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Biomechanics

Muscle's White Flag

TEAM 8

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***Abstract*—This study aimed to explore and quantify how to model failure during resistance training through kinematic analysis. The study used normalized acceleration and speed on 13 volunteers to explore how those metrics change as each volunteer approaches failure. The results show prominent success, with graphical representation of both metrics demonstrating a significant trend towards the proposed model of the paper. The paper succeeded in obtaining a threshold for what acceleration and speeds indicate a muscle failure, which was evaluated to be 0.5756 $\pm$ 0.149 for acceleration and 0.664 $\pm$ 0.162 for speed.**

***Index Terms*—Resistance Training, Kinematic Analysis, smartphone tracking**

I. Introduction

Exercising and Training has shown an increasing trend in the past 10 years. In the U.S, it is estimated that gym memberships have shown an average increase of 36.36% across all age groups since 2010 [1]. With such an increase, new techniques for training, especially those targeting hypertrophy - muscle growth - have emerged. Considered the main method for achieving muscle hypertrophy now [2], Resistance Training (RT) has been widely known in the fitness industry for its effectiveness. Resistance training is defined as the performance of static or dynamic muscle contractions against external resistance of varying intensities [3]. It is reported to have numerous benefits, including improvement of metabolic profile in type 2 diabetes (T2DM), slowing the progression of age-related sarcopenia, preventing osteoporosis, and reducing the risk of low-grade inflammation-related diseases [3]. Resistance Training can be categorized into Resistance Training performed till Failure (RTF) and RT not performed to failure (RTNF). RTF refers to the use of the maximum number of repetitions in each set [4]. On the other hand, RTNF is performing the set without achieving the same number of maximum repetitions.

It has been debated whether RTF is better for hypertrophy than RTNF or whether both are equivalent. Multiple studies suggest that RTF is superior to RTNF for optimal hypertrophy. Such studies include J. Willardson, which arrived at the conclusion that the potential mechanisms by which training to failure might provide an advantage are through greater activation of motor units and secretion of growth-promoting hormones [5]. Other studies arrive at results that include no change during High-Intensity RTF, including S. Nóbrega and C. Libardi who noted no change in hypertrophy achieved by high-intensity RT vs High-Intensity RTNF [2]. However, even this study mentioned that achieving muscle failure during Low-Intensity workouts is a strategy for achieving hypertrophy. Thus, It is apparent that optimizing RTF exercises is a prominent field in literature. Within this field, several papers emerged that attempt this optimization using smartphones. This approach utilizes the convenience and availability of smartphones within each household, which is ideal for measuring reliable data and making widely available solutions. This paper follows the same approach and aims to research how the acceleration performed by an exerciser changes over the course of an RTF workout. The contributions of the paper can be summarized as follows:

- Deriving a threshold for what normalized acceleration should correspond to failure during an RTF workout
- Developing a mobile application based on the proposed threshold to alarm the users whenever they reach failure during a workout.

II. Methodology

A. Collecting Data

13 videos were collected using a Samsung A21s mobile phone from 13 different individuals during a gym workout. The videos were recorded in 30 FPS 1080p format. To ensure proper tracking later, 1x3 cm stickers were placed on joints of interest before the videos were taken. In total, 4 different exercises were recorded: bicep curls, preacher curls with a machine, leg push with a machine, and ground back pull with a machine. The stickers were placed on the wrist in bicep curls, preacher curls, and ground back pulls. For the leg push, a fixated point on the movable leg cushion was chosen as the point of interest of the workout. The videos were recorded for an entire set for each participant. Before the workout, all participants were asked to train until failure. Upon stopping the set, participants were introduced to a cash prize of 20 EGP to see the effect of external stimuli on their muscle failure. For each machine recorded, a visible part of the machine within the clip was measured in cm to calibrate the videos during the analysis.

B. Processing Data

The videos were edited to remove any unwanted clips of talking with the participants, pre-workout stance, and post-workout stance. The filtered clips were then added into Kinovia and calibrated such that the known length is added and the grid system is standardized. The grid system was selected such that the concentric contraction of the muscle, the motion against the gravity, is positive. Thus, the eccentric contraction, which is assisted by gravity, is negative.

C. Data Constraints and Filteration

To ensure the validity of our analysis, several constraints were followed during the analysis. First, the monitored acceleration was chosen to be that in the opposite direction of the gravity - concentric contraction acceleration. This implies that gravity will be considered a resistance rather than an assistance during the motion. Thus, this ensures that the work done by the muscle is the only factor contributing to the acceleration being produced. The second factor is ensuring that the person is training until actual failure. This was noted by seeing how consistent their motion is and how they respond to the cash prize for one more rep. If they easily make the final rep and they haven't shown any signs of slowing down during the actual workout, then their video was discarded as it does not comply with the defined criteria for this project. 2 videos were filtered out through this constraint. Finally, the acceleration for each participant was normalized to the initial acceleration. This ensures a reliable comparison between the accelerations recorded by all participants.

