Machine Resistance Curve Analysis of Seven Resistance Training Machines

Original Research

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Abstract

Introduction: Resistance training (RT) is not only feasible but also widely recommended across a spectrum of chronic disease contexts as well as for those with functional limitations. Many RT machines incorporate mechanisms that alter the machine's resistance curve (MRC) in an attempt to match the variable strength of the participant through a resisted ROM (RROM). Several investigations have tested this relationship using weight selections greater than what might be appropriate for targeting low to moderate training intensities. This article presents an analysis of low to moderate RT selections offered by seven RT machines.

Methods: An evaluation of the MRCs of seven RT machines was performed. Three leg extension machines, two chest press machines, and two seated row machines were selected for analysis from three fitness centers in Baltimore, MD and Oklahoma City, OK. The method of analysis is described. The acquired force data were normalized and plotted in order to categorize the MRCs of each machine.

Results: Four of the seven machines offered more than one MRC based on the weight selected.

Conclusions: The selection of resistance on an individual machine might influence targeted factors such as participant effort or achievable RROM.

Key Words: multi-joint machines, single joint machines, resistance selection

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Introduction

Resistance training (RT) is not only feasible but also widely recommended across a spectrum of chronic disease contexts as well as for those with functional limitations[1]. Careful selection of resistance levels can empower exercise professionals to enhance control over outcomes and facilitate the attainment of desired adaptations through exercise interventions[1,2], especially with participants for whom safety and tolerance may be a primary concern. For an exercise professional, this is accomplished by having a clear understanding of the amount of resistance and the characteristics of the specific tool selected for a particular exercise. RT machines are widely available and are feasible for use with patients with functional limitations and variable tolerances to exercise[3,4,5]. Introduced nearly two centuries ago[6], RT machines increased the number of exercises available to people with varying degrees of strength[7]. In the early 1860s, Charles Fayette Taylor, MD and Gustav Zander, MD, independently constructed a new class of RT machines designed for their patients with functional deficits [8,9]. Both inventors incorporated mechanisms (e.g., changeable lever arm or cam) to match the resistance to a patient's shifting strength through a resisted ROM (RROM). These mechanisms altered the output resistance at the machine's interface (handle, input arm pad, platform,

etc.): "That the resistance is arranged in exactest harmony with the physiological and mechanical laws of the action of the muscles…" [8]. The concept of using a mechanism to change the resistance throughout an RROM, often referred to as a machine resistance curve (MRC), is similar to that which led Arthur Jones of Nautilus, Inc. to design the eccentric cam nearly 100 years later [10].

The MRC is a graphic plot that represents the change in a machine's force [11], torque [12,13], or cam moment arm length [14,15] measured at various positions of the machine during the lifting stroke. Several investigations on MRCs have been performed on single joint motion machines via qualitative photographic analysis[14,15] or by a quantitative analysis of direct measurements of the torque or force [11,12,13]. Most of this research investigated how effectively the MRC of a machine matched a human strength curve (HSC)[12,13,15]. Typically, strength is operationally defined as peak force or torque measured during the performance of a maximal voluntary isometric contraction or a maximal voluntary isokinetic contraction [16]. An HSC is a graphic plot of these maximal measurements across the ROM of a joint in the absence of fatigue. The HSC might inform certain expectations regarding strength as long as several rules are followed during its acquisition. It must be constrained to a single joint restricted to one degree of freedom[17], anatomically or via external restraint, and the resistance application must be maintained in a tangential relationship to the arc of motion of the bony lever. The HSC is correlated with changes in the agonist muscles' lengths and their angles of pull[18,19], however, care should be taken not to extend the HSC as representative of the strength output during repetitions performed while fatigued or for repetitions performed at angular velocities different than those measured. Several authors have categorized the MRC by its appearance as ascending, descending, flat, or in varying combinations of these descriptors[11,12,20]. More recent designers of single joint motion RT machines intended to create an ascending-descending (bell-shaped) MRC to match an ascending-descending HSC[11,12,13,15,20,21,22].

