bar also had a high apparent stiffness, the deformation of this bar was relatively high compared to other bars. The large deformation, despite a high apparent stiffness, is because of the shorter sleeves, which place the weights further from the center of the bar, generating a larger bending moment. Therefore, the benefit of a high apparent stiffness for this bar is offset by its physical dimensions.

A high apparent stiffness was expected for the Ivanko bar based on manufacturer claims and advertising. Ivanko bars are advertised as having a high tensile strength. For example, the York bar has been advertised as having a tensile strength of 185,000 psi and general weight training bars have a tensile strength of 115,000–140,000 psi, whereas Ivanko bars are advertised as exceeding 200,000 psi (3,11). Tensile strength is an indication of the ultimate strength a material is able to tolerate before permanent deformation. During bending tests, both tensile and compressive loads are placed on a beam. However, steel is linearly elastic (6); therefore, the tensile and compressive strengths are the same and should equally affect bending of a bar. A closely related parameter is yield strength, which is the point at which a material will fracture. In competition, the heaviest reported clean attempted was 272.5 kg by Chemerkin in the 2000 Olympics (8), and permanent deformation of the bar did not occur. This corresponds to greater than 405 kg in a static bending test. Eleiko bars are advertised as being subjected to 1,500 kg of force in a 3-point bending test, with bars returning to pretest straightness. Thus, an excessive tensile or yield strength for a bar is likely not an advantage under realistic training conditions and may be undesirable for use in weightlifting training and competition.

Chiu et al. (3) and Zernicke et al. (13) have described deformation of bars during clean pull exercise and the jerk, respectively. Empirically, weightlifting coaches have discussed bar oscillation and how to take advantage of such oscillation to maximize the weight that can be lifted. The IWF technical rules specifically prohibit *deliberate* oscillation of the bar before the jerk (9), possibly to eliminate an unfair advantage gained by such oscillation. These findings suggest that it is possible to take advantage of bar deformation and may be an important component in the skill of lifting heavy weights. As such, an excessively stiff bar would not be appropriate for use when performing weightlifting exercises.

The majority of bars tested in this investigation were designed for use in weightlifting according to the IWF technical rules for a men's bar. In women's competition, a women's bar is used, which is lighter (15 vs. 20 kg) shorter (2.01 vs. 2.20 m) and of smaller diameter (2.5 vs. 2.8 cm). Assuming a manufacturer uses the same steel alloy for both the men's and women's bars, the apparent stiffness of the women's bar will be lower than the men's as apparent stiffness (as operationally defined in this investigation) ignores the diameter of the bar. Future research should investigate the effect of the different apparent stiffness of men's and women's bars on the bar's bending behavior during weightlifting. Such differences may be important to determine how to optimize weightlifting technique in men vs. women.

The modified 4-point bending test used in this investigation provides a simple method for examining bar deformation and apparent stiffness. This test is easily repeatable, requiring only a pair of squat stands, a measuring tape, weights and a digital camera. The comparative bending behavior of men's vs. women's bars and bars designed for weight training purposes other than weightlifting can be assessed.

One area of potential concern is the use of position, velocity and acceleration transducer technology or video to assess exercise biomechanics (3,4,5). Typically, these devices are attached to the bar along the sleeve or inside collar. As the magnitude of deformation increases when moving toward the ends of the bars, this deformation may influence the results obtained using such technology. Investigators using these technologies should consider assessing how bar deformation may influence their results, as this may be dependent on the bar, the type of transducer, the point of attachment and the exercise investigated. The effects of bar deformation may be compounded by variability from human participants (3). Rossi et al. (12) reported no differences between the left and right ends of the bar during weightlifting movements; however, Chiu et al. (3) observed that asymmetrical lifting may be present that can only be accounted for when grouping the ends of the bar based on which end is displaced more. Thus, further validation studies are required to determine the optimal methodology for assessing bar mechanics during exercise.

Practical Applications

Bar deformation is a natural phenomenon resulting from the mechanical properties and physical dimensions of the bar. Anecdotally, bar deformation is desirable during weightlifting exercises to maximize the weights that can be lifted. The current results confirm anecdotal reports from weightlifters that Eleiko bars have considerable "spring," whereas Uesaka bars are stiffer. Because both these bars are frequently used in elite international weightlifting competitions, their apparent stiffness can be used as reference guides for determining which bars have appropriate stiffness for weightlifting training and competition. The majority of bars (Iron Grip [Olympic Competition], Mavrik, York, Uddeholm) studied in this investigation had an apparent stiffness between the Eleiko and Uesaka bars; thus, these bars would all be suitable for weightlifting exercises. Bars with greater stiffness than the Uesaka are likely not suitable for weightlifting exercises. Because the ease of measurement, the methodology described in this investigation may be applied to evaluate the mechanical properties of other commercially available bars. Individuals who purchase or select bars for various purposes (weightlifting, powerlifting, general weight training, research, etc.) should be aware of the deformable nature of bars and evaluate the influence and effect of bar deformation for the required purpose of the bar.

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