D. Data Finalization

The timestamps associated with the start and end of each rep were recorded. Within each of those timestamps, the average value of positive acceleration and speed was computed. Thus, each rep was represented by 3 values: The normalized average positive acceleration, the normalized average speed, and the timespan took to complete that rep.

III. Results and Discussion

Figures 1, 2, and 3 show the trends of each of the finalized data across all exercies. The trend observed in Figure 1 shows that the average time of a rep increases as volunteers approach failure. This aligns with the expected behavior of volunteers as their muscles weaken and approach failure. Figures 2 and 3 show how the average speed and acceleration of movement, respectively, decrease as the volunteer approaches failure. It is a trend observed in most workouts - further confirming the goals of this paper. Analysis of the end-workout velocity and acceleration result in the table below:

TABLE I
Workout Summary Table

Workout Name	Maximum Rep Time	Minimum Normalized Speed	Minimum Normalized Acceleration
BicepCurls1	2.03	1.043359128	0.740752328
BicepCurls2	7.07	0.730251349	0.647244404
GroundBackPull	4.967	0.437382918	0.416352019
LegPush1	2.03	0.627320022	0.462742299
LegPush3	4.06	0.435562422	0.362239944
LegPush4	3.9	0.442375879	0.437342699
LegPush5	1.2	0.570046009	0.605112441
PreacherCurl1	4.03	0.717044329	0.641470466
PreacherCurl2	1.77	0.962715338	0.990063023
PreacherCurl3	3.63	0.680193048	0.452979788

To obtain the required threshold for detecting whether failure as been achieved or not, the average and standard deviation of both normalized speed and normalized acceleration were computed. This results in an average speed value of 0.664 $\pm$ 0.162. and an average acceleration value of 0.5756 $\pm$ 0.149. Thus, the maximum acceptable acceleration percentage to achieve failure is no more than 72%, while that of speed is no more than 82%.

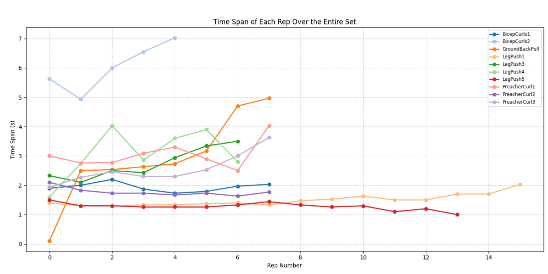

Fig. 1. The time span taken during each rep over the entire set across all exercises

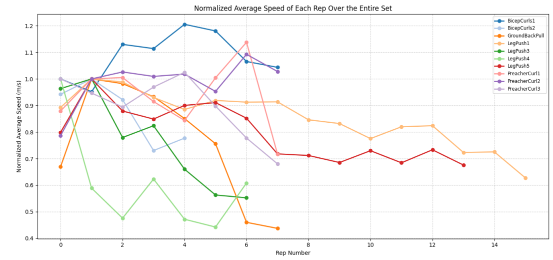

Fig. 2. Normalized average speed of each rep over the entire set across all exercises

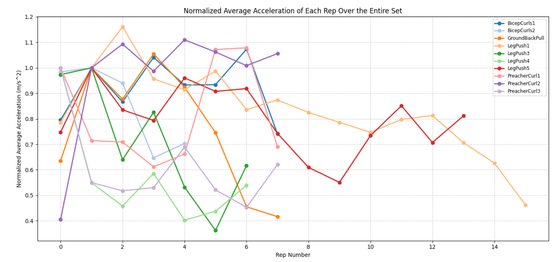

Fig. 3. Normalized average acceleration of each rep over the entire set across all exercises

IV. Conclusion

This study successfully demonstrated a kinematic-based approach for modeling muscular failure during resistance training using normalized acceleration and speed. By analyzing data from 13 participants performing resistance training to failure, a clear trend was observed: as individuals approached failure, their rep duration increased while both speed and acceleration declined. The final threshold values derived—0.5756 $\pm$ 0.149 for acceleration and 0.664 $\pm$ 0.162 for speed—represent significant indicators of predicting failure. These thresholds form the basis for future practical applications, including the development of real-time monitoring systems or mobile applications that can assist individuals in optimizing their workouts for hypertrophy. Ultimately, this work contributes a novel, accessible, and objective framework for enhancing resistance training effectiveness.

References

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