Previous investigations into this relationship measured the MRC using relatively heavy weight selections[11,12,13] or by qualitative analysis[14,15] in which forces such as the weight of the input arm and or the friction between the weight plates and rods would not present a major influence in the accounting of the MRC as they might at lower weight selections. Additionally, since the idea of the HSC should not be extended to multiple joint movements, few investigations have provided an analysis of the MRC of machines such as the seated row and chest press. The purpose of this article is to provide an analysis of MRCs in order to identify their categorical shapes on both multiple joint and single joint RT machines for low to moderate level weight selections. This information may assist an exercise professional in their understanding of the unique characteristics associated with each machine regarding resistance selection for low to moderate level training intensities.

Scientific Methods

Resistance Training Machines

Seven machines were selected for analysis from two fitness centers in Baltimore, MD and one in Oklahoma City, OK: one selectorized Life Fitness Signature Series Leg Extension (Life Fitness, Illinois, USA), one plate-loaded Cybex Leg Extension (Cybex International, Massachusetts, USA), one selectorized Cybex Prestige Leg Extension (Cybex International, Massachusetts, USA), one selectorized Cybex Eagle NX Row (Cybex International, Illinois, USA), one selectorized Cybex VR2 Seated Row (Cybex International, Massachusetts, USA), one selectorized Cybex Eagle NX Chest Press (Cybex International, Illinois, USA), and one selectorized Nautilus Nitro Vertical Chest press (Nautilus Inc., Virginia, USA).

Range of Motion

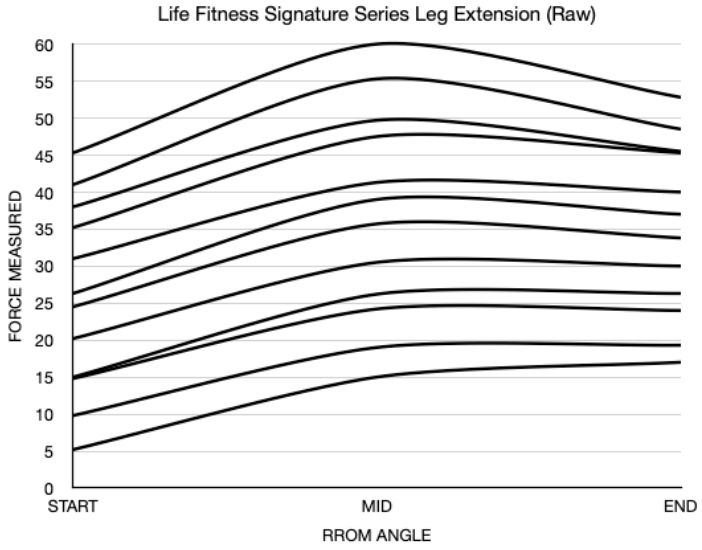
In order to provide a valid representation of an MRC, the force was measured at three angles (start, mid, and end) associated with the RROM of one of the authors (Male, Height: 73 in, Weight: 200 lbs.) which was used as the template for all machines except the Life Fitness Signature Series Leg Extension. The RROM of a research assistant (Female, Height: 65 in, Weight: 130 lbs.) served as the template for the Life Fitness Signature Series Leg Extension. A smartphone running the application TiltMeter (Hernandez, v.4.0.1) or an analog inclinometer (Johnson Level & Tool Mfg. Co., Wisconsin, USA) was attached to the input arm or handle of the machine to provide the start angle and end angle as well as controlling for all three angles during the angle-force measurements. In order to measure the total RROM, the lightest weight available was selected and moved through the entire lifting stroke to determine the total angular displacement. The associated angular distance was halved and then added to the start angle to provide the mid RROM angle. In the case of the Life Fitness Signature Series leg extension machine, the total lifting stroke angular distance was 114 degrees. Therefore, the forces were measured at a start angle of 0 degrees, a mid-angle of 57 degrees, and an end angle of 114 degrees. This process was repeated for all seven machines. The total RROM lifting stroke angular distances for the remaining six machines were: 112 degrees for the plate-loaded Cybex Leg Extension, 105

degrees for the Cybex Prestige Leg Extension, 25 degrees for the Cybex Eagle NX Row, 35 degrees for the Cybex VR2 Row, 24 degrees for the Cybex Eagle NX Chest Press, and 40 degrees for the Nautilus Nitro Vertical Chest press.

Force Measurements

Static forces were measured with a Chatillon DFE-II (Ametek STC, Largo, USA) digital force gauge attached to the machine with a Dynex runner (Black Diamond Equipment, Ltd., Utah, USA) affixed to the machine's input arm or handle corresponding with technical procedures previously reported [11]. Each force measurement was performed with the angle of pull measuring 90 degrees such that the line of force was perpendicular to the input arm, i.e., the longest moment arm. This ensured that the static force was measured tangential to the arc of motion. Forces were measured three times each at each of the three angles (start, mid, and end) within the lifting stroke RROM. For each machine, the force measurements started with the lowest available weight selection, or, in the case of the plate-loaded Cybex Leg Extension, with no weight plates added. Subsequent force measurements were performed at each angle within the lifting stroke in 5 lb increments for each MRC measurement until one quarter of the total weight available on the weight stack was measured on the selectorized machines or 60 lbs. of plates were measured on the plate loaded Cybex Leg Extension. Figure 1 represents the raw MRCs measured for each selection of weight on the Life Fitness Signature Series Leg Extension.

Figure 1. Raw MRCs for the Life Fitness Signature Series Leg Extension.



Note: Each curve represents the average of the three force measurements at each of the three angles for every selection of weight. The lightest selection available, 10 lbs., measured 5.2 lbs. at the start angle, 15 lbs. at the mid angle, and 17 lbs. at the end angle. The heaviest selection, 60 lbs., measured 45.3 lbs. at the start angle, 60 lbs. at the mid angle, and 52.8 lbs. at the end angle.

Machine Resistance Curves

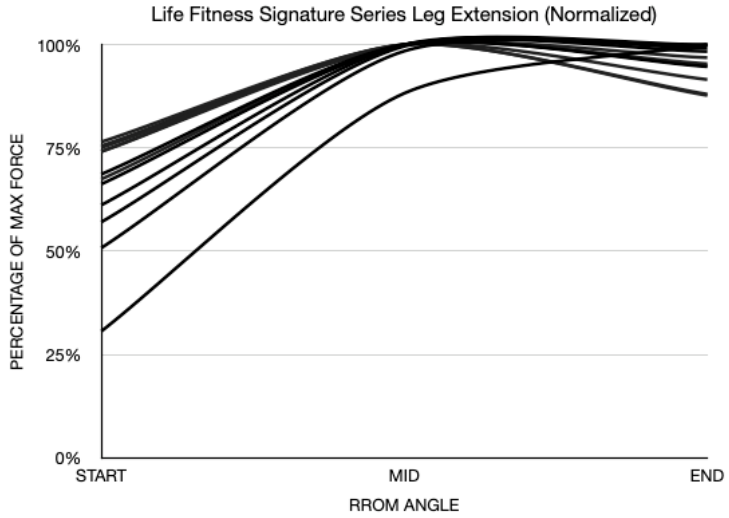
Following the data collection, the forces measured at each angle were averaged and normalized as a percentage of the maximum force measured of the three angles for each weight selection (Figure 2). The data were then grouped by visual examination into an appropriate MRC category description based on the total curve or each leg of the curve (e.g., ascending, ascending-flat, ascending-descending). The averages of the normalized force for each angle within each grouping were calculated and plotted graphically to represent one or more representative MRCs for each machine (Figure 3). This process was repeated for all seven machines.

Results

The analysis of the Life Fitness Signature Series Leg Extension yielded three MRC categories. Only one weight selection (10 lbs.) was represented by an ascending curve. Eight weight selections (15 – 50 lbs.) were represented by an ascending-flat curve and two weight selections (55 & 60 lbs.) were represented by an ascending-descending curve (Figure 3). The analysis of the Cybex Plate Loaded Leg Extension yielded two different MRC categories. Eight weight selections (0 – 35 lbs.) were represented by an ascending-descending curve and five weight selections (40 – 60 lbs.)

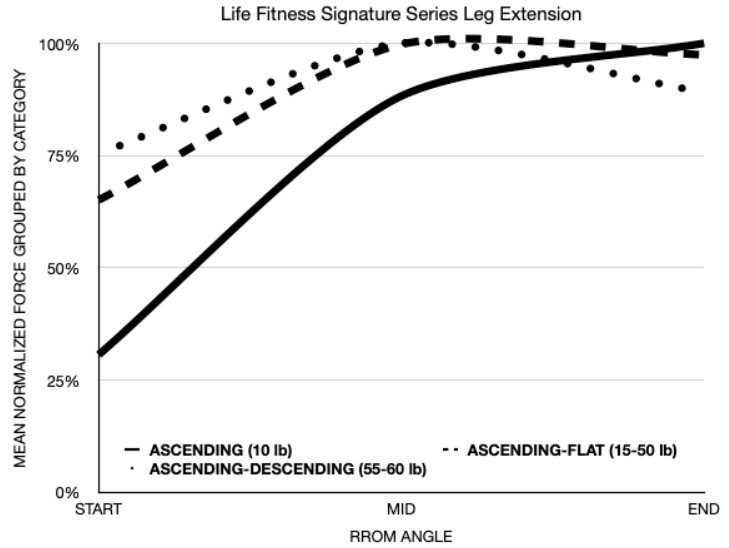
were represented by a descending curve. The analysis of the Cybex Prestige Leg Extension yielded two different MRC categories. Ten weight selections (10 – 55 lbs.) were represented by an ascending-descending curve and one weight selection (60 lbs.) was represented by a flat-descending curve. The Cybex Eagle NX Row analysis yielded one MRC category with all weight selections (10 – 65 lbs.) represented by a descending-descending curve. The Cybex VR2 Seated Row analysis yielded three different MRC categories (Figure 4). Two weight selections (10 & 15 lbs.) were represented by an ascending curve. Three weight selections (20 – 30 lbs.) were represented by a flat-descending curve and seven weight selections (35 – 65 lbs.) were represented by a descending curve. The analysis of the Cybex Eagle NX Chest Press yielded one MRC with all weight selections (10 – 70 lbs.) represented by an ascending-descending curve (Figure 5). The Nautilus Nitro Chest Press analysis yielded one MRC with all weight selections (20 – 65 lbs.) represented by an ascending curve.

Figure 2. Normalized MRCs for the Life Fitness Signature Series Leg Extension.



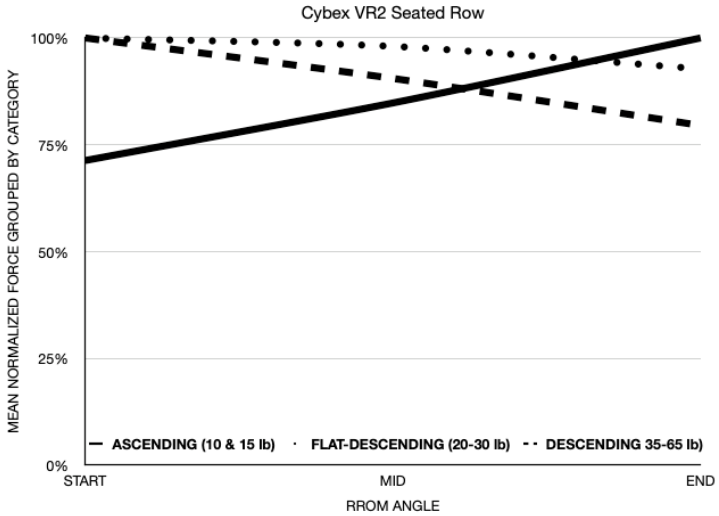
Note: Each line represents the normalized force as a percentage of the maximum raw force measured of the three angles for each weight selection.

Figure 3. MRC categories for the Life Fitness Signature Series Leg Extension.



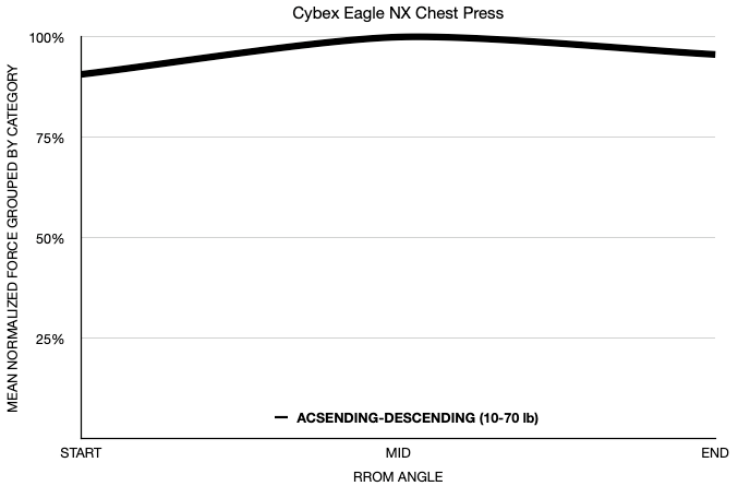
Note: Three different MRC categories are represented. Only one weight selection (10 lbs.) is represented by the ascending curve. Eight weight selections (15-50 lbs.) are represented by the ascending-flat curve and two weight selections (55 & 60 lbs.) are represented by the ascending-descending curve.

Figure 4. MRC categories for the Cybex VR2 Seated Row.



Note: Three different MRC categories are represented. Two weight selections (10 & 15 lbs.) are represented by the ascending curve. Three weight selections (20 – 30 lbs.) are represented by the flat-descending curve and seven weight selections (35 – 65 lbs.) are represented by the descending curve.

Figure 5. MRC category for the Cybex Eagle NX Chest Press.



Note: One MRC category is represented. Each weight selections (10 – 70 lbs.) is represented by the ascending-descending curve.

Discussion

In practical terms, assuming a similar RROM as the author, if the lowest weight available on the Life Fitness Signature Series Leg Extension machine was selected (10 lbs.), a participant would experience a continued increase in resistance as they concentrically extended their knee through the lifting stroke as indicated by the ascending-ascending MRC. It should be noted that the overall increase in resistance provided by the machine is added to the increasing resistance from the weight of the shank and foot (lower leg) due to the increase in the moment arm of that segment's center of mass through the same RROM. For the participant capable of using greater weight selections, the influence of the resistance due to the weight of the lower leg is less of a factor. For weight selections of 15 lbs. to 50 lbs., the MRC is ascending-flat increasing from the start angle to the mid angle and flat from the mid angle to the end angle. The weight selections of 55 lbs., 60 lbs., and 65 lbs. have an ascending-descending MRC. With these weight selections, the machine

resistance increases from the start angle to the mid angle and then decreases from the mid angle to the end angle. In many leg extensions such as this one, the shape of the MRC at higher weight selections more closely resembles the shape of the MRC if it was analyzed through qualitative analysis of the radius measurements (moment arms) of the eccentric cam[14,15].

Selecting a resistance dose regimen that is safe and effective for participants with chronic disease or functional limitations is one of the most important elements of an RT program. Optimal resistance selection elicits the desired responses and or adaptations while lessening the likelihood of adverse events and challenges to adherence[4]. Variable resistance is an assumed characteristic of an RT machine[22]. However, as is indicated by the MRCs represented, the exact nature of that variability should never be assumed by an exercise professional. This research suggests that the selection of resistance on a machine for a participant for whom a low to moderate level intensity is suited might provide a dramatically different RT response than expected. If the MRC is known and considered prior to a participant's performance of the repetition, the exercise professional can individualize the shape of the MRC by providing manual assistance, such as spotting, with precision during the lifting stroke RROM. This might have the effect of reducing the negative responses that might be incurred if a compromised participant failed to complete the repetition.

Conclusions

Understanding the variability of MRCs for various low to moderate intensity weight selections enables an exercise professional to manipulate the individual RT selection to suit the needs of the participant. The analysis in this article is limited to machines that the author was granted access to in two fitness centers located in Baltimore, MD and one in Oklahoma City, OK. This analysis encompasses several generations of machines including two of the most current. This analysis is limited to the specific machines that were measured and should not be considered representative of any other machine. This research has shown that an exercise professional should not assume that the MRC for a machine measured by qualitative analysis or with heavier weight selections will be indicative of the MRC for low to moderate weight selections. An objective method that an exercise professional can use to determine the MRC for a selection of weight on a specific machine is to measure it using similar methods as those described. It is important to note that the MRC for a weight selection only represents the normalized forces measured at the machine interface throughout the lifting stroke RROM. In order to determine the resistance curve of the exercise, a measurement of both the force and the moment arm of the resistance at the participant's relevant joint axes would need to be considered.

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